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The effect of motor relearning on balance, mobility and performance of activities of daily living among post-stroke patients

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DOCTORAL THESIS

The effect of motor relearning on balance, mobility and performance of activities of daily living among post-stroke patients

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A doctoral thesis submitted for the Degree of Doctor

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To my beloved wife, Tala, and our precious daughter, Bella ...

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Acronyms

10mWT 10-meter Walk Test.

ADL Activities of Daily Living.

AP Anteroposterior.

BBS Berg Balance Scale.

BI Barthel Index.

BOS Base of Support.

CNS Central Nervous System.

COG Center of Gravity.

COM Center of Mass.

CONSORT Consolidated Standards of Reporting Trials.

COP Center of Pressure.

CPT Conventional Physical Therapy.

GRF Ground Reaction Force.

IADL Instrumental Activities of Daily Living.

ICF International Classification of Functioning, Disability and Health.

LOS Limits of Stability.

ML Mediolateral.

MRP Motor Relearning Program.

NIHSS National Institutes of Health Stroke Scale.

PNF Proprioceptive Neuromuscular Facilitation.

RCT Randomized Controlled Trial.

RDC Rhythmic and Directional Control.

RGA Romberg Test with Eyes Open on Foam Cushion.

RGC Romberg Test with Eyes Closed on Foam Cushion.

ROA Romberg Test with Eyes Open.

ROC Romberg Test with Eyes Closed.

SCCs Semicircular Canals.

SIS–16 Stroke Impact Scale-16.

SOT Sensory Organization Test.

TIA Transient Ischemic Attack.

TUG Timed Up and Go Test.

VOR Vestibuloocular Reflex.

VSR Vestibulospinal Reflex.

WBA Weight-Bearing Asymmetry.

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Abstract

Background: Stroke is a prevalent neurological disorder worldwide and stands as a leading cause of long-term disability. Impaired balance and mobility are common consequences of stroke, significantly affecting patients' daily activities and overall quality of life. The motor relearning program (MRP) has shown promise in addressing these impairments. However, there is a scarcity of studies exploring the impact of task-specific training based on MRP using biomechanical balance and gait variables (i.e., kinetic and kinematic parameters), as well as posturography after stroke.

Objectives: The primary aim of this study is to assess the efficacy and long-term outcomes of task-specific training based on MRP on balance, mobility, and performance of activities of daily living (ADL) among post-stroke patients.

Methods: In this two-armed randomized controlled clinical trial, a total of 63 subacute stroke patients were randomly assigned to either task-specific training based on MRP (MRP group, n = 32) or conventional physical therapy (CPT group, n = 31). Both groups received 24 sessions of 1 hour each, three times a week for 8 weeks, followed by an analysis of changes in the patient's balance, gait, and performance of ADL at three time points: baseline, post-intervention, and follow-up after 3-months, using clinical outcome measures and instrumental evaluation of balance and gait.

Results: Both the MRP and CPT interventions showed significant improvements in clinical outcome measures and instrumental evaluation of functional balance and gait from baseline to post-intervention. However, the MRP group consistently displayed more substantial mean changes and larger effect sizes compared to the CPT group across all the measures. The between-group differences were significant, and the difference in effect size between the two groups was also substantial, favoring the MRP intervention, which further signified a meaningful difference between the groups and highlighted the significant impact of the MRP intervention. Both groups effectively maintained the achieved improvements at the 3-month follow-up. However, some notable differences between the two groups were observed, favoring the MRP intervention, highlighting the potential benefits of MRP for stroke patients in terms of long-term functional performance.

Conclusions: The MRP stands out as an effective and long-term rehabilitation strategy, with substantial potential to enhance functional recovery in stroke patients. Task-specific training based on MRP surpasses conventional therapy in improving balance, mobility (i.e., gait), and the performance of ADL post-stroke. This highlights its potential as a valuable addition to clinical practice and stroke rehabilitation protocols.

Keywords
Stroke, rehabilitation, motor relearning, task-specific training, balance, mobility, gait, activities of daily living.

Resumen

Antecedentes: El ictus es un trastorno neurológico prevalente en todo el mundo representa una de las principales causas de discapacidad a largo plazo. El equilibrio y la movilidad deteriorados son consecuencias comunes del ictus, que afectan significativamente las actividades diarias de los pacientes y la calidad de vida en general. El programa de reaprendizaje motor (MRP) ha demostrado ser prometedor para abordar estas deficiencias. Sin embargo, hay una escasez de estudios que exploren el impacto del entrenamiento específico de la tarea basado en MRP utilizando variables biomecánicas de equilibrio y marcha (es decir, parámetros cinéticos y cinemáticos), así como la posturografía después del ictus.

Objetivos: El objetivo principal de este estudio es evaluar la eficacia y los resultados a largo plazo del entrenamiento específico para tareas basado en MRP sobre el equilibrio, la movilidad y el desempeño de las actividades de la vida diaria (AVD) entre los pacientes después del ictus.

Métodos: En este ensayo clínico controlado aleatorio de dos brazos, un total de 63 pacientes con accidente cerebrovascular subagudo fueron asignados aleatoriamente a entrenamiento específico de tareas basado en MRP (grupo MRP, n = 32) o fisioterapia convencional (grupo CPT, n = 31). Ambos grupos recibieron 24 sesiones de 1 hora cada una, tres veces a la semana durante 8 semanas, seguidas de un análisis de los cambios en el equilibrio, la marcha y el rendimiento de la AVD del paciente en tres puntos temporales: línea de base, postintervención y seguimiento después de 3 meses, utilizando medidas de resultado clínico y evaluación instrumental del equilibrio y la marcha.

Resultados: Las intervenciones de MRP y CPT mostraron mejoras significativas en las medidas de resultado clínico y la evaluación instrumental del equilibrio funcional y la marcha desde el inicio hasta la posintervención. Sin embargo, el grupo MRP mostró consistentemente cambios medios más sustanciales y tamaños de efecto más grandes en comparación con el grupo CPT en todas las medidas. Las diferencias entre los grupos fueron significativas, y la diferencia en el tamaño del efecto entre los dos grupos también fue sustancial, favoreciendo la intervención de MRP, lo que significó una diferencia significativa entre los grupos y destacó el impacto significativo de la intervención de MRP. Ambos grupos mantuvieron efectivamente las mejoras logradas en el seguimiento de 3 meses. Sin embargo, se observaron algunas diferencias notables entre los dos grupos, favoreciendo la intervención de MRP, destacando los beneficios potenciales de MRP para pacientes con ictus en términos de rendimiento funcional a largo plazo.

Conclusiones: El MRP se destaca como una estrategia de rehabilitación efectiva y a largo plazo, con un potencial sustancial para mejorar la recuperación funcional en pacientes con ictus. El entrenamiento específico para tareas basado en MRP supera la terapia convencional en la mejora del equilibrio, la movilidad (es decir, la marcha) y el rendimiento de las AVD después del ictus. Esto destaca su potencial como una valiosa estrategia a añadir a la práctica clínica y los protocolos de rehabilitación de ictus.

Palabras clave
Ictus, rehabilitación, reaprendizaje motor, entrenamiento específico para tareas, equilibrio, movilidad, marcha, actividades de la vida diaria.

Section 1

Introduction

1.1 Stroke: Definition, classification, and epidemiology

1.1.1 Definition of stroke

Throughout history, stroke has been a medical condition that has perplexed physicians and researchers alike. Over time, our understanding of strokes and their underlying mechanisms has evolved, leading to significant changes in the way we define and diagnose this condition. The term "stroke" has a long history and has evolved over time to reflect advances in science and technology.

Historical perspective

The earliest description of stroke dates back to more than 2,400 years ago, when Hippocrates, the "father of medicine", recognized it as a condition characterized by sudden loss of consciousness and various manifestations of brain dysfunction. He called it "apoplexy", which is a Greek term that means "struck down by violence". This term has been used for centuries to describe any acute nontraumatic brain injury, regardless of the cause or location of the lesion [1].

The word "stroke" was first introduced into medicine in 1689 by William Cole, who used it as a synonym for apoplexy [2]. However, it was not adopted into the medical lexicon until the 19th century, when physicians started to use autopsy to examine the brains of stroke victims. They discovered that there were different types of stroke, depending on whether the blood flow interruption was caused by a clot (ischemic stroke) or a bleed (hemorrhagic stroke). They also noticed that different parts of the brain were responsible for different functions, and that the location and size of the lesion determined the severity and type of symptoms [2].

In the past, the definition of stroke was mainly based on clinical observation and postmortem examination. It did not account for the underlying mechanisms or the pathological processes involved in stroke. It also did not distinguish between symptomatic and asymptomatic strokes or between transient and permanent strokes.

Contemporary definitions

In 1970, the World Health Organization established a definition for stroke as "rapidly developed clinical signs of focal (or global) disturbance of cerebral function, lasting more than 24 hours or leading to death, with no apparent cause other than of vascular origin" [3]. While this definition continues to be widely used, it heavily relies on clinical symptoms and is now considered outdated by the American Heart Association and American Stroke Association. This is due to significant advancements in understanding the nature, timing, clinical identification of stroke and its mimics, as well as imaging findings that necessitate an updated definition [4].

The definition of stroke in the present day has become more comprehensive and precise, thanks to advancements in basic science, neuropathology, and neuroimaging. In 2013, the American Heart Association/American Stroke Association updated their endorsed definition of stroke [4]. According to this definition, "central nervous system infarction is defined as brain, spinal cord, or retinal cell death attributable to ischemia, based on neuropathological, neuroimaging, and/or clinical evidence of permanent injury". Stroke also encompasses a broader scope, including intracerebral hemorrhage and subarachnoid hemorrhage [4].

This definition incorporates both clinical and tissue criteria and recognizes that stroke occurs across a clinical spectrum. It encompasses silent infarctions, including those affecting the cerebral, spinal, and retinal areas, as well as silent hemorrhages. While the American Heart Association/American Stroke Association still include the traditional clinical definition of stroke, the addition of "silent" pathology represents a significant change. This alteration aims to shift towards a radiological demonstration, employing a tissue-based definition of infarction or hemorrhage [4, 5]. The present definition of stroke allows for more precise diagnosis and classification of stroke subtypes, considering factors such as the cause, location, size, and duration of the lesion. Furthermore, it reflects the current state of knowledge and technology in stroke research and management. This definition enables more accurate epidemiological studies, clinical trials, and public health assessments, while also facilitating the development of more effective prevention, treatment, and rehabilitation strategies for stroke patients [4, 5].

1.1.2 Classification and types

The classification of stroke is a method of categorizing strokes based on their underlying cause, the location of blood flow interruption, or clinical presentation. There are various classification systems for strokes, but the most commonly used ones are based on the pathophysiology of the stroke. The main types of stroke are as follows:

Ischemic stroke [6, 7]

Ischemic stroke is the most common type of stroke, accounting for approximately 87% of stroke cases. It occurs when a blood vessel in the brain gets blocked or narrowed, reducing blood flow. This blockage is often caused by a blood clot or atherosclerosis (the buildup of fatty deposits in the arteries). Ischemic strokes can be further categorized into two main types:

- **Thrombotic stroke** is characterized by the formation of a thrombus within an intracranial artery, leading to the obstruction of blood flow to the brain. The formation of this thrombus typically occurs locally due to atherosclerosis (at the fatty plaque) or other vascular conditions.

- **Embolic stroke** is characterized by the obstruction of a cerebral artery due to the presence of a blood clot that originated from a different location in the circulatory system, typically the large arteries in the upper chest and neck or the heart. The clot travels through the bloodstream until it reaches a smaller cerebral artery, where it impedes blood flow. A common cause of embolism is an irregular heart rhythm known as atrial fibrillation, which can cause clots to form in the heart, dislodge, and travel to the brain.

Hemorrhagic stroke [6, 7]

This type of stroke is less common but more serious and life-threatening, accounting for about 13% of all strokes. It occurs when a weakened blood vessel in the brain ruptures and bleeds into the surrounding brain tissue. The blood accumulates and compresses the surrounding brain tissue. The bleeding can be caused by an aneurysm (a weak area in the vessel wall), an arteriovenous malformation (an abnormal connection between arteries and veins), or high blood pressure. Hemorrhagic strokes can be further categorized into two main types:

- **Intracerebral hemorrhage** is characterized by the rupture of a blood vessel located within the brain, leading to bleeding directly into the brain tissue. It can occur as a result of either intraparenchymal hemorrhage, which refers to bleeding within the brain tissue, or intraventricular hemorrhage, which refers to bleeding within the brain's ventricular system.

- **Subarachnoid hemorrhage** refers to the occurrence of bleeding within the subarachnoid space, which is the area between the brain and the delicate tissues that cover it while remaining within the confines of the skull. This bleeding specifically takes place between the arachnoid and pia mater.

Transient ischemic attack (TIA) [6, 7]

A transient ischemic attack (TIA), commonly known as a "mini-stroke," is a temporary interruption of blood flow to the brain. TIAs share similar characteristics to ischemic strokes but resolve within a short period, typically within a few minutes to hours but less than 24 hours. Although the symptoms are temporary, TIAs should be taken seriously, as they can serve as a warning sign of an impending stroke.

Cryptogenic stroke [7, 8]

Cryptogenic strokes are a subset of ischemic strokes where the underlying cause remains unidentified despite a comprehensive assessment. It accounts for about 20–30% of ischemic strokes. These strokes may occur due to rare or undetectable causes such as a hidden clotting disorder, infection, inflammation, or other factors that are challenging to identify using standard diagnostic techniques.

Two prominent classification systems for ischemic strokes are the Trial of Org 10172 in Acute Stroke Treatment (TOAST) and the Oxford classifications. These systems differ in how they classify strokes based on their underlying causes and clinical features.

TOAST Classification [9]

The TOAST classification system classifies ischemic strokes into five distinct subtypes based on their underlying causes and the etiological factors contributing to the development of stroke:

- **Large-artery atherosclerosis (LAA):** stroke caused by the narrowing or blockage of large arteries supplying the brain due to atherosclerosis (buildup of plaque).
- **Cardioembolism (CE):** stroke caused by blood clots that originate in the heart, such as atrial fibrillation, and then travel to the brain, leading to blockage of smaller blood vessels.
- **Small-vessel occlusion (SVO):** stroke caused by occlusion (blockage) of small blood vessels within the brain, often due to conditions like lacunar infarcts.
- **Stroke of another determined cause:** stroke caused by identifiable causes other than those mentioned above, such as vasculitis or coagulopathies.
- **Stroke of undetermined etiology:** strokes that cannot be attributed to any specific cause after extensive evaluation.

Oxford Classification [10]

The Oxford classification is also known as the Bamford classification. It classifies ischemic strokes into four syndromes based on the clinical presentation and the vascular territory involved:

- **Total anterior circulation infarct (TACI):** stroke affecting the entire anterior circulation of the brain lead to significant and severe neurological deficits.
- **Partial anterior circulation infarct (PACI):** stroke affecting only part of the anterior circulation of the brain cause moderate neurological deficits but are less severe than TACI strokes.
- **Lacunar infarct (LACI):** stroke affecting the small penetrating arteries supplying the deep structures of the brain.
- **Posterior circulation infarct (POCI):** stroke affecting the posterior circulation of the brain, which includes the brainstem and cerebellum.

The main difference between the TOAST and Oxford classifications is that the former is based on etiology, or the underlying cause, whereas the latter is based on the clinical features or symptoms of stroke. The TOAST classification is particularly useful for determining the underlying cause of stroke and guiding secondary prevention strategies to prevent recurrence. On the other hand, the Oxford classification is more useful for predicting the prognosis and outcome of stroke [11].

1.1.3 Epidemiology: Incidence and prevalence of stroke

Stroke is a significant global health concern, and its incidence and prevalence vary across different regions and populations. Global stroke epidemiology is the study of the distribution and determinants of stroke and its subtypes across different populations and regions. The burden of stroke has risen dramatically in recent decades as a result of population growth, ageing, improved survival rates, and a rise in the prevalence of numerous modifiable stroke risk factors [12]. According to the World Stroke Organization (WSO) [12], stroke is the second-leading cause of death and the third-leading cause of disability and disability combined in the world, with nearly 50% of survivors experiencing chronic disability [13].

The Global Stroke Factsheet, published in 2022, indicates a 50% increase in the lifetime risk of developing a stroke over the past 17 years. Currently, 1 in 4 individuals over the age of 25 worldwide will experience a stroke during their lifetime. Each year, there are more than 12.2 million new cases of stroke, with around 16% occurring in individuals aged 15-49 and over 62% occurring in individuals under 70. In terms of gender, 47% of strokes occur in men and 53% in women [12]. There are over 101 million people currently living who have experienced stroke worldwide. Among this population, 22% are between the ages of 15 and 49, while 67% are below the age of 70. Women constitute slightly more than half (56%) of all stroke survivors worldwide. Annually, approximately six and a half million people die from stroke [12].

Between 1990 and 2019, there has been a significant increase in the global burden of stroke. Stroke incidence has increased by 70%, deaths due to stroke have increased by 43%, stroke prevalence has seen a 102% increase, and Disability Adjusted Life Years (DALY) associated with stroke have spiked by 143%. However, when considering age-standardized rates, there has been a decrease. Nonetheless, among individuals under the age of 70, both the prevalence and incidence rates have shown an increase. One particularly striking aspect is that the majority of the global stroke burden, encompassing 86% of deaths due to stroke and 89% of DALYs, is concentrated in lower and lower-middle-income countries [12, 14].

The Burden of Stroke in Europe report, conducted by King's College London for the Stroke Alliance for Europe (SAFE), aims to assess the stroke burden in each European Union country and provide projections for the next 30 years. According to the report, stroke remains one of the leading causes of death and disability in

Europe. It is estimated that the number of people living with stroke in the EU will increase by 27% between 2017 and 2047, primarily due to population aging and improved survival rates [15]. While the prevalence of stroke has increased, the incidence rate has remained stable compared to studies conducted earlier in the 21st century. The incidence rate of stroke in Europe is reported as 191.9 per 100,000 person-years, while the prevalence stands at 9.2% [16, 17]. In 2017, there were 1.12 million incident strokes, 9.53 million stroke survivors, 0.46 million deaths, and 7.06 million disability-adjusted life years lost due to stroke in the EU. By 2047, it is projected that there will be an additional 40,000 incident strokes (+3%) and 2.58 million prevalent cases (+27%) in the EU [15].

Regarding stroke incidence in Spain, it is lower compared to other countries, with no significant difference based on gender. The annual incidence of stroke in Spain is approximately 40,214 cases, equivalent to 46.2 strokes per 100,000 inhabitants. The prevalence of stroke in Spain is estimated to be 273,971 cases, accounting for 357.3 strokes per 100,000 inhabitants, with the majority of cases occurring in individuals over 65 years of age [15].

1.1.4 Clinical symptoms and sequelae of stroke

Stroke can occur in any region of the brain when blood supply to the brain is disrupted, resulting in brain cells being damaged or dying, which causes a loss of normal function in part of the body that may result in a disability [18]. Because one side of the brain (the left or right hemisphere) controls most functions on the opposite side of the body, a stroke affecting one side of the brain will result in neurological impairments on the opposite body side [18]. The signs and symptoms of a stroke usually emerge quickly. They can, however, take hours or even days to develop. The inability to move or feel one side of the body, trouble understanding or speaking, and a loss of vision on one side are early signs and symptoms of a stroke. These impairments vary depending on the type of stroke, the location of the brain lesion, and the amount of brain tissue affected [6].

Following a stroke, individuals may experience a wide range of clinical symptoms and sequelae. The effects of stroke can be long-lasting, impacting various aspects of an individual's life. From physical impairments to cognitive and emotional changes, stroke can have a profound impact on an individual's overall well-being and quality of life. Since the majority of stroke patients survive the initial stage, the most significant long-term effect is the development of impairment, disability (activity limitations), and handicap (limited participation) [19]. The consequences and impairments present in stroke patients depend on the type, location, extent, and progression of the brain lesion over time [20]. For this reason, stroke patients exhibit significant heterogeneity, i.e., a wide variety of symptoms at different levels and combinations.

Neurological complications and associated conditions

Following a stroke, individuals may experience a range of neurological complications and associated conditions that can have a significant impact on their daily functioning and quality of life. These complications may arise following a stroke, either as a direct result of the stroke or due to underlying conditions and secondary effects. Several prevalent neurological complications and associated conditions following stroke include:

Neurologic deterioration

Neurological deterioration is a common occurrence in stroke, impacting around half of patients who experience complications within 24 hours of the initial stroke event [21]. In the acute stage, these complications may involve brain swelling, the progression of ischemia leading to damage in nearby brain tissues, cerebral hemorrhage caused by the accumulation of small petechial hemorrhages, as well as hematomas, seizures, and even death [21, 22].

Neuromuscular impairments

Neuromuscular impairments are commonly observed after a stroke and can significantly affect a person's movement, coordination, and overall physical functioning. These impairments arise due to the disruption of the brain's ability to control and coordinate muscle activity [23]. Here are some key neuromuscular impairments that can occur after a stroke:

- **Hemiparesis or hemiplegia**: One of the most noticeable impairments is hemiparesis or hemiplegia. Hemiparesis refers to weakness on one side of the body, while hemiplegia refers to complete paralysis on one side. They are caused by damage to the motor cortex or its motor pathways in the brain on the opposite side of the body from where the stroke occurred. Hemiparesis, or hemiplegia, can affect the arm, leg, and face, significantly impairing balance, posture, mobility, and the performance of daily activities [7].

- **Spasticity and hypertonicity**: Spasticity is characterized by increased muscle tone and stiffness, resulting in involuntary muscle contractions or spasms. It is caused by damage to the upper motor neurons or their pathways that regulate muscle activity [24]. Typically, spasticity manifests in the muscles of the affected limbs, particularly the flexor muscles in the arm and the extensor muscles in the leg. It can restrict movement, impede function, impair coordination, and lead to muscle tightness and discomfort [24, 25]. Additionally, stroke can disrupt the balance between opposing muscle groups, leading to muscle imbalance. For example, in the upper limbs, there may be weakness in the muscles that extend the wrist and fingers (extensors) with spasticity in the muscles that flex the wrist and fingers (flexors), causing a characteristic clenched fist or wrist flexion posture [25].

- **Abnormal movement patterns**: Stroke can cause abnormal movement patterns, such as synergistic movements, where multiple muscle groups act together instead of moving independently. For example, when attempting to lift the arm, the shoulder may elevate with elbow flexion and wrist flexion, resulting in a stereotypical movement pattern known as flexion synergy [25].

- **Ideomotor apraxia**: This is the impaired ability to perform skilled or purposeful movements or actions that are not due to weakness, sensory loss, or a lack of comprehension. It is caused by damage to the parietal lobe or its connections to the motor cortex, the areas of the brain responsible for motor planning and coordination. It can affect one or both sides of the body, depending on the type and location of the stroke. It can impair activities of daily living that require planning and sequencing of movements, such as dressing, grooming, or using tools [26].

- **Sensory disturbances**: Sensory impairments can occur after a stroke, including changes in the perception of touch, pain, temperature, and proprioception (awareness of body position and movement). This can result in reduced sensitivity or altered sensation on the affected side of the body. These sensory deficits can further impact motor control and coordination [27].

- **Pain syndromes**: Post-stroke pain is an unpleasant sensation or discomfort that can be acute or chronic. It can have different causes and mechanisms after a stroke. It can limit movement, function, sleep, mood, and the quality of life [22]. Musculoskeletal pain experienced by stroke patients is attributed to impaired motor control and arises from the combined effects of neurological and musculoskeletal complications, such as improper limb and gait biomechanics. The pain can impact various areas of the body, including the shoulders, hips, muscles, and other regions. Hemiparetic shoulder pain is a debilitating and severe pain that frequently occurs on the side affected by hemiplegia or paralysis. It is often accompanied by a limited range of motion in the shoulder [28]. Another challenging pain syndrome is central post-stroke pain, which is characterized by heightened distress in response to unpleasant stimuli, like a pinprick. It is suggested that underlying causes of central post-stroke pain include hyperexcitation in the damaged sensory pathways, damage to the central inhibitory pathways, or a combination of the two [22, 28].

- **Impaired balance and coordination**: Stroke can disrupt the brain's ability to integrate sensory information for balance and coordination. This can lead to difficulties with maintaining a stable posture, walking, and performing activities that require precise movements and balance control [29].

Disorders of speech and language

Patients who have damage to the dominant hemisphere's cortex, which is typically the left hemisphere, exhibit impairments in speech and language. Aphasia is the term used to describe a communication disorder resulting from brain damage, characterized by difficulties in comprehending, formulating, and using language. It has been estimated that aphasia occurs in 21% to 38% of stroke patients [30]. Additionally, it is common for stroke patients to experience dysarthria, with reported incidences ranging from 48% to 57%. Dysarthria refers to a category of motor speech disorders caused by lesions in the central or peripheral nervous system involved in speech production. It can affect respiration, articulation, phonation, resonance, and/or sensory feedback. Lesions contributing to dysarthria can be found in the primary motor cortex in the frontal lobe, the primary sensory cortex in the parietal lobe, or the cerebellum [31].

Dysphagia

More than 50% of stroke patients experience dysphagia, which refers to difficulties or an inability to swallow. This condition can occur in cases of hemispheric stroke, brainstem stroke, or pseudobulbar and suprabulbar palsy. Brainstem stroke, in particular, has a reported incidence as high as 81%. Dysphagia can result from cranial nerve involvement, affecting the oral stage (CN V, trigeminal, and CN VII, facial), the pharyngeal stage (CN IX, glossopharyngeal, CN X, vagus, and CN XI, accessory), or both the oral and pharyngeal stages (CN XII, hypoglossal) [32]. Patients with dysphagia commonly experience various issues, including delayed triggering of the swallowing reflex, reduced pharyngeal peristalsis, and diminished lingual control. Contributing factors to swallowing difficulties include altered mental status, impaired sensation, inadequate jaw and lip closure, compromised head control, and poor sitting posture. Many patients exhibit multiple problems, such as drooling, difficulty swallowing food, compromised nutrition, and dehydration. Aspiration, which occurs when food, liquid, saliva, or gastric reflux enters the airway, is seen in approximately one-third of patients with dysphagia. Aspiration is a significant complication, as it can lead to acute respiratory distress within hours, aspiration pneumonia, and, if left untreated, even death [33].

Cognitive impairment

Post-stroke cognitive impairment is a common consequence among stroke survivors. Recent reviews and meta-analyses identified a pooled prevalence of post-stroke cognitive impairment of 53.4% and mild and major post-stroke cognitive impairment of 36.4 to 38 and 16%, respectively, measured within 1.5 years post-stroke [34, 35]. Stroke-induced cognitive impairment may be present depending on the location and extent of the brain damage and includes difficulties with memory, attention, executive functions, and visuospatial abilities. Memory problems may include difficulty recalling recent events or learning new information. Attention deficits can manifest as difficulties sustaining attention or easily becoming distracted. Executive functions, such as planning, organizing, and decision-making, may be impaired. Visuospatial impairments can affect the ability to judge distances, recognize objects, or navigate through space [36].

Stroke patients experience varied levels of memory loss, but the elderly are more prone to severe memory loss, or in extreme cases, dementia. Vascular dementia is the second-most common cause of dementia after Alzheimer's disease. About 10% of patients develop cognitive impairment after the initial stroke and about 30% at the end of one year. Risk factors for developing dementia include advanced age, previous stroke, lacunar infarction, diabetes mellitus, and left hemisphere stroke [23].

Spatial neglect

Spatial neglect, also known as hemispatial neglect, is a condition where individuals fail to be aware of or pay attention to one side of their body or the environment. It often occurs after damage to the right parietal lobe of the brain. Individuals with spatial neglect may ignore or neglect one side of their visual field, neglect the affected side of their body, or have difficulty with spatial orientation. This can result in challenges with daily activities, such as dressing, eating, or navigating their surroundings [37].

Post-stroke seizures

Seizures are frequently observed immediately after a stroke during the acute phase, typically within the first few weeks. While seizures can occur shortly after the stroke, they can also manifest weeks, months, or even years later. The development of scar tissue in areas of the brain affected by the stroke can generate abnormal electrical signals, leading to various types of seizures. Post-stroke seizures can be classified into three types: simple focal seizures, complex focal seizures, and generalized seizures. Simple focal seizures affect a small area of the brain and may cause muscle twitches or changes in taste or smell. Complex focal seizures affect a larger area of the brain and may cause confusion, memory loss, or altered awareness. Generalized seizures affect both sides of the brain and may cause loss of consciousness, stiffening, or jerking of the body [38, 39].

According to a meta-analysis conducted by Zou et al. [40], post-stroke seizures were found to affect approximately 6.93% of individuals who had experienced a stroke. The researchers further noted that post-stroke seizures were more prevalent in individuals who had suffered from a hemorrhagic stroke or a stroke involving the cerebral cortex.

Altered emotional status

Emotional and Psychological Changes: Stroke survivors may experience emotional disturbances, such as depression, anxiety, irritability, and emotional lability. These changes can result from the impact of stroke on the brain's emotional regulation centers. Depression is particularly common after stroke and can affect recovery and quality of life. Anxiety may arise due to concerns about future strokes or changes in abilities. Emotional lability refers to rapid and intense mood swings that are often unrelated to the individual's emotional state [41].

Medical complications

After a stroke, individuals may experience various medical complications that arise as direct or indirect consequences of the stroke or its resulting disabilities. These complications can occur during the acute phase of the stroke or during the long-term recovery phase. They can worsen the outcome and quality of life for stroke survivors and increase the risk of mortality, morbidity, disability, and stroke recurrence [42]. Some common medical complications after a stroke include:

Cardiac complications

Cardiac complications following a stroke are heart-related issues that can arise due to the stroke itself, its treatment, or its risk factors. These complications can impact the structure, function, or rhythm of the heart and increase the risk of death, disability, or recurrent strokes. They can manifest during the acute phase of a stroke or during the long-term recovery phase, and are often caused by factors such as direct brain damage, neurohormonal changes, inflammatory responses, or psychological stress [42]. Several examples of cardiac complications after a stroke include cardiac arrhythmias, heart failure, and coronary syndromes.

Cardiac arrhythmias refer to abnormal heart rhythms that may be too fast, too slow, or irregular. Damage to the insula, hypothalamus, or brainstem can result in them. These brain areas are also responsible for controlling blood pressure and heart rate. They can also be caused by increased sympathetic activity, a catecholamine surge, or an electrolyte imbalance after a stroke. They can impair cardiac output, blood flow, and oxygen delivery to the brain and other organs. They can lead to palpitations, dizziness, fainting, chest pain, or cardiac arrest. Common types of arrhythmias observed after a stroke include atrial fibrillation, atrial flutter, sinus bradycardia, sinus tachycardia, and ventricular tachycardia [42, 43].

Heart failure is another complication characterized by the heart's inability to pump an adequate amount of blood to meet the body's needs. It can arise from damage to the heart muscle or valves due to ischemia, infarction, inflammation, or stress following a stroke. Increased preload or afterload caused by fluid overload, hypertension, or pulmonary embolism can also contribute to heart failure post-stroke. This condition impairs cardiac output, blood flow, and oxygen delivery to the brain and other organs, resulting in symptoms such as shortness of breath, fatigue, edema, coughing, or even cardiogenic shock. Types of heart failure commonly observed after a stroke include systolic heart failure, diastolic heart failure, or neurogenic stress cardiomyopathy [42, 43].

Additionally, coronary syndromes can occur, which are conditions arising from reduced blood flow to the heart muscle due to the narrowing or blockage of the coronary arteries. Increased plaque formation, rupture, or thrombosis due to inflammation, oxidative stress, or hypercoagulability after a stroke can contribute to coronary syndromes. Furthermore, increased oxygen demand caused by factors like tachycardia, hypertension, or myocardial stunning post-stroke can also contribute to these syndromes. Coronary syndromes impair cardiac output, blood flow, and oxygen delivery to the brain and other organs, leading to symptoms such as angina, myocardial infarction, or sudden cardiac death. Examples of coronary syndromes commonly observed after a stroke include unstable angina, non-ST-segment elevation myocardial infarction (NSTEMI), or ST-segment elevation myocardial infarction (STEMI) [42, 43].

Pneumonia

Pneumonia is one of the most prevalent medical complications of stroke and the leading cause of fever within the first 48 hours following an acute stroke. After controlling for major confounders and covariates, pneumonia resulted in a three-fold higher risk of death in stroke survivors. Most stroke-related pneumonias are believed to result from aspiration. Aspiration pneumonia is a frequent complication after stroke. It occurs when food, liquid, or saliva enters the airway instead of the esophagus, leading to lung infections. Swallowing difficulties (dysphagia) can increase the risk of aspiration pneumonia [41, 42].

Post-stroke fatigue

Post-stroke fatigue is described as an overwhelming feeling of exhaustion or tiredness that is not related to physical exertion and does not typically improve with rest or sleep [44]. It is a frequently observed consequence of stroke, affecting a significant number of individuals, with estimates ranging from 25% to 85%. However, it is generally acknowledged that approximately 50% of stroke survivors experience post-stroke fatigue [45]. This fatigue is associated with unfavorable stroke outcomes and has implications for patients' adherence to medication, and effectiveness of rehabilitation. Consequently, it negatively impacts the quality of life and daily activities of patients while also adding to the burden experienced by family members and caregivers [44].

Poststroke fatigue is influenced by multiple factors according to a proposed model. These factors include predisposing factors such as prestroke fatigue or prestroke depression, triggers such as brain lesions and stroke-related inflammatory and neuroendocrine changes, as well as perpetuating factors including affective disorders, residual neurological deficits, cognitive decline, passive coping, reduced physical activity, and self-efficacy [46].

Incontinence

Bladder or bowel incontinence has a significant impact on the quality of life for stroke patients and is often a strong indicator of poor outcomes, disability, and the potential need for institutional care. During the acute phase, disturbances in bladder function are prevalent, affecting approximately 29% of cases [42]. Urinary incontinence can arise from either hyperreflexia or hyporeflexia of bladder function, impaired control of the sphincter muscles, and/or sensory deficits. Various factors contribute to post-stroke incontinence, including direct damage and disruption to the brain's micturition centers, leading to increased bladder reflexes and urgency [47]. While some stroke patients may retain normal bladder function, the development of mobility and cognitive impairments can hinder their ability to use the commode independently. This is especially common among individuals aged 75 and above, who may also have coexisting conditions like dysphagia and vision problems [48].

Frameworks and tools: assessing the impact and severity of stroke

International classification of functioning, disability and health (ICF) framework

The International Classification of Functioning, Disability and Health (ICF) is a framework for describing various aspects of functioning and disability at different levels (e.g., individual and societal levels) in relation to a health condition. In 2001, the World Health Organization developed and endorsed the ICF. The primary aim of this framework was to provide a common and universally understood language for health professionals, researchers, policymakers, and patients to describe human functioning and disability in a comprehensive and standardized way. The ICF consists of two parts: the first covers functioning and disability, which includes body functions and structures, activities, and participation. The second part covers contextual factors, which include environmental factors and personal factors. The ICF can be used to plan and evaluate interventions and policies for stroke prevention, treatment, rehabilitation, and support [49].

The ICF Core Set for stroke has been developed and defined following formal international consensus based on literature review, expert opinion, empirical data analysis, and field testing. The ICF Core Set for stroke consists of a comprehensive set of categories from the ICF framework that are considered relevant and specific to stroke-related impairments. These categories are organized into four domains: body functions, body structures, activities and participation, and environmental factors [50]. Here are the components within each domain:

- **Body functions**: This domain focuses on the physiological and psychological functions of the body. It includes categories such as muscle power functions, sensation of pain, sensory functions related to proprioception, muscle tone functions, motor reflex functions, gait pattern functions, functions of the cardiovascular system, functions of the digestive system, and functions of the genitourinary system. These categories assess impairments in body functions that can result from stroke.
- **Body structures**: This domain encompasses the anatomical parts of the body. Categories within this domain include structures related to the nervous system, structures related to the cardiovascular system, structures related to the respiratory system, and structures related to the musculoskeletal system. These categories assess structural changes or damage that may occur as a result of a stroke.
- **Activities and participation**: This domain focuses on the individual's ability to perform activities and participate in various life areas. It includes categories such as self-care, mobility, communication, interpersonal interactions, and major life areas (e.g., work, education, and leisure). These categories evaluate the impact of stroke on an individual's functional abilities and their ability to engage in daily activities and social roles.
- **Environmental factors**: This domain considers the external influences on the individual's functioning and participation. It includes categories such as support and relationships, attitudes of others, physical barriers, and social support services. These categories assess the environmental facilitators and barriers that may impact an individual's ability to participate fully in society.

The ICF Core Set for stroke provides a comprehensive framework for assessing and describing the functional consequences of stroke across these four domains. It enables healthcare professionals to evaluate the specific areas affected by stroke, develop tailored interventions, and monitor the individual's progress in their rehabilitation journey. The ICF Core Set can also assist in communicating and comparing information across different healthcare settings, promoting a holistic and patient-centered approach to stroke care [50].

National Institutes of Health Stroke Scale (NIHSS)

Stroke severity refers to the extent and impact of neurological deficits resulting from a stroke. Assessing stroke severity is crucial for guiding treatment decisions, predicting outcomes, and monitoring changes in the patient's condition over time. One widely used tool for evaluating stroke severity is the National Institutes of Health Stroke Scale (NIHSS) [51].

The NIHSS is a standardized neurological examination that evaluates specific functions to objectively quantify the severity of stroke-related impairments. It consists of 15 items that assess various aspects of neurological functions, including level of consciousness, extraocular movements, visual fields, facial muscle function, extremity strength, sensory function, coordination (ataxia), language (aphasia), speech (dysarthria), and hemi-inattention (neglect) [52, 53]. Each item on the NIHSS is scored based on the individual's performance. Each item on the NIHSS is scored on a scale from 0 to 4, with 0 representing normal function and 4 indicating severe impairment. The scores from each item are summed to calculate the total NIHSS score, which ranges from 0 (no stroke-related impairments) to 42 (maximum severity). Higher scores on the NIHSS indicate more severe stroke-related impairments [52, 53].

The NIHSS is commonly used in clinical practice, research, and clinical trials to assess stroke severity at the time of presentation and track changes over time. Moreover, the NIHSS score can provide valuable prognostic information, with higher scores generally associated with worse outcomes, including increased mortality and disability [51, 54].

1.2 Effect of stroke on balance and postural control

1.2.1 Definitions of balance and postural control

Balance and postural control are closely related concepts that involve the ability to maintain stability and control the body's movements, but they differ slightly in their meanings and aspects related to maintaining stability and motor control.

Balance refers to the ability to maintain the body's center of mass (COM) over its base of support (BOS) in both static and dynamic conditions [55]. This is achieved when all forces acting on the body are balanced, ensuring that the COM remains within the boundaries of the BOS and stability limits in a given sensory environment [56]. Postural control, on the other hand, refers to the ability to maintain a stable and upright posture in the face of external perturbations, such as sudden movements or changes in surface support [55]. This involves maintaining an appropriate relationship between the body segments and controlling the movement of the COM, as well as maintaining an appropriate relationship between the body and the environment for a task to adjust the body's posture to maintain balance [57]. To achieve this, postural control involves controlling the relative positions of body parts by skeletal muscles with respect to each other and gravity [58]. Balance and postural control are essential for most everyday activities, such as sitting, standing, reaching, and walking [59].

According to the scientific literature, the COM is a point that represents the average location of the total body mass, which is calculated by determining the weighted average of the COM of each body segment [60, 61]. The nervous system plays a critical role in regulating and controlling the motion of the body's COM by generating forces that control and manipulate the motion of the COM, resulting in coordinated movements that maintain the stability and balance of the individual [56]. To ensure that the COM stays within the support base, the center of pressure (COP) is constantly moving around the COM, creating a feedback loop that ensures the COM stays within the boundaries of the support base [62]. The COP refers to the point where the total force applied to the supporting surface is distributed evenly. This movement is necessary to adjust the body's orientation and balance during locomotion and other movements [57].

According to various researchers, examining the relationship between the COM and the COP provides a more comprehensive understanding of stability compared to analyzing either the COM or COP alone [57, 63]. Stability is determined by the scalar distance between the COM and the COP at a particular time [62]. When standing still, the difference between the COM and the COP is directly related to the horizontal acceleration of the COM [63]. The COP-COM scalar distance is considered as an "error" signal that is detected and utilized to regulate the postural control to maintain balance [64]. Therefore, researchers have employed the interaction between the COP and COM as an indicator of the effectiveness of postural control [62].

It has been suggested that the postural control system primarily regulates the COM, which is often used interchangeably with the center of gravity (COG). The COG refers to the vertical projection of the COM, while the BOS is the area of the body in contact with the supporting surface [65]. While stability is frequently discussed as controlling the COM relative to the BOS, what researchers usually imply is managing the COG's vertical projection relative to the BOS [62].

Specifically, the COG is a hypothetical point in space, determined biomechanically by measuring forces and moments, at which the net sum of all the forces is zero [65]. During quiet standing, the COG is situated just in front of the spine at around the S2 level. However, the position of the COG changes constantly as the body and its various segments move [65]. The base of support refers to the body surface that endures pressure as a result of the weight of the body and gravity. For instance, in a standing position, the feet serve as the base of support while, in a sitting position, it comprises the thighs and buttocks [66, 67]. The size of the BOS plays a significant role in determining the level of difficulty involved in maintaining balance. A broader BOS makes the task of balancing easier while a narrower base makes it more challenging. A larger BOS allows the COG to travel a farther distance while remaining over the base. Furthermore, the shape of the BOS can also affect the distance that the COG can move in specific directions [68].

The distance a body can move without falling or readjusting its BOS is limited by the size of the BOS. If the COG exceeds the BOS, the body will fall. To maintain balance, the individual may need to establish a new BOS by taking a step or reaching out. This boundary is commonly known as the stability limit or limit of stability [56].

The term "limits of stability" (LOS) refers to the farthest distance that a person can lean in any direction without losing their balance or changing their BOS. This means that a person can shift forward or backward, as well as side-to-side, while standing without taking a step or losing balance (falling over) [69]. The LOS is affected by several factors, including individual traits like height and the distance between the feet for mediolateral (ML) LOS, and height and foot length for anteroposterior (AP) LOS [70]. The position and movement of the COM, such as velocity and displacement, also affect LOS [61]. The midpoint at which LOS is centered is called the COM alignment, and the capacity to maintain a particular position or posture with as minimum movement or sway as possible is known as steadiness [71]. When standing, an individual typically demonstrates slight movements in their posture called postural sway, where they intermittently cycle back and forth from side to side and from heel to toe within a limited range [68, 72]. The path of the body's movement during standing is referred to as the sway envelope. Walking involves minimal up and down and side to side movements COM, resulting in a smooth, sinusoidal curve [73]. During sitting, the BOS is wider, and the COM moves downwards, positioned just above the supporting base, leading to increased LOS [56].

The postural control system works towards achieving stability and function through an integrated systems of control within the central nervous system (CNS) [74]. When external forces act on the body, such as displacement of the COM or movement of the BOS due to perturbations or a moveable platform, reactive postural control kicks in [75]. Corrective responses are initiated by the sensory inputs provided by feedback systems. On the other hand, proactive or anticipatory postural control is a pre-emptive response to destabilizing forces generated internally due to the body's own movements, such as catching a weighted ball [76]. Prior experiences of an individual allow various elements of the postural control system to be primed for upcoming movements using feedforward mechanisms [77]. The requirements for maintaining a posture can differ based on the specific task at hand and the surrounding environment [75]. With adaptive postural control, individuals are able to adjust their sensory and motor systems to accommodate the changing demands of the task and environment [68].

Achieving balance is the result of a multifaceted interplay between three main systems. Firstly, there are the sensory and perceptual systems that are responsible for detecting the position and movement of the body. Secondly, the motor systems are responsible for organizing and executing coordinated movements (motor synergies). Lastly, higher-level processes within the CNS are responsible for integrating these various systems and planning appropriate actions. Therefore, when studying balance, it is essential to scrutinize each of these three domains [56].

Sensory integration for balance control

Balance is a complex process that involves sensory information from multiple sources, including vision, somatosensory (proprioceptive and tactile), and vestibular (inner ear) systems [75]. The CNS receives crucial inputs from these sensory systems and integrates this information to generate motor responses that adjust body position and maintain posture control and balance [78]. These inputs include feedback about the outcomes of our actions and our surrounding environment [79]. By amalgamating these inputs, the CNS prompts both voluntary conscious actions and automatic unconscious modifications in movement and posture [78]. While each sensory system offers distinctive information, no single system can provide all the necessary information required for postural control and balance [80].

Somatosensory inputs refer to the sensory information received by the body, which includes cutaneous and pressure sensations from the body segments that are in contact with a supporting surface (such as the feet while standing and the buttocks, thighs, and feet while sitting), as well as muscle and joint proprioception throughout the body [81]. This gives information about the body's relative orientation and movement in reference to the support surface in order to maintain balance [78]. The maintenance of upright postural control heavily relies on cutaneous sensation and proprioception in the feet/ankles and hips, which trigger automatic postural responses [81]. Somatosensory loss can significantly impair balance, making it crucial to conduct sensory examinations of the trunk and extremities [56].

The visual system is crucial for perceiving movements, detecting the orientation of body segments, and determining the body's orientation in space, which is known as visual proprioception [78]. There are two distinct functional visual systems: focal vision (also called cognitive or explicit vision), and ambient vision (also called sensorimotor or implicit vision). Focal vision responds consciously to visual stimuli, and is essential for environmental navigation, as well as the identification of environmental hazards. While ambient vision uses the entire visual field to unconsciously detect movement of the self in relation to its surroundings, such as head movements and postural sway. Therefore, each visual system serves a distinct purpose [65, 81].

Furthermore, vision contributes to the righting reactions of the head, trunk, and limbs, commonly referred to as optical righting reactions [82]. Typically, both focal and ambient vision are required for postural control [83]. Vision is essential for feedforward or anticipatory postural control in various environments [84]. This includes planning for functional activities like reaching and grasping, as well as successful navigation during gait [82]. Balance is also impaired by vision loss [83]. For instance, in individuals with optic ataxia caused by brain injury, focal vision allows them to recognize objects, but their impaired ambient vision makes it difficult to accurately guide their hand to reach or grasp the object [56]. Conversely, patients with visual agnosia caused by stroke cannot recognize objects but can use their ambient visual system to navigate an environment or accurately reach and grasp objects [56]. Furthermore, vision contributes to the righting reactions of the head, trunk, and limbs, commonly referred to as optical righting reactions [81, 83].

The vestibular system plays a crucial role in maintaining postural control and balance by providing the CNS with information regarding the head's position and motion [85]. This system consists of two distinct parts: the otolith system and the semicircular canals. The otolith system detects the head's position with relation to gravity by sensing linear acceleration and orientation of the head in the horizontal and vertical planes. On the other hand, the semicircular canals (SCCs) detect head movements by sensing angular acceleration and deceleration forces acting on the head [86]. Both sets of semicircular canals are stimulated by head movements, with the vestibular nerve on one side becoming inhibited while the other becomes excited [85]. The otoliths respond to slow movements of the head and positional changes in relation to gravity, while the SCCs respond to rapid (phasic) movements of the head [65].

The vestibular system is responsible for stabilizing gaze during head movements through the vestibuloocular reflex (VOR) and regulating postural tone and muscle activation through the vestibulospinal reflex (VSR) [85]. It also provides sensory redundancy by obtaining information from each separate vestibular apparatus. If one side of the peripheral vestibular system is damaged, the intact canals on the opposite side can capture the information [86].

The ability to differentiate self-motion from environmental motion is essential for maintaining balance, and the vestibular system plays a crucial role in this process. Balance is impaired when there is a loss of vestibular function, which can happen when the peripheral sensory receptors or afferent cranial nerves are damaged due to injury or disease. Testing for vestibular function can be done using positional and movement tests, and symptoms of vestibular dysfunction, such as dizziness, vertigo, and nystagmus, are observed in patients during these tests [56, 65]. During standing, all sensory information plays a role in maintaining posture [87]. The sensory weighting theory suggests that the CNS assigns varying degrees of importance to different sensory inputs based on the specific sensory environment and task [87]. Quiet stance refers to standing on a stable surface with no disturbances in the surroundings, while perturbed stance involves standing during a brief movement of the support surface or when the COM is shifted over the BOS [57, 88].

In healthy adults during quiet stance, somatosensory inputs are given greater weight by the CNS [79]. However, in the event of an unexpected perturbation, somatosensory inputs are activated quickly and contribute significantly to the initial postural re-stabilization, while vision and vestibular inputs with slower processing speeds are utilized for later components of the response [74]. When there is impairment of somatosensory inputs or when there is somatosensory conflict (e.g., standing on dense foam), the CNS relies more on visual inputs [74]. When both visual and somatosensory inputs are impaired or absent, vestibular inputs become extremely important for the maintenance of posture and the resolution of sensory conflicts [79].

The use of sensory inputs by the CNS is adaptable and varies based on the specific task and context. The CNS weighs and prioritizes sensory inputs based on their availability, timing, and accuracy to generate appropriate balance responses [89].

Stable balance can be maintained with considerable disability, on unstable surfaces, or in sensory conflict situations because sensory inputs are redundant. Nonetheless, significant impairments in balance control will be evident if more than one sensory system is impaired [80, 90]. For instance, a patient with chronic diabetes who has both severe diabetic neuropathy (loss of foot and ankle somatosensory inputs) and severe diabetic retinopathy (impairment of vision) will show severe postural instability and fall risk [56]. Furthermore, the cognitive system plays a crucial role in processing and interpreting information enabling the CNS to plan optimal postural responses [91]. The attentional demands can vary depending on the task (familiar response versus new learning) and the environment (dual-tasking or open versus closed) [92, 93]. Individuals with cognitive or attention impairments show a higher risk of falling, particularly during activities that require a high level of stability [93].

Motor strategies for balance control

The process of postural adjustments is intricate and shows a remarkable ability to adapt to the demands of both the task and the surrounding environment [72]. These adjustments can range from simple stretch reflex reactions to more complex movement patterns or synergies that involve specific muscle groups working together [68]. The muscles closest to the body's BOS play a critical role in maintaining balance, and as the COM is displaced farther from the BOS, the postural response becomes more pronounced [63].

Reflexes

In order to generate typical postural movements, multiple levels of neuromuscular control must operate effectively. At the fundamental level, postural orientation is aided by reflexes and righting reactions [94]. Additionally, the VOR and the VSR assist in orienting the eyes, head, and body in relation to the self and the surrounding environment [95].

The semicircular canals in the head detect movement, which then elicits a response in the oculomotor system known as the vestibuloocular reflex. This results in the eyes moving in a direction opposite to that of the head, but with equivalent speed [96]. The otoliths are also stimulated by movement and trigger a response within the eyes to linear head motion. When the head is quickly moved, the VOR is activated [96, 97].

The VOR enables the synchronization of eye and head actions. It assists in stabilizing gaze when the head is in motion while the eyes are fixated on an object [98]. Along with the VOR, visuo-ocular responses function simultaneously to allow "smooth pursuit" when the head is stationary while the eyes are moving, and visual tracking when both the eyes and the head are moving together [99].

The VSR is responsible for regulating movement and providing stability to the body. It is activated by both the semicircular canals and the otoliths, which in turn modulate the muscles of the neck, trunk, and limbs after any head movement to maintain balance [100]. The VSR is crucial in maintaining body stability during head movements and also for coordinating the trunk's movements with those of the limbs in upright postures [100]. Righting reactions are also significant, as they assist in maintaining the head's orientation with respect to the trunk and the position of the head in relation to gravity. These reactions include optical head righting, labyrinthine head righting, and body-on-head righting [65].

Automatic postural responses

The automatic postural responses function by maintaining the body's COM over the BOS, serving as a set of organized, long-loop responses that strive to maintain balance. These responses are functionally organized in that they are specific to the perturbing stimulus's direction and amplitude, yet remain stereotypical [101]. For instance, if a push is exerted on the right side, the response will be a shift towards the left, in the direction of the midline [59]. The size of the stimulus directly correlates with the magnitude of the response [102]. Such responses occur in reaction to unexpected stimuli and are typically triggered by somatosensory inputs. Since they happen swiftly, taking less than 250 milliseconds, they do not fall under immediate voluntary control [88, 103].

There are four different automatic postural responses that have been identified. The ankle strategy refers to controlling postural sway by utilizing movements in the ankles and feet. This strategy involves moving the body, including the legs and trunk, as a pendulum around the ankle joints in order to shift the COM forwards and backwards [65]. The ankle strategy is mainly used to control anteroposterior sway, as the ankle joint has the greatest range of motion in this direction [104]. When using the ankle strategy, muscles are activated in a specific sequence, beginning distally to proximally. During forward sway, the gastrocnemius muscle is activated first, followed by the hamstrings and paraspinal muscles. During backward sway, the anterior tibialis muscle is activated first, followed by the quadriceps and abdominals [105, 106]. The ankle strategy is typically used when the frequencies of sway are low and COM disturbances are small and within the LOS [56].

The hip strategy involves using the pelvis and trunk to control postural sway. This strategy includes shifting the COM by flexing or extending at the hips, resulting in movements of the trunk and hips in opposite directions [65]. The hip strategy uses a pattern of muscle activation that begins with proximal muscles before distal muscles. During forward sway, the abdominal muscles activate first, followed by the quadriceps, while during backward sway, the paraspinal muscles activate first, followed by the hamstrings [105, 106]. The hip strategy is essential for maintaining mediolateral stability, activating hip muscles like abductors and adductors to control lateral sway. This strategy is particularly useful when sway frequencies are faster, disturbances of the COM are larger, or the support surface is small or compliant, such as standing on foam [56].

The suspensory strategy aims to make it easier to control the body's COM by lowering it closer to the BOS. This is achieved through flexion of both lower extremities or a small squatting movement, which shortens the distance between the COM and the BOS. The suspensory strategy is commonly utilized in situations that require both stability and mobility, such as windsurfing [65].

The stepping strategy involves using quick steps or hops in the direction of a displacing force (such as forward or backward) to realign the body's BOS with its COM [65]. In cases of lateral instability, the individual will take side or cross steps in order to bring the BOS back under the COM. Typically, the stepping strategy is used when ankle and hip strategies are insufficient to regain balance in response to fast, significant postural perturbations, especially when the COM goes beyond the BOS [56].

Despite these strategies being studied as separate movement patterns, studies have demonstrated that combinations of these strategies are used during normal balance. It is important to consider the control of these strategies as a continuum, as the CNS switches between patterns swiftly based on the surroundings and activity's control requirements [107]. For example, when faced with a destabilizing force, an individual may first use an ankle strategy, but may progress to a hip strategy as more control is needed to regain balance. In cases where ankle and hip strategies are insufficient, a stepping strategy may be required to prevent falling [108]. The CNS constantly monitors sensory feedback and adapts movement strategies for multidirectional postural control, enabling flexibility and adaptability [109].

When sitting, the base of support consists of the buttocks, thighs, and feet if touching the support surface. To maintain balance, the body uses postural strategies that involve moving the trunk around the hips [110]. When swaying backward, the hip flexors are primarily activated, along with the abdominals and neck flexors. When swaying forward, the hip extensor muscles, along with the extensors of the neck and trunk, are activated [111]. When reaching forward with the arm, the tibialis anterior muscle is recruited, and the gastrocnemius muscle helps to stop forward movements and return the body to an upright sitting position [112]. Inputs from the somatosensory system resulting from pelvic rotation backwards may play a significant role in initiating postural strategies during sitting [113]. When there are lateral movements in the frontal plane, the hip abductor and adductor muscles, along with the quadratus lumborum muscle, are important for maintaining mediolateral stability [114].

1.2.2 Clinical assessment of balance and postural control

Balance tests can be categorized according to their type, with each type of test measuring various aspects of postural control. Static balance tests, also known as quiet standing, involve the individual standing still, and the objective is to maintain balance. These tests may or may not include balance disturbances, also referred to as perturbations. Dynamic balance or active standing tests, on the other hand, require the patient to voluntarily shift their weight while standing. Sensory manipulation tests employ changing surface and visual conditions to assess how effectively the CNS uses and reweights sensory inputs for postural control. Functional balance, and mobility scales evaluate the ability to perform whole-body movement tasks like sitting to standing, walking, and stepping over obstacles [65].

Static (quiet standing)

The classic Romberg test was initially designed to assess the integrity of the dorsal column of the spinal cord, which can provide important information about the presence of diseases in the proprioceptive pathway when standing upright [115]. During the test, the patient stands upright with feet together, arms at their sides, and eyes open for 20 to 30 seconds while postural sway is observed. Next, the patient closes their eyes for another 20 to 30 seconds, and postural sway is again observed and compared to the previous open-eye observation. The examiner judges the amount of sway subjectively, considering the degree of oscillation and its location (whether it's from the ankles, hips, or the entire body). Any excessive sway, loss of balance, or stepping during the test is considered abnormal [116]. To quantify the sway, a videotape, forceplate, or accelerometer can be used [117].

The Sharpened Romberg or tandem Romberg test, on the other hand, requires the patient to stand in a heel-to-toe position, with one foot directly in front of the other and their arms folded across their chest. As with the original Romberg test, the patient is assessed with their eyes open first, followed by the same test with their eyes closed for 60 seconds [115, 116].

The One-legged stance test (OLST) is a widely used assessment method that involves testing both legs alternately while observing any differences between them. During the test, the patient stands on both feet with hands on hips or crossed over the chest. They then lift one leg and hold it with the hip in a neutral position and the knee flexed to a 90-degree angle, without pressing the lifted leg against the stance leg [115]. The duration of the test is timed with a stopwatch, and five 30-second trials are conducted for each leg in alternating fashion. The highest possible score for each leg is 150 seconds [118].

Dynamic (active standing)

To assess volitional control of the COM, the patient is instructed to perform voluntary movements that necessitate weight shifting [119]. The Functional Reach Test was designed to quickly screen balance issues in the elderly individuals and assess their risk of falling [120]. The test measures the maximum distance a person can reach forward, beyond their arm's length, while maintaining a stable BOS in a standing position. The assessment involves utilizing a horizontal measuring tool affixed to the wall, set at the same level as the patient's acromion. The patient will stand alongside the wall without making contact, with their feet positioned at a regular stance width and their weight evenly distributed. They will then flex their shoulder to a 90-degree angle while keeping their elbow extended and their hand clenched into a fist. Firstly, the position of the third metacarpal is measured along the length of the yardstick to establish a baseline. To test the patient's forward reach ability, they will be directed to lean forward as far as they can while maintaining their balance and without stepping forward. Using the third metacarpal as a reference, a second measurement will then be taken. The difference between the initial and second measurements will be calculated [120, 121].

The Functional Reach Test has a major limitation as it only measures sway in the forward direction. To overcome this limitation, a modified version of the test has been developed that measures sway in four different directions. The Multidirectional Reach Test evaluates an individual's ability to reach in the forward, backward, and lateral directions [122]. To test backward reach, the patient is positioned in the same way as in the Functional Reach Test, but with the yardstick in a reversed position to detect posterior movements. For lateral reach, the patient stands facing away from the wall and reaches as far as possible to the right and left sides. The test consists of three trials, preceded by one practice trial. The therapist records the reach in inches for all three trials and calculates the average of the three. The reach distance is influenced by various factors, such as the individual's size, height, gender, age, and health. It is important to document the movement strategy used during the test, such as the use of ankle or hip strategy, trunk rotation, or scapular protraction [122].

The limits of stability test measures postural sway away from the midline in eight directions using a computerized forceplate. To perform the test, individuals adopt a predetermined foot position and control a cursor on the computer screen by shifting their weight. They are required to navigate the cursor from midline to eight different targets on the screen while maintaining balance. The test evaluates various parameters, including movement velocity, directional control or path sway, excursion measures which calculate the length of the trajectory of the COG, and reaction time. It is recommended that the test be performed twice, once for familiarization and subsequently repeated for scoring purposes [123].

Functional scales

To conduct a comprehensive assessment of balance, it is important to use tests that evaluate both impairment-based tests that evaluate body systems and activity-based functional measures. Functional balance scales are useful in identifying activity limitations. By observing the individual's performance in tasks that require balance skills, a clinician can identify any activity limitations that may impact the individual's ability to participate in daily life activities and determine the tasks that require practice. Clinical balance measures typically involve scoring or timing the patient's ability to maintain balance in certain postures or while performing motor tasks [124].

The Tinetti "Performance Oriented Mobility Assessment" (POMA) was developed to evaluate the balance and gait function of older adults [125]. It is a reliable and brief tool that measures both static and dynamic balance [126]. The test is organized into two subtests which assess balance and gait separately. The balance subtest contains nine items which evaluate the ability of the individual to perform sit-to-stand tasks, while the gait subtest consists of eight items that focus on spatiotemporal gait characteristics. The scoring for the Tinetti POMA assessment varies between items, with some scored on a two-point scale (0 or 1) and others on a three-point (0 to 2) scale, where higher scores indicating better performance [127]. The Tinetti POMA is the oldest clinical balance assessment tool and is widely used among older adults [126]. It is also utilized to predict fall risk in individuals who have had a stroke [128]. However, some of the items are challenging to assess using a three-point scale, resulting in poor specificity. Although the Tinetti POMA is widely used in gerontology, the gait subtest is seldom used, and it may not be suitable for younger people with balance impairments due to ceiling effects [126].

The "Berg Balance Scale" (BBS) is a tool utilized to evaluate functional balance, consisting of 14 tasks that patients are instructed to perform [129]. A rating system on an ordinal scale of 0 to 4 is employed by the examiner to assess the client's performance on each task, with 0 representing inability to perform and 4 signifies the ability to perform without difficulty. Originally, this scale was designed to determine the risk of falls in elderly people, but it has also been employed in stroke patients and is perhaps considered the most commonly used balance measure in stroke rehabilitation [130]. Despite the fact that the BBS has proven to be an effective balance assessment tool in poststroke patients, some studies have noted limitations such as floor and ceiling effects, and thus, it has been suggested that it be used in combination with other balance measures [131].

The "Timed Up and Go Test" (TUG) [132] is a clinical balance test that is simple and quick, and it is likely the most reliable due to its use of stopwatch timings instead of rating scales. It is widely used in clinical settings because of its ease of administration [126]. The aim of the test is to determine how many seconds it takes an individual to perform a set task that involves rising from a standard chair, walking 3 meters, turning around, returning to the chair, and sitting back down. During the test, patients are instructed to perform the task at their usual pace. They are also required to wear their regular footwear and use assistive devices if necessary [133]. While the test was initially developed to assess frailty in older adults, it is now commonly used to evaluate the risk of falls in this population. However, it can also be used with other individuals, including those who have had a stroke [134]. The TUG's clinical usefulness is likely due to its ability to evaluate several important mobility skills, such as turning and sit-to-stand transitions that require balance control, as well as gait. However, like other clinical scales, the TUG has limitations, as it cannot differentiate between the various subcomponents of balance and gait that may be affected [134, 135].

Posturography

Posturography is a computerized laboratory test that quantitatively assesses balance. This test has several advantages over traditional functional clinical balance examinations, which include the inconsistency in test performance both within and between examiners, the subjectivity of scoring, and the sensitivity to minor changes [136]. Posturography also used to assess the effectiveness of therapeutic interventions, and to predict the risk of falling [137]. Two tests are used in posturography the sensory organization test and the motor control test.

The role of sensory inputs is crucial in maintaining balance, but there are only a few tests available to assess their influence on achieving a balanced performance outcome. The Sensory Organization Test (SOT) is a computerized system developed by Nashner to evaluate this aspect. It consists of a movable forceplate and visual surround that can be adjusted systematically to alter the surface and visual environments [101, 103]. The patient is asked to stand quietly on the forceplate with feet parallel and arms at the sides while undergoing one of the six tests, with their eyes open or closed depending on the condition being tested. The SOT test involves performing three 20-second trials under each of the six sensory conditions. During conditions one, two, and three, the support surface is fixed, while during conditions four, five, and six, it is sway referenced to the patient's body sway [138].

The SOT test is based on the fact that the integration of three peripheral inputs - vision, the vestibular system, and proprioception - to enable patients to maintain their balance. If any one of these inputs is absent, the patient must depend on the remaining inputs to maintain equilibrium [138]. In conditions one and four, visual inputs are undisturbed, while in conditions two and five, vision is absent as the eyes are closed. Conditions three and six involve a movable visual surround that is sway-referenced, maintaining a constant distance between the eyes and the visual environment despite body sway, rendering visual inputs inaccurate for balance maintenance. Similarly, the responsive surface movement in conditions four, five, and six maintains a near-constant ankle joint angle despite body sway, making somatosensory information from the feet and ankles unreliable for use in balance maintenance. The SOT test, therefore, provides a comprehensive assessment of the influence of sensory inputs on balance maintenance [65, 138].

The motor control test assesses reflexive motor responses to sudden and unexpected movements of the supporting surface, both forward and backward [139]. The magnitude of the movements is determined by the patient's height, and the test involves three consecutive trials of varying intensities of perturbations in both directions [140]. Latency, which refers to the time it takes for the body to respond to the movement, is calculated for each leg and direction and can be used to detect abnormalities in the motor system [136]. If the latency is prolonged in both directions, it indicates a central lesion, whereas if it is prolonged in only one direction, it could indicate a peripheral or central lesion [139].

1.2.3 Balance and postural control impairments after stroke

A stroke can cause a variety of impairments that make individuals more susceptible to falls. One significant impairment frequently observed in this group is balance dysfunction [141]. Research indicates that 83% of stroke patients suffer from balance impairments, which can cause gait problems, including reduced gait speed and alterations in different phases of gait, ultimately increasing the risk of falling [142]. Within the initial six months following a stroke, the incidence of falls in this population is approximately 37% to 73%, with chronic stroke patients having a two-fold higher rate of falls than healthy individuals [141].

Falls and the fear of falling can contribute to a sedentary lifestyle, leading to more significant limitations in activities of daily living (ADL) and a reduced quality of life [143]. Furthermore, falls can increase the duration of hospitalization and have a substantial emotional and economic impact on the patients, their families, and society as a whole [142]. Stroke can affect both the sensory input and motor output systems involved in balance control, leading to deficits in balance control and an increased risk of falls [144].

After a stroke, hemiparesis is the most common neurological impairment, and patients with hemiparetic strokes often experience balance and postural control abnormalities [145]. These abnormalities are prevalent in hemiparetic stroke patients and are believed to contribute to hinder their ability to recover their independence in activities of daily living and mobility, and also increase their risk of falls [130]. The balance impairment experienced after a stroke is multifaceted. It includes weight-bearing asymmetry [146], muscle weakness [147], decreased range of movement [145], abnormal muscle tone (spasticity) [29], disturbed sensory organization and multisensory integration [148], decreased motor coordination [130], and cognitive failure [149]. All of these factors contribute to balance and postural disturbances at different levels.

Biomechanical constraints

The capacity to maintain balance while keeping the body's COM within the stability limits or boundaries of the BOS is defined as postural stability. These limits are not fixed and can be adjusted based on the task, movement, individual biomechanics, and environmental factors [62]. Impairments in muscle control, strength, tone, and range of motion can affect postural control. The CNS possesses an internal representation of stability limits, which it utilizes to determine the appropriate movements and balance maintenance [150].

The quality and size of the BOS is the most significant biomechanical constraints to balance [150]. In patients with hemiparesis, the BOS may be affected by weight-bearing asymmetry, muscle weakness, impaired muscle control of the affected limb, spasticity, and limited range of motion. Individuals who have experienced a stroke have been found to have a decreased BOS, particularly in the medial-lateral direction, compared to healthy individuals during quiet standing [29, 137, 146]. This decrease in BOS can negatively impact the ability to maintain balance, especially during tasks involving weight shifting or reaching. Consequently, stroke patients may widen their stance to increase their BOS and improve balance control [151]. Furthermore, they may struggle to shift their BOS in response to external perturbations, which may result in falls [128].

Postural sway refers to the movement of the COM while standing [150]. Research on balance impairments has consistently found that individuals who have suffered a stroke exhibit greater postural sway compared to healthy volunteers of similar age [137, 152, 153]. This is accompanied by changes in weight distribution patterns, resulting in reduced weight being borne by the weaker leg and smaller excursions when shifting weight around the BOS, especially towards the weaker leg. This pattern is observed across all balance aspects, including static and dynamic balance, as well as responses to external perturbations, even in individuals with stroke who have recovered high levels of function and are ambulatory in the community [29, 151]. Static and dynamic posturography assessments have revealed that postural sway is heightened after a stroke and is associated with prolonged weight-bearing asymmetry [154].

Stroke can significantly affect the COP of an individual. The COP is the point where the total force exerted by the body on the ground is concentrated, and it reflects a response from the neuromuscular system to correct deviations in the COM. The COP is a critical parameter in assessing postural stability and balance [57]. There are numerous post-stroke deficits that compromise postural control and would be reflected in COP differences between the two legs, such as sensorimotor changes [124], muscle activation patterns [155], weight bearing asymmetry, and difficulty shifting the weight to the paretic limb [145]. can lead to a shift in the COP, resulting in a more variable and unstable COP. This instability can make it challenging to control the body's movement and maintain balance during weight-bearing activities [29]. The COP could shift towards the non-paretic side during standing to minimize instability due to unilateral lower limb impairment, indicating a shift in weight distribution towards the unaffected side of the body [145]. Additionally, stroke survivors often demonstrate increased sway of their COP during quiet standing. This is because stroke patients have a higher COP velocity during quiet standing in comparison to healthy individuals, which suggests that their COP is more variable and unstable and a reduced ability to maintain balance and postural control [156, 157].

Weight-bearing asymmetry (WBA) refers to the distribution of body weight between the legs during standing or movement. After a stroke, individuals may experience weakness or paralysis in one leg, which can lead to a reduced weight-bearing capacity on the paretic leg and greater weight distribution on the non-paretic leg. This imbalance in weight-bearing can make it difficult to maintain balance and perform weight-bearing activities, such as standing or walking [130, 158]. In hemiparetic patients, clinical and laboratory assessments can reveal unequal distribution of weight in the lower extremities, leading to a displacement of the COM towards the unaffected side [145]. It has been found that individuals with stroke had a greater anterior shift in their COM, and a higher COM displacement during standing and walking compared to healthy individuals [159]. Patients may also experience difficulties in actively shifting and maintaining their COM on the affected side, particularly in the lateral and anterior directions [160]. In addition, patients may exhibit reduced stability in the frontal plane, compromised muscle control, which results in increased body oscillations while standing [137, 152, 161]. Moreover, individuals with stroke may have difficulty shifting their COM during tasks that require reaching, indicating a decreased ability to control the COM, which can affect their ability to maintain balance, leading to balance impairments [159].

Post-stroke individuals exhibit reduced static and dynamic postural stability in comparison to their healthy peers. These individuals display difficulties in controlling their posture both when standing upright and when leaning forward and attempting to regain balance by taking a step to prevent a fall. During quiet standing, they display greater postural sway which is characterized by larger vertical displacement and speed of their COM as well as a smaller anteroposterior maximal COM displacement. These factors increase their risk of falling when encountering postural challenges in their daily life [162]. Furthermore, stroke can affect the LOS by reducing the ability to control the COM within the BOS, leading to a smaller LOS. This results in a reduced ability to control body movements within the stability limits, which can make it challenging to perform activities that require reaching or shifting weight, and is associated with an increased risk of falls. Individuals with stroke may have difficulty adjusting their LOS in response to external perturbations, which can affect their ability to maintain balance [163].

Sensory impairments and post-stroke balance control

The control of posture relies on three primary sensory modalities: somatosensory, visual, and vestibular. It is essential to integrate information from these systems to maintain proper balance and postural control. This sensory input is not static and is continuously regulated and modified by changes in the environment [79]. In situations where multiple sensory inputs are available, the CNS prioritizes one system over the others to maintain balance in the upright position [164]. Typically, healthy adults rely on somatosensory information from their feet in contact with a firm BOS to maintain balance, with somatosensory inputs accounting for 70% of the required information, while vestibular and visual inputs account for 20% and 10%, respectively [165]. However, when proprioceptive information is unreliable, such as during sway, visual and vestibular inputs become more relevant sources of information [79, 165]. This ability to select and rely on the most relevant sensory input for any given circumstance is known as sensory reweighting [89]. For example, when standing on an unstable surface, the CNS increases the weighting of vestibular and visual information and reduces dependence on surface somatosensory inputs for postural orientation. Conversely, in darkness, balance control relies on somatosensory and vestibular feedback.

One area that is commonly affected by stroke is the sensory organization and regulation of balance control. The regulation of balance control involves using this sensory information to generate appropriate motor responses to maintain balance [148]. Stroke can disrupt this integration, leading to deficits in balance control and increased risk of falling [166]. Sensory impairments can affect post-stroke balance by reducing an individual's ability to detect changes in their body position and movement, which can further increase the risk of falls [148]. The effects of stroke on the sensory organization and regulation of balance control depend on several factors, including the location and size of the stroke, the severity of resulting impairments, and the individual's pre-stroke functional status [167].

Visual input is essential for integrating sensory information required for balance control. It plays a crucial role in balance control by providing information about the environment, which allows individuals to perceive potential hazards and the body's position relative to the environment, and regulate body orientation during movement. Stroke can lead to visual impairments, such as hemianopia, visual neglect, or visual processing deficits, which can impair the ability to process visual information accurately and affect balance control. Individuals with visual impairments after a stroke often rely more on somatosensory and vestibular inputs to maintain balance, which can lead to compensatory strategies that may not be optimal for stability [167].

Studies have shown that individuals with visual deficits after stroke have increased postural sway, longer reaction times, and difficulty adapting to changes in the environment. This can lead to a higher risk of falls, decreased mobility, and reduced quality of life. These findings suggest that vision plays a significant role in balance control and that visual deficits after a stroke can have a detrimental effect on balance [148, 168]. Deficits in visual processing can lead to postural instability, decreased gait speed, and an increased risk of falls [166]. Furthermore, research has investigated interventions that can improve balance control in individuals with visual deficits after a stroke. These interventions may include visual training programs to improve visual processing and compensate for visual field deficits, as well as balance training programs that incorporate visual feedback to enhance balance control [168, 169].

A stroke can affect the vestibular system in several ways, which can affect the integration of sensory inputs needed for balance control. It can cause damage to the vestibular nuclei in the brainstem, which are responsible for processing information from the vestibular organs located in the inner ear. Damage to the vestibular nuclei can result in decreased vestibular input, leading to dizziness, vertigo, and a loss of balance control. Additionally, a stroke can also cause damage to the cerebellum, which is responsible for coordinating movements and maintaining balance. Damage to the cerebellum can result in ataxia, a condition characterized by uncoordinated movements and an inability to maintain balance [170, 171].

Patients with stroke-related vestibular dysfunction may experience dizziness and vertigo, which can be exacerbated by head movements. They may also exhibit abnormal eye movements, such as nystagmus, which can affect their ability to maintain visual stability and contribute to dizziness [164]. Studies have shown that individuals with vestibular dysfunction after stroke have increased sway during standing and walking tasks and rely more on visual and somatosensory inputs to maintain balance [164, 172]. In addition, vestibular dysfunction has been associated with an increased risk of falls in individuals with stroke [173]. It has been found that damage to the vestibular system after stroke was associated with balance impairment, with greater impairment in patients with more severe vestibular dysfunction [174]. Furthermore, stroke-related vestibular dysfunction can also lead to gait abnormalities, such as decreased gait speed and increased variability in step length and timing [175]. Vestibular rehabilitation has been shown to be effective in improving balance and reducing symptoms of dizziness and vertigo in patients with stroke-related vestibular dysfunction [176]. Additionally, it has been found that vestibular rehabilitation was effective in improving balance, independence in ADLs, and improving overall quality of life in these patients [177].

One of the common consequences of stroke is the disruption of the somatosensory system, with a prevalence of between 50 and 80% of stroke survivors [178]. This system plays an important role in maintaining balance and posture. It provides critical sensory feedback to the brain about the body's position and movement, which is necessary for maintaining a stable stance and making adjustments to maintain balance [78]. A stroke can affect the somatosensory system, which includes the sensory receptors and processing centers responsible for balance control. When a stroke occurs, it can damage the brain areas responsible for receiving and interpreting sensory input from the body's muscles, joints, and skin [178]. This can result in sensory deficits, including loss of sensation or altered perception of touch, pressure, proprioception (the sense of body position and movement), or altered spatial perception, that can have a significant impact on balance control and mobility [179].

Research has shown that stroke survivors commonly experience somatosensory deficits, particularly on the side of the body opposite to where the stroke occurred [178]. The severity of somatosensory deficits depends on the location and extent of brain damage caused by the stroke. For example, a stroke that affects the somatosensory cortex, which is responsible for processing sensory information from the body, can cause loss of sensation on one side of the body (hemianesthesia) or altered sensation [180]. Additionally, the somatosensory deficits caused by stroke can also lead to changes in the motor control systems involved in balance control, such as the cerebellum and basal ganglia. When these areas are damaged, it can impair the ability to coordinate movements and adjust posture in response to sensory input, leading to difficulties with balance and coordination [181].

Impairment of somatosensory function in the legs can have negative effects on both balance and gait. A study by Annino et al. [182] found that stroke survivors with somatosensory deficits had poorer balance and reduced postural stability, and were more likely to experience falls compared to those without somatosensory deficits. After a stroke, deficits in tactile sensation in the soles of the feet are linked to lower balance scores and increased postural sway while standing [183]. Feedback from tactile and proprioceptive senses is essential for detecting the amount of weight borne through the limb. Therefore, deficits in these senses may hinder the ability to detect the load on the paretic limb, which can lead to reduced weight-bearing and contribute to balance problems and falls [184]. In fact, stroke survivors with somatosensory impairment are more likely to experience falls than those without [27]. Impaired load detection can also lead to gait asymmetry, especially during the push-off phase [184], and proprioception in the legs affects variability in stride length, gait speed [185], and gait endurance in stroke survivors [186]. Leg somatosensory impairment is considered the third most significant independent factor contributing to reduced gait speed in these individuals [187]. Moreover, a study found that somatosensory deficits were associated with reduced participation in life activities after stroke [188]. Physical therapy and rehabilitation can help stroke survivors improve their somatosensory perception, balance, and mobility. Specific interventions may include sensory re-education, balance training, and gait training [189].

Some studies have shown that somatosensory training programs can lead to improvements in balance and mobility in stroke survivors [182, 190].

Motor strategies and post-stroke balance control

Stroke can have a significant impact on the automatic postural responses of an individual. Postural responses are the complex motor actions that are automatically generated in response to external perturbations or changes in body position to maintain balance and prevent falls when standing or walking. These responses involve a coordinated interaction between sensory information from the body and the brain's motor output and include ankle, hip, and step strategies [59].

The ankle strategy is better suited for maintaining an upright position during minor disturbances while standing. On the other hand, the hip strategy is more effective for larger and faster COM movements. To use the hip strategy effectively, sufficient vestibular information is required, whereas the ankle strategy relies more on precise somatosensory information [191]. When the BOS is reduced, such as on a narrow surface or due to ankle muscle weakness, the ankle strategy cannot be employed efficiently [145]. There are often smooth transitions from the ankle to the hip strategy during changes in posture. However, the step strategy is an independent, since it adjusts the BOS according to the movement of the COM, while the other strategies maintain the COM within the BOS [191]. The ability of the CNS to anticipate and identify instabilities and generate suitable patterns of muscle activation is a key factor in postural responses. The response time for postural adjustments can be delayed due to a gradual rise in muscle activity or modifications in the temporal and spatial coordination of muscle groups working together (synergies) [191].

Following a stroke, damage to the brain can disrupt the normal functioning of the sensory and motor systems that control postural responses. This can affect muscle activation, as well as cause weakness or spasticity in the lower limb muscles. These deficits can lead to a range of postural control deficits, including increased sway, reduced postural stability, and difficulty adjusting to changes in body position or external perturbations [130, 151]. In stroke patients, the effectiveness of ankle and hip strategies is decreased, and their ability to generate and execute step strategies may be impaired. Consequently, they are at an increased risk of falls when encountering external perturbations [155]. Stroke patients adopt compensatory strategies such as holding onto objects or walls, and tend to use the step strategy more frequently than people of similar age without stroke [145]. In order to maintain the BOS, stroke patients rely heavily on the hip strategy, while using the ankle strategy less often [192]. However, these strategies are typically not effective for maintaining stability, which explains the increased incidence of falls observed in stroke patients [193].

Even though patients with hemiparesis can exhibit some anticipatory control while standing upright, their performance is generally not as good as that of age-matched controls. Inadequate generation of propulsive forces to move the body's COM or stop it from advancing beyond the boundaries of the BOS is common among hemiparetic patients [145]. However, individuals with mild motor impairments and a high level of functioning tend to have better anticipatory postural reactions, despite having abnormal patterns of movement activation [194]. The activation of muscle synergies and motor responses can be influenced by various factors such as sensory feedback, expectation, attention, environmental context, experience, and intention [93]. In tasks that involve static postural control, patients with stroke may require a higher attentional demand, especially as the task becomes more challenging. If attention is not adequately allocated, there may be a higher risk of instability and increased probability of falling [195].

1.3 Effect of stroke on gait

1.3.1 Gait terminology

The gait cycle and phases of gait

The basic element of walking is the gait cycle, which involves both spatial (distance) and temporal (time) measurements (Figure 1.1). In normal walking, a gait cycle initiates when the heel of one extremity makes contact with the supporting surface and concludes when the heel of that same extremity contacts the ground once more. The gait cycle consists of two phases, stance and swing. In normal gait at a comfortable walking speed, stance makes up about 60% of the gait cycle, and is the time when the reference foot is on the ground. Swing makes up about 40% of the gait cycle, and is the time when the reference foot is off the ground. A single gait cycle has both stance and swing phases for both the right and left limbs [62, 196].

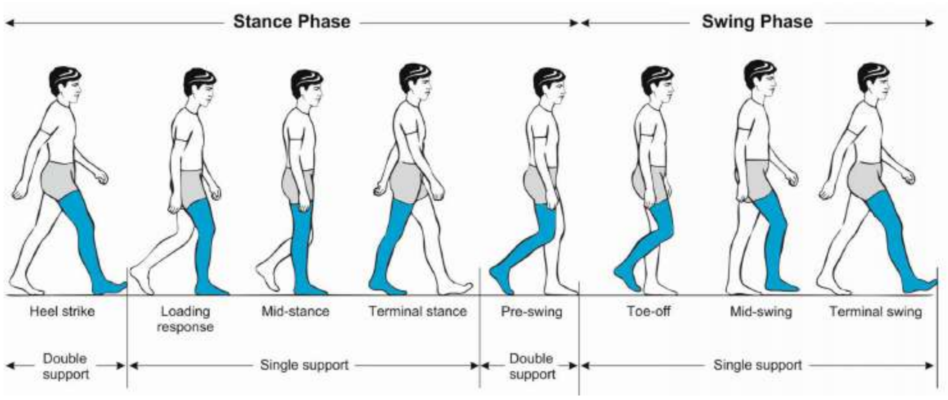

Figure 1.1: Phases of the gait cycle. Adapted from Pirker W, Katzenschlager R. Gait disorders in adults and the elderly: A clinical guide. *Wien Klin Wochenschr*. 2017; 129(3–4):81–95. Figure 1. Licensed under CC BY 4.0 [197].

During the gait cycle, there are two instances of double limb stance, where both limbs are in contact with the ground simultaneously. These periods facilitate the smooth transfer of body weight from one limb to the other. The initial double limb stance, happens at the beginning of the gait cycle as weight shifts from the trailing limb to the extended reference limb. The terminal double limb stance, occurs at the end of stance as body weight transfers from the trailing reference limb to the leading limb. Single-limb support is the part of the gait cycle when only one limb is supporting the body's weight. It occurs between the two double limb stance periods. A gait cycle is equal to a stride, which consists of two steps, one with the right foot and one with the left foot. The concepts of step and stride can be described in terms of two dimensions: distance and time. Step length refers to the distance between the heel strike of one limb and the heel strike of the opposite limb, while stride length pertains to the distance from the heel strike of one limb to the subsequent heel strike of the same limb [62, 196].

The phases of gait used to be described with terms for both stance (i.e., heel strike, footflat, midstance, heel-off, and toe-off) and swing (i.e., acceleration, mid-swing, and deceleration). These terms are helpful for describing normal gait, but they can be misleading when there is pathology. For instance, individuals exhibiting pretibial weakness or plantarflexion contractures often exhibit a lack of heel first contact during the "heel strike" phase. Certain individuals exhibiting plantarflexor spasticity tend to sustain their heel in an elevated position from the ground during the stance phase rather than solely during the heel-off phase. Individuals exhibiting significant weakness in their plantarflexor muscles may experience difficulty attaining a phase of heel-off during the stance phase of gait, resulting in complete elevation of the foot from the ground [62, 196].

Perry and colleagues from Rancho Los Amigos National Rehabilitation Center created a general terminology to describe the eight functional phases of gait to avoid the problems with earlier terms. Stance consists of the initial five phases: initial contact, loading response, mid stance, terminal stance, and pre-swing. Swing consists of the remaining three phases: initial swing, mid swing, and terminal swing [198, 199].

The first phase of the stance is known as "initial contact," which occurs when the extended limb makes contact with the ground. In the following (subsequent) phase, called the "loading response," the body weight is promptly transferred onto the extended limb. A slight knee flexion aids in the dissipation of impact forces that arise from the loading of body weight onto the limb. These two phases, initial contact and loading response, make up the initial double-limb stance, also referred to as weight acceptance. The initial double limb stance ends when the foot contralateral to the reference limb lifts off the ground for the swing phase [196, 198].

The next two phases, "mid-stance" and "terminal stance," involve the body's weight shifting forward over a single stable limb. By terminal stance, the heel lifts off the ground, resulting in the leg assuming a "trailing limb" position, and the trunk moving significantly forward beyond the reference foot. The phases of mid-stance and terminal stance can be combined and referred to as single limb support, as they signify the period during which only one limb is in contact with the ground [196, 198].

The final phase of the stance, known as "pre-swing," is occasionally denoted as terminal double limb stance or "push-off". In the pre-swing phase of gait, there is a transfer of body weight from the trailing limb to the contralateral lead limb, which undergoes initial contact and loading response. As the proportion of body weight supported by the trailing limb decreases, the stored energy in the Achilles tendon, accumulated during mid and terminal stance, rapidly flexes the ankle, despite a lack of considerable activity from the ankle plantarflexor muscles. The knee flexes to about 40 degrees, which is more than half of the 60 degrees required for foot clearance in the subsequent phase [196, 198].

The lifting of the foot from the ground indicates the beginning of the primary phase of the swing, commonly referred to as the “initial swing” phase, characterized by rapid flexion of the knee and hip. In “mid-swing,” the thigh exhibits a continued advancement towards flexion, ultimately reaching a maximum angle of approximately 25 degrees relative to the vertical position. The knee starts to extend, and the tibia assumes a vertical position by the end of mid-swing. The ankle joint attains a state of neutral position (0 degrees of dorsiflexion). In the phase of “terminal swing,” the range of thigh flexion is limited, while the extension of the knee continues until it appears to be in a neutral position. The ankle joint maintains a neutral position in anticipation of heel-first initial contact [196, 198].

1.3.2 Neural control of gait

The neural regulation of human locomotion, commonly referred to as gait, is a complex process involving the coordinated activation of various neural circuits and musculoskeletal structures [200]. Gait is a motor task that requires the control system to provide support for body weight, ensure forward and lateral stability, and facilitate forward movement with each step. The control system encompasses postural antigravity control to prevent falls while maintaining forward progression [201]. Furthermore, adaptation facilitates the modification of locomotion patterns in response to the surroundings [200]. The human body is composed of a series of articulated segments that possess varying mass and inertia. These segments are connected by muscles that exhibit unique viscoelastic properties. The collective behavior of these segments and muscles is responsible for generating both force and kinematic motion. As a result, every individual joint movement entails dynamic interactions with the other segments of the kinematic chain, leading to postural disturbance [202]. The locomotion pattern of the body and limbs during walking is influenced by the combined effects of neural and mechanical factors, which result in net forces and torques [202].

Muscle control is modular and organized into functional groups known as modules or muscle synergies [203]. Each module exhibits a fixed co-activation pattern across multiple muscles at a certain time. These modules are involved in various motor tasks such as balance control and walking. They can produce specific biomechanical functions for whole limbs or the entire body during locomotion [203, 204]. Altering the recruitment of muscle synergies in terms of duration, phase, or amplitude can generate different locomotor behaviors [200, 203]. Modules enable the nervous system to consistently produce biomechanical functions [204]. Typically, five motor modules are sufficient to reconstruct a locomotor task effectively. For example, Module 1 (hip and knee extensors, hip abductors) provides body support in early stance, while Module 2 (plantarflexors) does so in late stance. Forward propulsion is facilitated by Module 4 (hamstrings) in early stance and by Module 2 in late stance, with net braking occurring in Modules 1 and 2. Module 3 (ankle dorsiflexors, rectus femoris) and Module 5 (hip flexors and adductors, excluding adductor magnus) accelerate the ipsilateral leg forward in an early swing, while Module 4 decelerates it before heel-strike [204]. Other studies showed that, interestingly, modules identified in one task can also be recruited by different neural pathways for other motor tasks. They are involved in abnormal phases of gait, accounting for anticipatory modifications and reactive responses to perturbations [203].

Motor modules are primarily controlled by the brainstem and spinal network, with cortical modulation during voluntary walking [200]. The motor output during walking achieves rhythmic patterns for progression, support the body against gravity, and balance functions. The vestibular nuclei and pontomedullary reticular formation in the brainstem play a significant role in support and balance control, which are regulated by the cerebellum [200, 205]. Adequate postural muscle tone is crucial for inducing rhythmic activity, while suppression of muscle tone inhibits locomotor movements [200]. Walking initiation relies on either a voluntary (conscious) decision involving the cerebral cortex or an emotional trigger involving the limbic system. Both processes use the automatic processes for support, balance, and rhythmic activity. The voluntary process involves cortical activation and projections to the brainstem and spin [205]. Once initiated, walking generally occurs without conscious awareness, but intentional gait modifications are needed when encountering obstacles, requiring motor planning and programming in the premotor brain cortices [205]. The cerebellum adjusts both voluntary and automatic processes, integrating feed-forward information from the cerebral cortex and real-time sensory feedback [205]. It is also essential for locomotor adaptation and learning [200]. The cerebral cortex provides inputs to the basal ganglia, which affect voluntary, emotional, and automatic processes via projecting to the brainstem, limbic system, and cerebral cortex, respectively. Overall, walking primarily relies on automatic processing, which has advantages over cognitive processing that is intentionally controlled [205].

1.3.3 Gait analysis

There are two main categories of gait analyses: kinematic and kinetic. Kinematic gait analysis is used to describe how the body or its parts move during gait without considering the forces that cause the movement. A kinematic gait analysis consists of a description of how the body as a whole and/or body segments move in relation to each other during gait. Kinematic gait analysis can be either qualitative or quantitative. Kinetic gait analysis is used to determine the forces that are involved in gait [62, 196].

Kinematic qualitative gait analysis [196, 206]

Kinematic qualitative gait analysis is the predominant method used in clinical settings. It typically requires only a few pieces of equipment and a short amount of time. This method is used to assess and describe the quality and characteristics of an individual's walking pattern. It involves examining and interpreting the movements, postures, and alignments of various body segments during the gait cycle, as well as joint angles at specific points in the cycle. The primary focus is on analyzing overall movement patterns, coordination, and deviations from normal gait. Kinematic qualitative gait analysis can be performed through visual inspection or by utilizing instruments such as cameras, markers, sensors, or motion capture systems. The most commonly used method for kinematic qualitative gait analysis is observational gait analysis (OGA), which involves visually observing and describing the quality of an individual's walking pattern.

Kinematic quantitative gait analysis [62, 207]

Kinematic quantitative gait analysis is used to determine spatial and temporal gait variables as well as motion patterns. Spatial and temporal variables of gait are measurements of distance and time related to gait. These variables provide quantitative measurements and insights into different aspects of an individual's gait pattern. The following is a depiction of spatial and temporal variables that are commonly used in gait analysis:

Spatial variables

- Step length: it is the distance between the heel strike of one foot and the subsequent heel strike of the opposite foot. Step length can vary depending on the individual's gait pattern and is typically measured in meters or centimeters (Figure 1.2).

- Stride length: it is the distance covered from one heel strike to the subsequent heel strike of the same foot. It reflects the overall step length and is also measured in meters or centimeters (Figure 1.2).

- Step width: it is the lateral distance between the midpoints of the heel placements of two consecutive steps. It indicates the degree of lateral movement and the width of the base of support during gait, and is measured in centimeters (Figure 1.2).

- Base of support: it is the distance between the midpoints of the heel placements of both feet. It represents the width of the area enclosed by the feet during walking and provides information about stability and balance.

- Foot angle: it represents the angle formed by the foot with respect to the line of progression. It can indicate any abnormality in foot positioning or alignment.

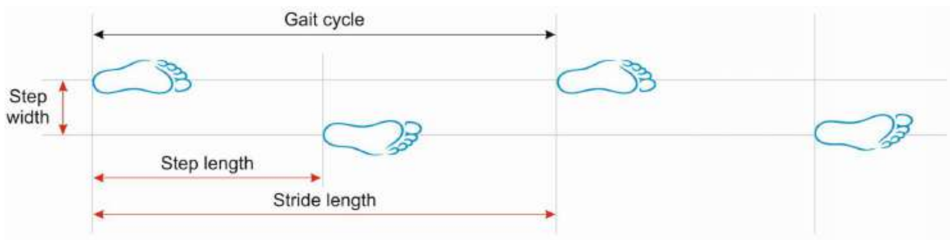

Figure 1.2: Spatial gait variables. Adapted from Pirker W, Katzenschlager R. Gait disorders in adults and the elderly: A clinical guide. *Wien Klin Wochenschr*. 2017; 129(3–4):81–95. Figure 2. Licensed under CC BY 4.0 [197].

Temporal variables

- Gait speed: it is the average speed at which an individual walks and is typically measured in meters per second. Gait speed is an essential temporal variable and can influence other gait parameters.

- Cadence: it is the number of steps taken per unit of time, typically expressed as steps per minute. Cadence is influenced by gait speed and can be used as an indicator of gait rhythm.

- Stride time: it is the time duration for completing one gait cycle, starting from the heel strike of one foot to the next heel strike of the same foot. It is typically measured in seconds.
- Step time: it is the time duration for completing one step, starting from the heel strike of one foot to the heel strike of the opposite foot. It is also measured in seconds.
- Double support time: it refers to the duration within the gait cycle where both feet are in contact with the ground simultaneously. It is measured in seconds.

Kinetic gait analysis [62, 208]

Kinetic gait analyses are focused on finding and analyzing the forces involved in gait, such as ground reaction forces (GRFs), joint torques, COP, COM, mechanical energy, joint reaction forces, and intrinsic foot pressure. The analysis usually begins with the forces that act on the foot, which are determined by a force plate integrated into the floor. These plates are equipped with load transducers that measure the COP, COM, and GRFs during gait.

The GRF refers to the total vertical and horizontal (shear) forces created as a result of foot contact with the supporting surface. These forces are equal in magnitude and opposite in direction to the force applied by the foot to the ground. Ground reaction forces are measured with force platforms in newtons (N) or pound force. The GRF operates in three dimensions and can be broken down into three components: vertical, anteroposterior, and mediolateral forces. Each component changes during the gait cycle and is influenced by factors such as velocity, cadence, and body mass.

The averaged wave shapes of the vertical and anteroposterior force components as a percentage of body weight demonstrate consistent loading rate, peak force, average force, and unloading rate among individuals with normal gait. The vertical force wave shape displays a characteristic double hump, while the anteroposterior force exhibits a negative phase (representing deceleration of body mass after the foot makes contact with the ground) followed by a positive phase (reflecting acceleration as body mass propels forward during late stance).

1.3.4 Gait impairments after stroke

As mentioned previously, mobility is achieved through the interaction of different systems, including the central nervous system, peripheral neuromuscular system, and sensory systems, which all play a crucial role. The ability to stand and walk involves maintaining body support against gravity to prevent falls and generating propulsion forces for movement [201]. After a stroke, individuals may experience gait deficits due to impairments at the neural, sensory, and muscular levels as well as ineffective coordination between these systems. These deficits manifest as a combination of sensorimotor impairments, including muscle weakness, impaired selective motor control, spasticity, ataxia, and sensory or proprioceptive deficits, which are commonly observed in individuals after a stroke during neurological examinations. These impairments significantly affect motor control and consequently impact gait performance [201, 209].

Gait recovery is a primary goal in the rehabilitation of stroke patients. The level of walking ability after stroke varies depending on the severity of the sensorimotor impairment [200]. Following a stroke, approximately 80% of patients experience walking difficulties within three months of onset [210]. Initially, around 50% of patients are unable to walk, 12% need assistance to walk, and 37% can walk independently. After 11 weeks of stroke rehabilitation, 18% of patients still unable to walk, 11% require assistance, and 50% can walk independently [211]. Furthermore, stroke patients with functional ambulation exhibit gait patterns that differ from those of healthy individuals, putting them at an increased risk of falling. Approximately 70% of post-stroke individuals living in the community experience falls within the first year, with most falls occurring due to balance loss during walking. Therefore, patients with post-stroke symptoms who can walk independently are still at a high risk of falling [212].

The majority of stroke survivors exhibit reduced gait speed and abnormal gait kinematics and kinetics, along with asymmetries between the paretic and nonparetic limbs in most gait parameters. Their gait pattern is characterized by spatial and temporal asymmetries, as well as poor selective motor control. Furthermore, they also experience decreased weight-bearing on the paretic limb, reduced force output from the paretic limb, reduced ability to generate forward propulsion force with the paretic limb, and an overall increased mechanical energetic cost has been observed [209, 213].

Gait speed in hemiparetic gait

Gait speed is a significant indicator of locomotor function and quality of life following a stroke. The preferred (self-selected) speed, which represents the speed at which a person walks comfortably, is commonly used as a measure of overall gait performance. It serves as a useful indicator for monitoring locomotor performance and evaluating the effectiveness of rehabilitation in individuals with neurological disorders [214]. It has been suggested that a gait speed more than 0.80 m/s is necessary for effective community ambulation, such as safely crossing a street in a timely manner [214]. Independent community walking enhances the likelihood of engaging in community activities, such as employment. However, individuals who have experienced a stroke often exhibit significantly slower gait speeds compared to their healthy counterparts. This significantly impacts their ability to participate in daily activities [209].

Reduced gait speed is a feature sign of hemiparetic gait [209]. Studies have reported that the average self-selected gait speed in post-stroke individuals is lower than that of healthy individuals, with values ranging from 0.23 m/s (SD = 0.11 m/s) to 0.73 m/s (SD = 0.38 m/s) [215]. However, higher-functioning post-stroke individuals have been reported to achieve gait speeds of 0.78 m/s and 0.95 m/s [200]. The maximum walking speed in stroke patients, a less frequently measured parameter, has been reported to range from 0.76 m/s to 1.09 m/s [216]. The wide variation in reported values can be attributed to several factors, including variations in measurement techniques and equipment used, the level of assistance during measurement (such as walking aids, orthoses, and external support), and the severity and chronicity of the stroke [209]. Along with decreased velocity, both stride length and cadence are lower compared to healthy individuals. Nakamura et al. [217] demonstrated a linear relationship between cadence and velocity up to approximately 0.33 m/s and a cadence of around 90 steps per minute, with further improvements primarily due to increased stride length.

Olney et al. [218] conducted principal component analysis on the kinematic and kinetic gait parameters of stroke survivors. They found that the first principal component was associated with gait speed and explained 41% of the variance, while the second component was related to inter-limb asymmetry and explained 13% of the variance. It has been observed that only around 40% of individuals who regain walking ability after a stroke achieve velocities suitable for community ambulation, with half of them still walking at speeds below 0.5 m/s [209, 219]. Generally, post-stroke individuals are more limited in their gait speed choices. However, when requested, some individuals are able of significantly increasing their gait speed, or at least up to 0.2-0.3 m/s faster than their spontaneous speed [213, 216]. This suggests the existence of additional functional resources that are not commonly utilized during daily walking, possibly due to the need to maintain balance or divide attention between walking and various environmental demands. Studies have indicated that gait speed can continue to improve over time following a stroke, with increases observed from 3 months to 12-18 months post-stroke, whereas improvements in the Fugl-Meyer sensorimotor scale and Barthel functional independence index are observed up to 6 weeks and 3 months post-stroke, respectively [220]. Consequently, gait speed has been proposed as an outcome measure for assessing locomotor recovery in post-stroke individuals who are capable of walking faster than 0.33 m/s [220].

In summary, gait speed is reduced in individuals who have experienced a stroke, ranging from exceedingly slow to nearly normal. However, there is considerable variability in the preferred gait speed among these patients. The decrease in speed can be attributed to various factors, including poor motor control, reduced muscle strength of the lower limbs, and impaired balance. Nevertheless, as muscle strength and motor control improve, gait speed increases, and abnormal movements decrease [213, 216].

Temporospatial features of gait after stroke

Significant asymmetries in temporal and spatial parameters between limbs are common in post-stroke individuals, with temporal inter-limb asymmetries occurring in 48% to 82% of cases, and spatial inter-limb asymmetries occurring in 44% to 62% of cases [221]. Gait speed, as a clinical measurement, serves as an indicator of overall gait performance, and it is correlated with various other temporospatial gait parameters. These parameters include cadence, stride duration, stride length, paretic and nonparetic stance duration, and double support duration [213].

The temporal characteristics of hemiparetic gait are characterized by an increased stride time and reduced cadence [213]. In individuals with hemiparesis, alterations in the duration of stance and swing phases have been observed, with increased stance periods in both lower limbs compared to healthy individuals [213]. The paretic limb exhibits a shorter stance time and longer swing time [221], resulting in a prolonged stance period and reduced swing period in the nonparetic limb [211]. An increase in double support periods has also been reported, with a tendency for increased double support time on the nonparetic limb [213]. However, reports on the amount of time spent in single-limb support on each leg by hemiparetic patients are inconsistent. When calculated as a percentage of the gait cycle, there is a reduction in the duration of the cycle spent in single-limb support. On the nonparetic limb, an increase in the duration of single-limb support as a percentage of the gait cycle has been reported to be comparable to that of healthy individuals [219]. Consequently, these bilateral differences result in significant asymmetry in various temporal and spatial parameters of walking in hemiparetic patients [211]. Additionally, on the paretic side, the pre-swing phase tends to be more prolonged than the loading response phase, particularly at lower velocities [200]. In a cross-sectional study conducted by Patterson et al. [222], it was found that swing time, stance time, and step symmetry demonstrated a systematic linear trend towards greater asymmetry in later stages after a stroke, while speed, neurological deficit, and lower-extremity motor impairment did not exhibit a significant linear trend. These findings suggest that speed and symmetry are independent measures of gait characteristics.

The primary spatial feature of hemiparetic gait is the marked asymmetry in step length between the paretic and nonparetic limbs. It has been consistently reported that the nonparetic limb exhibits a shorter step length compared to the paretic limb, although the opposite can also occur. However, it is important to note that there is variability among individuals, as some people with hemiparesis display substantial asymmetry in the opposite direction [221]. Balasubramanian et al. [223] found a relationship between step-length asymmetry and propulsive force generation during hemiparetic walking. Their findings suggested that patients who generated less propulsion with the paretic leg tended to take relatively longer steps with the paretic limb, indicating that increased propulsion from the nonparetic leg may contribute to an increase in step length on the paretic limb.

The reduction in swing time of the nonparetic limb often leads to a shorter step length on that side [200]. The asymmetry ratios, which compare the paretic and nonparetic limbs in terms of stance time, swing time, and step length, are significantly negatively correlated with self-selected gait velocity [221]. Furthermore, individuals who exhibit greater step length asymmetry at their self-selected velocity have been found to walk significantly slower at their highest comfortable velocity

[224]. Moreover, it has been observed that patients with more severe hemiparesis, characterized by reliance on abnormal flexor and extensor synergies, tend to have the longest paretic step length relative to the nonparetic step length during walking [223]. Nevertheless, these results suggest that asymmetrical step length does not necessarily impede an individual's self-selected walking speed, as some individuals with a longer paretic step length are able to walk at a faster pace, possibly due to compensatory generation of propulsion by the nonparetic leg [225].

Kinetic disturbances of gait after stroke

The temporospatial parameters and locomotor kinematics of individuals are determined by the moments of forces generated at their joints, known as kinetic variables. Several studies have investigated the kinetic patterns during walking in hemiparetic patients and have observed that these patients exhibit distinct patterns in both paretic and nonparetic limbs (with considerable individual variations) that differ from those observed in healthy individuals [213, 226]. Consequently, there is an absence of bilateral symmetry in the kinetic patterns, with changes occurring in both the paretic and nonparetic limbs. However, it has been reported that hemiparetic patients demonstrate their own unique characteristic pattern [227, 228].

The preferred gait speed is linked to stride length, and as the speed increases, the stride length and/or cadence also increase. Nevertheless, this requires the production of mechanical work at both the distal and proximal joints [215, 216]. Post-stroke individuals distribute this work production differently between the distal and proximal joints, depending on their functional abilities. Analyzing the kinetics of gait involves measuring the ground reaction forces, which can help determine the moments and power at the joints. This understanding of kinetics can provide insights into the underlying causes of gait impairment after a stroke [209]. In both able-bodied and hemiparetic gait, the muscle groups primarily responsible for generating energy for forward propulsion during gait are the hip extensors in early stance, the plantar flexors during push-off, and the hip flexors during pre-swing [229]. In able-bodied individuals, faster walking speeds are associated with greater bursts of power generation from the same muscle groups, with the ankle plantar flexors contributing approximately 75% of the force [213]. In hemiparetic gait, the magnitude of power generation is reduced at both the hip and ankle joints, and the patterns of muscle activation tend to deviate in terms of timing and magnitude compared to normal values when both groups walk at their self-selected speeds

[213]. However, when comparing the joint power production of individuals post-stroke to that of healthy controls walking at matched speeds, the most abnormal parameter is the power generation at the ankle, while the power generation at the hip seems to be mostly within the range of that observed in healthy controls [216]. Post-stroke individuals are likely to compensate for limited power generation at the ankle by augmenting power generation at the hip joint. Hsu et al. [187] stated that the strength of the hip flexor and knee extensor muscles in the paretic limb is the most crucial factor determining a comfortable or fast gait speed. However, gait speed is also affected by the plantar flexor muscles. When individuals post-stroke are requested to walk at their maximum or near maximum capacity for gait velocity, the reduced distal power generation is compensated either by increasing proximal power generation or by increasing ankle power generation in the nonparetic limb [230, 231].

These findings were supported by the results of a study conducted by Jonsdottir et al. [216]. When comparing the gait parameters of post-stroke individuals walking at their preferred speed with those of able-bodied individuals walking at similar speeds, the most prominent difference was observed in the positive work generated at the ankle. Approximately 64% of the hemiparetic participants exhibited significantly lower values compared to their healthy counterparts. This difference became much more pronounced at faster speeds, with over 80% of the hemiparetic participants generating significantly less ankle work. Conversely, the positive work generated by the hip flexors in post-stroke participants was comparable to that of able-bodied participants. Approximately 89% and 75% of the participants demonstrated normal values during self-selected and fast gait, respectively.

Ground reaction forces

Ground reaction force (GRF) refers to the force exerted by the body onto the surface it is walking on. Direct measurement of GRF is not possible; instead, it is calculated using inverse dynamics through a force platform embedded in the walking surface. This type of analysis allows for the assessment of vertical forces exerted by the foot, as well as anteroposterior and mediolateral shear forces [211]. Several researchers have investigated the force patterns in hemiparetic patients during walking and have observed distinct patterns that differ from those seen in healthy individuals, affecting both the paretic and nonparetic limbs. These patterns exhibit significant variability between individuals [200, 213]. Consequently, the force curve patterns on both the paretic and nonparetic lower limbs lack bilateral symmetry. However, it was shown that hemiparetic patients have their own distinct pattern [211].

Vertical force patterns

The vertical GRF during gait can display two peaks, one occurring during weight acceptance and the other during push-off, with an intermediate trough in midstance, as in healthy individuals. The vertical component of the GRF has been observed in individuals with stroke during gait [211]. Specifically, beneath the paretic limb, the vertical GRF is significantly reduced, displaying a one-peak pattern [200]. In contrast, the nonparetic limb often exhibits a higher vertical force following initial foot contact and during push-off compared to the paretic limb [232]. Some hemiparetic patients maintain a relatively constant vertical force, showing three or more small irregular peaks and troughs in the paretic limb [213].

The findings from studying the vertical force curves in stroke patients indicate a decrease in vertical loading and more variable loading patterns in the paretic foot upon initial contact. Similar characteristics have also been observed in the vertical forces recorded from the nonparetic limb [211]. Carlsoo et al. [233] proposed three distinct patterns of vertical force observed in hemiparetic gait. The first pattern displayed vertical curves similar to those of individuals without stroke, with two peaks in vertical force occurring during weight acceptance and push-off, and an intermediate trough in midstance. The second pattern exhibited a relatively constant vertical force throughout the stance phase, with irregularly occurring peaks and crests. The third pattern demonstrated a single peak in vertical force during the early part of the stance phase, gradually decreasing to zero in late stance. Lehmann et al. [234] found no significant differences in the maximum vertical forces of hemiparetic patients compared to normal participants walking at similar speeds. However, the hemiparetic patients exhibited either three peaks or a plateau in vertical loading, deviating from the typical bimodal shape. In contrast to previous findings, Hesse et al. [235] reported an increased vertical loading in the paretic limb after initial contact compared to the nonparetic limb. The authors noted a decrease in vertical push-off forces during terminal stance, a delay in loading during initial contact, and a premature unloading during terminal stance while in the paretic limb's stance phase.

Anteroposterior shear forces

The anteroposterior shear forces in individuals with stroke have been observed to exhibit differences compared to those in normal participants. Specifically, on the paretic limb, the retrograde force following initial contact was found to be of shorter duration, and the distance between the horizontal peaks was increased. Additionally, the magnitudes of the anteroposterior forces were higher on the paretic limb compared to the nonparetic limb [211].

The anteroposterior component exhibits a greater braking force than propulsive force, particularly at slower gait speeds, in individuals with chronic stroke, whether or not they use a cane [236]. Gait speed was found to be significantly related to both the affected propulsive force and the unaffected braking force [236]. The affected propulsive force is highly positively correlated with plantarflexor activity, but negatively correlated with leg flexor activity (tibial anterior and rectus femoris muscles), particularly in severe post-stroke cases [200]. It should be noted that foot placement in relation to the body's center of mass influences both propulsive and braking forces, in addition to the muscle force generated [237]. Therefore, a reduced posterior foot position of the paretic limb during pre-swing would tend to decrease the affected propulsive force, while a longer step with the paretic limb during loading response would tend to increase the affected braking force [236, 237]. Additionally, foot contact with the ground typically occurs either flat or with the forefoot (prevalence of 76-89%), accompanied by an anterior shift of the center of pressure at initial contact and a reduction in its longitudinal course [238–240]. Therefore, the plantarflexor muscles exhibit activity from the initial contact phase and play a significant role in generating higher ground friction, greater ankle negative work, and partially contributing to body support and trunk forward deceleration [241, 242]. In their study, Wong and colleagues [239] categorized the foot contact pattern into three distinct groups: forefoot, flatfoot, and heel-initial contact. They found a significant association between the foot contact pattern and the GRF pattern, gait speed, and Brunnstrom's recovery stages. As a result, a greater degree of neurological impairment was associated with a greater anterior displacement of the center of pressure trajectory at initial contact [239]. Furthermore, the categories of foot contact patterns are strongly associated with three distinct subgroups of lower limb joint kinematics and serve as early predictors of future functional outcomes following rehabilitation in stroke patients [200, 243].

Mediolateral shear forces

The medial shear force during the initial contact phase was generally absent. Throughout most of the stance phase, lateral forces were observed to be exerted on both the paretic and nonparetic limbs. This observation suggests that the body's center of gravity was positioned medially to the support foot, similar to what is observed in healthy individuals [211, 233]. The patients were evenly distributed based on the position of the center of gravity in relation to the supporting limb. Half of the hemiparetic patients positioned their body's center of gravity closer to the nonparetic limb during stance compared to when the paretic limb was in stance. Conversely, the remaining hemiparetic patients demonstrated the opposite pattern, with the center of gravity closer to the paretic limb during stance [211, 233]. Nonetheless, Iida and Yamamuro [244] revealed that hemiparetic patients exhibited a significantly larger mediolateral displacement width of the body's center of gravity compared to healthy individuals. Furthermore, the magnitude of center of gravity displacement was greater in patients classified in the lower Brunnstrom stages.

1.4 Effect of stroke on performance of activities of daily living

1.4.1 Definitions and importance

Activities of daily living (ADL) are the fundamental tasks that individuals engage in on a daily basis to independently take care of themselves and maintain their independence. These activities are essential for a person's overall well-being and include tasks such as bathing, dressing, grooming, eating, toileting, transferring (moving from one position to another, such as from a bed to a chair), and mobility (walking or using assistive devices for movement) [245].

The performance of daily living tasks can be categorized into two main groups: basic ADL and instrumental ADL (IADL). Basic ADL, also known as physical ADL or BADL, encompass the essential skills necessary to meet one's fundamental physical needs. These tasks involve personal hygiene or grooming, dressing, toileting, transferring or walking, and eating. On the other hand, instrumental activities of daily living (IADL) comprise more complex activities that are crucial for independent living within the community. These activities encompass tasks such as housekeeping, food preparation, transport, communication, shopping, and managing finances and health [245, 246].

A person's functional status can be determined based on their ability to perform ADL. The inability to carry out ADL leads to dependence on external support, such as other individuals or mechanical aids. The inability to perform fundamental tasks required for daily living may result in hazardous circumstances and poor quality of life [247]. Furthermore, individuals who experience limitations in ADL tend to exhibit lower levels of life satisfaction and encounter challenges when reintegrating into the community [248].

1.4.2 Assessment of activities of daily living

Assessment of ADL and IADL function and independence is integral for practitioners to determine an individual's ability to live independently, assess the effectiveness of interventions, and quantify the level of disability [246]. A variety of assessment scales have been used to quantify the level of independence in ADL for stroke patients. ADLs can be assessed by direct observation, proxy or caregiver reporting, or self-report. These tools help determine the general level of assistance required as well as the type of setting most suitable for the patient. Self-report tests are easy to administer and are typically employed when direct observation is not available or when people have relatively intact cognitive abilities [246, 249].

While there is no universal assessment, below are the most commonly used ADL outcome measures in stroke rehabilitation: [245, 250, 251]

Barthel index: The Barthel index is one of the most widely used assessments of functional independence. It is an ordinal scale used to measure performance in ADL. The index evaluates the level of assistance required by an individual across ten self-care ADL and mobility items. Each item is scored on a scale of 0 to 10 or 0 to 15 points, reflecting the amount of time and physical assistance needed to complete the task. The assigned value for each item is based on the level of support required. A higher score on the Barthel Index, with a maximum of 100, indicates a greater ability to function independently.

Katz index of independence in activities of daily living: The Katz scale is used to assess an individual's independence in performing common basic ADLs. The scale evaluates six activities, including bathing, dressing, toileting, transferring, continence, and feeding. Each activity is scored on a scale of 0 (indicating independence) to 1 (indicating dependence). A score of one signifies independence, while a score of zero indicates that the person requires supervision, direction, personal assistance, or total care. The total score on the Katz scale ranges from 0 to 6. A higher score reflects a greater level of independence.

Functional independence measure (FIM): The FIM is a widely accepted functional assessment tool used in rehabilitation populations. It consists of an 18-item ordinal scale that assesses six areas of function, including independent performance in self-care, sphincter control, transfers, locomotion, communication, and social cognition. The items are categorized into two domains: motor (13 items) and cognitive (5 items). The motor items are derived from the Barthel Index. These domains are known as the Motor-FIM and the Cognitive-FIM. FIM scores range from 1 to 7, with 1 indicating total assistance and 7 indicating complete independence. Scores below 6 indicate the need for supervision or assistance from another person.

1.4.3 Limitations in activities of daily living after stroke

A stroke can pose significant challenges to everyday activities, leading to a high rate of disability among patients. Stroke is ranked as the third leading cause of disability, following musculoskeletal and mental disorders, and it is considered one of the most common causes of complex disability [252]. On average, stroke survivors experience approximately 0.86, 1.24, and 1.39 years of mild, moderate, and severe disabilities, respectively [253]. The degree of disability following a stroke is influenced by several factors, including older age, co-morbidities, impaired cognition, and the severity of the stroke at its onset. However, even individuals with mild strokes can experience a dependence on ADL in their everyday lives and have unmet rehabilitation needs. Therefore, the prognosis cannot be solely determined based on stroke severity [254–256]. The majority of recovery in ADL typically occurs within the first six weeks after the stroke and is linked to the initial severity of the stroke. In the later stages of stroke, there is generally no significant decline or improvement in ADL functioning [257]. Studies have demonstrated that patients who are dependent on ADLs during the first week after a stroke tend to remain dependent at six months and three years' post-stroke [256, 258].

Stroke can have a significant impact on the performance of ADL by causing impairment related functional limitations, leading to difficulties in carrying out ADL tasks independently, without supervision, direction, or physical assistance [259]. ADL limitations refer to experiencing difficulty or requiring assistance with at least one task [260]. ADL dependency is a common outcome after stroke, with an estimated

25% to 74% of the 50 million stroke survivors worldwide requiring some level of assistance or being fully dependent on ADL [261]. A study by Appelros et al. [262] found that ADL dependency persists in 35% of stroke survivors during the first-year after stroke. Among stroke survivors, more than 20% experience limitations in ADLs and over 30% in IADLs, and these percentages tend to increase in the years following the stroke event. This makes stroke the primary cause of long-term disability, particularly in aging populations, and the burden of stroke is expected to rise in the coming decades [263, 264]. Previous research has shown that 40% of acute stroke survivors have total or severe ADL disabilities at the time of hospital discharge [248, 265]. While limitations in ADLs and IADLs vary widely during the sub-acute phase, they tend to decrease in the sub-acute phase and plateau in the chronic phase, typically 2 to 5 years after the stroke [263]. Stroke patients with greater difficulty performing IADL tasks generally exhibit poorer walking capacity, upper limb strength, and neurological recovery [265]. The majority of chronic stroke patients require assistance with bathing, and approximately half of them are unable to engage in activities such as meal preparation, housework, shopping, and outdoor walking [248].

The effect of stroke on the performance of ADL can vary depending on the severity and location of the brain damage, the type and extent of impairments, and the individual's personal and environmental factors [255]. Stroke can impair cognitive and physical functions such as memory, attention, language, vision, sensation, strength, coordination, and balance. These impairments can affect the ability to perform both basic and instrumental ADL [19]. For example, stroke can cause hemiplegia (paralysis of one side of the body), which can make it hard to dress, bathe, or feed oneself [19]. Stroke can also cause aphasia (loss of language ability), which can affect communication and understanding of instructions [266]. Stroke can also cause neglect (lack of awareness of one side of the body or space), which can affect safety and orientation [267]. Some people may recover most or all of their ADL abilities after a stroke, while others may remain dependent on others or assistive devices for some or all ADL [19].

The limitations in the performance of ADL after a stroke can be attributed to various factors. Here are some common causes:

Motor impairments: stroke often results in motor impairments, including muscle weakness, paralysis (hemiparesis or hemiplegia), muscle stiffness (spasticity), and ataxia. These motor deficits can pose challenges in initiating and controlling movements required for ADL, such as walking, transferring, and using stairs [268].

Sensory impairments: stroke can result in sensory changes, including decreased sensation or altered perception of touch, temperature, or proprioception (awareness of body position in space). These sensory deficits can affect a person's ability to feel or interpret sensory information needed for performing ADL tasks accurately [27, 269].

Balance and coordination impairments: stroke can disrupt the brain's control of balance and coordination, leading to difficulties in maintaining stability and performing coordinated movements. Challenges with balance and coordination can impact tasks such as standing, transferring, or walking, affecting independence in ADL performance [270].

Cognitive impairments: stroke can cause cognitive impairments, which may include difficulties with memory, attention, problem-solving, and aphasia. These cognitive deficits can have an impact on communication, planning, executing the steps involved in ADL tasks, and utilizing devices [248, 271].

Perceptual deficits: some stroke survivors experience perceptual deficits, such as spatial neglect or visual field cuts, which influence their awareness of one side of the body or the surrounding environment. These perceptual deficits can make it challenging to recognize objects, locate body parts, or navigate the environment effectively, thus hindering their ability to perform ADL and avoid obstacles [157].

Fatigue and energy conservation: many stroke survivors experience fatigue, which can limit their endurance and ability to sustain prolonged activities. Fatigue may arise from the increased effort required for movement or from the brain's general recovery process after a stroke. Fatigue can impact the performance of multiple ADL tasks throughout the day [46].

Emotional and psychological factors: stroke can also have emotional and psychological effects, such as depression, anxiety, emotional lability, or apathy, which can influence a person's motivation, mood, engagement, and overall functional performance in ADL tasks [272, 273].

1.5 Stroke recovery and rehabilitation

Stroke is a major contributor to acquired adult long-term disability worldwide [18]. The majority of stroke patients survive the initial illness, and as a result, the main health impact is frequently caused by the long-term consequences for stroke survivors and their families [274]. A stroke can cause a wide range of long-term impairments, which are reported by stroke survivors between one and five years after the onset of the stroke [275]. The most common persistent impairments include motor functional impairments, balance disturbances, difficulties with mobility, impaired speech, cognitive dysfunction, and psychological issues [274, 276]. Approximately 80% of patients with stroke have a unilateral motor deficit, impacting their balance, mobility, daily life activities, and participation in social life. All of these factors contribute to a low overall quality of life [277, 278].

Despite significant progress achieved in the medical management of stroke, most post-stroke care will continue to depend on rehabilitation interventions in the absence of a widely applicable or effective medical treatment to reduce post-stroke disabilities, particularly motor impairments [278, 279]. After acute hospitalization, more than two-thirds of stroke patients receive rehabilitation services. Early treatment and rehabilitation following a stroke can significantly enhance recovery, with many people regaining significant improvement in function [280].

Rehabilitation in stroke patients aims to reduce neurological deficits and complications, encourage family involvement, and facilitate social reintegration of the individual in order to improve their quality of life [279]. The period following a stroke is commonly categorized into different phases. According to the Stroke Roundtable Consortium [281], the initial 24 hours are referred to as the hyperacute phase, the initial 7 days as the acute phase, the first 3 months as the early sub-acute phase, months 4-6 as the late sub-acute phase, and beyond 6 months as the chronic phase. This classification is based on the understanding that post-stroke recovery processes are time-dependent.

1.5.1 Neuroplasticity and functional recovery

The recovery process after a stroke relies on the brain's ability to restructure and repair the damaged area, a phenomenon known as neuroplasticity. Neuroplasticity refers to the brain's capacity to change, learn, and re-learn in response to internal and external stimuli [282]. It serves as the underlying mechanism driving stroke recovery and plays a crucial role in facilitating functional improvement by enabling the brain to adapt, rewire neural circuits, and establish new connections to compensate for the damaged regions [283]. Understanding the mechanisms and factors that influence neuroplasticity and functional recovery after a stroke is crucial in order to optimize rehabilitation strategies and enhance outcomes for individuals who have experienced a stroke. Consequently, one of the key objectives in stroke patient rehabilitation is to effectively harness the potential of neuroplasticity for functional recovery [283, 284].

Plasticity of the nervous system

The nervous system consists of billions of neurons and their connections, called synapses, that form complex networks that mediate various functions, such as sensation, movement, cognition, and emotion. These networks are not fixed or static but rather dynamic and flexible, changing their activity and connectivity in response to changing environments, experiences, learning, or injury. This ability to change is called plasticity, and it enables the brain to reorganize neural circuits and establish new connections, facilitating functional recovery after a stroke. Plasticity operates at various levels, including molecular, cellular, and systemic levels [285].

At the molecular level, neuroplasticity involves changes in gene expression and protein synthesis, leading to modifications in synaptic strength and the growth of new connections. Cellular plasticity encompasses phenomena such as axonal sprouting, dendritic remodeling, and neurogenesis, where new neurons are generated in certain brain regions. System-level plasticity involves the reorganization of brain networks and the redistribution of functional responsibilities to compensate for damaged areas [285].

Plasticity can be induced by various factors, such as environmental enrichment, physical exercise, cognitive training, pharmacological agents, electrical stimulation, or brain injury. The effects of plasticity on function can be positive or negative, depending on the type, timing, location, and extent of the changes [286]. For instance, synaptic plasticity can enhance learning and memory by strengthening neural connections that are repeatedly activated (long-term potentiation) or weaken neural connections that are rarely activated (long-term depression) [286]. However, synaptic plasticity can also contribute to chronic pain by increasing the sensitivity of nociceptive neurons (central sensitization) [287].

Mechanisms of functional recovery

Functional recovery after brain injury, specifically after a stroke, involves the restoration or improvement of function. This can be achieved through two primary mechanisms: neurorestoration and neurocompensation. Neurorestoration involves repairing or regenerating damaged neural tissue or function, while neurocompensation involves recruiting or reorganizing alternative neural pathways or regions to compensate for lost functions [285].

Neurorestoration encompasses processes such as neurogenesis (generation of new neurons from neural stem cells), synaptogenesis (formation of new synapses between existing or new neurons), angiogenesis (formation of new blood vessels), gliosis (proliferation of glial cells), remyelination (repair of damaged myelin sheaths), or neuroprotection (prevention of further damage). Neurorestoration can occur spontaneously, but it can also be enhanced through interventions such as pharmacological agents, stem cell therapy, gene therapy, or nanotechnology [283, 285].

On the other hand, neurocompensation involves processes such as synaptic plasticity (changes in synaptic strength or number), structural plasticity (changes in dendritic spines or axonal sprouting), functional plasticity (changes in neural activity or connectivity), cortical reorganization (changes in cortical maps that represent specific functions), interhemispheric reorganization (changes in the balance of activity between the two hemispheres), subcortical reorganization (changes in the activity of subcortical structures such as the basal ganglia or cerebellum), or behavioral adaptation (changes in strategy or technique). Similar to neurorestoration, neurocompensation can occur spontaneously, but it can also be enhanced by interventions such as rehabilitation, exercise, cognitive training, or brain stimulation [283, 285].

Neuroplasticity plays a crucial role in mediating various mechanisms that facilitate functional recovery following a stroke. Axonal sprouting enables surviving neurons adjacent to the damaged area to send out new branches (sprouts) to form connections with neighboring cells, allowing for the rewiring of neural circuits, bypassing the damaged region, and restoring lost connections. Synaptic plasticity occurs, leading to changes in the strength and structure of synapses. Long-term potentiation (LTP) and long-term depression (LTD) are forms of synaptic plasticity involved in learning, memory, and functional recovery. LTP strengthens synaptic connections, while LTD weakens them, allowing for the rewiring of neural networks. Cortical reorganization occurs as unaffected brain regions assume new roles to compensate for impaired functions, leading to changes in functional maps that allow the brain to reroute signals and restore lost abilities. In cases of functional substitution, unaffected brain regions take over the functions previously performed by damaged areas, primarily through interhemispheric interactions, where the unaffected hemisphere assumes control over motor, sensory, or cognitive functions [283, 285, 288].

Understanding and harnessing these mechanisms can guide rehabilitation strategies and improve outcomes for individuals recovering from strokes [289]. Neuroplasticity is influenced by various factors, including the type, intensity, frequency, and duration of rehabilitation interventions. Therefore, it is crucial to design rehabilitation programs that are based on the principles of neuroplasticity and motor learning [286].

By recognizing the dynamic nature of neuroplasticity, rehabilitation efforts can be tailored to maximize its potential. The type of rehabilitation intervention chosen should align with the specific mechanisms of neuroplasticity involved in functional recovery after a stroke. For example, interventions that promote axonal sprouting, such as task-specific training and repetitive practice, can help rewire neural circuits and restore lost connections [279, 286].

The intensity of rehabilitation is another important factor to consider. Research suggests that higher-intensity interventions, involving more frequent and longer-duration sessions, may lead to greater neuroplastic changes and functional improvements. By challenging the brain through intensive training, rehabilitation programs can drive neuroplasticity processes and optimize functional recovery [279, 286].

Furthermore, the principles of motor learning play a vital role in neuroplasticity-based rehabilitation. These principles emphasize the importance of active engagement, repetition, feedback, and progressively challenging tasks. By incorporating motor learning principles into rehabilitation programs, individuals can enhance their ability to relearn and regain functional skills [283, 286].

Evolution of functional recovery after stroke

During the initial days and weeks following a stroke, numerous biological processes occur within the brain in a natural or spontaneous manner. These processes involve the repair of injured neurons and other brain cells that have not died, as well as the removal of dead brain cells to clean up the affected area [282]. Within hours of experiencing stroke, a series of mechanisms that enhance plasticity are triggered, resulting in the growth of dendrites, the sprouting of axons, and the formation of new synapses [290]. The most substantial improvements in recovery typically occur during the first few weeks following a stroke, with progress becoming less significant after 3 months, particularly regarding motor symptoms [290]. After 6 months, spontaneous recovery typically reaches its maximum level, resulting in a more or less stable chronic deficit [291].

Functional recovery after a stroke is not a static process; rather, it follows a dynamic and nonlinear course influenced by various factors. These factors include age, sex, genetics, comorbidities, lesion characteristics, spontaneous recovery, neuroplasticity, and interventions [288]. The functional recovery trajectory after a stroke can be divided into three distinct phases: acute, subacute, and chronic. These phases also align with the stroke rehabilitation process [284, 288].

The acute phase occurs within the immediate aftermath of a stroke and extends for the first hours or days. During this phase, patients receive urgent medical attention and stabilization in a hospital setting. The acute phase is characterized by a rapid deterioration of function due to primary damage and secondary mechanisms such as inflammation, edema, or apoptosis. However, it is also a period of high potential for spontaneous recovery and neuroplasticity. The brain initiates immediate neuroplastic responses, including the activation of compensatory mechanisms and the formation of alternative pathways or regions. Some spontaneous recovery may occur due to the resolution of swelling, the restoration of blood flow, and the brain's adaptive mechanisms. Nonetheless, the extent of recovery during this phase is limited. The primary goals of the acute phase are to stabilize the patient, prevent complications, and initiate early interventions [284, 288].

The subacute phase occurs in the weeks to months following a stroke, typically spanning from 1 to 6 months. During this phase, there is a gradual improvement in function attributed to spontaneous recovery and ongoing neuroplasticity. Processes such as axonal sprouting, synaptic remodeling, and cortical reorganization contribute to the enhanced recovery observed. The subacute phase is a critical period for effective rehabilitation, with interventions such as physical therapy, occupational therapy, and speech therapy playing a crucial role in promoting neuroplasticity and facilitating functional gains. The primary objectives of this phase are to maximize recovery, prevent deterioration, and promote adaptation [284, 288].

The chronic phase emerges beyond the initial six months after a stroke. It is characterized by a plateau or stabilization of functional recovery as spontaneous recovery and neuroplasticity decline. Nevertheless, neuroplasticity still occurs, albeit at a reduced level. Rehabilitation interventions remain valuable during this phase, focusing on refining skills, maintaining function, promoting independence, preventing complications, managing long-term impairments (particularly motor deficits), and improving overall quality of life [284, 288].

1.5.2 Current approaches to stroke rehabilitation

Stroke rehabilitation is a critical component of the recovery process for individuals who have experienced a stroke. It aims to enhance functional abilities and promote independence in daily activities. Over the years, various approaches and techniques have been developed to facilitate the rehabilitation process and optimize outcomes. The following are the common approaches to stroke rehabilitation:

Bobath approach

The Bobath approach, also known as the neuro-developmental technique (NDT), is a widely recognized and utilized method in stroke rehabilitation. Developed by Karl Bobath, this technique provides insights into the motor dysfunctions experienced by patients with hemiplegia. The Bobath approach is based on the assumption that abnormal movement patterns after stroke are caused by abnormal tone and reflexes that interfere with normal postural control and selective movement. It aims to inhibit abnormal tone and reflexes and facilitate normal movement patterns through specific handling techniques that provide sensory input and guidance to the patient. The approach emphasizes the importance of integrating sensory and motor functions in a holistic manner [292, 293].

Therapists use key points of handling and reflex inhibiting patterns for performing exercises. Manual handling involves strategically holding the patient at specific proprioceptive points, such as joint compression and distraction, to enable active patient response in performing functions. Manual handling can be of different types and is slowly removed to make the patient independent in motor activities. This therapy approach promotes improved functional control and independence [292, 293].

The Bobath approach has been shown to be effective in improving motor function and activities of daily living after stroke [294]. However, the approach has also been criticized for being too passive and prescriptive. Based on current evidence, the Bobath concept does not appear to be superior to other approaches in terms of regaining mobility, lower limb motor control, gait, balance, and activities of daily living in stroke patients [295, 296].

Brunnstrom approach

The Brunnstrom approach is a widely used method in stroke rehabilitation that focuses on the promotion of voluntary movement recovery. Developed by Swedish physical therapist Signe Brunnström, this approach is based on the concept of synergy patterns, which are stereotypical movement patterns observed during stroke recovery. The approach aims to promote the recovery of voluntary movement by stimulating these synergistic patterns [297, 298].

The Brunnstrom approach is based on the observation that patients with hemiplegia after stroke tend to recover in a predictable sequence of stages that reflect different levels of motor control. By integrating synergistic movements into functional activities, the approach aims to promote motor recovery. It emphasizes the importance of incorporating voluntary movement into reflexive synergies. During early recovery, the approach promotes the development of flexor and extensor synergies, with the intention that, through training, synergic muscle activation will transition into voluntary movement activation. Therapists employ sensory stimulation, proprioceptive input, and repetitive task training to facilitate sequential progress through the stages of motor recovery, starting from basic reflexive movements and progressing to more complex voluntary movements [297, 298].

Research has shown that the Brunnstrom approach is effective in improving motor function and activities of daily living after stroke. However, it has also been criticized for being too rigid, stereotyped, and not individualized. Therefore, the Brunnstrom approach may need to be adapted or combined with other approaches that can address these criticisms [299, 300]. Furthermore, in a study conducted by Wagenaar and colleagues [301], the relative effectiveness of the Brunnstrom approach and the Bobath/NDT method was examined from the perspective of functional recovery in stroke patients. The study revealed no clear differences in effectiveness between the two methods within the framework of functional recovery.

Proprioceptive neuromuscular facilitation

Proprioceptive neuromuscular facilitation (PNF) is a widely used approach in the rehabilitation of patients with musculoskeletal or neuromuscular disorders, including stroke. Originating in the late 1930s and '40s, PNF was developed by physician and neurologist Herman Kabat, along with physiotherapist Margaret Knott. Initially applied to younger individuals with cerebral palsy and other neurological conditions, the primary objective of PNF is to assist patients in reaching their highest level of function [302].

PNF is based on the principle that the stimulation of proprioceptors can enhance neuromuscular performance. This is achieved through specific movement patterns, manual resistance, and verbal commands to facilitate or inhibit muscle contraction and movement. PNF techniques incorporate a combination of passive stretching, resisted movement (contracting specific muscle groups), and diagonal movement patterns. These techniques are designed to stimulate sensory receptors and promote neuromuscular coordination, strength, and range of motion [302].

Research has demonstrated the effectiveness of PNF in improving motor function, balance, and gait in stroke patients. However, PNF does have certain limitations, such as the lack of standardization, specificity, and intensity. To address these limitations, it may be necessary to optimize PNF or integrate it with other approaches that can overcome these challenges and enhance its effectiveness [303, 304].

Robotic and electromechanics-assisted training

Robot-assisted rehabilitation is a novel and promising approach to stroke rehabilitation. It involves the utilization of mechanical devices that assist or resist movement and provide sensory feedback. Robotic-assisted training has gained attention in stroke rehabilitation due to its ability to deliver intensive, repetitive, and task-based training. Additionally, robotic training offers objective measurements of performance and progress, enhancing the rehabilitation process. Robotic devices enable individuals to engage in repetitive practice of motor tasks by assisting or resisting movement. These devices provide precise control and real-time feedback. They can be employed to target upper limb, lower limb, or whole-body movements, facilitating motor recovery and functional improvement in stroke survivors [289, 305].

Research has demonstrated the effectiveness of robotic approaches in enhancing motor function and activities of daily living post-stroke. However, the implementation of robotic rehabilitation may present certain limitations, such as cost, availability, accessibility, usability, or acceptability. To address these challenges, customization or combination with other approaches may be necessary to optimize their effectiveness and feasibility [305, 306].

Virtual reality

Virtual reality (VR) has emerged as a promising tool in stroke rehabilitation, offering innovative possibilities for patient recovery. VR-based rehabilitation involves the use of computer-generated visual interactive environments that simulate real or imaginary situations, enabling users to interact with them through various sensory modalities. By immersing stroke patients in these virtual environments, rehabilitation programs can simulate real-life scenarios and enable repetitive and task-based training, while providing real-time feedback and performance monitoring [307].

Research has demonstrated the effectiveness of VR in enhancing motor function, cognition, and overall quality of life for stroke survivors. However, the implementation of VR in rehabilitation programs may present certain challenges. Factors such as cost, availability, accessibility, usability, and safety can pose hurdles to widespread adoption [307, 308].

Telerehabilitation for post-stroke

Telerehabilitation is an emerging method of healthcare delivery that offers medical rehabilitation care remotely, especially when in-person therapy is difficult to access. It utilizes communication technologies to provide rehabilitation services from a distance. By using videoconferencing, individuals can conveniently receive assessments, guidance, and supervision from healthcare professionals within the comfort of their own homes [309]. Telerehabilitation has the potential to serve as a convenient, accessible, and cost-effective alternative or complement to traditional rehabilitation services for post-stroke patients. It promotes continuity of care, increases access to rehabilitation services, and promotes self-management and independence among stroke survivors [310, 311].

To ensure the effectiveness of telerehabilitation, it is crucial that the quality of services delivered remotely be consistent with the quality of services delivered face-to-face. Various healthcare professionals, including physiotherapists, occupational therapists, speech therapists, psychologists, nurses, and social workers, can provide telerehabilitation for post-stroke patients. This approach can be applied across different settings and phases of stroke rehabilitation [311]. Research has demonstrated the effectiveness of telerehabilitation in improving motor function, cognition, communication, and overall quality of life for individuals recovering from stroke [312].

In conclusion, stroke rehabilitation is a complex and multifaceted process that focuses on restoring or improving function after a stroke. Different approaches to stroke rehabilitation are based on different principles of recovery, including adaptation, restitution, and neuroplasticity. While there is no evidence adequately supporting the superiority of one type of exercise approach over another, the primary goal of these therapeutic approaches is to enhance physical independence and facilitate the acquisition of motor control skills. Notably, there is robust evidence supporting the effectiveness of rehabilitation in terms of improved functional independence and reduced mortality rates [274, 313].

1.6 Motor relearning program

1.6.1 Definition and principles of motor relearning program

The motor relearning program (MRP) is a rehabilitation approach used in the treatment of individuals with neurological difficulties, such as stroke. It was developed by Australian physiotherapists Janet Carr and Roberta Shepherd in 1980. The MRP approach is a task-oriented approach that emphasizes the practice of specific motor tasks and the relearning of real-life activities that hold meaning for patients, rather than facilitation or the practice of non-specific exercises. It focuses on improving motor control through the practice of specific motor tasks and training in controlled muscle action and movement components involved in these tasks. This approach is rooted in theories of kinesiology, which highlight the importance of distributed motor control. MRP theory explains how motor patterns can be acquired and modified through learning, making task-oriented training a crucial component [314, 315].

The MRP approach is based on several key assumptions about motor control. First, it assumes that the process of regaining the ability to perform motor tasks such as walking, reaching, and standing up involves a learning process and that individuals with disabilities require the same learning opportunities as those without disabilities (i.e., the need to practice, get feedback, understand the goal of the task, etc.). Second, MRP recognizes that motor control is exercised in both anticipatory and ongoing modes and that postural adjustments and focal limb movements are interrelated. Third, the approach emphasizes that control of a specific motor task can best be regained through practice of that specific motor task and that such tasks need to be practiced in their various environmental contexts. Lastly, MRP acknowledges the importance of sensory input in modulating action, highlighting its role in facilitating motor performance [314, 315].

The MRP approach adopts that the brain possesses a capacity for recovery, as it is dynamic and capable of reorganization and adaptation following brain injury. It further asserts that functional training, which involves the training of motor tasks, can itself be a remedial process. The MRP approach is based on principles of learning, biomechanical movement analysis, and the importance of functional tasks in rehabilitation. Learning in this approach involves repetitive and intense training that progressively increases in difficulty, accompanied by feedback and motivation strategies to regain lost motor functions. The ultimate goal is to enhance the execution of practical tasks that are significant in the patient's life, thereby improving their overall motor skills and capabilities [314, 315].

The MRP is based on four factors known to be essential for motor skill learning and assumed to be crucial for relearning motor control after a stroke: the elimination of unnecessary muscle activity, the provision of feedback, practice, and the interrelationship between postural adjustment and movement. The approach encourages the active participation of patients in functional and task-oriented activities to achieve optimal recovery following an injury. Throughout the approach, emphasis is on the patient consciously practicing specific motor tasks, increasing their awareness of muscle activation and movement control. This progresses to more automatic levels of practice, ensuring that the tasks are learned and skills acquired. It is possible that the emphasis placed on cognitive function and learning itself serves as an important stimulus for brain recovery [314, 315].

1.6.2 Components of motor relearning program

The MRP can be initiated as soon as the patient is medically stable. The plan of action for MRP consists of four steps [314, 315], which are outlined in Table 1.1.

Table 1.1: The steps of the motor relearning program

Step 1	**Analysis of task**
	Observation
	Comparison
	Analysis
Step 2	**Practice of missing components**
	Explanation – identification of goal
	Instruction
	Practice + verbal and visual feedback + manual guidance
Step 3	**Practice of task**
	Explanation – identification of goal
	Instruction
	Practice + verbal and visual feedback + manual guidance
	Re-evaluation
	Encourage flexibility
Step 4	**Transference of training**
	Opportunity to practice in context
	Consistency of practice
	Organization of self-monitored practice
	Structured learning environment
	Involvement of relatives and staff

Step 1 involves analyzing the patient's performance or their attempts to perform a motor task, as well as identifying any problems associated with their performance. This analysis enables decisions to be made regarding intervention and helps clarify the goal for the patient. During this step, the therapist carefully observes the patient and compares their performance with a list of essential components. The therapist assesses whether the patient achieves the intended goal and analyzes the means by which the goal is achieved. This includes noting any missing components or incorrect timing of components within the synergy, as well as identifying the absence of muscle activity, the presence of excessive or inappropriate muscle activity, and any compensatory motor behaviors [314, 315].

To guide treatment effectively, it is essential to differentiate between primary problems and secondary problems that arise as compensatory mechanisms. This differentiation allows for accurate decision-making regarding the specific problems that should be addressed through treatment. Consequently, in order to make appropriate decisions about intervention, the therapist must conduct a comprehensive analysis of each motor task and its associated problems. This analysis encompasses various factors, including anatomical, biomechanical, physiological, and behavioral considerations. By thoroughly examining these factors, the therapist can make informed decisions about the most suitable interventions to implement, leading to effective motor relearning and rehabilitation [314, 315].

Although Steps 2 and 3 are delineated separately to highlight the part-whole nature of practice, they actually have overlapping elements. Step 2 only precedes Step 3 when a patient lacks the ability to contract or control the necessary muscles. In such cases, the patient needs to dedicate time to practicing this specific component before integrating it into the overall complex task. The continuous re-evaluation provides feedback to the therapist regarding the effectiveness of analysis, decision-making, and treatment [314, 315].

Step 4 outlines various methods to ensure that what the patient has been practicing during therapy sessions can be effectively incorporated into their daily routine. This step is of utmost importance because, although the patient may be capable of performing a particular component or activity correctly under the guidance of the therapist, true learning and mastery require practice at other times during the day. In addition to physical practice, the patient should also engage in mental practice to reinforce the learning process [314, 315].

There are three important points to consider when using the MRP [314, 315]:

1. Motor tasks are practiced in their entirety. However, if necessary, individual components can be practiced separately, with practice of each component followed immediately by practice of the entire activity. During the practice of the entire activity, the therapist provides manual guidance to ensure the normal speed, rhythm, timing, and sequencing are maintained. This manual guidance serves as a trigger, facilitating the required motor activity and promoting effective motor learning.

2. Techniques are principally those associated with teaching, and involve various methods to identify goals and provide instructions on how to achieve them. These techniques encompass verbal and visual feedback as well as manual guidance. To ensure comprehension, it is helpful to provide patients with explanations and demonstrations that aid in their understanding the reason they are having difficulty performing a particular task, that is, the necessity of the component on which they will concentrate in practice.

The instructions provided in the Program serve as a guide for highlighting crucial points for the patient. It is important for these instructions to be concise and to the point. In cases where the patient has dysphasia, non-verbal communication such as gestures and demonstrations may be necessary to supplement or reinforce the instructions. Instructions help in identifying the goal, and certain goals are more effective in prompting action than others. For instance, if the goal is expressed as "Reach forward," a patient may struggle to accomplish it. However, if the goal is rephrased as "Touch the glass," the patient may find it easier to perform the action. After each performance, it is beneficial to provide brief, relevant, and concise verbal feedback regarding the patient's performance.

In this program, manual guidance can be classified into two types. The first involves the therapist passively moving the patient's limbs to position them correctly for movement or to demonstrate the desired movement, providing a model for the task. This method helps the patient avoid excessive difficulty and gain an understanding of the goal and the spatio-temporal characteristics of the task. The therapist may guide the patient through the entire movement once or twice.

The second type of manual guidance entails the therapist applying spatial and temporal constraints or physical restrictions to the patient's attempts at a specific motor task. For example, the therapist may stabilize a part of the limb to constrain spatial movement while the patient focuses on generating specific components independently. This restriction reduces the degrees of freedom the patient needs to control, allowing them to concentrate on the specific muscle activation associated with achieving the goal. As the patient gains more control, the therapist gradually reduces the physical constraint, increasing the number of degrees of freedom the patient needs to control.

3. Methods of progression. It is important that the patient consistently practices at their peak performance, continuously pushing their abilities to their limits. It is essential to avoid wasting time by practicing tasks that the patient can already perform with ease. Instead, activities should progress as soon as the patient demonstrates some level of control. To increase the complexity of movements, several strategies can be employed. Manual guidance and feedback are gradually decreased, allowing the patient to rely more on their own abilities and judgment. Alterations in speed, either by increasing or decreasing it, can also add an additional challenge. Furthermore, introducing variety in movements and tasks further enhances the patient's progression. During Step 3, as the patient develops their skills, they undergo a transition from the cognitive phase of learning to the automatic phase.

1.6.3 Evidence for the effectiveness of motor relearning program

The MRP, which is based on the principles of motor learning and neural plasticity, involves task-specific training with feedback and practice. Its effectiveness in stroke rehabilitation has been supported by various studies and clinical evidence. MRP has been investigated for its effectiveness in stroke rehabilitation, with the studied intervention programs falling into two types: those based solely on the MRP and protocols that combine the MRP with other therapy approaches. Here is a summary of common studies that have explored the effectiveness of MRP in stroke rehabilitation:

Langhammer and Stanghelle (2000) [316] conducted a randomized trial to compare the effectiveness of Bobath therapy and MRP in the rehabilitation of stroke patients. The study aimed to assess whether these two approaches differed in terms of motor function, ADL, life quality, length of hospital stay, use of assistive devices, and accommodation after discharge. A total of 61 patients with acute first-ever stroke were included in the study and block randomized into two groups, stratified by gender and hemiplegic site. The participants were assigned to either the Bobath or MRP group and received the respective physiotherapy interventions for a minimum of 40 minutes per session, five days a week, during their hospitalization. All patients received the same multidisciplinary treatment in addition to physiotherapy, as per the recommendations for stroke units.

Group 1 consisted of 33 patients who received physiotherapy according to the MRP approach, while Group 2 comprised 28 patients who received physiotherapy based on the Bobath concept. The supplemental treatment provided to both groups was similar. The study utilized several outcome measures, including the Motor Assessment Scale (MAS), the Sødring Motor Evaluation Scale (SMES), the Barthel ADL Index, the Nottingham Health Profile (NHP), and additional parameters. These outcomes were assessed at three time points: admission, discharge, and three months after discharge. The results indicated that both groups showed improvement across all outcome measures. However, the MRP group demonstrated significantly better motor function outcomes as assessed by the MAS and SMES. Additionally, the MRP group had a shorter hospital stay compared to the Bobath group. No significant differences were observed between the two groups concerning the Barthel ADL Index, the NHP life quality test, or the use of assistive devices.

In 2003 [317], the same authors conducted a follow-up study to investigate the long-term effects of the initial physiotherapy approach, specifically the Bobath and MRP, on various outcomes in stroke patients, including mortality, motor function, postural control, ADL, life quality, follow-up from community services, and living conditions. The study utilized the same outcome measures as the previous study. Follow-up assessments were conducted at admission, discharge, one year after discharge, and four years after discharge. The results indicated that mortality rates were comparable between the two groups. However, both groups experienced a rapid deterioration in motor function, postural control, and ADL, leading to increased dependence and a heightened risk of falls among the patients. Although there was an improvement in life quality compared to the acute stage, it remained lower than that of healthy individuals. The patients from both groups resided at home but required assistance from relatives and community services. The utilization of physiotherapy as a follow-up service was infrequent. The authors concluded that the initial physiotherapy approach did not have a significant impact on patients' long-term coping abilities. They highlighted the rapid deterioration in ADL and motor function, increased reliance on relatives, and the lack of follow-up physiotherapy or other rehabilitation activities after the acute phase.

Moreover, in 2011 [318], the same authors conducted a study comparing the Bobath concept to the MRP approach, using data from their 2000 study to examine whether the Bobath concept resulted in improved movement quality compared to MRP. The study employed the same outcome measures and utilized a triangulation of test scores with reference to the Movement Quality Model and biomechanical, physiological, psycho-socio-cultural, and existential themes. The results indicated that the MRP group achieved significantly better scores than the Bobath group in arm, sitting, and hand function, as measured by the MAS and SMES. However, no significant differences were found between the groups regarding leg function, balance, transfer, walking, or stair climbing. The MRP group demonstrated higher scores in the Movement Quality Model and movement qualities related to biomechanical, physiological, and psycho-socio-cultural aspects, suggesting better overall movement quality across all assessed items. Regression models established significant relationships between motor performance and self-reported physical mobility, energy, emotion, and social interaction. The authors concluded that task-oriented exercises of the MRP type were more effective in enhancing movement quality in stroke rehabilitation compared to the facilitation/inhibition strategies employed in the Bobath concept.

Nilsson et al. (2001) [319] conducted a randomized controlled study to compare the effectiveness of walking training on a treadmill with body weight support (BWS) and walking training on the ground in patients with hemiparesis after stroke. The study aimed to assess the impact of these two types of walking training on functional independence, walking velocity, ambulation ability, motor function, and balance. A total of 73 patients were included in the study and were randomized into two groups, stratified by gender and hemiplegic site. The treatment group, consisting of 33 patients, received walking training on a treadmill with BWS for 30 minutes five days a week. The control group, comprising 28 patients, received walking training on the ground following the MRP approach for the same duration and frequency. Both groups received professional stroke rehabilitation in addition to the walking training. The outcome measures included the Functional Independence Measure (FIM), walking velocity for 10 meters, Functional Ambulation Classification (FAC), Fugl-Meyer Stroke Assessment, and Berg's Balance Scale. These outcomes were assessed at admission, discharge, and a 10-month follow-up. The results indicated that both groups showed improvement across all outcome measures from admission to the 10-month follow-up. However, there were no significant differences between the groups at discharge or at the 10-month follow-up in any of the outcome measures. Based on these findings, the authors concluded that treadmill training with BWS was a comparable option to walking training on the ground following the MRP approach at the early stage of stroke rehabilitation. They suggested that both types of walking training were beneficial for enhancing functional recovery and mobility in stroke patients.

Krutulyte et al. (2003) [320] conducted a randomized controlled trial comparing the Bobath method and the MRP method in stroke rehabilitation. They enrolled 240 stroke patients, assigning them to the Bobath group (n=147) or the MRP group (n=93) while ensuring group matching based on sex, age, time since stroke onset, and degree of impairment. The researchers evaluated the patients' mobility using the European Federation for Research in Rehabilitation (EFRR) scale and their activities of daily living using the Barthel index, both before and after the physical therapy intervention. The results indicated that the MRP group exhibited significantly superior outcomes compared to the Bobath group in terms of mobility and activities of daily living. Thus, the authors concluded that task-oriented physiotherapy strategies, such as MRP, are more effective in stroke rehabilitation compared to facilitation/inhibition strategies like Bobath.

In their randomized controlled trial, Chan et al. (2006) [321] compared the effectiveness of the MRP with a conventional therapy program in promoting physical function and task performance for stroke patients. The study aimed to assess the efficacy of the MRP, which incorporates principles of motor learning and task-specific training. The trial included 52 matched-paired outpatients with thrombotic or hemorrhagic strokes who were randomized into two groups. The study group (26 patients) received 18 two-hour sessions over six weeks of MRP, while the control group (26 patients) received 18 two-hour sessions over the same period of a conventional therapy program. Outcome measures included the Berg Balance Scale, the Timed Up and Go Test, the Functional Independence Measure (FIM), the modified Lawton Instrumental Activities of Daily Living (IADL) test, and the Community Integration Questionnaire. Measurements were taken at baseline (after randomization), two weeks, four weeks, and six weeks. The results indicated that the MRP group demonstrated significantly better performance on all outcome measures, except for the Timed Up and Go Test, compared to the control group. The interactions between group and occasion were significant for all five outcome measures, indicating differing rates of change over time between the MRP and control groups. The MRP group also exhibited significant improvements in balance, mobility, ADL performance, and motor control compared to their baseline scores. The authors concluded that the MRP was effective in enhancing the functional recovery of stroke patients. They emphasized the importance of both the 'sequential' and 'function-based' concepts in applying the MRP to stroke rehabilitation.

Bhalerao et al. (2013) [322] conducted a randomized controlled trial to compare the effectiveness of the MRP versus the Bobath approach on ADL and ambulation in acute stroke rehabilitation. They recruited 32 subjects with the first unilateral stroke and allocated them into two groups using block randomization. Group A received MRP, and Group B received the Bobath approach for six weeks. They assessed ADL using the Functional Independence Measure and Barthel Index, and ambulation using the Functional Ambulation Category and Dynamic Gait Index at baseline and every two weeks. The findings revealed that MRP was more effective than the Bobath approach in improving ADL and ambulation at all time points, with significant differences observed in the Barthel Index, Functional Independence Measure, Functional Ambulation Category, and Dynamic Gait Index. Based on these results, the authors concluded that MRP was a preferable approach over the Bobath method for enhancing ADL and ambulation in acute stroke rehabilitation.

In a randomized controlled trial conducted by Singha (2017) [323], the effects of the MRP and the proprioceptive neuromuscular facilitation (PNF) technique on the basic mobility of chronic stroke patients were compared. Basic mobility refers to the ability to perform sit-to-stand and walking tasks. The study included 30 chronic stroke patients who were randomly assigned to either the MRP group or the PNF group. Both groups received 30 minutes of treatment per day, three times per week for three weeks, in their home setting. The outcome measures used were the Timed Up and Go (TUG) test and the Sit to Stand (STS) item of the Motor Assessment Scale (MAS). The results demonstrated that the MRP group exhibited significantly greater improvements than the PNF group in both TUG and STS scores after the intervention as well as at the one-month follow-up. Based on these findings, the study concluded that the MRP approach is more effective than PNF for enhancing basic mobility in chronic stroke patients and maintaining those improvements over time.

Chen et al. (2019) [324] conducted a randomized controlled trial to compare the effects of the MRP and the Bobath approach on the prevention of poststroke apathy. Apathy, characterized by reduced motivation and interest, is commonly observed in stroke survivors. The study included 488 acute stroke patients without apathy or depression at baseline, who were randomly assigned to either the MRP group (n = 245) or the Bobath group (n = 243). Both groups received physiotherapy based on their assigned approach for a duration of four weeks, in addition to other supplementary treatments. The primary outcome measure was the Apathy Evaluation Scale-Clinical, which assesses apathy severity in clinical settings. The study also evaluated stroke severity, functional independence, cognitive function, depression, and anxiety at baseline and at 1-, 3-, 6-, 9-, and 12-month follow-up. The results indicated that the MRP group exhibited significantly lower apathy scores compared to the Bobath group at each time point, indicating reduced apathy severity. Moreover, the Bobath group had a higher risk of developing poststroke apathy over the course of 12 months compared to the MRP group. The study concluded that the

MRP approach was more effective than the Bobath approach in preventing post-stroke apathy.

Kanase (2020) [325] conducted an experimental study to compare the effects of MRP and conventional training on the functional mobility of post-stroke patients. Functional mobility encompasses activities such as lying, sitting, walking, and using the upper limbs. The study included 30 post-stroke patients who were randomly assigned to either the MRP group or the conventional training group. Both groups underwent treatment for six weeks, with sessions held four times per week. The Motor Assessment Scale (MAS) and the modified Barthel index were used as outcome measures to assess the level of independence in various activities. Data were collected before and after the treatment. The results indicated that both groups demonstrated significant improvements in functional mobility following the treatment; however, the MRP group exhibited a significantly greater improvement compared to the conventional training group. In conclusion, the study suggested that the MRP approach is more effective than conventional training in enhancing functional mobility among post-stroke patients.

Raval (2020) [326] conducted an interventional study to assess the effectiveness of the MRP on functional balance, functional mobility, and quality of life in post-stroke patients. The study enrolled 34 patients who had experienced their first stroke within the past six months and provided them with MRP training in conjunction with conventional exercises over a six-week period. The study aimed to enhance the patients' motor performance and examine its impact on their quality of life. The Motor Assessment Scale (MAS), Barthel Index (BI), and Stroke Specific Quality of Life (SSQOL) were used as outcome measures. Data were collected before and after the intervention. The results revealed a significant improvement in MAS, BI, and SSQOL scores following the intervention. Additionally, the study found a noteworthy correlation between post-intervention BI and SSQOL scores, while the correlation between post-intervention MAS and SSQOL scores was less significant. Consequently, the study concluded that MRP, when combined with conventional therapy, is effective in enhancing functional balance, functional mobility, and quality of life among post-stroke patients.

Mufidah et al. (2020) [327] conducted a quasi-experimental study to compare the effects of the MRP and the Bobath Method on the standing balance of stroke patients. The study included 24 stroke patients who were randomly assigned to either the MRP group or the Bobath group, with 12 patients in each group. Both groups received their respective interventions for a specified duration. The Berg Balance Scale (BBS), which assesses balance in various tasks, was used as the outcome measure. BBS scores were collected before and after the intervention. The results revealed that both the MRP and the Bobath Method demonstrated improvements in the standing balance of the patients. However, the MRP group exhibited significantly greater improvement compared to the Bobath group. The study attributed the superior effectiveness of MRP to its incorporation of cognitive, associative, and autonomic processes that enhanced standing balance in stroke patients.

In a systematic review and network meta-analysis conducted by Zhang et al. (2020) [328], the effects of various exercise-based interventions on the social participation of post-stroke patients were compared. The study systematically searched multiple databases for randomized controlled trials that included exercise interventions for post-stroke patients, with social participation as the primary outcome. A total of 16 trials, comprising 1704 patients and 12 intervention arms, were included in the analysis. Subgroup analyses were conducted based on follow-up time (short-term or long-term) and intervention adherence. The study utilized surface under cumulative ranking curve values (SUCRCV) and standardized mean difference (SMD) to rank the interventions and estimate their effects. The findings revealed that the Motor Relearning Program (MRP) was the most effective intervention overall and showed significant improvement in short-term treatment efficacy for enhancing social participation in post-stroke patients. In the long-term subgroup, home-based combined exercise involving aerobic and resistance training emerged as the best intervention. Additionally, in the high-adherence subgroup, cognitive-based exercise incorporating mental imagery and dual-task training demonstrated the most favorable outcomes. The study concluded that these interventions hold potential for improving social participation among post-stroke patients and should be considered in clinical practice.

Recently, Naz et al. (2022) [329] conducted a randomized controlled trial to compare the effects of combining the MRP with routine physical therapy versus routine physical therapy alone on the balance and upright mobility of sub-acute stroke patients. Balance and upright mobility encompass the ability to maintain a stable posture and perform tasks such as sit-to-stand and walking. The study enrolled 68 subacute stroke patients who were randomly assigned to either the experimental group or the control group, with 34 patients in each group. The experimental group received MRP training, a task-specific learning approach, in addition to routine physical therapy involving sit-to-stand, gait, balance, stretching, and strengthening exercises. The control group received routine physical therapy only. The intervention lasted for eight weeks, with follow-up assessments conducted at four and eight weeks. The outcome measures utilized were the Berg Balance Scale (BBS), which evaluates balance performance in various tasks, and the Time Up and Go (TUG) test, which measures the time taken to complete sit-to-stand and walking tasks. The findings indicated that both groups exhibited significant improvement in BBS and TUG scores after the intervention, but the experimental group demonstrated a significantly greater improvement compared to the control group. Thus, the study concluded that combining MRP with routine physical therapy was more effective than routine physical therapy alone in enhancing balance and upright mobility among sub-acute stroke patients.

In a recent systematic review of the literature conducted by Mateus-Aria et al. (2023) [330], the aim was to determine the effects of the MRP compared to different physiotherapeutic treatments on the functional independence of adults after stroke. The study conducted a comprehensive search of various databases and manual sources to identify relevant clinical trials published in Spanish, English, or Portuguese that compared MRP with other interventions. Out of 984 potential studies, eight trials were included in the review. The results of the included trials consistently demonstrated a clinically significant improvement in functional independence among individuals who received MRP interventions. The study concluded that MRP has a notable clinical impact on the functional independence of patients with stroke sequelae. However, the authors emphasized the need for further research with rigorous methodological quality to provide more robust evidence and evaluate the long-term effects of MRP on functional independence.

1.7 The research gap: The rationale of the study

Despite the growing body of research investigating the effectiveness of various rehabilitation approaches in stroke rehabilitation, there remains a significant gap in the literature concerning the specific effects of the MRP. While the MRP has shown promise in improving motor function and movement quality among stroke patients, there is a need for more rigorous and comprehensive research to further validate its efficacy.

A notable gap in the research is the limited number of large-scale randomized controlled trials (RCTs) that specifically examine the outcomes of MRP in stroke rehabilitation. Many existing studies on MRP have small sample sizes, which limit the generalizability of the findings to a broader stroke population. Moreover, there is a lack of evidence-based guidelines and recommendations for the optimal use and integration of MRP in stroke rehabilitation. Therefore, there is a need for more systematic reviews, meta-analyses, and larger-scale RCTs that can provide more robust evidence regarding the effectiveness of MRP in improving motor function, functional independence, and overall quality of life for stroke survivors.

Another area that requires further investigation is the long-term effects of the MRP. While some studies have explored the immediate or short-term outcomes, there is a paucity of research examining the durability of the effects over an extended period. Understanding the sustainability of the MRP's benefits is crucial for informing long-term rehabilitation plans and optimizing stroke recovery outcomes.

Moreover, the lack of standardized protocols and criteria for MRP implementation and evaluation is another gap in the research. Additional research is needed to elucidate the optimal dosage, frequency, and duration of MRP interventions. The current literature provides limited guidance on the optimal implementation of the program, with different studies using different specific exercise contents, durations, frequencies, intensity levels, and progression strategies. A better understanding of these parameters would enable clinicians to tailor MRP interventions to individual stroke patients' needs and maximize their rehabilitation potential.

Another significant gap in research regarding the effect of MRP in stroke rehabilitation is the lack of comprehensive and patient-centered outcome measures, especially those that use biomechanical balance and gait variables and posturography to evaluate its outcomes. Existing evidence predominantly relies on traditional clinical outcome measures, and studies investigating the impact of task-specific training based on MRP using these instrumental evaluation tools are scarce or nonexistent. These outcome measures can provide more objective and detailed information about the biomechanical changes and adaptations that occur after MRP intervention. Therefore, there is a need for research that bridges this gap and explores the effectiveness of task-specific training based on MRP using both clinical outcome measures and objective biomechanical assessments.

To address these research gaps, the present study aims to assess the efficacy and long-term outcomes of task-specific training based on MRP in improving balance, mobility, and activities of daily living performance among post-stroke patients. The study recognizes the limitation of relying solely on traditional outcome measures and seeks to incorporate instrumental evaluation tools, such as biomechanical balance and gait variables and posturography, to provide a more comprehensive assessment of the intervention's effects. By including these objective measures, the study seeks to enhance our understanding of how task-specific training based on MRP impacts not only clinical outcomes but also biomechanical parameters related to balance and gait. This approach can provide valuable insights into the specific mechanisms through which MRP influences motor function and movement quality in stroke rehabilitation.

Furthermore, the study aims to evaluate the long-term outcomes of task-specific training based on MRP, which is crucial for assessing the sustainability of the intervention's effects beyond the immediate post-intervention period. Long-term follow-up assessments can provide valuable information about the durability and maintenance of the improvements achieved through MRP and inform recommendations for ongoing rehabilitation and support for stroke survivors.

In conclusion, the current study addresses the research gap by investigating the effectiveness of task-specific training based on MRP in stroke rehabilitation using both clinical outcome measures and instrumental evaluation tools to assess biomechanical balance and gait variables. By focusing on the efficacy and long-term outcomes of this intervention, the study contributes to the existing literature, provides valuable insights for optimizing stroke rehabilitation approaches, and provides clinicians with evidence-based guidelines for incorporating the MRP into comprehensive stroke rehabilitation programs.

Section 2

Study justification

Stroke is a prevalent cause of long-term disability worldwide, with the incidence of this condition on the rise globally. Stroke patients commonly experience a range of physical impairments, including impaired balance and mobility, which can significantly impact their ability to perform activities of daily living (ADL) and can negatively affect the quality of life of stroke survivors, leading to reduced participation and integration into society. Rehabilitation programs are essential to promoting functional recovery in stroke survivors, with improving balance, mobility, and ADL performance being key goals of stroke rehabilitation.

Cramer and colleagues [331] identified two specific issues that need to be addressed to advance research on stroke recovery and rehabilitation. The first issue concerns the inconsistency of post-acute stroke care delivery patterns, which can significantly vary, while the second issue is the lack of agreement on the most effective methods for measuring improvement in research studies to yield conclusive outcomes. In a systematic review and meta-analysis conducted by Hugues et al. [332] on the effectiveness of physical therapy (PT) on balance after stroke, they found that the heterogeneity of PT studies and the weak methodological quality of studies strongly limited the meaning and confidence in findings.

Furthermore, in their review, Stinear et al. [333] highlighted the challenges facing stroke rehabilitation research, including the need to improve treatment fidelity and the use of domain-specific primary endpoint measures aligned with the intervention's mechanisms of action. Additionally, they noted that most large intervention trials targeting motor recovery in stroke rehabilitation produce similar benefits for both the intervention and control groups. These neutral results might reflect the absence of additional benefit from the tested interventions or the many challenges of designing and conducting large stroke rehabilitation trials.

The American Heart Association/American Stroke Association guidelines emphasize the need for research to identify effective interventions for stroke survivors. There is a need to consider the use of multiple self-report outcomes and computer-adapted assessments to personalize and tailor interventions for stroke survivors. Additionally, the guidelines suggest exploring effective models of care that consider stroke as a chronic condition rather than a single acute event [289, 334]. In addition, the Action Plan for Stroke in Europe 2018–2030 [335] highlights the need to efficiently implement long-term rehabilitation strategies to improve participation and integration into society among stroke survivors. The plan also emphasizes the need to expand our knowledge on functional recovery mechanisms and potential therapeutic targets to enhance the effects of physical rehabilitation in the sub-acute and chronic phases after stroke.

Arienti and colleagues [336] conducted a systematic review to assess the effectiveness of interventions for improving balance in stroke patients. However, they found that the majority of the studies had poor methodological quality, which made it difficult to draw any conclusive implications. Therefore, the study highlighted the need for and importance of addressing methodological issues in rehabilitation research. Moreover, Stroke survivors prioritized research on impairment of balance control and walking difficulties due to concerns about fall incidents and disability in daily activities. Future research should focus on developing strategies to address these challenges [337].

Thus, there is a need for high-quality studies that address these limitations and provide robust evidence for the effectiveness of specific interventions that can significantly improve outcomes for stroke survivors. Therefore, this PhD dissertation aims to address the issues and gaps identified by conducting a randomized controlled trial with a parallel-group design to evaluate the effectiveness of motor relearning program (MRP) on the balance, mobility, and performance of ADL among sub-acute stroke patients using both clinical outcome measures, and instrumental evaluation tools to measure the biomechanical balance and gait variables. The control group will receive a standardized rehabilitation program, which will serve as a benchmark to assess the effectiveness of the intervention.

Previous studies on stroke have widely used standardized outcome measures to evaluate motor deficits, such as balance and gait. However, studies investigating the effects of task-specific training using biomechanical balance and gait variables (i.e., kinematic and kinetic parameters) as well as posturography after stroke are scarce. In this respect, this study adopted an instrumental balance and gait analysis as part of the approach for evaluating the results. This will provide quantitative data about balance and gait, reduce the interference of subjective factors in the evaluation, and provide a more comprehensive evaluation of the program's effectiveness. Additionally, it will improve our understanding of the underlying mechanisms of the intervention's effects, helping to inform the development of effective rehabilitation interventions and appropriate outcome measures.

Finally, this study is justified by the need to identify effective stroke rehabilitation interventions that improve functional outcomes and reduce long-term disability. By addressing the limitations of previous research and employing rigorous methodology, this study contributes to the growing body of stroke rehabilitation research, aimed at improving interventions and outcomes. The information gathered from this study will be useful for clinicians and researchers in developing evidence-based interventions for stroke patients, thereby improving the quality of stroke rehabilitation research. The findings of this study contribute to the development of more effective stroke rehabilitation strategies, enhancing the participation and integration of stroke survivors into society. These results are significant for healthcare providers, policymakers, and stroke patients and their families, ultimately improving functional outcomes and the quality of life of stroke survivors.

Section 3

Hypothesis

3.1 Experimental hypothesis

The experimental hypothesis of this study is that subacute stroke patients who receive task-specific training based on the motor relearning program (MRP) will show a statistically significant greater improvement in balance, mobility (i.e., gait), and activities of daily living performance compared to those who receive conventional physical therapy program.

3.2 Null hypothesis

The null hypothesis of this study is that there will be no statistically significant difference in balance, mobility (i.e., gait), and activities of daily living performance between subacute stroke patients who receive task-specific training based on the motor relearning program (MRP) and those who receive conventional physical therapy program.

Section 4

Study objectives

4.1 Primary objective

The primary objective of this study was to assess the effectiveness of task-specific training based on a motor relearning program (MRP) on balance and postural control among sub-acute stroke patients, as compared to a conventional physical therapy program.

4.2 Secondary objectives

- To investigate the effect of task-specific training based on MRP on mobility, specifically gait, in sub-acute stroke patients. By focusing on gait, the study compared the outcomes of MRP with those of conventional physical therapy in improving the ability to walk and overall mobility in post-stroke patients.
- To investigate the impact of task-specific training based on MRP on activities of daily living (ADL) performance in sub-acute stroke patients. Stroke patients often experience difficulties in performing ADL, such as bathing, dressing, eating, and toileting, etc., which are essential for maintaining independence and negatively affect their participation in society and quality of life. The study compared the outcomes of MRP with those of conventional physical therapy in improving ADL performance and independence in sub-acute stroke patients.
- To evaluate which intervention group maintained the long-term improvement after three months from the post-intervention assessment session of each par-

ticipant. The long-term maintenance of treatment effects is essential for determining the efficacy of any rehabilitation approach. Therefore, this study conducted a 3-month follow-up assessment after the intervention to assess the retention of gains and which intervention group maintained the long-term improvement in balance, mobility, and ADL performance. The study compared the changes in the outcomes of the two intervention groups at both the post-intervention and 3-month follow-up sessions.

Overall, the study aimed to contribute to the existing knowledge of stroke rehabilitation and provide evidence-based recommendations for clinical practice by demonstrating the effectiveness of task-specific training based on MRP, particularly in terms of improving balance, mobility, and ADL performance. The study could potentially enhance rehabilitation outcomes of the post-stroke patients, resulting in a better functional independence and quality of life. The results of this study would be valuable in guiding the development of effective rehabilitation programs for stroke patients and identifying the most effective interventions for improving long-term outcomes in this population.

Section 5

Methodology

The current chapter presents the development of the research methods and the methodology implemented to complete the experimental portion of this study. The chapter begins with a description of the research design that was chosen for the purpose of this study and the reasons for this choice. In addition, it provides information on the participants, that is, the criteria for inclusion in the study and the sample size. Furthermore, the chapter describes the procedures followed in carrying out this study and includes the outcome measures and instrumental assessment tools used for data collection. Moreover, it discusses the data analysis methods which have been used. It concludes with a discussion of the ethical considerations that were followed. The study protocol was approved by the Medical Research Ethics Committee of Parc de Salut MAR (CEIm) with a registration number (REC No: 2021/9986/I), and the study was registered on ClinicalTrials.gov with a registration number (NCT05076383).

5.1 Study design

This study is a two-armed randomized controlled clinical trial (RCT) of parallel design, which aims to investigate the effectiveness of motor relearning program (MRP) on balance, mobility and performance of activities of daily living among sub-acute stroke patients. Patients who meet the defined eligibility criteria were randomly assigned to either the MRP group or the conventional physical therapy program (CPT) group, with an allocation ratio of 1:1. The study consisted of an 8-week intervention and evaluations at three time points: baseline, post-intervention and 3-month follow-up. The Consolidated Standards of Reporting Trials (CONSORT) flow chart of the study is displayed in Figure 5.1. The development of the study protocol followed the Standard Protocol Items: Recommendations for Interventional Trials (SPIRIT) guidelines [338]. The primary reason for choosing the current design for this study was that RCTs are considered the most reliable method of obtaining clinical evidence to determine the actual relative effectiveness of an intervention [339]. RCTs have numerous advantages, most notably their ability to minimize selection bias by distributing the characteristics of patients that may impact the outcome randomly between the groups so that any differences in outcomes can only be attributed to the treatment [340]. Therefore, random assignment increases the likelihood that baseline systematic differences across intervention groups will be balanced with respect to known and unknown characteristics, such as age, gender, and disease duration, that may have an impact on the outcome [341].

5.2 Study settings

The study was carried out at the Department of Physical Medicine and Rehabilitation at two hospitals of the Parc de Salut Mar Consortium (Hospital de l'Esperança and Centre Fòrum-Hospital del Mar), Barcelona, Spain. The clinical outcome measures, instrumental analysis, and intervention were conducted in the Functional and Movement Analysis Laboratory at Centre Fòrum-Hospital del Mar.

5.3 Participants

The study participants were subacute stroke patients aged 18 to 85 years old who were admitted to an outpatient rehabilitation department.

5.3.1 Eligibility criteria for participants

Inclusion criteria

Participants that meet the following criteria were included in the study:

- First-ever subacute (1-6 months) stroke patients.
- Able to give informed consent.
- Patients with hemiparesis exhibit lower limb muscle power ranging from 2 to 4 on the Medical Research Council (MRC) Muscle Scale on the affected side.

- Able to stand independently for at least one minute.
- Can ambulate 25 feet/10 meters (with or without the assistive device).

Exclusion criteria

Participants were excluded for meeting any of the following criteria:

- Post-stroke patients with major cognitive deficits (Montreal Cognitive Assessment-MoCA score $\leq$ 20) [342] and/or communication impairments that do not allow patients to follow directions (i.e., deafness, aphasia, etc.).
- Patients with visual impairments such as visuospatial neglect, diplopia and/or hemianopia, etc.
- Patients who are receiving other related therapy through the study may affect the efficacy of this study.
- Those with any medical contraindications to start rehabilitation (i.e., severe uncontrolled hypertension, uncontrolled diabetes or unstable angina).
- Those with a history of disability related to neurological deficits other than stroke.

5.3.2 Sample size

The sample size for this trial was calculated by using balance impairment as the main indicator, that is, Berg Balance Scale (BBS). The expected mean effect size based on previous studies was around d = 0.65 [318, 321, 327]. Using the statistical program G* power Software (version 3.1; Henrich-Heine-Universitat Dusseldorf, Germany) [343], at alpha level (α) of 0.05 and power ($1 - \beta$) of 0.80. This generated a sample size of 30 patients in each group. Considering a 10% drop-out, the total sample size for this study was about 66 patients randomized to one of the two treatment groups (study group or the control group).

5.4 Procedure

The study procedure, which includes enrolment (recruitment and assessment for eligibility), randomization, and intervention, occurred from October 2021 to October 2022. The study was completed in January 2023. The schedule of enrolment, interventions and assessments as per SPIRIT [338] is outlined in Table 5.1.

5.4.1 Recruitment and consent

Participants were recruited consecutively from the outpatient Physical Medicine and Rehabilitation Department, where a specialist physician referred patients. The principal investigator screened the enrolled patients who met the selection criteria and provided detailed and understandable verbal and written information about the study, and possible benefits of the rehabilitation and the relevant safety during the study to obtain informed consent. Once the consent was obtained, the principal investigator proceeded with the baseline assessment (clinical outcome measures and instrumental analysis). Lastly, participants who completed the baseline assessment were randomly assigned to one of the two groups and subjected to the intervention programs. The study organization of participants through each stage of the study is shown in Figure 5.1.

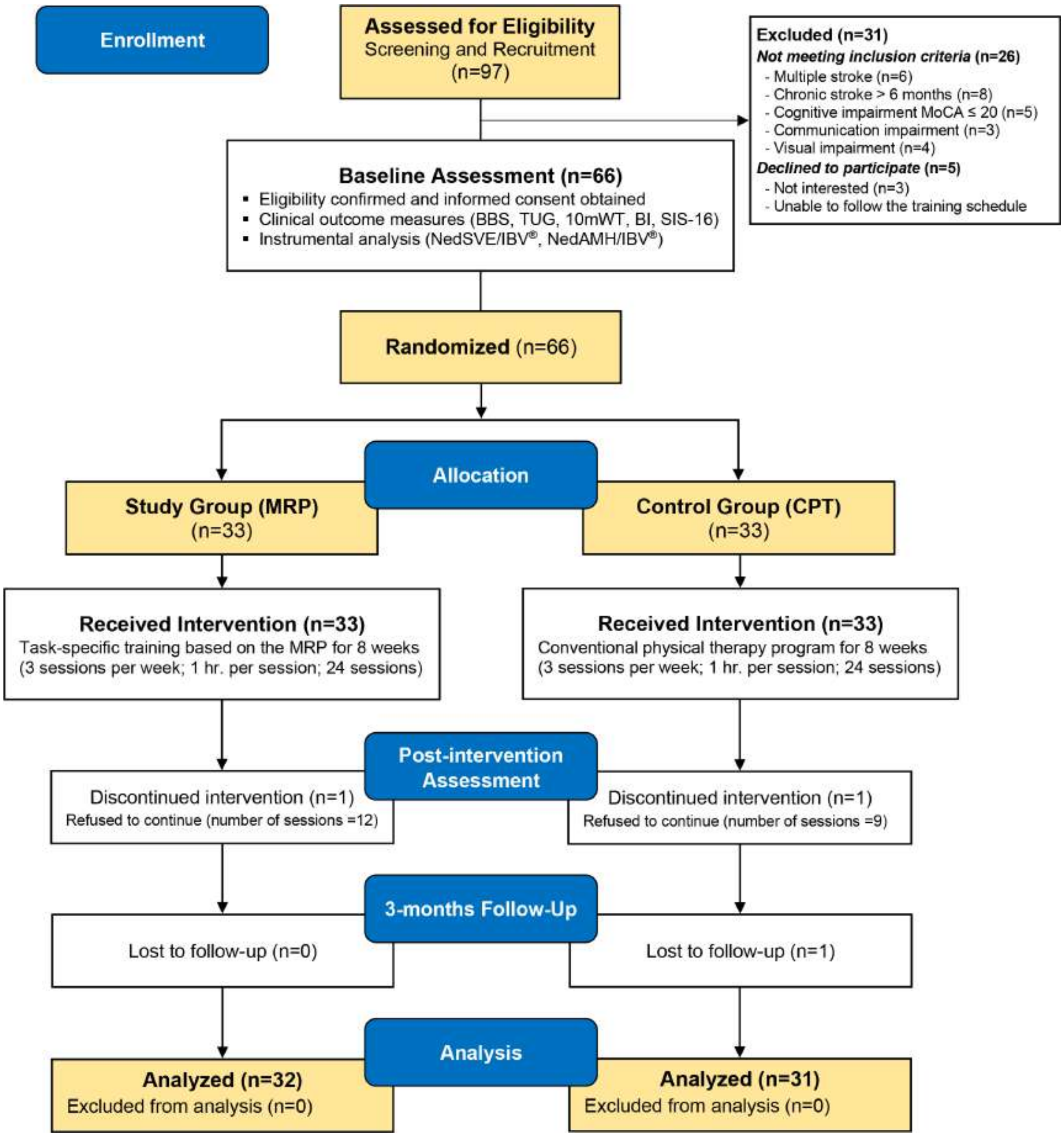

Figure 5.1: CONSORT flow chart of the study.

Table 5.1: Schedule of enrolment, interventions and assessments.

STUDY PERIOD						
	-t_1	***t_0*** *(week 0-1)*		***t_1*** *(8 weeks)*	***t_2*** *(week 9-10)*	***t_x***
TIME POINT	**Enrollment**	**Baseline**	**Allocation**	**Intervention**	**Post-intervention**	**3-months follow-up**
ENROLLMENT						
Eligibility screening	X					
Informed consent	X					
Demographic data collection	X					
Randomization and allocation			X			
INTERVENTIONS						
Study group (MRP)				←——→		
Control group (CPT)				←——→		
ASSESSMENTS						
Anthropometric measurement		X				
Clinical outcome measures						
BBS		X			X	X
TUG		X			X	X
10mWT		X			X	X
BI		X			X	X
SIS-16		X			X	X
Instrumental analysis						
NedSVE/IBV® Posturography		X			X	X
NedAMH/IBV® System		X			X	X

5.4.2 Randomization and allocation

Sequence generation

The eligible participants were randomly allocated to one of the two groups (study group or control group) using a web-based tool (www.sealedenvelope.com). The random sequence was generated using permuted block randomization with a block size of 4 and a 1:1 allocation ratio.

Concealment mechanism

The results of sequence generation were distributed and stored in sealed envelopes and kept confidential by the principal investigator who conducted the randomization procedure. For allocation in groups, each participant blindly pulled up a sealed envelope indicating one of the intervention groups. Participants were informed about their assigned intervention group.

5.4.3 Blinding

The study was an exercise-based intervention where the therapist and participants actively participated, so both of them could not be blinded to the intervention after the assignment. Moreover, the principal investigator who was in charge of assessments (outcome assessor) was also involved in most of the interventions; consequently, this study was an open-label trial except for the person who did the data analysis.

5.5 Interventions

The participants had been randomly assigned to the study (MRP) or control (CPT) group. Individuals in the study group received task-specific training based on the motor relearning program (MRP), while individuals in the control group received a conventional physical therapy program (CPT) based on standard stroke rehabilitation. The principal investigator performed interventions for both groups.

In order to obtain a significant improvement in the study outcomes, the intensity of interventions in this study followed international guidelines for stroke rehabilitation [289, 344]. All the participants in the two groups underwent a 1-hour exercise session, 3 sessions per week over a duration of 8 weeks, with a total of 24-sessions.

Intervention sessions were scheduled on non-consecutive days of the week. Various strategies had been adopted to improve adherence to interventions. To begin with, participants had received a comprehensive, simplified verbal and written description of why the study was being done and what it involved. In addition, to establish a good relationship with the participants and provide needed guidance to gain their trust and cooperation. Furthermore, a flexible schedule of training sessions was offered to motivate participants to improve adherence. The interventions carried out on the two groups were as follows:

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5.5.1 Study group (MRP)

Task-specific training based on MRP was performed for the study group. The training program was designed, organized and carried out by the principal investigator, who drew inspiration from the MRP approach [314, 315, 321, 323, 345, 346]. Each training session consisted of the following five training tasks (as listed in Table 5.2): (1) bed mobility and sitting up over the side of the bed: bed mobility exercises included trunk rotation, bridging exercise, progressed to single-leg bridge, then followed by transition from supine position to sitting at the edge of the bed; (2) balanced sitting including trunk lateral flexion and rotation in a seated position with feet and knees around 15 cm apart and multidirectional reaching activities; (3) standing up and sitting down: standing up with the upper body upright and feet placed backward from a seated position on a firm flat surface without arm rests, and was followed by sitting down by bending the hips, knees, and ankles;(4) balanced standing which included practicing multidirectional reaching activities, heel and toe raises, single leg standing and knee extension combined with a heel strike while standing; and (5) practice of walking which began with practice of walking components followed by practice of backwards, sideways and braiding walking, then heel to toe walking (tandem walking), and finally walking with head turns and tilts. A demonstration of the MRP training program's exercises as well as a detailed description of the exercises, their intensity level, and progression, can be found in Appendix 11.1.

Table 5.2: Structure of the MRP training program session.

Tasks	**Exercise(s)**
Bed mobility and sitting up over the side of the bed	Supine trunk rotation Bridging exercise Single-leg bridge exercise Sitting up over the side of bed
Balanced Sitting	Seated lateral trunk flexion Sitting trunk rotation Sitting multidirectional reaching
Standing up and sitting down	Sit-to-stand exercise
Balanced standing	Standing multidirectional reaching Standing heel and toe raises Single leg standing Standing knee extension with heel strike
Practice of walking	Practice of walking components Backwards walking Sideways walking Braiding walking Heel to toe walking (tandem walking) Walking with head turns and tilts

5.5.2 Control group (CPT)

For the control group, the CPT training program was carried out. The principal investigator was responsible for developing and implementing the training program, which was modeled after a standard (conventional) stroke rehabilitation program [289, 347–350]. Each CPT training session consisted of five training components (see Table 5.3) which included the following: (1) gradual progressive stretching of the shoulder, elbow, forearm, wrist, hamstrings and calf; (2) active-assisted range of motion exercises for the affected upper and lower extremity including the hip, knee, ankle, shoulder, elbow, forearm and wrist; (3) strengthening exercises of the hip abductors, quadriceps and hamstrings; (4) balance training including practicing reaching beyond arm's length while sitting and standing; and (5) walking training that involves a dynamic balance challenge (e.g. overground walking and obstacle courses). The exercises of the CPT training program are demonstrated in Appendix 11.2, along with a detailed description of the exercises, including their intensity level and progression.

Table 5.3: Structure of the CPT training program session.

Components	Exercise(s)
Gradual progressive stretching	Shoulder flexion-extension, abduction-adduction and internal-external rotation. Elbow flexion-extension. Forearm pronation-supination. Wrist flexion-extension. Hamstring stretching. Heel-cord stretching.
Active-assisted range of motion exercises for the upper and lower extremities	Hip and knee flexion in supine. Hip abduction-adduction in supine. Ankle dorsiflexion-plantarflexion in supine. Shoulder flexion-extension, abduction-adduction, and horizontal abduction-adduction. Elbow flexion-extension. Forearm pronation-supination. Wrist flexion-extension, and radial-ulnar deviation.
Strengthening exercises	Seated knee extension. Standing knee flexion (hamstring curl). Standing hip abduction.
Sitting and standing balance training	Forward reach in sitting. Forward reach in standing.
Walking training	Gait training with parallel bars progress to overground walking. Stepping over a series of obstacles.

5.6 Assessments and outcomes

Assessment variables for this study included the patient's basic information, clinical outcome measures and instrumental analysis of balance, postural control and gait. The principal investigator carried out these assessments. Patients from the two groups were assessed at baseline (t_0), post-intervention (t_2), and 3-month follow-up (t_x). The patient's assessment followed a standard sequence outlined in Table 5.1.

The study assessments began with the baseline assessment, which included the participants' basic information (the demographic data), clinical outcome measures, and instrumental analysis. Then the participants received an 8-week intervention based on their group's allocation. To evaluate which interventional group was more effective, individuals from the two groups were re-assessed after completing the intervention. The post-intervention assessment session included clinical outcome measures, instrumental analysis, as well as participants' satisfaction with the intervention they received. Lastly, to investigate which treatment group maintained long-term improvement, participants from both groups were re-assessed after three months of the post-intervention assessment session for the same components using the same assessment tools. Participants were also asked if they had received any rehabilitation sessions during this 3-month period to take into consideration the continuity of the rehabilitation of the two groups (i.e., type of rehabilitation and number of sessions), which might affect the overall performance of both groups.

The duration of each assessment session ranged from 50 to 60 minutes based on the participant's abilities. After each assessment session, the participants received feedback on their results and performance, as knowing the results of the outcomes might serve as a motivator during the study. Study assessments focused on the body function/structure level, activities level, and participation level of the International Classification of Functioning, Disability, and Health (ICF) [49]. The ICF categorization of assessments used in the current study is demonstrated in Figure 5.2.

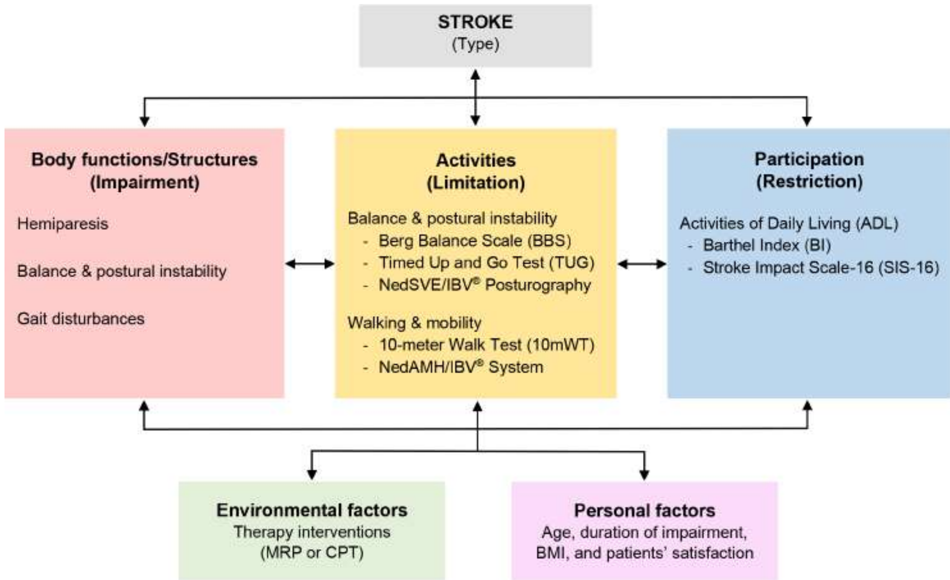


Figure 5.2: International Classification of Functioning, Disability and Health (ICF) categorization of assessments used in the current study.

5.6.1 Clinical outcome measures

Berg balance scale (BBS)

The BBS (Appendix 11.3) is a clinical performance measure used to assess functional balance ability and fall risk in adults. It quantitatively assesses both static and dynamic balance through a series of predetermined tasks [129, 351].

It is comprised of 14 functional balance items that focus on the capacity to maintain a position and make postural modifications in order to accomplish functional mobility tasks, with varied levels of difficulty for the tasks. In the majority of items, participants must maintain a specific position for a certain amount of time [351, 352]. Tasks can be classified into three main categories: sitting balance, standing balance, and dynamic balance. The task of evaluating sitting balance involves sitting unsupported. The standing balance is evaluated with the following tasks: standing unsupported, standing unsupported with eyes closed, standing unsupported with feet together, tandem standing, reaching forward with an outstretched arm, turning to look behind over left and right, standing on one leg, and pick up an object from the floor. Lastly, the dynamic balance is assessed with tasks that include sitting to standing, standing to sitting, transferring, turning 360 degrees, and stool stepping [353, 354].

The task-level is assessed on a 5-point ordinal scale ranging from 0 to 4, with a maximum score of 56. The total scoring range is from 0 to 56, with higher scores indicating better performance. The range of possible scores is 0 (total inability to execute the task) to 4 (full ability to accomplish the task independently without assistance). Tasks are graded based on time, level of independence or supervision needed. Points are deducted if a task requires supervision, assistance, or more time than allotted to complete [355–357].

The suggested "cut-off" score for interpreting the results of the BBS in individuals with stroke regarding functional balance and fall risk as such: scores of 0 to 20 represent poor balance as the patient is currently or potentially in the future wheelchair-bound and carries a 100% fall risk; of 21 to 40 represent fair balance, the patient may require assistance in their movement or some type of walking assistance, such as a cane or a walker, and carries a high fall risk; of 41 to 44 represent acceptable balance, the patient is mostly independent or need minimal assistance in their movement but carries a significant risk of falling; and of 45 to 56 represent good balance, the patient is mostly independent in their movement and carries a low risk of falling [131, 352, 358].

The BBS has been identified as the most widely used assessment tool across the spectrum of stroke rehabilitation [359]. It has been demonstrated that the BBS is reliable [360–363], valid [361, 363–365], and responsive [363, 366, 367] measure of balance impairment in post-stroke patients.

Timed up and go test (TUG)

The TUG is a physical performance test used to measure basic functional mobility with correlates to balance and fall risk [132, 133]. In particular, it evaluates the ability to carry out sequential motor tasks associated with sitting to standing, walking and turning, and requires both static and dynamic balance [368, 369]. The TUG can be used with individuals with balance disturbances, including but not limited to stroke patients [363].

The TUG requires the participant to stand up from a seated position on a standard chair with an armrest (46cm seat height and 65cm armrest height), walk at a comfortable and safe pace for 3-meters to a mark on the floor, turn around at the mark, walk back to the start, and then sit back down in the chair (same seated position). The participant wears regular footwear and can use an assistive mobility aid if necessary. There is no physical assistance provided. The score for the test is determined by the amount of time (in seconds) it takes the participant to accomplish the test. Timing starts when the participant is verbally instructed to "go" and ends when the participant returns to a seated position [133, 369, 370].

In terms of functional mobility, participants who can complete the test in 10 seconds or less are entirely independent of ambulation and transfers (with or without a walking aid). Those who finish the test in less than 20 seconds are probably independent mobile for main transfers (with or without a walking aid) and able to climb most stairs and go outside alone. Those who require more than 30 seconds to finish the test are dependent on physical assistance for mobility and basic transfers and cannot manage to go outside alone [133]. In terms of predicting falls, those who take 14 seconds or longer to complete the TUG are at a high risk of falling $\leq$ 14 seconds is used as a "cut-off" score to identify those at high risk of falls in the stroke population) [370–372].

Considerable evidence indicates that the TUG is reliable [133, 371, 373], valid [371, 372, 374], and sensitive [370, 375] test for quantifying functional mobility, which may also be useful in following clinical improvement over time to assess the efficiency of rehabilitation.

10-meter walk test (10mWT)

The 10mWT is a performance measure that assesses the gait speed in meters per second (m/s) over a distance of 10 meters [376, 377]. A participant walks 10 meters, and the total time taken to ambulate the intermediate 6 meters is recorded to allow for acceleration and deceleration. The timing starts when the toes of the leading foot cross the plane of the 2-meter mark and stop when the toes of the leading foot cross the plane of the 8-meter mark. The 6 meters is then divided by the total time recorded (in seconds) to complete to get a speed in m/s [378–380]. Two trials were administered at the participant's self-selected or comfortable walking speed, followed by two trials at his/her fast or maximum walking speed. The two trials for each speed were averaged, and the two gait speeds were documented in m/s [380–382].

Ambulation ability has been correlated with gait speed [214], and it is predicted by gait speed. It is a reliable method of classifying patients [383]. To interpret test performance, the cut-off score that was used for the stroke population in conjunction with a complete evaluation of a participant's comfortable walking speed (10mWT score) is as follows: walking speed <0.40 m/s indicate "household ambulators", 0.40 to <0.80 m/s indicate "limited community ambulators", and indicate $\geq$ 0.80 m/s "community ambulators" [214].

The 10mWT is easy to set up and administer and is well-tolerated by most patient groups. It has been widely recommended [289, 344] as it is reliable [371, 381, 384], valid and feasible [385–387], responsive [388], and interpretable [389, 390] test for measuring gait speed and well suited to evaluating clinical interventions among individuals with a stroke [391].

Barthel index (BI)

The BI (Appendix 11.4) is a standard ordinal scale that measures performance in activities of daily living (ADL) or patient functional independence (or degree of assistance required/The index also indicates the need for assistance in care.) in the domains of self-care and locomotion in patients with disabling conditions, especially in the rehabilitation settings [392–394].

The index consists of 10 items that relate to ADLs, including evaluation of independency in feeding, bowel control, bladder control, toilet use, dressing, grooming, bathing, transfer from chair to bed and return, ambulation on a level surface, and ascending and descending stairs [393].

The test was administered as a self-report and takes 2-5 minutes to be completed [395, 396]. Each item is rated in terms of whether the individuals can perform the task independently, with some assistance, or are dependent on help. The response categories of disability in activity were defined and rated in scale steps (0, 5), (0, 5, 10), (0, 5, 10, 15), dependent on the item. The scores for each item are summed to create a total score out of 100, with higher scores indicating higher levels of functional independence [397]. Following Shah et al. [398] for interpreting Barthel scores, scores of 0-20 indicate "total dependency", 21-60 indicate "severe dependency", 61-90 indicate "moderate dependency", and 91-99 indicate "slight dependency".

In patients with stroke, the BI is a frequently used stroke outcome measure to determine the extent of post-stroke disability, self-care activities and ability to live independently. It has been repeatedly shown to be a reliable, valid, and sensitive measure to change, mainly in predicting the functional outcomes related to stroke [392, 398–404]. More recently, Duffy et al. [405] in their systematic review and meta-analysis, reported that the BI has excellent inter-rater reliability for standard administration after stroke, and it seems an appropriate outcome measure for stroke trials and practice.

Stroke impact scale-16 (SIS-16)

The SIS–16 (Appendix 11.5) is a stroke-specific, self-report outcome measure to assess physical function following a stroke. It is a short instrument created from the physical composite domain of the Stroke Impact Scale (SIS) 3.0 and was developed to assess the effect of physical function on disability post-stroke, especially in mild to moderate strokes [406, 407].

The SIS-16 consists of 16-items measuring four domains, including strength, mobility, activities of daily living (ADL)/instrumental ADL (IADL), and hand function [406]. The SIS-16 is a patient-based self-report questionnaire. A 5-point Likert scale (1 to 5) is used to rate each item. The patient rates how difficult it is to complete each item: 1 = could not do at all, 2 = very difficult, 3 = somewhat difficult, 4 = a little difficult, and 5 = not difficult at all. The final score is the sum of all 16 items to create a single physical dimension score ranging from 16 to 80, where a higher score suggests better performance [408, 409].

The measure was devised to be utilized in both clinical and research settings and was designed for repeated administration to track change over time [410]. It has been reported that SIS-16 is reliable [406, 411–413], valid [406, 412, 414, 415], a sensitive and responsive measure of physical functioning after stroke [415, 416].

Patients' satisfaction after the interventions

To assess the patients' level of satisfaction of the interventions, the Satisfaction Pound Scale was used. The Satisfaction Pound Scale is a validated specific questionnaire to evaluate satisfaction with the rehabilitation program after a stroke [417, 418]. It comprises three sections: Inpatient Care, which evaluates the care and information received during admission (5 items); Therapy and Recovery, which assesses the quantity and quality of treatment (3 items); and The Services After Discharge, which examines the information and support provided after discharge (4 items) [418]. The scale has been adapted to Spanish and validated in a sample of

74 patients who underwent stroke rehabilitation. The scale showed good reliability and validity, and was found to be a useful tool to assess satisfaction with the post-stroke rehabilitation program in the Spanish context [419]. For the scope of this study, three items from the second section (Therapy and Recovery) were adopted to assess the study patients' satisfaction after the interventions. These questionnaire items are adapted to fit for the context of this study, and the items are as follows:

1. I am satisfied with the type of exercises and training the therapist has given me.
   Estoy satisfecho con el tipo de ejercicios y entrenamiento que me ha dado el terapeuta.

2. I think this exercise training program has helped me to improve my ability to manage my daily life activities (personal hygiene, dressing, transferring/mobility, etc.).
   Pienso que este programa de entrenamiento de ejercicios me ha ayudado a mejorar mi habilidad para gestionar mis actividades de la vida diaria (higiene personal, vestirse, traslados/movilidad, etc.).

3. I am happy with the amount of recovery I have made since joining this exercise training program.
   Estoy feliz con la cantidad de recuperación que he hecho desde que me uní a este programa de entrenamiento de ejercicios.

The patient responds to a three questionnaire items using a 5-point Likert scale to rate the satisfaction with each item: very dissatisfied, dissatisfied, neither satisfied nor dissatisfied, satisfied, and very satisfied.

5.6.2 Instrumental analysis of balance and gait

The instrumental analysis of balance and gait was performed using NedSVE/ IBV® and NedAMH/IBV® systems based on the Dinascan/IBV P600 dynamometric platform specifically designed to study balance and gait [420, 421].

The NedSVE/IBV® is a computerized posturography software application that uses the data provided by the dynamometric force platform for analyzing balance disorders by comparing them with normality patterns. The application combines static posturography tests with dynamic tests based on gait analysis, limits of stability and tracking with the center of pressure (COP) of moving targets, differentiating assessments in the anteroposterior (AP) and mediolateral (ML) planes [420].

The elements that make up the evaluation system are the following (see Figure 5.3):

1. Dinascan/IBV P600 dynamometric platform of 600x370 mm active area, 100 mm height, and 25 kg weight.
2. Platform and mechanical structure that serves as an anchor for the platform and as a support for accessories. Approximate measurements are 3.5 x 1.5m of surface and 2.4m in height.
3. Patient monitor (height-adjustable flat screen, integrated into the mechanical structure).
4. Double photocell barrier, integrated into the mechanical structure, to record walking speed.
5. Evaluation table (computer, 17" flat screen, and color printer) for data recording and analysis.
6. Accessories for carrying out balance tests (stadiometer and support safety harnesses).
7. Foam cushion with the following characteristics:
   - Thickness: 9 cm.
   - Size: that of the platform.
   - Density: 56.7 Kg/m3.
   - Resistance to penetration of 25%: 246 N.

Figure 5.3: NedSVE/IBV ® posturography (balance and gait measurement) system: 1) Dynamometric platform. 2) Walking pathway. 3) Patient monitor. 4) Photoelectric cells. 5) Computer for data recording. 6) Foam cushion to be placed over the dynamometric platform. 7) Support for safety harnesses.

Functional balance assessment tests

The balance assessment tests are divided into two groups: (1) sensory-dynamic assessment, which includes static posturography tests and gait analysis, and (2) postural control assessment, which includes limits of stability analysis and rhythmic and directional control assessment. The overall balance assessment is obtained by assigning weights to all the tests. Thus, the global score of the functional balance assessment corresponds to the weighted average of the assessment tests performed and is expressed as a percentage of normality. It is calculated as follows:

- 50% of the sensory-dynamic assessment: calculated as the average of the 5 rating indices of the static and dynamic tests: 4 Romberg tests and 1 dynamic gait test.
- 30% of the limits of stability assessment.
- 10% of the valuation index of the mediolateral rhythmic and directional control test.
- 10% of the anteroposterior rhythmic and directional control test.

The functional balance assessment is considered normal when the global assessment is between 90 and 100%, slightly impaired between 80 and 89% and functionally impaired when it is below 79%.

Static posturography tests

The static balance assessment was carried out by performing 4 Romberg tests on the dynamometric platform. Each test lasted for 30 seconds (s), and the sampling frequency was 40Hz. This test involves creating various situations where the sensory input (visual, proprioceptive, and vestibular) necessary to maintain balance in this position is either cancelled or altered, as illustrated in Figure 5.4 [422].

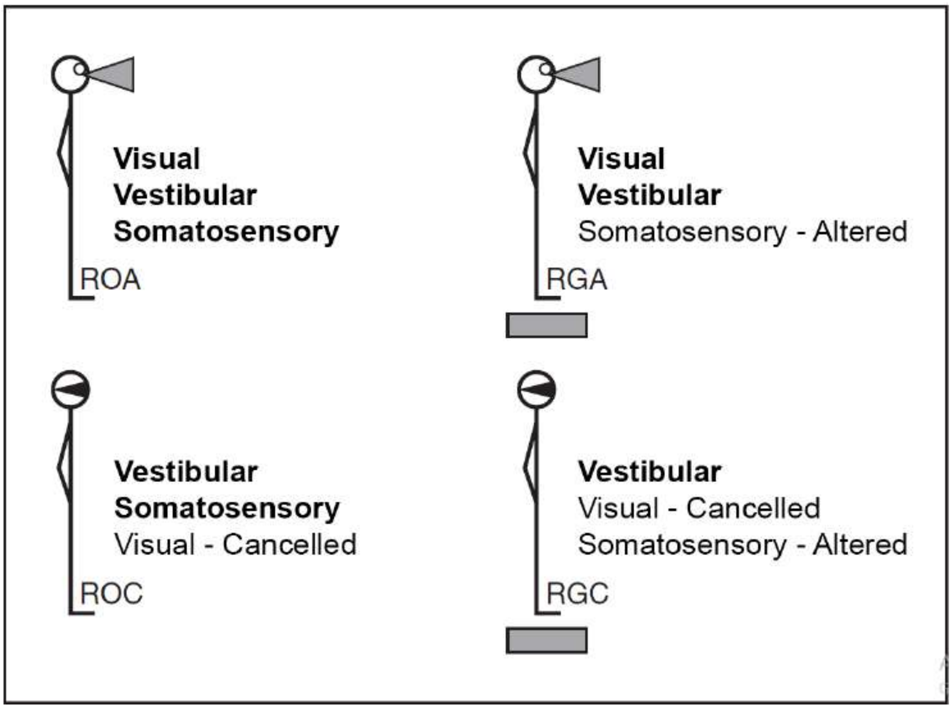


Figure 5.4: Sensory analysis exploration conditions. The systems responsible for balance in each test are indicated in bold. (ROA: Romberg Test with Eyes Open. ROC: Romberg Test with Eyes Closed. RGA: Romberg Test with Eyes Open on Foam Cushion. RGC: Romberg Test with Eyes Closed on Foam Cushion). Adapted from De Moya MP, Bertomeu JB, and Broseta MV. Evaluación y rehabilitación del equilibrio mediante posturografía. *Rehabilitación*. 2005; 39(6):315–23. Figure 5 [422].

The tests must be carried out with the participant barefoot, with at least two repetitions of each Romberg test. **The included tests are:**

Romberg test with eyes open (ROA): The participant stands on the platform with bare feet, aligning them with marked footprints on the platform forming an opening angle of 30° (heels together and aligned with the line) (see Figure 5.5 A), The participant extends their arms outstretched and relaxed close to the body, keeps their head in a neutral position, looks straight ahead at a fixed point, and tries not to move. The participant maintains balance for 30 seconds (see Figure 5.6).

Romberg test with eyes closed (ROC): The participant is in the same position as in the ROA test, but with their eyes closed (cancellation of visual information). The participant maintains balance for 30 seconds (see Figure 5.6).

Romberg test with eyes open on foam cushion (RGA): For this test, a 9 cm foam cushion is placed on top of the platform (alteration proprioceptive information) (see Figure 5.5 B). The participant follows the same procedure as in the ROA test, keeping their eyes open but with their feet on an unstable surface, in this case, the foam cushion. The participant maintains balance for 30 seconds (see Figure 5.6).

Romberg test with eyes closed on foam cushion (RGC): The same procedure described in the RGA test is followed, but with the participant closing their eyes to cancel the visual information and further alter proprioception. The participant maintains balance on the foam cushion for 30 seconds (see Figure 5.6).

Figure 5.5: Foot position during the functional balance assessment tests. **A**) Standing on the dynamometric platform (firm surface). **B**) Standing on a foam cushion placed over the platform (unstable surface).

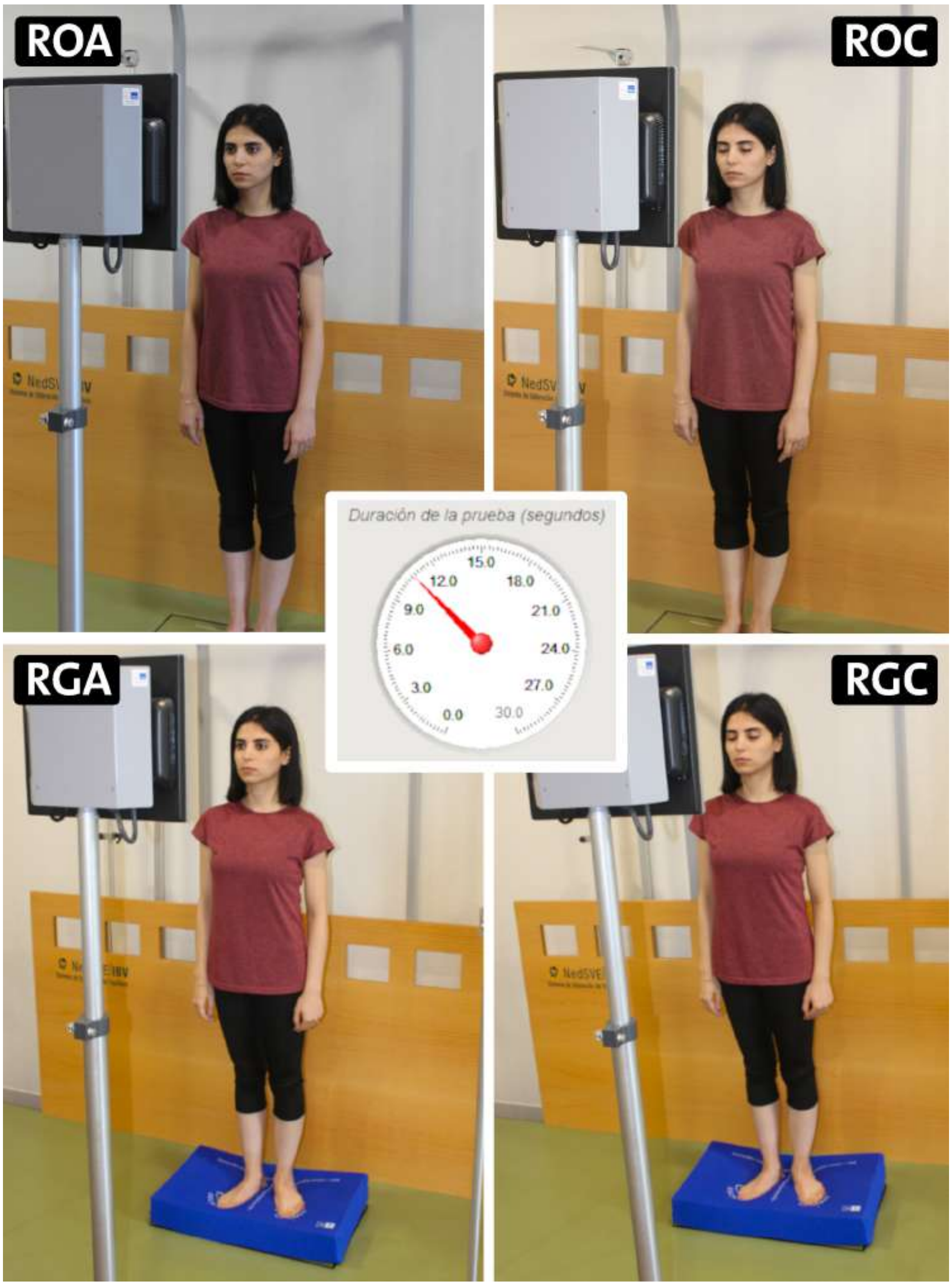


Figure 5.6: ROA, ROC, RGA, and RGC tests.

The tests were carried out in the following order of progressive difficulty: ROA, ROC, RGA, and RGC, respectively. The system records the postural oscillation, which represents the displacement of the COP, during the four tests. The COP is the vertical projection of the center of gravity (COG) and is recorded using the dynamometric platform (Figure 5.7).

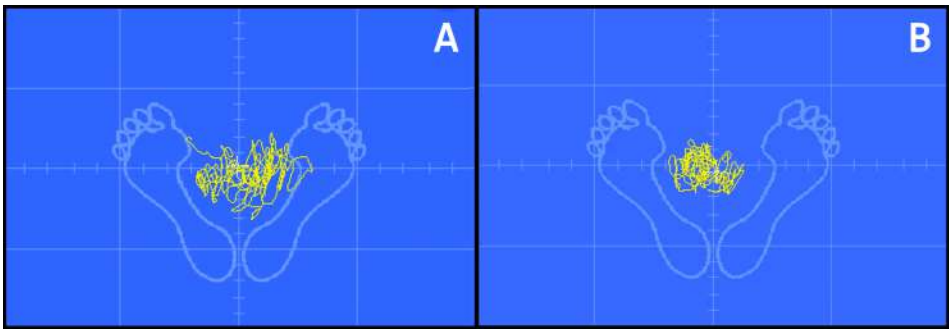


Figure 5.7: Recording of postural oscillation using the dynamometric platform. **A**) Result of the RGC test in a participant with balance disturbances, 67%. **B**) Result of the RGC test in a participant without balance disturbances, 100%.

A total of two 30-second recordings were made for each test, and a third recording was added if the repeatability between the first two measurements was less than 50%. Repeatability is an index that measures the similarity between the records of the same test, comparing it to the similarity between repetitions in the normal population. For instance, a repeatability index of 100% in three repetitions of the Romberg test with eyes open indicates that the participant has performed the three tests with a similar variability as the reference normal population group.

In each of the sensory analysis tests (Romberg tests; ROA, ROC, RGA and RGC), the following parameters were recorded:

Total displacement (mm): The distance from the origin of the platform to the COP of the point cloud (displacement vector) described by the projection of the COG, expressed in millimeters.

Displacement angle (°): The orientation of the displacement vector, expressed in degrees. The displacement vector extends from the initial point where the participant starts to its final position.

Disperse X, Y (mm): Dispersion of the cloud of points described by the projection of the COG in the ML and AP directions, expressed in millimeters.

Average speed (m/s): It is an estimate of the average speed of the participant's COP (the projection of the participant's COG) during the test, expressed in meters per second. It is calculated by dividing the total distance traveled by the COG during the test by the elapsed time, starting from the beginning of the test until its end. The application performs this calculation to provide the average speed measurement.

Mediolateral (ML) and anteroposterior (AP) displacement (mm): Represent the maximum displacement in the ML and AP directions during the test, measured in millimeters. It indicates the furthest point reached by the COP in each direction during the recording time.

Maximal mediolateral (ML) and anteroposterior (AP) forces (N): Represent the maximum forces exerted in the ML and AP directions during the test, measured in Newtons. It indicates the peak forces exerted by the participant in each direction during the recording time.

Assessment indices of the contribution of sensory systems:

The application calculates 4 indices or estimators to assess the contribution of the somatosensory (SOM), visual (VIS), vestibular (VEST), and dynamic (DYN) systems. These indices are calculated as ratios between the scores of the ROC, RGA, RGC, and gait tests, and the score of the ROA test. These ratios are then compared to the normality database segmented by age and sex.

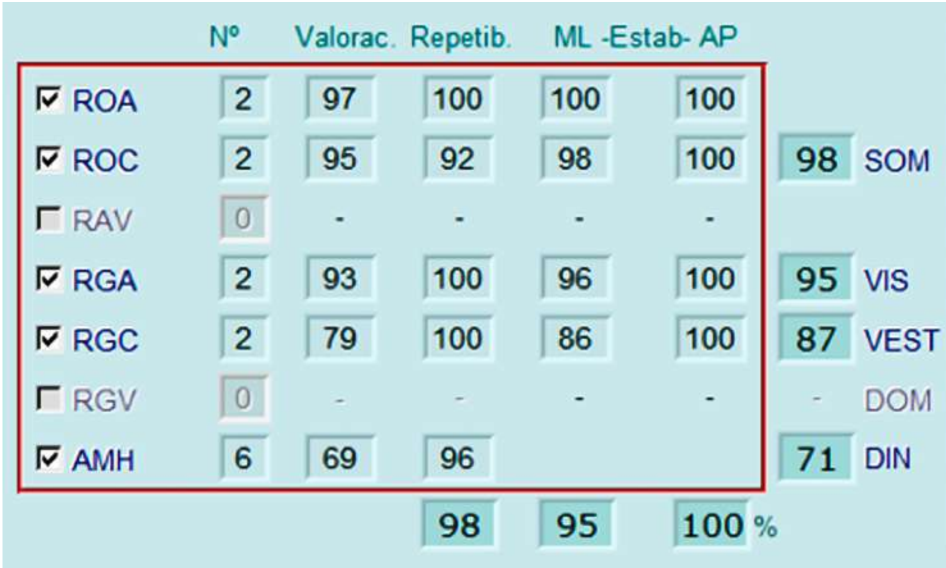
Somatosensory index (SOM): The percentage assessment of the somatosensory system, calculated as a quotient between the assessments of the ROC and ROA tests and referenced to normality (normality >95%). It indicates the impact of canceling the visual system on balance. If the index is abnormally low, it indicates poor stability when visual information is cancelled. In such cases, the participant relies heavily on vision to maintain balance, suggesting insufficient proprioceptive and vestibular inputs for maintaining normal balance. This pattern is referred to as somatosensory dysfunction [422, 423].

Visual index (VIS): The percentage assessment of the visual system, calculated as the quotient between the assessments of the RGA and ROA tests and referenced to normality (normality >95%). This index indicates the impact of decreased or inaccurate proprioceptive information on balance. In the RGA test, the participant stands on an unstable surface, leading to altered somatosensory information. An abnormally low RGA/ROA ratio suggests poor stability when proprioceptive stimuli are altered, indicating a reliance on proprioceptive inputs for maintaining balance. In such cases, visual information combined with vestibular inputs is insufficient for maintaining proper balance. This pattern is referred to as visual dysfunction, and the participant may experience difficulties walking on loose or uneven surfaces [422, 423].

Vestibular index (VEST): The percentage assessment of the vestibular system, calculated as the quotient between the assessments of the RGC and ROA tests and referenced to normality (normality >95%). This index indicates the impact of canceling the visual system and altering the proprioceptive system on balance. An abnormally low RGC/ROA ratio suggests poor stability when visual information is canceled and proprioceptive information is altered simultaneously. In such cases, the participant relies on the vestibular system for balance, but the information received from the vestibular system alone is insufficient for maintaining adequate balance. This pattern is referred to as vestibular dysfunction [422, 423].

Dynamic index (DYN): The dynamic index represents the percentage assessment of dynamic performance, calculated as the quotient between the gait assessment and ROA test, and referenced to normality (normality >95%).

Through the results obtained in each of these tests, which are repeated at least twice each, and comparing them with a normality database [424], the participant's sensory-dynamic balance capacity can be determined. Additionally, this evaluation provides information about the type of strategy used and the degree of contribution from each sensory input in maintaining balance [425, 426] (see Figure 5.8).



	Nº	Valorac.	Repetib.	ML -Estab-	AP		
☑ ROA	2	97	100	100	100		
☑ ROC	2	95	92	98	100	98	SOM
☐ RAV	0	-	-	-	-		
☑ RGA	2	93	100	96	100	95	VIS
☑ RGC	2	79	100	86	100	87	VEST
☐ RGV	0	-	-	-	-	-	DOM
☑ AMH	6	69	96			71	DIN
			98	95	100 %		

Figure 5.8: Results of the sensory and dynamic evaluation of a study participant. The last row shows the final assessment obtained after performing two repetitions of each Romberg test, the repeatability of the test, and the mediolateral and anteroposterior stability. The results are expressed in percentages. The last column displays the sensory indices. Overall Result: Slightly impaired (87%).

Finally, this assessment also provides information on the type of movement strategy the participant uses to maintain balance. If the participant correctly uses these automatic movements in the initial ROA tests, which involve a stable surface and good support, it is normal for them to employ an ankle strategy. However, as the tests progress, there will be a decrease in the use of this strategy and a shift towards a hip strategy, particularly in the RGC test where the surface is unstable and there are no visual references [422]. It is important to emphasize that achieving normal or compensated results in all the tests (ROA, ROC, RGA, and RGC) does not necessarily indicate the absence of pathology. It simply implies that the pathology is insufficient to alter the participant's postural behavior or that its influence has been mitigated by central compensation mechanisms [422].

Postural control assessment

This part of the assessment includes determining the limits of stability (LOS) and analyzing rhythmic and directional control (RDC). To perform the RDC tests, it is necessary to have previously determined the LOS, as these tests are tailored to the participant's LOS results. The postural control assessment is calculated by assigning a weight of 60% to the LOS analysis, 20% to the mediolateral rhythmic and directional control test, and 20% to the anteroposterior rhythmic and directional control test.

Limits of stability (LOS)

This test independently determines the LOS of the participant under study in eight directions. The computer application provides a percentage evaluation for each of these directions as well as a combined evaluation (global percentage) of the stability limits test.

During this test, the participant was initially asked to stand on the platform with bare feet, aligning their feet with the marked footprints on the platform. The feet were positioned so that the heels were together and the toes diverged at an angle of 30°, while the participant's arms remained relaxed and parallel to the body.

Next, the participant observed a cursor on the screen located in front of them at eye level, which reflected the position of their COG. They had to move the cursor in different directions as indicated by targets (8 targets) that appeared on the monitor, without moving their base of support. The targets were positioned at the stability limit, at 45° intervals (see Figure 5.9).

The participant had 8 seconds to move their COG to each target and had to maintain that position for as long as possible. The sequence began with the frontal target, followed by a clockwise order. The distance at which each target appears is determined by the participant's age and height, as per the segmentation of the IBV normality database.

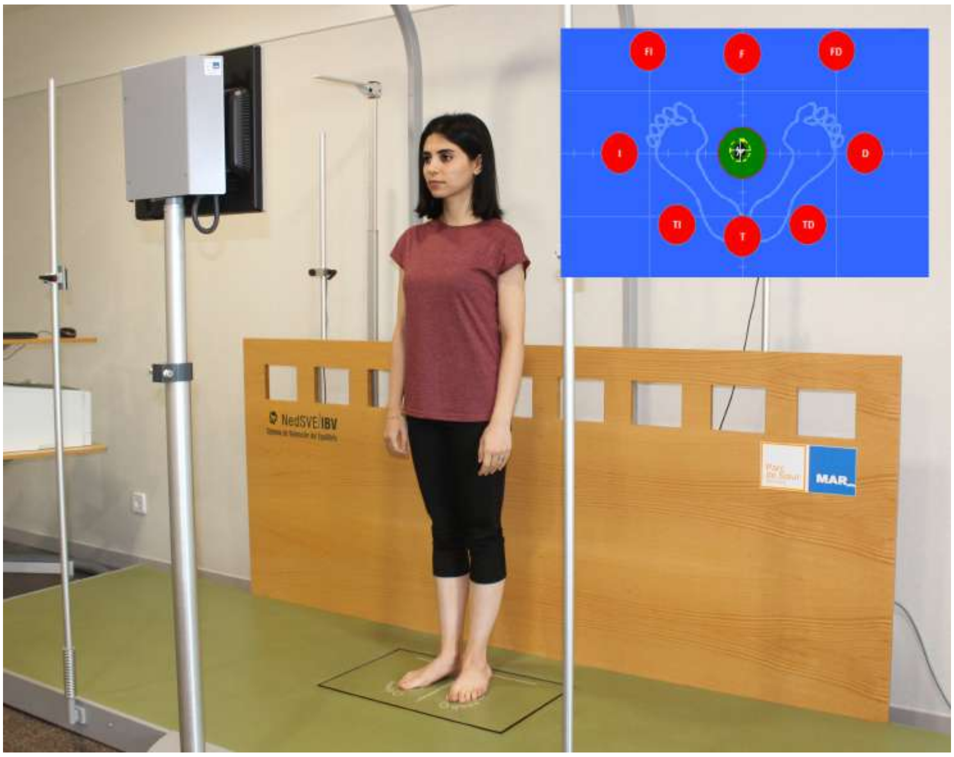


Figure 5.9: Limits of stability (LOS) test.

The assessment of each stability limit (forward, right-forward, right, right-backwards, backward, left-backwards, left, and left-forward) is based on a weighting of different parameters referring to normality patterns (the average of each parameter is also included) (see Figure 5.10). These parameters include the following:

- **Maximum displacement (%)**: the percentage, relative to the normal pattern segmented by sex, age, and height, of the achieved displacement in each direction (greatest distance reached in each direction). A value of 100% indicates that the distance reached in the direction of the limit, obtained as a projection on the line connecting the origin and the target (limit), is equal to that of the normality pattern.

- **Directional control (%)**: an estimator of the linearity of the trajectory followed by the participant under study to reach each of the stability limits. This estimator is calculated as the percentage of trajectory points that fall within the rectangle formed by the target and the starting point, relative to the total trajectory points.

- **Reaction time to reach the target (s)**: an estimator of the participant's response speed in initiating movement towards each of the stability limits to reach the target. Expressed in seconds, it represents the time elapsed from the beginning of the test until the projection of the participant's COG reaches the central target.

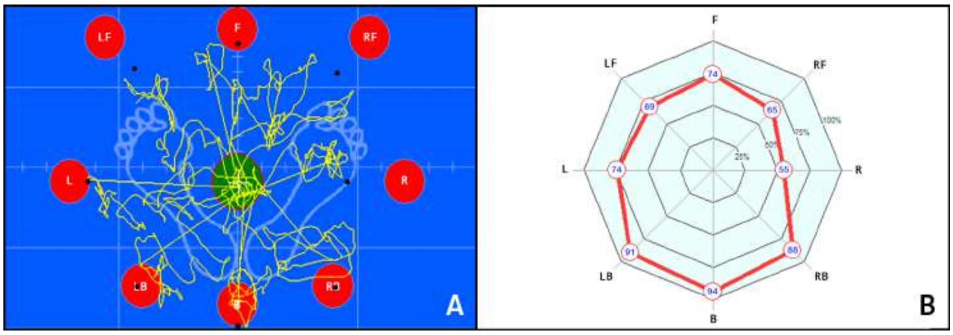


Figure 5.10: Limits of stability (LOS) analysis. **A**) Test record showing the displacement of the center of gravity (COG) to reach the different targets. The yellow trace and small black points indicate the direction and maximum ranges of each limit. **B**) Graphical representation of the scores obtained for each direction of the stability limits.

Rhythmic and directional control (RDC)

The objective of these rhythmic and directional control tests was to evaluate the participant's ability to execute rhythmic displacements of their COG. In this test, the participant is required to track a moving target with the projection of their COG at varying speeds on a screen (monitor) positioned in front of them at eye level. It provides for an independent assessment in each direction (mediolateral and anteroposterior).

This evaluation consisted of two tests: in one of them, the target moved rhythmically and horizontally (mediolateral direction) on the screen, and the participant had to move their COG from left to right and vice versa, following its movement (see Figure 5.11). In the other test, the target moved rhythmically and vertically (anteroposterior direction) on the screen, and the participant had to move their COG from front to back and vice versa, attempting to track it (see Figure 5.12). Two attempts were made for each test. For each test, the target was moved at three different speeds: slow for the first 3.5 seconds, followed by intermediate speed for 2.5 seconds, and finally at a faster pace for 1.5 seconds.

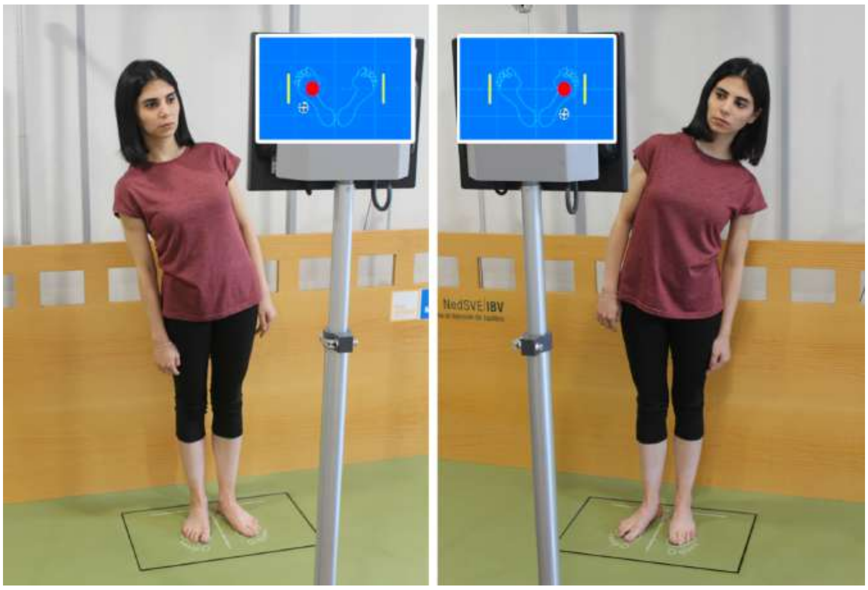


Figure 5.11: Mediolateral rhythmic and directional control test.

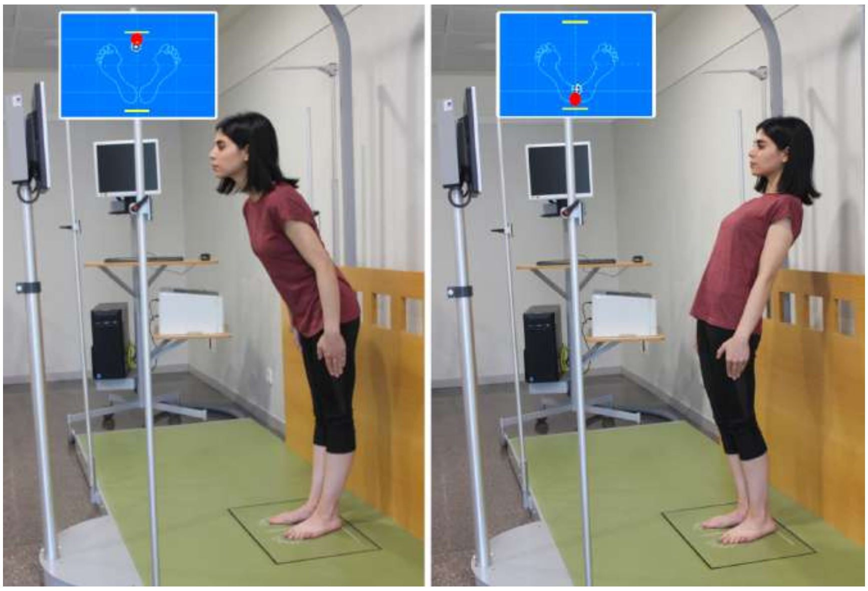


Figure 5.12: Anteroposterior rhythmic and directional control test.

To conduct this test, it was necessary to determine the participant's stability limits beforehand. Once established, the application sets the maximum excursion of the mediolateral and anteroposterior targets at 60% of the maximum distances reached in each direction based on the participant's own limits of stability. The evidence is presented in Figure 5.13 for the mediolateral direction and Figure 5.14 for the anteroposterior direction.

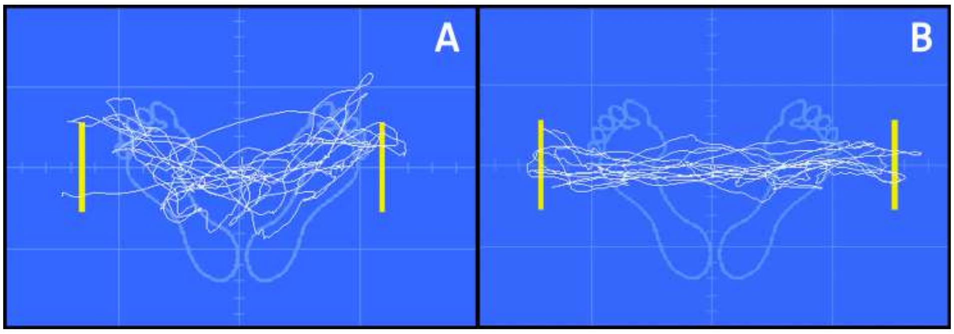


Figure 5.13: Mediolateral rhythmic and directional control test record. Recording of the center of gravity (COG) trajectory while following a target in mediolateral movement. **A**) Record for a participant with impairment. The result was 79%. **B**) Record for a participant without impairment. The result was 100%.

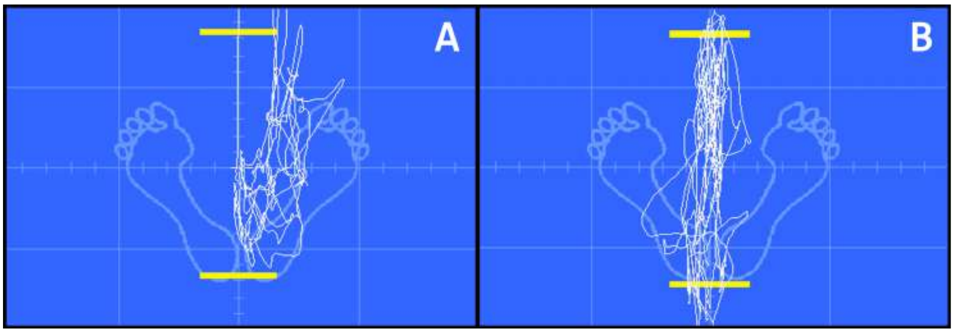


Figure 5.14: Anteroposterior rhythmic and directional control test record. Recording of the center of gravity (COG) trajectory while following a target in anteroposterior movement. **A**) Record for a participant with impairment. The result was 74%. **B**) Record for a participant without impairment. The result was 100%.

For each of the rhythmic and directional control tests (mediolateral and anteroposterior), the following indices were calculated:

- **Ability (%)**: This statistical parameter estimates how closely the participant's COG follows the movement direction of the moving target.
- **Control and efficiency (%)**: This statistical parameter estimates the tracking performance of the participant's COG in the direction perpendicular to the target's movement.

- **Weighted valuation (%)**: The weighted value of the previous indices (ability and control and efficiency) in both study directions. These indices assign a value, relative to normality, to the scores obtained by the participant in each test, with the following weightings: ability: 70% and control and efficiency: 30%.

Functional gait analysis

The gait was assessed using the NedAMH/IBV® system, a software application for biomechanical gait analysis (kinematic and kinetic gait analysis). This evaluation system consists of a dynamometric platform (Dinascan/IBV P600) that records the reaction forces exerted against the ground during walking. It is integrated into a 3.5m long and 1.5m wide walkway and includes two photocell barriers at its ends for speed recording. Additionally, a computer application is used for recording and analyzing the results [421]. (Figure 5.15).

Figure 5.15: NedAMH/IBV® gait analysis system that allows the integration of gait and balance analysis.

Before starting the assessment session, the patient's weight is measured using the dynamometric platform, as the parameters will be standardized based on weight. Subsequently, the participants were instructed to walk barefoot across the walkway at a comfortable speed, several times and in both directions. During this phase, they were encouraged to disregard the presence of the dynamometric platform in order to familiarize themselves with the measuring equipment.

Once the participant's gait had stabilized, the walking speed (a single value) was recorded as the participant's reference speed. Following this, the actual measurement acquisition phase commenced. The participant was required to walk on the dynamometric platform repeatedly (see Figure 5.16) to obtain a minimum of three valid measurements with each foot. A valid measurement was defined as the participant fully supporting the entire surface of one foot on the dynamometric platform, while their walking speed did not differ by more than 10% from the reference speed.

Figure 5.16: Detail of the dynamometric platform used for gait assessment. Participants walked repeatedly while stepping on the dynamometric platform.

The dynamometric platform utilizes four transducers to record kinetic gait parameters, including the duration of forces exerted by each foot (support time) and the magnitude of various reaction forces exerted against the ground by both lower limbs during the stance phase of gait in three axes: anteroposterior (Fx), mediolateral (Fy), and vertical (Fz) (see Figure 5.17). This allows for the evaluation of each force component individually and provides a functional assessment of gait based on a percentage of normal. The photocell barriers are used to measure the time it takes for participants to walk the distance between the two cells, enabling the calculation of walking speed. To conduct the assessment, the NedAMH/IBV® system compares the obtained parameters of both lower limbs with a normality database. This database comprises individuals with characteristics comparable to the patient's gait and has been prepared by the Institute of Biomechanics of Valencia (IBV). It is segmented by age, gender, presence of footwear, and walking speed [421, 427].

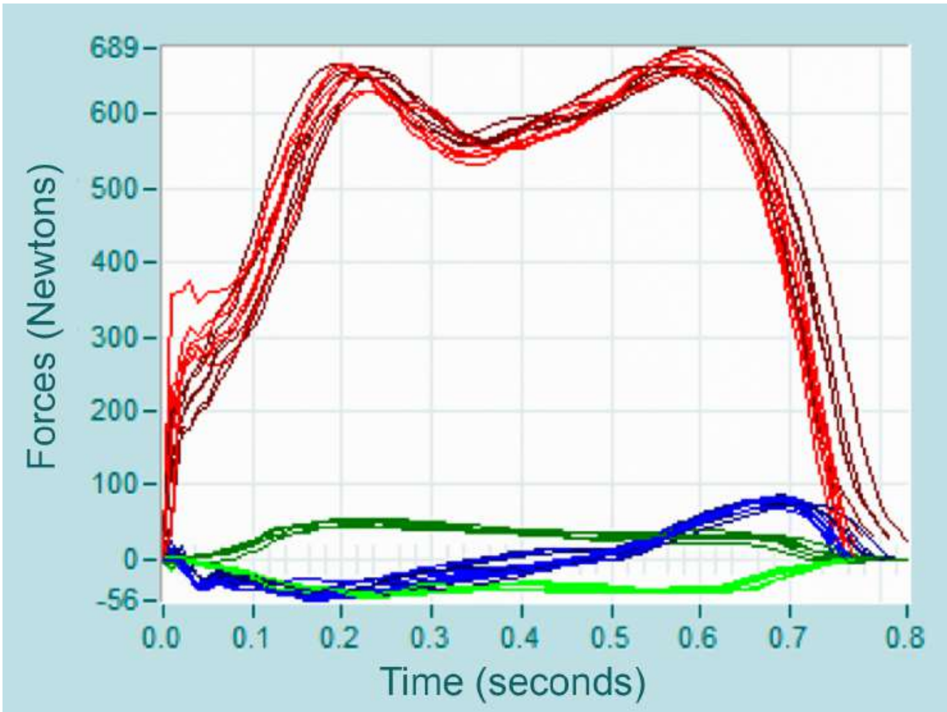


Figure 5.17: Schematic representation of forces generated in each step in the three axes. Vertical forces (Fz) are represented by red curves, anteroposterior forces (Fx) are represented by blue curves, and mediolateral forces (Fy) are represented by green curves.

Based on the recorded data, the computer application calculates the functional assessment of gait (global score) and the gait parameters for analysis (see Table 5.4). The global score represents the weighted average of the assessment expressed as a percentage of normality for all analyzed parameters in this test (averaging between the two feet for each parameter). It is calculated for both lower limbs globally, as well as individually for the right and left lower limbs [428].

The function of gait is considered normal when the global assessment falls between 90 and 100%, slightly impaired between 80 and 89%, and functionally impaired when it is below 79%. The gait analysis reports the final results, which are presented in Figure 5.18, Figure 5.19, and Figure 5.20.

Table 5.4: Definitions of the analyzed gait parameters.

Parameter Name	**Description**
Gait speed	Reflects the time required to walk a specific distance. It is measured in meters per second (m/s) and expressed as a percentage of normality.
Foot support time	Reflects the duration of the interval when each foot is in contact with the ground. It is measured in seconds (s).
Difference in support time	Represents the disparity between the support time of each foot. This parameter is expressed as a percentage of normality. It quantifies the difference in support times between the left and right legs.
Anteroposterior braking force	Refers to the horizontal force exerted by the foot during initial contact with the ground, specifically during the heel strike phase of the gait cycle. This parameter is normalized by dividing it by the participant's weight and is also expressed as a percentage of normality.
Anteroposterior propulsion force	Reflects the horizontal force exerted by the foot at the end of the stance phase of the gait cycle, aimed at propelling the body forward and initiating the next step. This parameter is normalized by dividing it by the participant's weight and is also expressed as a percentage of normality.
Vertical take-off force	This refers to the vertical force exerted by the foot at the end of the stance phase to lift the foot off the ground and, in combination with the propulsion force, initiate the next step. This parameter is normalized by dividing it by the participant's weight and is also expressed as a percentage of normality.

Oscillation force	Refers to the vertical force exerted by the foot against the ground during the intermediate phase of foot stance (middle phase of foot support). This parameter is normalized by dividing it by the participant's weight and is also expressed as a percentage of normality.
Anteroposterior force morphology (Fx Morphology)	Compares the similarity of the anteroposterior force during the foot support phase (stance phase/time) with the normality pattern. This combined parameter assesses the shape of the anteroposterior forces in relation to the normality bands used. It is expressed as a percentage of normality.
Mediolateral force morphology (Fy Morphology)	Compares the similarity of the mediolateral force during the foot support phase (stance phase/time) with the normality pattern. This combined parameter assesses the shape of the mediolateral forces in relation to the normality bands used. It is expressed as a percentage of normality.
Vertical force morphology (Fz Morphology	Compares the similarity of the vertical force during the foot support phase (stance phase/during the support time) with the normality pattern. This combined parameter assesses the shape of the vertical forces in relation to the normality bands used. It is expressed as a percentage of normality.

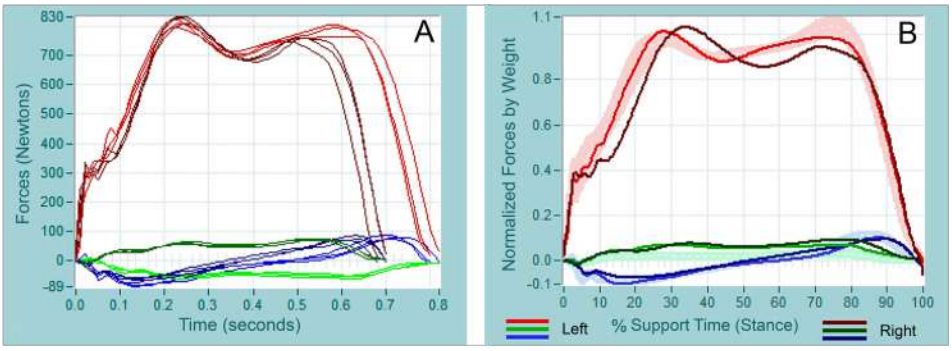


Figure 5.18: Graphic representation of the reaction forces vs. time records for both feet. **A**) Shows the superimposition of different footstep records with the three components of the reaction force (Fz, Fx, and Fy). **B**) Represents the average curves (normalized by participant's weight and converted to a percentage of stance time) of the recorded left and right footstep recordings against the normal pattern, along with their corresponding dispersion band (shaded). The mean pattern of the recorded footsteps is also included. The shaded band of normality (mean ± 1 standard deviation) will vary based on factors such as sex, age, footwear, and speed group. (Darker strokes represent right forces, while lighter strokes represent left forces).

Parámetros significativos	Promedios Izquierda	Promedios Derecha
Velocidad de marcha (m/s)	0.79	
Tiempo de apoyo (s)	0.81	0.70
(2) Fuerza de Frenado Antero-Posterior	0.10	0.08
(2) Fuerza de Propulsión Antero-Posterior	0.10	0.09
(2) Fuerza de Despegue Vertical	0.98	0.94
(2) Fuerza de Oscilación	0.88	0.86

(2) Valores normalizados por el peso.

Figure 5.19: Results in absolute values of average gait parameters normalized by participant's weight.

Parámetros	Izquierda	Derecha	Global	Repetibilidad
Veloc. media			100	100
Difer. T. Apoyo			6	100
F. Frenado AP	103	100	100	100
F. Propulsión AP	99	93	96	100
F. Despegue Vert.	99	84	91	100
F. Oscilación	102	143	100	100
Morfología F. AP	86	84	85	100
Morfología F. ML	27	18	23	100
Morfología F. Vert.	95	52	73	100
Valoración final	**91**	**78**	**78**	**100**

Figure 5.20: Functional gait analysis results. Presented in table format, the assessment is represented by percentage values indicating the normality of average gait parameters. These parameters are averaged from both left and right foot records. Values below 90% are considered abnormal or indicative of functional impairment.

5.7 Statistical analysis

The descriptive statistics for the two treatment groups included the use of mean and standard deviation to describe continuous variables. Categorical variables were described using a frequencies table, which displayed absolute numbers and percentages. The statistical tests used for these comparisons were the Chi-square or Fisher exact tests, as appropriate, for categorical variables, and the Mann-Whitney U test for continuous variables. The non-parametric option of the Mann-Whitney U test was chosen due to the violation of the normality assumption for a significant number of continuous variables.

Between-group differences (MRP vs. CPT) were tested for statistical significance using Mann-Whitney U tests. For within-group differences, the Wilcoxon signed-rank test was employed to calculate differences between time points for participants within each group separately. Furthermore, paired differences between time points (baseline, post-intervention, and 3-month follow-up) were calculated for all participants, without grouping, and tested using the Wilcoxon signed-rank test.

Cohen's *d* effect sizes were reported to assess differences between the groups and within each group. A larger Cohen's *d* indicates a greater difference between the means. The following interpretation for the magnitude of the effect size is suggested: very small effect (< 0.2), small effect (0.2–0.4), medium effect (0.5–0.7), and large effect (≥ 0.8) [429].

Statistical significance was set at *P*-values less than 0.05 with 95% confidence intervals (CI). The statistical analysis was conducted using STATA version 15.1 (StataCorp, College Station, TX, USA).

5.8 Ethical considerations

This study was conducted in accordance with the national and international research ethics guidelines (code of ethics, Declaration of Helsinki). The study protocol was submitted to the Medical Research Ethics Committee of the Parc de Salut MAR (CEIm), Barcelona, Catalonia, Spain, for approval before initiating the study. The study protocol (REC No: 2021/9986/I) and the informed consent received approval on September 17th, 2021. The approval letter is available in Appendix 11.6.

Before agreeing to participate in the study, all participants received information about the study verbally and were provided with an information sheet (see Appendix 11.7). This includes information about the study's protocol, objectives, possible benefits, adverse effects, funding, and institutional approval. Written informed consent was obtained from each study participant prior to the study taking place (the informed consent form was available in Catalan and Spanish languages and shown in Appendix 11.8). Participants were given the right to opt out of the study at any time, which would not affect the care they received. No adverse events and harms were reported during the study period.

Each participant was assigned a unique enrolment identification number at the start of the assessment. To maintain participants' confidentiality, neither the database nor the relevant study reports contained the participants' personal identifiable information. Data was stored according to the guidelines of the Regional Medical Research Ethics Committee of the Parc de Salut MAR and complied with the provisions of Spanish Organic Law 3/2018, and European Parliament and Council Regulation EU 2016/619, on the Protection of Personal Data and the guarantee of digital rights. The usage of the study data was under the control of the principal investigator; access to the data, which only contained coded data, was limited to those directly involved in the study's statistical analysis. All study data were analyzed anonymously and will be stored securely for 5 years after the termination of the study.

Section 6

Results

This chapter presents the results of the current study that aimed to examine the efficacy and long-term outcome of task-specific training based on the motor relearning program (MRP) in improving balance, mobility, and performance of activities of daily living among sub-acute stroke patients. The study compared task-specific training based on MRP to conventional physical therapy (CPT) through a randomized controlled trial. The primary outcomes of interest were balance, mobility (including gait), and functional independence, measured using clinical outcome measures and instrumental evaluation tools to assess biomechanical balance and gait variables.

The purpose of this chapter is to provide a detailed analysis of the collected data and present the study's findings in a clear and concise manner. This chapter outlines the key results obtained from the two groups, including the effects of the interventions on the study's assessments and outcomes, using appropriate statistical methods.

The results presented in this chapter are organized into several sections. The first section provides a description of the demographic information of the study participants and their clinical characteristics. The second section presents the results of the statistical analysis, including comparisons of the clinical outcome measures and instrumental evaluation tools between the two groups at each time point (i.e., baseline, post-intervention, and 3-month follow-up). This includes mean scores and standard deviations (SD) for continuous variables, as well as frequencies (n) and percentages (%) for categorical variables. In addition, the participants' satisfaction with the intervention is provided.

The third section presents the results of the statistical analysis that compare the changes in the study and control groups throughout the course of the study. The aim is to examine whether the study group showed greater improvements in balance, mobility, and performance of daily life activities compared to the control group at post-intervention and 3-month follow-up and whether these improvements were maintained over time. Specifically, the change in mean scores over time was calculated for both groups. The statistical significance level of within-group improvement was also determined, along with the statistical significance level of any differences between the changes observed in the two groups. Furthermore, the effect size (d) was calculated to measure the magnitude of the difference between and within the groups over the study time points.

6.1 Participant characteristics

6.1.1 Flow of study participants

The study's participant recruitment process began with an initial screening of 97 stroke patients who were admitted to the outpatient rehabilitation department. Of these, 26 patients were excluded due to not meeting the inclusion criteria (e.g., multiple stroke, chronic stroke, cognitive impairment, communication impairment, visual impairment). A total of 71 patients were assessed for eligibility, of which 5 declined to participate in the study. The remaining 66 patients fulfilled the eligibility criteria and provided written informed consent. After completing the baseline assessment, the patients were randomized into either the study group (n=33) or the control group (n=33). During the course of the study, 1 participant from the study group and 1 participant from the control group dropped out due to personal reasons, and 1 participant in the control group was lost to follow-up. Thus, the final sample size for analysis included 32 participants in the study group and 31 participants in the control group. Figure 5.1 represents the CONSORT flow chart of participants through each stage of the study.

6.1.2 Demographic and clinical characteristics

The mean age of participants was 64.22 years (SD=10.18) in the MRP group and 66.29 years (SD=8.60) in the CPT group. There were slightly more male participants in the MRP group (71.9%) compared to the CPT group (58.1%). The mean score of body mass index (BMI) for the MRP group was 26.65 (SD=4.66), while for the CPT group was 28.06 (SD=5.63). All participants in the two groups were right-dominant in both upper and lower limbs.

The majority of participants in both groups had suffered an ischemic stroke (71.9% in the MRP group and 74.2% in the CPT group). The mean time since stroke onset was 3.01 months (SD=1.21) in the MRP group and 3.19 months (SD=0.98) in the CPT group. Of the participants in the MRP group 18 (56.3%) had right-sided hemiparesis, while 18 (58.1%) participants in the CPT group had right-sided hemiparesis. The mean stroke severity score on discharge from inpatient as measured by the National Institutes of Health Stroke Scale (NIHSS) was 5.19 (SD=3.02) in the MRP group (50% minor stroke and 50% moderate stroke), and 4.97 (SD=2.83) in the CPT group (48.4% minor stroke and 51.6% moderate stroke).

There were no statistically significant differences in demographic or clinical characteristics between the MRP and CPT groups at baseline ($p>0.05$). Table 6.1 presents the baseline demographic and clinical characteristics of the participants in each group.

Table 6.1: Demographic and clinical characteristics of study participants.

Demographic/Clinical Characteristic	**MRP Group (n = 32)**	**CPT Group (n = 31)**	**All Participants (n = 63)**	***p*-Value***
Age (years), mean (SD)	64.22 (10.18)	66.29 (8.60)	65.24 (9.42)	0.375
Gender, n (%)				
Male	23 (71.9%)	18 (58.1%)	41 (65.1%)	
Female	9 (28.1%)	13 (41.9%)	22 (34.9%)	
Weight (kg), mean (SD)	73.49 (16.33)	72.78 (15.82)	73.14 (15.95)	0.864
Hight (cm), mean (SD)	165.59 (9.71)	160.97 (8.86)	163.32 (9.52)	0.086
BMI (kg/m2), mean (SD)	26.65 (4.66)	28.06 (5.63)	27.34 (5.17)	0.293
BMI (categories), n (%)				
Underweight (<18.5)	1 (3.1%)	1 (3.2%)	2 (3.2%)	
Healthy weight (18.5-24.9)	10 (31.3%)	9 (29.0%)	19 (30.2%)	
Overweight (25-29.9)	14 (43.8%)	10 (32.3%)	24 (38.1%)	
Obese (≥ 30)	7 (21.9%)	11 (35.5%)	18 (28.6%)	
Dominant upper limb, n (%)				
Right	32 (100.0%)	31 (100.0%)	63 (100.0%)	
Left	0 (0.0%)	0 (0.0%)	0 (0.0%)	
Dominant lower limb, n (%)				
Right	32 (100.0%)	31 (100.0%)	63 (100.0%)	
Left	0 (0.0%)	0 (0.0%)	0 (0.0%)	
Type of stroke, n (%)				
Ischemic stroke	23 (71.9%)	23 (74.2%)	46 (73.0%)	

Hemorrhagic stroke	9 (28.1%)	8 (25.8%)	17 (27.0%)	
Time post-stroke (months), mean (SD)	3.01 (1.21)	3.19 (0.98)	3.10 (1.10)	0.611
Time post-stroke (days), mean (SD)	90.31 (36.30)	95.81 (29.47)	93.02 (32.97)	0.606
Side of the paresis, n (%)				
Right	18 (56.3%)	18 (58.1%)	36 (57.1%)	
Left	14 (43.8%)	13 (41.9%)	27 (42.9%)	
NIHSS on discharge, mean (SD)	5.19 (3.02)	4.97 (2.83)	5.08 (2.91)	0.869
Stroke severity, n (%)				
No stroke symptoms (NIHSS 0)	0 (0.0%)	0 (0.0%)	0 (0.0%)	
Minor stroke (NIHSS 1-4)	16 (50.0%)	15 (48.4%)	31 (49.2%)	
Moderate stroke (NIHSS 5-15)	16 (50.0%)	16 (51.6%)	32 (50.8%)	
Moderate to severe stroke (NIHSS 16-20)	0 (0.0%)	0 (0.0%)	0 (0.0%)	
Severe stroke (NIHSS 21-42)	0 (0.0%)	0 (0.0%)	0 (0.0%)	
Type of assistive device and/or bracing used, n (%)				
Unaided	11 (34.4%)	11 (35.5%)	22 (34.9%)	
Quadruped cane	2 (6.3%)	2 (6.5%)	4 (6.3%)	
Single point stick (SPS)	5 (15.6%)	5 (16.1%)	10 (15.9%)	
Forearm crutch	11 (34.4%)	8 (25.8%)	19 (30.2%)	
Ankle-foot orthosis (AFO)	0 (0.0%)	1 (3.2%)	1 (1.6%)	
Quadruped cane + AFO	1 (3.1%)	2 (6.5%)	3 (4.8%)	
Single point stick (SPS) + AFO	0 (0.0%)	0 (0.0%)	0 (0.0%)	
Forearm crutch + AFO	2 (6.3%)	2 (6.5%)	4 (6.3%)	

Abbreviations: BMI, body mass index; NIHSS, National Institutes of Health Stroke Scale; SD, standard deviation.

***** $p<0.05$ indicates a statistically significant difference between the groups, as determined by the Mann-Whitney U test.

6.2 Descriptive results at baseline

6.2.1 Clinical outcome measures at baseline

At baseline, the mean BBS score for the MRP group was 36.94 (SD=5.53; 95% CI=34.94–38.93), and for the CPT group was 37.42 (SD=5.01; 95% CI=35.58–39.26); the difference in mean BBS score between the two groups was not statistically significant (p=0.918; d=0.09). In terms of BBS score interpretation, there was no statistically significant difference between the two groups (p=0.269). In the MRP group, 9 (28.1%) patients had acceptable balance, and 23 (71.9%) patients had fair balance; while in the CPT group, 3 (9.7%) patients had good balance, 7 (22.6%) patients had acceptable balance, and 21 (67.7%) patients had fair balance (see Table 6.2).

For the TUG test, the mean baseline TUG time for the MRP group was 19.19 seconds (SD=7.92; 95% CI=16.34–22.05), and for the CPT group was 17.33 seconds (SD=4.55; 95% CI=15.66–19.00); the difference in mean TUG time between the two groups was not statistically significant (p=0.853; d=0.29). In terms of functional mobility, there was no statistically significant difference between the two groups (p=0.257). In the MRP group, 21 (65.6%) patients had good mobility and independent for main transfers, and 11 (34.4%) patients require assistance with mobility and basic transfers; while in the CPT group, 25 (80.6%) patients had good mobility and independent for main transfers, and 6 (19.4%) patients require assistance with mobility and basic transfers. In terms of predicting falls, there was no statistically significant difference between both groups (p=0.536). In the MRP group, 8 (25.0%) patients had a low risk of falls, and 24 (75.0%) patients had a high risk of falls; while in the CPT group, 5 (16.1%) had a low risk of falls, and 26 (83.9%) had a high risk of falls (see Table 6.2).

For the self-selected gait velocity on 10mWT, the mean baseline score for the MRP group was 0.72 m/s (SD=0.18; 95% CI=0.65–0.78), and for the CPT group was 0.71 m/s (SD=0.14; 95% CI=0.66–0.76); the difference in mean score between the two groups was not statistically significant (p=0.601; d=0.04). In terms of self-selected gait velocity interpretation, there was no statistically significant difference between the two groups (p=0.108). In the MRP group, 3 (9.4%) patients were household ambulators, 17 (53.1%) patients were limited community ambulators, and 12 (37.5%) patients were community ambulators; while in the CPT group, 23 (74.2%) patients were limited community ambulators, and 8 (25.8%) patients were community ambulators. Regarding the fast gait velocity on 10mWT, the mean scores were 0.93 m/s (SD=0.23; 95% CI=0.84–1.01) in the MRP group, and 0.90 m/s (SD=0.16; 95% CI=0.84–0.96) in the CPT group; the difference in mean score between the two groups was not statistically significant (p=0.240; d=0.15) (see Table 6.2).

For the BI of functional independence, the MRP group had a mean baseline BI score of 79.84 (SD=12.54; 95% CI=75.32–84.36), while the CPT group had a mean score of 82.26 (SD=11.82; 95% CI=77.92–86.59); the difference in mean BI score between the two groups was not statistically significant (p=0.523; d=0.20). In terms of BI score interpretation, there was no statistically significant difference between the two groups (p=0.387). In the MRP group, 4 (12.5%) patients were severe dependency, 24 (75.0%) patients were moderate dependency, 2 (6.3%) patients were slight dependency, and 2 (6.3%) patients were independent; while in the CPT group, 2 (6.5%) patients were severe dependency, 20 (64.5%) patients were moderate dependency, 6 (19.4%) patients were slight dependency, and 3 (9.7%) patients were independent (see Table 6.2).

Regarding the SIS-16 of physical function following a stroke, the MRP group had a mean baseline SIS-16 score of 55.00 (SD=8.25; 95% CI=52.03– 57.97), and the CPT group had a mean score of 57.32 (SD=8.17; 95% CI=54.33 –60.32). There was no statistically significant difference between the two groups in the mean SIS-16 score (p=0.306; d=0.28) (see Table 6.2).

Table 6.2: Clinical outcome measures of study participants at baseline.

Clinical Outcome Measures	MRP Group (n = 32)		CPT Group (n = 31)		*p*-Value*	Effect Size (*d*)
	Mean (SD)	95% CI of Mean	Mean (SD)	95% CI of Mean		
BBS total score	36.94 (5.53)	34.94 - 38.93	37.42 (5.01)	35.58 - 39.26	0.918	0.09
BBS score interpretation, n (%)					0.269	
Good balance (45-56)	0 (0.0%)		3 (9.7%)			
Acceptable balance (41-44)	9 (28.1%)		7 (22.6%)			
Fair balance (21-40)	23 (71.9%)		21 (67.7%)			
Poor balance (0-20)	0 (0.0%)		0 (0.0%)			
TUG time (seconds)	19.19 (7.92)	16.34 - 22.05	17.33 (4.55)	15.66 - 19.00	0.853	0.29
TUG interpretation (functional mobility), n (%)					0.257	
Normal mobility and completely independent in transfers (≤ 10 seconds)	0 (0.0%)		0 (0.0%)			
Good mobility and independent for main transfers (≤ 20 seconds)	21 (65.6%)		25 (80.6%)			
Requires assistance with mobility and basic transfers (≤ 30 seconds)	11 (34.4%)		6 (19.4%)			
TUG interpretation (risk of falls), n (%)					0.536	
Low risk of falls (<14 seconds)	8 (25.0%)		5 (16.1%)			
High risk of falls (≥ 14 seconds)	24 (75.0%)		26 (83.9%)			

10mWT (self-selected gait velocity) (m/s)	0.72 (0.18)	0.65 - 0.78	0.71 (0.14)	0.66 - 0.76	0.601	0.04
Self-selected gait velocity interpretation, n (%)					0.108	
Household ambulator (<0.40 m/s)	3 (9.4%)		0 (0.0%)			
Limited community ambulator (0.40 to <0.80 m/s)	17 (53.1%)		23 (74.2%)			
Community ambulator (≥ 0.80 m/s)	12 (37.5%)		8 (25.8%)			
10mWT (fast gait velocity) (m/s)	0.93 (0.23)	0.84 - 1.01	0.90 (0.16)	0.84 - 0.96	0.240	0.15
BI total score	79.84 (12.54)	75.32 - 84.36	82.26 (11.82)	77.92 - 86.59	0.523	0.20
BI score interpretation, n (%)					0.387	
Total dependency (0-20)	0 (0.0%)		0 (0.0%)			
Severe dependency (21-60)	4 (12.5%)		2 (6.5%)			
Moderate dependency (61-90)	24 (75.0%)		20 (64.5%)			
Slight dependency (91-99)	2 (6.3%)		6 (19.4%)			
Independent (100)	2 (6.3%)		3 (9.7%)			
SIS-16 total score	55.00 (8.25)	52.03 - 57.97	57.32 (8.17)	54.33 - 60.32	0.306	0.28

Abbreviations: BBS, Berg Balance Scale; TUG, Timed Up and Go Test; 10mWT, 10-meter Walk Test; BI, Barthel Index; SIS-16, Stroke Impact Scale-16; MRP, study group (motor relearning program); CPT, control group (conventional physiotherapy program); SD, standard deviation; CI, confidence interval.

***** $p<0.05$ indicates a statistically significant difference between the groups, as determined by the Mann-Whitney U test.

6.2.2 Instrumental analysis of balance and gait at baseline

Functional balance assessment

The instrumental balance assessment was measured for all participants using the NedSVE/IBV® computerized posturography system. It combines static posturography tests with dynamic tests based on gait analysis, and postural control assessment, which includes limits of stability analysis and mediolateral (ML) and anteroposterior (AP) rhythmic and directional control assessment. By weighting all of the tests, an overall balance assessment is derived. This results in a global score for functional balance assessment, which is expressed as a percentage of normality and corresponds to the weighted average of the assessment tests conducted.

At baseline, the results showed that there were no statistically significant differences between the MRP and CPT groups in any of the static posturography tests. Particularly, the mean Romberg test with eyes open (ROA) score was 96.47 (SD=4.30; 95% CI=94.92–98.02) for the MRP group, and 95.71 (SD=5.32; 95% CI=93.76–97.66) for the CPT group (p=0.597; d=0.16); the mean Romberg test with eyes closed (ROC) score was 92.13 (SD=8.45; 95% CI=89.08–95.17) for the MRP group, and 91.94 (SD=8.11; 95% CI=88.96–94.91) for the CPT group (p=0.731; d=0.02); the mean Romberg test with eyes open on foam cushion (RGA) score was 91.66 (SD= 7.36; 95% CI=89.00–94.31) for the MRP group, and 88.06 (SD=10.13; 95% CI=84.35 – 91.78) for the CPT group (p=0.216; d=0.41); and the mean Romberg test with eyes closed on foam cushion (RGC) score was 71.97 (SD=11.64; 95% CI=67.77–76.16) for the MRP group, while 72.71 (SD=11.49; 95% CI=68.49–76.93) for the CPT group (p=0.815; d=0.06) (see Table 6.3).

For the ML stability during the Romberg tests, the mean score was 89.63 (SD=5.53; 95% CI=87.63–91.62) for the MRP group, and 90.61 (SD=6.51; 95% CI=88.22–93.00) for the CPT group; the difference between the two groups was not statistically significant (p=0.322; d=0.16). Moreover, the mean AP stability during the Romberg tests was 94.66 (SD=5.61; 95% CI=92.63–96.68) in the MRP group, and 95.55 (SD=4.74; 95% CI=93.81–97.29) in the CPT group; the difference between both groups was not statistically significant (p=0.695; d=0.17) (see Table 6.3).

Regarding the assessment indices of the contribution of sensory systems, there were no statistically significant differences between the two groups in any of indices. Specifically, the mean somatosensory index score was 92.44 (SD=7.70;

95% CI=89.66–95.21) for the MRP group, and 93.06 (SD=6.70; 95% CI=90.61–95.52) for the CPT group (p=0.896; d=0.09); the mean visual index score was 94.50 (SD=5.90; 95% CI=92.37–96.63) for the MRP group, and 92.61 (SD=5.78; 95% CI=90.49–94.73) for the CPT group (p= 0.171; d= 0.32); the mean vestibular index score was 77.00 (SD=10.95; 95% CI=73.05 – 80.95) for the MRP group, and 78.68 (SD=10.82; 95% CI=74.71–82.65) for the CPT group (p=0.716; d=0.15); and the mean dynamic index score was 73.91 (SD=9.90; 95% CI=70.34–77.47) for the MRP group, and 74.61 (SD=10.06; 95% CI=70.92–78.30) for the CPT group (p=0.789; d=0.07). Moreover, the mean sensory-dynamic total score was 84.59 (SD=5.05; 95% CI=82.77–86.41) for the MRP group, and 84.06 (SD= 5.97; 95% CI=81.88–86.25) for the CPT group; the difference between the two groups was not statistically significant (p=0.705; d=0.10) (see Table 6.3).

For the limits of stability (LOS) assessment at baseline, there were no statistically significant differences between the two groups in any of the LOS tests. Specifically, the mean maximum displacement score was 92.06 (SD=11.39; 95% CI=87.96–96.17) for the MRP group, and 92.32 (SD=8.04; 95% CI=89.37–95.27) for the CPT group (p=0.902; d=0.03); the mean directional control score was 55.13 (SD=9.37; 95% CI=51.75–58.50) for the MRP group, and 56.16 (SD=11.21; 95% CI=52.05–60.27) for the CPT group (p=0.621; d=0.10); and the mean reaction time was 1.36 seconds (SD=0.28; 95% CI=1.25–1.46) for the MRP group, and 1.45 seconds (SD=0.34; 95% CI=1.33–1.58) for the CPT group (p=0.284; d= 0.32). Furthermore, the mean LOS total score was 77.72 (SD=8.12; 95% CI=74.79–80.65) for the MRP group, and 78.94 (SD=5.76; 95% CI=76.82–81.05) for the CPT group; the difference between the two groups was not statistically significant (p=0.810; d=0.17) (see Table 6.3).

Besides, there was a statistically significant difference between the two groups in terms of ML rhythmic and directional control at baseline (p=0.041; d=0.57). The mean ML rhythmic and directional control score was 83.09 (SD=7.20; 95% CI=80.50–85.69) for the MRP group, while 87.42 (SD=7.96; 95% CI=84.50–90.34) for the CPT group. However, there was no statistically significant difference between the two groups in terms of AP rhythmic and directional control (p=0.173; d=0.30). The mean AP rhythmic and directional control score was 85.75 (SD=7.31; 95% CI=83.11–88.39) for the MRP group, and 87.84 (SD=6.76; 95% CI=85.36–90.32) for the CPT group. Furthermore, there was no statistically significant difference in the mean postural control assessment total score between the two groups (p=0.326; d=0.35). The mean postural control assessment total score was 80.28 (SD=6.79; 95% CI=77.83– 82.73) for the MRP group, and 82.42 (SD=5.26; 95% CI=77.83–82.73) for the CPT group (see Table 6.3).

In terms of functional balance assessment global score, there was no statistically significant difference between the two groups in the functional balance assessment global score at baseline. The mean functional balance assessment global score was 82.22 (SD=5.04; 95% CI=80.40 - 84.04) in the MRP group, and 83.16 (SD=4.37; 95% CI=81.56 - 84.77) in the CPT group, (p=0.621; d= 0.20). Regarding the functional balance assessment global score interpretation, there was no statistically significant difference between both groups (p=0.701). In the MRP group, 8 (25.0%) patients had functionally impaired balance, 23 (71.9%) patients had slightly impaired balance, and 1 (3.1%) patient had normal balance; while in the CPT group, 8 (25.8%) patients had functionally impaired balance, 20 (64.5%) patients had slightly impaired balance, and 3 (9.7%) patients had normal balance (see Table 6.3).

Additional parameters and data tables related to the functional balance assessment results at baseline are presented in Appendix 11.9.

Table 6.3: Instrumental functional balance assessment of study participants at baseline.

Functional Balance Assessment Tests	MRP Group (n = 32)		CPT Group (n = 31)		*p*-Value*	Effect Size (*d*)
	Mean (SD)	95% CI of Mean	Mean (SD)	95% CI of Mean		
Static posturography tests						
ROA (%)	96.47 (4.30)	94.92 - 98.02	95.71 (5.32)	93.76 - 97.66	0.597	0.16
ROC (%)	92.13 (8.45)	89.08 - 95.17	91.94 (8.11)	88.96 - 94.91	0.731	0.02
RGA (%)	91.66 (7.36)	89.00 - 94.31	88.06 (10.13)	84.35 - 91.78	0.216	0.41
RGC (%)	71.97 (11.64)	67.77 - 76.16	72.71 (11.49)	68.49 - 76.93	0.815	0.06
Romberg test ML stability (%)	89.63 (5.53)	87.63 - 91.62	90.61 (6.51)	88.22 - 93.00	0.322	0.16
Romberg test AP stability (%)	94.66 (5.61)	92.63 - 96.68	95.55 (4.74)	93.81 - 97.29	0.695	0.17
Somatosensory index (%)	92.44 (7.70)	89.66 - 95.21	93.06 (6.70)	90.61 - 95.52	0.896	0.09
Visual index (%)	94.50 (5.90)	92.37 - 96.63	92.61 (5.78)	90.49 - 94.73	0.171	0.32
Vestibular index (%)	77.00 (10.95)	73.05 - 80.95	78.68 (10.82)	74.71 - 82.65	0.716	0.15
Dynamic index (%)	73.91 (9.90)	70.34 - 77.47	74.61 (10.06)	70.92 - 78.30	0.789	0.07
Sensory-Dynamic total score (%)	84.59 (5.05)	82.77 - 86.41	84.06 (5.97)	81.88 - 86.25	0.705	0.10
Postural control assessment						
Avg. score of maximum displacement (%)	92.06 (11.39)	87.96 - 96.17	92.32 (8.04)	89.37 - 95.27	0.902	0.03
Avg. score of directional control (%)	55.13 (9.37)	51.75 - 58.50	56.16 (11.21)	52.05 - 60.27	0.621	0.10
Avg. score of reaction time (seconds)	1.36 (0.28)	1.25 - 1.46	1.45 (0.34)	1.33 - 1.58	0.284	0.32
Limits of stability (LOS) analysis score (%)	77.72 (8.12)	74.79 - 80.65	78.94 (5.76)	76.82 - 81.05	0.810	0.17

ML rhythmic and directional control (%)	83.09 (7.20)	80.50 - 85.69	87.42 (7.96)	84.50 - 90.34	0.041	0.57
AP rhythmic and directional control (%)	85.75 (7.31)	83.11 - 88.39	87.84 (6.76)	85.36 - 90.32	0.173	0.30
Postural control assessment total score (%)	80.28 (6.79)	77.83 - 82.73	82.42 (5.26)	80.49 - 84.35	0.326	0.35
Functional balance assessment global score (%)	82.22 (5.04)	80.40 - 84.04	83.16 (4.37)	81.56 - 84.77	0.621	0.20
Functional balance assessment global score interpretation, n (%)					0.701	
Functionally impaired (≤ 79%)	8 (25.0%)		8 (25.8%)			
Slightly impaired (80-89%)	23 (71.9%)		20 (64.5%)			
Normal (90-100%)	1 (3.1%)		3 (9.7%)			

Abbreviations: ROA, Romberg Test with Eyes Open; ROC, Romberg Test with Eyes Closed; RGA, Romberg Test with Eyes Open on Foam Cushion; RGC, Romberg Test with Eyes Closed on Foam Cushion; ML, mediolateral; AP, anteroposterior; Avg., Average; MRP, study group (motor relearning program); CPT, control group (conventional physiotherapy program); SD, standard deviation; CI, confidence interval.

***** $p<0.05$ indicates a statistically significant difference between the groups, as determined by the Mann-Whitney U test.

Functional gait analysis

The instrumental gait analysis was measured for all participants using the NedAMH/IBV® system for biomechanical gait assessment (kinetic gait analysis). This evaluation system records the gait speed as m/s and calculated the average gait speed as a percentage of normality. In addition, the dynamometric platform recorded the kinetic gait parameters; the difference in support time that the forces exerted by each foot, and the magnitude of the different reaction forces exerted against the ground by both lower limbs during the stance phase of gait, which include: AP braking force, AP propulsion force, vertical take-off force, oscillation force, AP force morphology, ML force morphology, and vertical force morphology. The global score is determined by calculating the weighted average of the assessment for all parameters analyzed and expressing it as a percentage of normality. This score is calculated globally for both lower limbs, as well as for each of the right and left lower limbs separately. The NedAMH/IBV® system assesses the obtained parameters by comparing them to a normality database. This database comprises individuals with similar gait characteristics to the patient, segmented by age, gender, presence of footwear, and walking speed.

At baseline, the results showed that there were no statistically significant differences between the two groups in any of the kinetic gait parameters ($p>0.05$ for all comparisons). To begin with, there were no statistically significant differences between the two groups in the gait speed as m/s and as a percentage of normality. The mean of gait speed was 0.59 m/s (SD=0.16; 95% CI=0.53–0.65) for the MRP group, and 0.56 m/s (SD=0.12; 95% CI=0.52–0.61) for the CPT group ($p=0.417$; $d=0.20$); and the mean gait speed as percentage of normality was 81.09% (SD=20.90; 95% CI=73.56– 88.63) for the MRP group, and 81.97% (SD=15.81; 95% CI=76.17–87.77) for the CPT group ($p=0.831$; $d=0.05$). Also, there was no statistically significant difference between the two groups in the difference in support time score, the mean of difference in support time score was 60.09 (SD=24.21; 95% CI=51.37–68.82) for the MRP group, and 63.97 (SD=21.15; 95% CI=56.21– 71.72) for the CPT group ($p=0.501$; $d=0.17$) (see Table 6.4).

Furthermore, there were no statistically significant differences between the two groups in the global scores of the AP braking force, vertical take-off force, and oscillation force. Specifically, the mean AP braking force global score was 84.25 (SD=20.81; 95% CI=76.75–91.75) for the MRP group, and 86.16 (SD=22.93; 95%

CI=77.75–94.57) for the CPT group (p=0.805; d=0.09); the mean AP propulsion force global score was 76.91 (SD=25.61; 95% CI=67.67–86.14) for the MRP group, and 79.71 (SD=27.29; 95% CI=69.70–89.72) for the CPT group (p=0.409; d=0.11); the mean vertical take-off force global score was 93.63 (SD=11.83; 95% CI=89.36–97.89) for the MRP group, and 97.81 (SD=4.66; 95% CI=96.10–99.51) for the CPT group (p=0.073; d= 0.46); and the mean oscillation force global score was 95.69 (SD=9.46; 95% CI=92.28– 99.10) for the MRP group, and 99.16 (SD=2.63; 95% CI=98.20–100.13) for the CPT group (p=0.176; d=0.50) (see Table 6.4).

In terms of force morphology, there was no statistically significant difference between the two groups in the AP force morphology global score. The mean AP force morphology global score was 53.66 (SD=14.58; 95% CI=48.40–58.91) for the MRP group, and 48.71 (SD=14.78; 95% CI=43.29– 54.13) for the CPT group (p=0.251; d=0.34). On the contrary, there was significant difference between the two groups in the ML force morphology global score. the mean ML force morphology global score was 25.28 (SD=15.89; 95% CI=19.55–31.01) for the MRP group, while 19.13 (SD=17.63; 95% CI=12.66– 25.60) for the CPT group (p=0.043; d=0.37). However, there was no statistically significant difference between the two groups in the vertical force morphology global score. The mean vertical force morphology global score was 65.34 (SD=20.20; 95% CI=58.06–72.62) for the MRP group, and 63.84 (SD=19.71; 95% CI=56.61–71.07) for the CPT group (p=0.907; d=0.08) (see Table 6.4).

Lastly, the results revealed that there was no statically significant difference between the two groups in terms of functional gait analysis global score. The mean functional gait analysis global score was 72.03 (SD=10.28; 95% CI=68.32–75.74) for the MRP group, and 72.26 (SD=10.11; 95% CI=68.55– 75.96) for the CPT group (p=0.967; d=0.02). Regarding the gait analysis global score global score interpretation, there was no statistically significant difference between the two groups (p=1.000). In the MRP group, 25 (78.1%) patients had functionally impaired gait, and 7 (21.9%) patients had slightly impaired gait; while in the CPT group, 24 (77.4%) patients had functionally impaired gait, and 7 (22.6%) patients had slightly impaired gait (see Table 6.4).

Additional parameters and data tables related to the functional gait analysis results at baseline are presented in Appendix 11.10.

Table 6.4: Instrumental functional gait analysis of study participants at baseline.

Functional Gait Analysis Parameters	MRP Group (n = 32)		CPT Group (n = 31)		*p*-Value*	Effect Size (*d*)
	Mean (SD)	**95% CI of Mean**	**Mean (SD)**	**95% CI of Mean**		
Gait speed (m/s)	0.59 (0.16)	0.53 - 0.65	0.56 (0.12)	0.52 - 0.61	0.417	0.20
Average gait speed (%)	81.09 (20.90)	73.56 - 88.63	81.97 (15.81)	76.17 - 87.77	0.831	0.05
Difference in support time (%)	60.09 (24.21)	51.37 - 68.82	63.97 (21.15)	56.21 - 71.72	0.501	0.17
AP braking force global score (%)	84.25 (20.81)	76.75 - 91.75	86.16 (22.93)	77.75 - 94.57	0.805	0.09
AP propulsion force global score (%)	76.91 (25.61)	67.67 - 86.14	79.71 (27.29)	69.70 - 89.72	0.409	0.11
Vertical take-off force global score (%)	93.63 (11.83)	89.36 - 97.89	97.81 (4.66)	96.10 - 99.51	0.073	0.46
Oscillation force global score (%)	95.69 (9.46)	92.28 - 99.10	99.16 (2.63)	98.20 - 100.13	0.176	0.50
AP force morphology (Fx Morphology) (%)	53.66 (14.58)	48.40 - 58.91	48.71 (14.78)	43.29 - 54.13	0.251	0.34
ML force morphology (Fy Morphology) (%)	25.28 (15.89)	19.55 - 31.01	19.13 (17.63)	12.66 - 25.60	0.043	0.37
Vertical force morphology (Fz Morphology) (%)	65.34 (20.20)	58.06 - 72.62	63.84 (19.71)	56.61 - 71.07	0.907	0.08
Functional gait analysis global score (%)	72.03 (10.28)	68.32 - 75.74	72.26 (10.11)	68.55 - 75.96	0.967	0.02
Functional gait analysis global score interpretation, n (%)					1.000	
Functionally impaired (≤ 79%)	25 (78.1%)		24 (77.4%)			
Slightly impaired (80-89%)	7 (21.9%)		7 (22.6%)			
Normal (90-100%)	0 (0.0%)		0 (0.0%)			

Abbreviations: AP, anteroposterior; ML, mediolateral; MRP, study group (motor relearning program); CPT, control group (conventional physiotherapy program); SD, standard deviation; CI, confidence interval.
***** $p<0.05$ indicates a statistically significant difference between the groups, as determined by the Mann-Whitney U test.

6.3 Post-intervention

6.3.1 Clinical outcome measures at post-intervention

At post-intervention, the mean BBS score for the MRP group was 50.72 (SD=3.79; 95% CI= 49.35–52.08), while for the CPT group it was 44.32 (SD=4.00; 95% CI=42.85–45.79); the difference in mean BBS score between the two groups was statistically significant ($p<0.001$; d=1.64). In terms of BBS score interpretation, there was a statistically significant difference between the two groups (p=0.001). In the MRP group, 28 (87.5%) patients had good balance, and 4 (12.5%) patients had acceptable balance; while in the CPT group, 14 (45.2%) patients had good balance, 10 (32.3%) patients had acceptable balance, and 7 (22.6%) patients had fair balance (see Table 6.5).

For the TUG test, the mean TUG time for the MRP group was 11.80 seconds (SD=3.04; 95% CI=10.70–12.90), while for the CPT group it was 14.80 seconds (SD=2.80; 95% CI=13.77–15.82); the difference in mean TUG time between the two groups was statistically significant ($p<0.001$; d=1.03). In terms of functional mobility, there was a statistically significant difference between the two groups ($p<0.001$). In the MRP group, 12 (37.5%) patients had normal mobility and completely independent in transfers, and 20 (62.5%) patients had good mobility and independent for main transfers; while in the CPT group, 29 (93.5%) patients had good mobility and independent for main transfers, and 2 (6.5%) patients require assistance with mobility and basic transfers. In terms of predicting falls, there was a statistically significant difference between the two groups (p=0.036). In the MRP group, 25 (78.1%) patients had a low risk of falls, and 7 (21.9%) patients had a high risk of falls; while in the CPT group, 16 (51.6%) had a low risk of falls, and 15 (48.4%) had a high risk of falls (see Table 6.5).

For the self-selected gait velocity on 10mWT, the mean score for the MRP group was 1.00 m/s (SD=0.15; 95% CI=0.94–1.05), while for the CPT group it was 0.82 m/s (SD=0.12; 95% CI=0.77–0.86); the difference in mean score between the two groups was statistically significant ($p<0.001$; d=1.32). In terms of self-selected gait velocity interpretation, there was a statistically significant difference between the two groups (p=0.011). In the MRP group, 4 (12.5%) patients were limited community ambulators, and 28 (87.5%) patients were community ambulators; while in the group, 13 (41.9%) patients CPT were limited community ambulators, and 18

(58.1%) patients were community ambulators. Regarding the fast gait velocity on 10mWT, the mean score for the MRP group was 1.27 m/s (SD=0.22; 95% CI=1.20–1.35), while for the CPT group it was 1.01 m/s (SD=0.17; 95% CI=0.95–1.07); the difference in mean score between the two groups was statistically significant (p<0.001; d=1.38) (see Table 6.5).

For the BI, the MRP group had a mean BI score of 97.66 (SD=4.40; 95% CI=96.07–99.24), while the CPT group had a mean score of 90.48 (SD=8.40; 95% CI=87.40–93.57); the difference in mean BI score between the two groups was statistically significant (p<0.001; d=1.07). In terms of BI score interpretation, there was statistically significant difference between the two groups (p=0.001). In the MRP group, 4 (12.5%) patients were moderate dependency, 5 (15.6%) patients were slight dependency, and 23 (71.9%) patients were independent; while in the CPT group, 16 (51.6%) patients were moderate dependency, 7 (22.6%) patients were slight dependency, and 8 (25.8%) patients were independent (see Table 6.5).

Regarding SIS-16, the MRP group had a mean SIS-16 score of 69.59 (SD=6.21; 95% CI=67.36–71.83), while the CPT group had a mean score of 64.39 (SD=6.80; 95% CI=61.89–66.88). The difference in mean SIS-16 score between the two groups was statistically significant (p=0.003; d=0.80) (see Table 6.5).

Table 6.5: Clinical outcome measures of study participants at post-intervention.

Clinical Outcome Measures	MRP Group (n = 32)		CPT Group (n = 31)		*p*-Value*	Effect Size (*d*)
	Mean (SD)	**95% CI of Mean**	**Mean (SD)**	**95% CI of Mean**		
BBS total score	50.72 (3.79)	49.35 - 52.08	44.32 (4.00)	42.85 - 45.79	<0.001	1.64
BBS score interpretation, n (%)					0.001	
Good balance (45-56)	28 (87.5%)		14 (45.2%)			
Acceptable balance (41-44)	4 (12.5%)		10 (32.3%)			
Fair balance (21-40)	0 (0.0%)		7 (22.6%)			
Poor balance (0-20)	0 (0.0%)		0 (0.0%)			
TUG time (seconds)	11.80 (3.04)	10.70 - 12.90	14.80 (2.80)	13.77 - 15.82	<0.001	1.03
TUG interpretation (functional mobility), n (%)					<0.001	
Normal mobility and completely independent in transfers (≤ 10 seconds)	12 (37.5%)		0 (0.0%)			
Good mobility and independent for main transfers (≤ 20 seconds)	20 (62.5%)		29 (93.5%)			
Requires assistance with mobility and basic transfers (≤ 30 seconds)	0 (0.0%)		2 (6.5%)			
TUG interpretation (risk of falls), n (%)					0.036	
Low risk of falls (<14 seconds)	25 (78.1%)		16 (51.6%)			
High risk of falls (≥ 14 seconds)	7 (21.9%)		15 (48.4%)			

10mWT (self-selected gait velocity) (m/s)	1.00 (0.15)	0.94 - 1.05	0.82 (0.12)	0.77 - 0.86	<0.001	1.32
Self-selected gait velocity interpretation, n (%)					0.011	
Household ambulator (<0.40 m/s)	0 (0.0%)		0 (0.0%)			
Limited community ambulator (0.40 to <0.80 m/s)	4 (12.5%)		13 (41.9%)			
Community ambulator (≥ 0.80 m/s)	28 (87.5%)		18 (58.1%)			
10mWT (fast gait velocity) (m/s)	1.27 (0.22)	1.20 - 1.35	1.01 (0.17)	0.95 - 1.07	<0.001	1.38
BI total score	97.66 (4.40)	96.07 - 99.24	90.48 (8.40)	87.40 - 93.57	<0.001	1.07
BI score interpretation, n (%)					0.001	
Total dependency (0-20)	0 (0.0%)		0 (0.0%)			
Severe dependency (21-60)	0 (0.0%)		0 (0.0%)			
Moderate dependency (61-90)	4 (12.5%)		16 (51.6%)			
Slight dependency (91-99)	5 (15.6%)		7 (22.6%)			
Independent (100)	23 (71.9%)		8 (25.8%)			
SIS-16 total score	69.59 (6.21)	67.36 - 71.83	64.39 (6.80)	61.89 - 66.88	0.003	0.80

Abbreviations: BBS, Berg Balance Scale; TUG, Timed Up and Go Test; 10mWT, 10-meter Walk Test; BI, Barthel Index; SIS-16, Stroke Impact Scale-16; MRP, study group (motor relearning program); CPT, control group (conventional physiotherapy program); SD, standard deviation; CI, confidence interval

***** *p*<0.05 indicates a statistically significant difference between the groups, as determined by the Mann-Whitney U test.

6.3.2 Instrumental analysis of balance and gait at post-intervention

Functional balance assessment

At post-intervention, the MRP group exhibited a greater mean score improvement in the functional balance assessment tests compared to the CPT group. The results revealed that there was no statistically significant difference between the two groups in the ROA test of static posturography (p=0.224; d=0.41). The mean ROA score was 99.16 (SD=1.63; 95% CI=98.57–99.74) for the MRP group and 97.97 (SD=3.78; 95% CI=96.58– 99.35) for the CPT group. However, statistically significant differences were observed between the two groups in other static posturography tests. Particularly, the mean ROC score was 97.25 (SD=5.25; 95% CI=95.36–99.14) for the MRP group, while 94.61 (SD=6.75; 95% CI=92.14–97.09) for the CPT group (p=0.037; d=0.44); the mean RGA score was 97.06 (SD=4.35; 95% CI=95.50–98.63) for the MRP group, while 91.42 (SD=8.41; 95% CI=88.34– 94.50) for the CPT group (p=0.003; d=0.85); and the mean RGC score was 86.28 (SD=8.64; 95% CI=83.17–89.40) for the MRP group, while 78.23 (SD=9.93; 95% CI=74.58–81.87) for the CPT group (p=0.002; d=0.87) (see Table 6.6).

However, there were no statistically significant differences between the two groups in the ML and AP stability during the Romberg tests. The mean ML stability score was 95.03 (SD=3.54; 95% CI=93.75–96.31) for the MRP group, while 93.19 (SD=5.33; 95% CI=91.24–95.15) for the CPT group (p=0.199; d=0.41). Also, the mean AP stability score was 98.38 (SD=3.10; 95% CI=97.26–99.49) for the MRP group, while 97.35 (SD=3.42; 95% CI=96.10–98.61) for the CPT group (p=0.069; d=0.31) (see Table 6.6).

Regarding the assessment indices of the contribution of sensory systems, there were statistically significant differences between the two groups in all indices. Specifically, the mean somatosensory index score was 97.69 (SD=4.18; 95% CI=96.18–99.19) for the MRP group, while 95.65 (SD=5.69; 95% CI=93.56–97.73) for the CPT group (p=0.024; d=0.41); the mean visual index score was 97.38 (SD=4.15; 95% CI=95.88–98.87) for the MRP group, while 95.19 (SD=4.48; 95% CI=93.55–96.84) for the CPT group (p =0.028; d=0.51); the mean vestibular index score was 91.81 (SD=6.69; 95% CI=89.40– 94.22) for the MRP group, while 83.87 (SD=9.16; 95% CI=80.51 – 87.23) for the CPT group (p=0.001; d=0.99); and the mean dynamic index score was 87.59 (SD=5.48; 95% CI=85.62–89.57) for the MRP group, while 80.58 (SD=8.76; 95% CI=77.37–83.79) for the CPT group (p<0.001; d=0.96). Moreover, participants in the MRP group had a significantly higher mean score in terms of sensory-dynamic total score compared to the CPT group. The mean sensory-dynamic total score was 93.31 (SD=3.21; 95% CI=92.16–94.47) for the MRP group, compared to 87.97 (SD=4.83; 95% CI=86.19–89.74) for the CPT group (p<0.001; d=1.31) (see Table 6.6).

For the limits of stability assessment at post-intervention, the results showed that there were statistically significant differences between the two groups in all LOS tests. Specifically, the mean maximum displacement score was 109.63 (SD=5.46; 95% CI=107.66–111.59) for the MRP group, while 103.45 (SD=7.37; 95% CI=100.75–106.16) for the CPT group (p=0.001; d=0.95); the mean directional control score was 71.81 (SD=8.32; 95% CI=68.81–74.81) for the MRP group, while 66.06 (SD=9.43; 95% CI=62.60–69.52) for the CPT group (p=0.013; d=0.65); and the mean reaction time was 0.96 seconds (SD=0.26; 95% CI=0.86–1.05) for the MRP group, while 1.25 seconds (SD=0.33; 95% CI=1.12–1.37) for the CPT group (p<0.001; d=0.98). Furthermore, participants in the MRP group had a significantly higher mean scores in terms of LOS total score compared to the CPT group. The mean LOS total score was 91.16 (SD=3.17; 95% CI=90.01–92.30) for the MRP group, compared to 85.39 (SD=4.23; 95% CI=83.83–86.94) for the CPT group (p<0.001; d=1.55) (see Table 6.6).

Besides, there were statistically significant differences between the two groups in terms of rhythmic and directional postural control tests. The mean ML rhythmic and directional control score was 97.03 (SD=4.22; 95% CI=95.51–98.55) for the MRP group, while 91.81 (SD=6.85; 95% CI=89.29– 94.32) for the CPT group (p=0.001; d=0.92); and the mean AP rhythmic and directional control score was 96.50 (SD=4.66; 95% CI=94.82–98.18) for the MRP group, while 92.29 (SD=5.46; 95% CI=90.29–94.29) for the CPT group (p<0.001; d=0.83). Furthermore, participants in the MRP group had a significantly higher mean scores in the postural control assessment total score compared to the CPT group. The mean postural control total score was 93.38 (SD=3.16; 95% CI=92.24–94.51) for the MRP group, compared to 87.94 (SD=4.01; 95% CI=86.47–89.41) for the CPT group (p<0.001; d=1.51) (see Table 6.6).

In terms of functional balance assessment global score, the results showed that the MRP group had a significantly higher mean score compared to the CPT group at post-intervention. The mean functional balance assessment global score was 93.41

(SD=2.84; 95% CI=92.38–94.43) for the MRP group, while 87.77 (SD=3.50; 95% CI=86.49–89.06) for the CPT group ($p<0.001$; $d=1.77$). Regarding the functional balance assessment global score interpretation, there was a statistically significant difference between the two groups ($p<0.001$). In the MRP group, 3 (9.4%) patients had slightly impaired balance, and 29 (90.6%) patients had normal balance; while in the CPT group, 21 (67.7%) patients had slightly impaired balance, and 10 (32.3%) patients had normal balance (see Table 6.6).

Additional parameters and data tables related to the functional balance assessment results at post-intervention are presented in Appendix 11.11.

Table 6.6: Instrumental functional balance assessment of study participants at post-intervention.

Functional Balance Assessment Tests	MRP Group (n = 32)		CPT Group (n = 31)		*p*-Value*	Effect Size (*d*)
	Mean (SD)	**95% CI of Mean**	**Mean (SD)**	**95% CI of Mean**		
Static posturography tests						
ROA (%)	99.16 (1.63)	98.57 - 99.74	97.97 (3.78)	96.58 - 99.35	0.224	0.41
ROC (%)	97.25 (5.25)	95.36 - 99.14	94.61 (6.75)	92.14 - 97.09	0.037	0.44
RGA (%)	97.06 (4.35)	95.50 - 98.63	91.42 (8.41)	88.34 - 94.50	0.003	0.85
RGC (%)	86.28 (8.64)	83.17 - 89.40	78.23 (9.93)	74.58 - 81.87	0.002	0.87
Romberg test ML stability (%)	95.03 (3.54)	93.75 - 96.31	93.19 (5.33)	91.24 - 95.15	0.199	0.41
Romberg test AP stability (%)	98.38 (3.10)	97.26 - 99.49	97.35 (3.42)	96.10 - 98.61	0.069	0.31
Somatosensory index (%)	97.69 (4.18)	96.18 - 99.19	95.65 (5.69)	93.56 - 97.73	0.024	0.41
Visual index (%)	97.38 (4.15)	95.88 - 98.87	95.19 (4.48)	93.55 - 96.84	0.028	0.51
Vestibular index (%)	91.81 (6.69)	89.40 - 94.22	83.87 (9.16)	80.51 - 87.23	0.001	0.99
Dynamic index (%)	87.59 (5.48)	85.62 - 89.57	80.58 (8.76)	77.37 - 83.79	<0.001	0.96
Sensory-Dynamic total score (%)	93.31 (3.21)	92.16 - 94.47	87.97 (4.83)	86.19 - 89.74	<0.001	1.31
Postural control assessment						
Avg. score of maximum displacement (%)	109.63 (5.46)	107.66 - 111.59	103.45 (7.37)	100.75 - 106.16	0.001	0.95
Avg. score of directional control (%)	71.81 (8.32)	68.81 - 74.81	66.06 (9.43)	62.60 - 69.52	0.013	0.65
Avg. score of reaction time (s)	0.96 (0.26)	0.86 - 1.05	1.25 (0.33)	1.12 - 1.37	<0.001	0.98
Limits of stability (LOS) analysis score (%)	91.16 (3.17)	90.01 - 92.30	85.39 (4.23)	83.83 - 86.94	<0.001	1.55

ML rhythmic and directional control (%)	97.03 (4.22)	95.51 - 98.55	91.81 (6.85)	89.29 - 94.32	0.001	0.92
AP rhythmic and directional control (%)	96.50 (4.66)	94.82 - 98.18	92.29 (5.46)	90.29 - 94.29	<0.001	0.83
Postural control assessment total score (%)	93.38 (3.16)	92.24 - 94.51	87.94 (4.01)	86.47 - 89.41	<0.001	1.51
Functional balance assessment global score (%)	93.41 (2.84)	92.38 - 94.43	87.77 (3.50)	86.49 - 89.06	<0.001	1.77
Functional balance assessment global score interpretation, n (%)					<0.001	
Functionally impaired (≤ 79%)	0 (0.0%)		0 (0.0%)			
Slightly impaired (80-89%)	3 (9.4%)		21 (67.7%)			
Normal (90-100%)	29 (90.6%)		10 (32.3%)			

Abbreviations: ROA, Romberg Test with Eyes Open; ROC, Romberg Test with Eyes Closed; RGA, Romberg Test with Eyes Open on Foam Cushion; RGC, Romberg Test with Eyes Closed on Foam Cushion; ML, mediolateral; AP, anteroposterior; Avg., Average; MRP, study group (motor relearning program); CPT, control group (conventional physiotherapy program); SD, standard deviation; CI, confidence interval.

***** $p<0.05$ indicates a statistically significant difference between the groups, as determined by the Mann-Whitney U test.

Functional gait analysis

With regard to the instrumental gait analysis at post-intervention, the results showed that there were statistically significant differences between the two groups in the gait speed as m/s and as percentage of normality. The mean gait speed was 0.79 m/s (SD=0.13; 95% CI=0.74–0.84) for the MRP group, while 0.65 m/s (SD=0.12; 95% CI=0.61–0.69) for the CPT group ($p<0.001$; d=1.09); and the mean gait speed as percentage of normality was 98.22% (SD=4.07; 95% CI=96.75–99.69) for the MRP group, while 91.26% (SD=11.76; 95% CI=86.94–95.57) for the CPT group ($p=0.004$; d=0.80). Also, there was statistically significant difference between both groups in the difference in support time score, the mean difference in support time score was 89.41% (SD=9.64; 95% CI=85.93–92.88) for the MRP group, compared to 73.81% (SD=18.77; 95% CI=66.92–80.69) for the CPT group ($p<0.001$; d=1.05) (see Table 6.7).

There were no statistically significant differences between the two groups in the global scores of the AP braking force, AP propulsion force, vertical take-off force, and oscillation force at post-intervention. Specifically, the mean AP braking force global score was 98.38 (SD=3.60; 95% CI=97.08–99.67) for the MRP group, compared to 91.87 (SD=17.93; 95% CI=85.29–98.45) for the CPT group ($p=0.060$; d=0.51); the mean AP propulsion force global score was 94.88 (SD=13.04; 95% CI=90.18–99.57) for the MRP group, while 84.90 (SD=24.93; 95% CI=75.76–94.05) for the CPT group ($p=0.167$; d=0.50); the mean vertical take-off force global score was 99.69 (SD=0.64; 95% CI= 99.46–99.92) for the MRP group, while 99.42 (SD=1.69; 95% CI=98.80–100.04) for the CPT group ($p=0.773$; d=0.21); and the mean oscillation force global score was 99.16 (SD=3.89; 95% CI=97.76–100.56) for the MRP group, while 99.81 (SD=0.79; 95% CI=99.52–100.10) for the CPT group ($p=0.554$; d= 0.23) (see Table 6.7).

In terms of force morphology, there was statistically significant difference between the two groups in AP force morphology global score. The mean AP force morphology global score was 70.88 (SD=11.53; 95% CI=66.72–75.03) for the MRP group, while 58.87 (SD=13.96; 95% CI=53.75–63.99) for the CPT group ($p<0.001$; d=0.94). Moreover, the mean ML force morphology global score was statistically significantly different between the two groups, the mean ML force morphology global score was 41.78 (SD=23.14; 95% CI=33.44–50.12) for the MRP group, compared to 24.32 (SD=18.19; 95% CI=17.65–31.00) for the CPT group ($p=0.001$;

d=0.84). On the contrary, there was no significant difference between the two groups in the mean vertical force morphology global score, the mean vertical force morphology score was 77.28 (SD=15.08; 95% CI=71.84–82.72) for the MRP group, while 71.74 (SD=16.36; 95% CI=65.74–77.74) for the CPT group (p=0.187; d=0.35) (see Table 6.7).

Lastly, the results showed that participants in the MRP group had significantly higher mean scores in terms of functional gait analysis global score compared to the CPT group. The mean functional gait analysis global score was 86.72 (SD=5.55; 95% CI=84.72–88.72) for the MRP group, compared to 78.61 (SD=8.58; 95% CI=75.47–81.76) for the CPT group (p<0.001; d=1.13). Regarding the gait analysis global score global score interpretation, there was statistically significant difference between both groups (p<0.001). In the MRP group, 3 (9.4%) patients had functionally impaired gait, 17 (53.1%) patients had slightly impaired gait, and 12 (37.5%) patients had normal gait; while in the CPT group, 16 (51.6%) patients had functionally impaired gait, 13 (41.9%) patients had slightly impaired gait, and 2 (6.5%) patients had normal gait (see Table 6.7).

Additional parameters and data tables related to the functional gait analysis results at post-intervention are presented in Appendix 11.12.

Table 6.7: Instrumental functional gait analysis of study participants at post-intervention.

Functional Gait Analysis Parameters	MRP Group (n = 32)		CPT Group (n = 31)		*p*-Value*	Effect Size (*d*)
	Mean (SD)	95% CI of Mean	Mean (SD)	95% CI of Mean		
Gait speed (m/s)	0.79 (0.13)	0.74 - 0.84	0.65 (0.12)	0.61 - 0.69	<0.001	1.09
Average gait speed (%)	98.22 (4.07)	96.75 - 99.69	91.26 (11.76)	86.94 - 95.57	0.004	0.80
Difference in support time (%)	89.41 (9.64)	85.93 - 92.88	73.81 (18.77)	66.92 - 80.69	<0.001	1.05
AP braking force global score (%)	98.38 (3.60)	97.08 - 99.67	91.87 (17.93)	85.29 - 98.45	0.060	0.51
AP propulsion force global score (%)	94.88 (13.04)	90.18 - 99.57	84.90 (24.93)	75.76 - 94.05	0.167	0.50
Vertical take-off force global score (%)	99.69 (0.64)	99.46 - 99.92	99.42 (1.69)	98.80 - 100.04	0.773	0.21
Oscillation force global score (%)	99.16 (3.89)	97.76 - 100.56	99.81 (0.79)	99.52 - 100.10	0.554	0.23
AP force morphology (Fx Morphology) (%)	70.88 (11.53)	66.72 - 75.03	58.87 (13.96)	53.75 - 63.99	<0.001	0.94
ML force morphology (Fy Morphology) (%)	41.78 (23.14)	33.44 - 50.12	24.32 (18.19)	17.65 - 31.00	0.001	0.84
Vertical force morphology (Fz Morphology) (%)	77.28 (15.08)	71.84 - 82.72	71.74 (16.36)	65.74 - 77.74	0.187	0.35
Functional gait analysis global score (%)	86.72 (5.55)	84.72 - 88.72	78.61 (8.58)	75.47 - 81.76	<0.001	1.13
Functional gait analysis global score interpretation, n (%)					<0.001	
Functionally impaired (≤ 79%)	3 (9.4%)		16 (51.6%)			
Slightly impaired (80-89%)	17 (53.1%)		13 (41.9%)			
Normal (90-100%)	12 (37.5%)		2 (6.5%)			

Abbreviations: AP, anteroposterior; ML, mediolateral; MRP, study group (motor relearning program); CPT, control group (conventional physiotherapy program); SD, standard deviation; CI, confidence interval.
***** $p<0.05$ indicates a statistically significant difference between the groups, as determined by the Mann-Whitney U test.

6.3.3 Patients' satisfaction after the interventions

Regarding the patients' satisfaction after the interventions, there was a statistically significant difference between the two groups in all questionnaire items ($p<0.001$). For the first item, in the MRP group, 32 (100.0%) patients reported being very satisfied, while in the CPT group, 13 (41.9%) patients reported being satisfied and 18 (58.1%) patients reported being very satisfied. For the second item, in the MRP group, 5 (15.6%) patients reported being satisfied and 27 (84.4%) patients reported being very satisfied, while in the CPT group, 7 (22.6%) patients reported being neither satisfied nor dissatisfied, 18 (58.1%) patients reported being satisfied, and 6 (19.4%) patients reported being very satisfied. For the third item, in the MRP group, 2 (6.3%) patients reported being satisfied and 30 (93.8%) patients reported being very satisfied, while in the CPT group, 4 (12.9%) patients reported being neither satisfied nor dissatisfied, 17 (54.8%) patients reported being satisfied, and 10 (32.3%) patients reported being very satisfied (see Table 6.8).

Table 6.8: Patients' satisfaction after the interventions.

Questionnaire Items	**MRP Group (n = 32) n (%)**	**CPT Group (n = 31) n (%)**	**All Participants (n = 63) n (%)**	***p*-Value***
I am satisfied with the type of exercises and training the therapist has given me.				<0.001
Very dissatisfied	0 (0.0%)	0 (0.0%)	0 (0.0%)	
Dissatisfied	0 (0.0%)	0 (0.0%)	0 (0.0%)	
Neither satisfied nor dissatisfied	0 (0.0%)	0 (0.0%)	0 (0.0%)	
Satisfied	0 (0.0%)	13 (41.9%)	13 (20.6%)	
Very satisfied	32 (100.0%)	18 (58.1%)	50 (79.4%)	
I think this exercise training program has helped me to improve my ability to manage my daily life activities (personal hygiene, dressing, transferring/mobility, etc.).				<0.001
Very dissatisfied	0 (0.0%)	0 (0.0%)	0 (0.0%)	
Dissatisfied	0 (0.0%)	0 (0.0%)	0 (0.0%)	
Neither satisfied nor dissatisfied	0 (0.0%)	7 (22.6%)	7 (11.1%)	
Satisfied	5 (15.6%)	18 (58.1%)	23 (36.5%)	
Very satisfied	27 (84.4%)	6 (19.4%)	33 (52.4%)	

I am happy with the amount of recovery I have made since joining this exercise training program.				<0.001
Very dissatisfied	0 (0.0%)	0 (0.0%)	0 (0.0%)	
Dissatisfied	0 (0.0%)	0 (0.0%)	0 (0.0%)	
Neither satisfied nor dissatisfied	0 (0.0%)	4 (12.9%)	4 (6.3%)	
Satisfied	2 (6.3%)	17 (54.8%)	19 (30.2%)	
Very satisfied	30 (93.8%)	10 (32.3%)	40 (63.5%)	

* $p<0.05$ indicates a statistically significant difference between the groups, as determined by the Mann-Whitney U test.

6.4 3-months follow-up

6.4.1 Clinical outcome measures at 3-months follow-up

At 3-months follow-up after the post-intervention, the results showed that participants in the MRP group had significantly higher mean scores in all clinical outcome measures compared to the control group. In particular, the mean BBS score was 51.13 (SD=3.71; 95% CI=49.79–52.46) for the MRP group, while 44.42 (SD=4.23; 95% CI=42.87–45.97) for the CPT group; the difference in mean BBS score between the two groups was statistically significant (p<0.001; d=1.69). In terms of BBS score interpretation, there was a statistically significant difference between the two groups (p=0.004). In the MRP group, 29 (90.6%) patients had good balance, and 3 (9.4%) patients had acceptable balance; while in the CPT group, 18 (58.1%) patients had good balance, 8 (25.8%) patients had acceptable balance, and 5 (16.1%) patients had fair balance (see Table 6.9).

For the TUG test, the mean TUG time was 11.57 seconds (SD=2.88; 95% CI=10.53–12.61) for the MRP group, while 14.80 seconds (SD=2.80; 95% CI=13.77–15.83) for the CPT group; the difference in mean TUG time between the two groups was statistically significant (p<0.001; d=1.14). In terms of functional mobility, there was a statistically significant difference between the two groups (p<0.001). In the MRP group, 13 (40.6%) patients had normal mobility and completely independent in transfers, and 19 (59.4%) patients had good mobility and independent for main transfers; while in the CPT group, 29 (93.5%) patients had good mobility and independent for main transfers, and 2 (6.5%) patients require assistance with mobility and basic transfers. In terms of predicting falls, there was a statistically significant difference between the two groups (p=0.010). In the MRP group, 25 (78.1%) patients had a low risk of falls, and 7 (21.9%) patients had a high risk of falls; while in the CPT group, 14 (45.2%) had a low risk of falls, and 17 (54.8%) had a high risk of falls (see Table 6.9).

For the self-selected gait velocity on 10mWT, the mean score for the MRP group was 1.01 m/s (SD=0.15; 95% CI=0.96–1.07), while for the CPT group it was 0.82 m/s (SD=0.12; 95% CI=0.78–0.87); the difference in mean score between the two groups was statistically significant (p<0.001; d=1.37). In terms of self-selected gait velocity interpretation, there was no statistically significant difference between the two groups (p=0.075). In the MRP group, 4 (12.5%) patients were limited community ambulators, and 28 (87.5%) patients were community ambulators; while in the CPT group, 10 (32.3%) patients were limited community ambulators, and 21 (67.7%) patients were community ambulators. Regarding the fast gait velocity on 10mWT, the mean score for the MRP group was 1.29 m/s (SD=0.22; 95% CI=1.21–1.37), while for the CPT group it was 1.00 m/s (SD=0.16; 95% CI=0.94–1.06); the difference in mean score between the two groups was statistically significant ($p<0.001$; d=1.49) (see Table 6.9).

For the BI, the MRP group had a mean BI score of 98.28 (SD=3.50; 95% CI=97.02–99.54), while the CPT group had a mean score of 92.58 (SD=7.06; 95% CI=89.99–95.17); the difference in mean BI score between the two groups was statistically significant (p=0.001; d=1.03). In terms of BI score interpretation, there was statistically significant difference between the two groups (p=0.001). In the MRP group, 4 (12.5%) patients were moderate dependency, 3 (9.4%) patients were slight dependency, and 25 (78.1%) patients were independent; while in the CPT group, 14 (45.2%) patients were moderate dependency, 7 (22.6%) patients were slight dependency, and 10 (32.3%) patients were independent (see Table 6.9).

Regarding SIS-16, the MRP group had a mean SIS-16 score of 71.22 (SD=6.00; 95% CI=69.06–73.38), while the CPT group had a mean score of 66.10 (SD=6.95; 95% CI=63.55–68.65). The difference in mean SIS-16 score between the two groups was statistically significant (p=0.002; d=0.79) (see Table 6.9).

Table 6.9: Clinical outcome measures of study participants at 3-months follow-up.

Clinical Outcome Measures	MRP Group (n = 32)		CPT Group (n = 31)		*p*-Value*	Effect Size (*d*)
	Mean (SD)	95% CI of Mean	Mean (SD)	95% CI of Mean		
BBS total score	51.13 (3.71)	49.79 - 52.46	44.42 (4.23)	42.87 - 45.97	<0.001	1.69
BBS score interpretation, n (%)					0.004	
Good balance (45-56)	29 (90.6%)		18 (58.1%)			
Acceptable balance (41-44)	3 (9.4%)		8 (25.8%)			
Fair balance (21-40)	0 (0.0%)		5 (16.1%)			
Poor balance (0-20)	0 (0.0%)		0 (0.0%)			
TUG time (seconds)	11.57 (2.88)	10.53 - 12.61	14.80 (2.80)	13.77 - 15.83	<0.001	1.14
TUG interpretation (functional mobility), n (%)					<0.001	
Normal mobility and completely independent in transfers (≤ 10 seconds)	13 (40.6%)		0 (0.0%)			
Good mobility and independent for main transfers (≤ 20 seconds)	19 (59.4%)		29 (93.5%)			
Requires assistance with mobility and basic transfers (≤ 30 seconds)	0 (0.0%)		2 (6.5%)			
TUG interpretation (risk of falls), n (%)					0.010	
Low risk of falls (<14 seconds)	25 (78.1%)		14 (45.2%)			
High risk of falls (≥ 14 seconds)	7 (21.9%)		17 (54.8%)			

10mWT (self-selected gait velocity) (m/s)	1.01 (0.15)	0.96 - 1.07	0.82 (0.12)	0.78 - 0.87	<0.001	1.37
Self-selected gait velocity interpretation, n (%)					0.075	
Household ambulator (<0.40 m/s)	0 (0.0%)		0 (0.0%)			
Limited community ambulator (0.40 to <0.80 m/s)	4 (12.5%)		10 (32.3%)			
Community ambulator (≥ 0.80 m/s)	28 (87.5%)		21 (67.7%)			
10mWT (fast gait velocity) (m/s)	1.29 (0.22)	1.21 - 1.37	1.00 (0.16)	0.94 - 1.06	<0.001	1.49
BI total score	98.28 (3.50)	97.02 - 99.54	92.58 (7.06)	89.99 - 95.17	0.001	1.03
BI score interpretation, n (%)					0.001	
Total dependency (0-20)	0 (0.0%)		0 (0.0%)			
Severe dependency (21-60)	0 (0.0%)		0 (0.0%)			
Moderate dependency (61-90)	4 (12.5%)		14 (45.2%)			
Slight dependency (91-99)	3 (9.4%)		7 (22.6%)			
Independent (100)	25 (78.1%)		10 (32.3%)			
SIS-16 total score	71.22 (6.00)	69.06 - 73.38	66.10 (6.95)	63.55 - 68.65	0.002	0.79

Abbreviations: BBS, Berg Balance Scale; TUG, Timed Up and Go Test; 10mWT, 10-meter Walk Test; BI, Barthel Index; SIS-16, Stroke Impact Scale-16; MRP, study group (motor relearning program); CPT control group (conventional physiotherapy program); SD, standard deviation; CI, confidence interval

***** $p<0.05$ indicates a statistically significant difference between the groups, as determined by the Mann-Whitney U test.

6.4.2 Instrumental analysis of balance and gait at 3-months follow-up

Functional Balance Assessment

At 3-months follow-up, the results revealed that there were statistically significant differences between the MRP and CPT groups for all static posturography tests. Particularly, the mean ROA score was 99.47 (SD=1.27; 95% CI=99.01–99.93) for the MRP group, while 97.94 (SD=3.52; 95% CI=96.64– 99.23) for the CPT group (p=0.012; d=0.58); the mean ROC score was 97.53 (SD=5.28; 95% CI=95.63–99.43) for the MRP group, while 95.19 (SD=5.99; 95% CI=93.00–97.39) for the CPT group (p=0.039; d=0.41); the mean RGA score was 97.91 (SD=3.01; 95% CI=96.82–98.99) for the MRP group, while 92.10 (SD=8.06; 95% CI=89.14–95.05) for the CPT group (p=0.003; d=0.96); and the mean RGC score was 87.69 (SD=8.56; 95% CI=84.60–90.77), while 78.68 (SD=10.37; 95% CI=74.87–82.48) for the CPT group (p=0.001; d=0.95) (see Table 6.10).

However, there were no statistically significant differences between the two groups in the ML and AP stability during the Romberg tests. The mean ML stability score was 95.84 (SD=2.94; 95% CI=94.78–96.90) for the MRP group, while 93.32 (SD=4.98; 95% CI=91.49– 95.15) for the CPT group (p=0.051; d=0.62). The mean AP stability score was 98.53 (SD=2.75; 95% CI=97.54–99.52) for the MRP group, while 97.52 (SD= 3.21; 95% CI=96.34–98.69) for the CPT group (p=0.187; d=0.34) (see Table 6.10).

Regarding the assessment indices of the contribution of sensory systems, there were statistically significant differences between the two groups in all indices. Specifically, the mean somatosensory index score was 97.97 (SD=4.23; 95% CI=96.44–99.49) for the MRP group, while 96.23 (SD=4.96; 95% CI=94.41–98.04) for the CPT group (p=0.017; d=0.38); the mean visual index score was 97.88 (SD=3.35; 95% CI=96.67–99.08) for the MRP group, while 95.52 (SD=4.24; 95% CI=93.96–97.07) for the CPT group (p = 0.026; d=0.62); the mean vestibular index score was 93.00 (SD=6.23; 95% CI=90.75–95.25) for the MRP group, while 83.97 (SD=9.51; 95% CI=80.48 – 87.45) for the CPT group (p<0.001; d=1.13); and the mean dynamic index score was 88.75 (SD=5.19; 95% CI=86.88–90.62) for the MRP group, while 81.71 (SD=8.15; 95% CI=78.72–84.70) for the CPT group (p<0.001; d=1.03). Moreover, participants in the MRP group had a significantly higher mean score in terms of sensory-dynamic total score compared to the CPT group. The mean sensory-dynamic total score was 94.13 (SD=2.92; 95% CI=93.07–95.18) for the MRP group, compared to 88.55 (SD=4.78; 95% CI=86.79–90.30) for the CPT group ($p<0.001$; d=1.41) (see Table 6.10).

For the limits of stability assessment at 3-months follow-up, the results showed that there were statistically significant differences between the two groups in all LOS tests. The mean maximum displacement score was 110.84 (SD=5.36; 95% CI=108.91–112.78) for the MRP group, while 104.23 (SD=7.40; 95% CI=101.51–106.94) for the CPT group (p=0.001; d=1.03); the mean directional control score was 73.81 (SD=7.45; 95% CI=71.12–76.50) for the MRP group, while 65.77 (SD=8.79; 95% CI=62.55–69.00) for the CPT group ($p<0.001$; d=0.99); and the mean reaction time was 0.94 seconds (SD=0.24; 95% CI=0.85–1.02) for the MRP group, while 1.22 seconds (SD=0.27; 95% CI=1.12–1.31) for the CPT group ($p<0.001$; d=1.09). Furthermore, participants in the MRP group had a significantly higher mean score in terms of LOS total score compared to the CPT group. The mean LOS total score was 91.97 (SD=2.69; 95% CI=91.00–92.94) for the MRP group, compared to 85.84 (SD=4.25; 95% CI=84.28–87.40) for the CPT group ($p<0.001$; d=1.73) (see Table 6.10).

Besides, there were statistically significant differences between the two groups in terms of rhythmic and directional postural control tests. The mean ML rhythmic and directional control score was 97.41 (SD=3.84; 95% CI=96.02–98.79) for the MRP group, while 92.39 (SD=6.26; 95% CI=90.09 – 94.68) for the CPT group (p=0.001; d=0.97); and the mean AP rhythmic and directional control score was 96.50 (SD=3.94; 95% CI=95.08–97.92) for the MRP group, while 92.42 (SD=5.73; 95% CI=90.32–94.52) for the CPT group (p=0.001; d=0.83). Furthermore, participants in the MRP group had a significantly higher mean score in the postural control assessment total score compared to the CPT group. The mean postural control total score was 93.81 (SD=2.72; 95% CI=92.83–94.79) for the MRP group, compared to 87.94 (SD=3.86; 95% CI=86.52– 89.35) for the CPT group ($p<0.001$; d=1.76) (see Table 6.10).

In terms of functional balance assessment global score, the results showed that the MRP group had a significantly higher mean score compared to the CPT group at 3-months follow-up. The mean functional balance assessment global score was 94.06 (SD=2.49; 95% CI=93.17–94.96) for the MRP group, while 88.03 (SD=3.41; 95% CI=86.78–89.28) for the CPT group ($p<0.001$; d=2.03). Regarding the functional balance assessment global score interpretation, there was statistically significant difference between the two groups ($p<0.001$). In the MRP group, 2 (6.3%) patients had slightly impaired balance, and 30 (93.8%) patients had normal balance; while in the CPT group, 21 (67.7%) patients had slightly impaired balance, and 10 (32.3%) patients had normal balance (see Table 6.10).

Additional parameters and data tables related to the functional balance assessment results at 3-months follow-up are presented in Appendix 11.13.

Table 6.10: Instrumental functional balance assessment of study participants at 3-months follow-up.

Functional Balance Assessment Tests	MRP Group (n = 32)		CPT Group (n = 31)		*p*-Value*	Effect Size (*d*)
	Mean (SD)	**95% CI of Mean**	**Mean (SD)**	**95% CI of Mean**		
Static posturography tests						
ROA (%)	99.47 (1.27)	99.01 - 99.93	97.94 (3.52)	96.64 - 99.23	0.012	0.58
ROC (%)	97.53 (5.28)	95.63 - 99.43	95.19 (5.99)	93.00 - 97.39	0.039	0.41
RGA (%)	97.91 (3.01)	96.82 - 98.99	92.10 (8.06)	89.14 - 95.05	0.003	0.96
RGC (%)	87.69 (8.56)	84.60 - 90.77	78.68 (10.37)	74.87 - 82.48	0.001	0.95
Romberg test ML stability (%)	95.84 (2.94)	94.78 - 96.90	93.32 (4.98)	91.49 - 95.15	0.051	0.62
Romberg test AP stability (%)	98.53 (2.75)	97.54 - 99.52	97.52 (3.21)	96.34 - 98.69	0.187	0.34
Somatosensory index (%)	97.97 (4.23)	96.44 - 99.49	96.23 (4.96)	94.41 - 98.04	0.017	0.38
Visual index (%)	97.88 (3.35)	96.67 - 99.08	95.52 (4.24)	93.96 - 97.07	0.026	0.62
Vestibular index (%)	93.00 (6.23)	90.75 - 95.25	83.97 (9.51)	80.48 - 87.45	<0.001	1.13
Dynamic index (%)	88.75 (5.19)	86.88 - 90.62	81.71 (8.15)	78.72 - 84.70	<0.001	1.03
Sensory-Dynamic total score (%)	94.13 (2.92)	93.07 - 95.18	88.55 (4.78)	86.79 - 90.30	<0.001	1.41
Postural control assessment						
Avg. score of maximum displacement (%)	110.84 (5.36)	108.91 - 112.78	104.23 (7.40)	101.51 - 106.94	0.001	1.03
Avg. score of directional control (%)	73.81 (7.45)	71.12 - 76.50	65.77 (8.79)	62.55 - 69.00	<0.001	0.99
Avg. score of reaction time (s)	0.94 (0.24)	0.85 - 1.02	1.22 (0.27)	1.12 - 1.31	<0.001	1.09
Limits of stability (LOS) analysis score (%)	91.97 (2.69)	91.00 - 92.94	85.84 (4.25)	84.28 - 87.40	<0.001	1.73

ML rhythmic and directional control (%)	97.41 (3.84)	96.02 - 98.79	92.39 (6.26)	90.09 - 94.68	0.001	0.97
AP rhythmic and directional control (%)	96.50 (3.94)	95.08 - 97.92	92.42 (5.73)	90.32 - 94.52	0.001	0.83
Postural control assessment total score (%)	93.81 (2.72)	92.83 - 94.79	87.94 (3.86)	86.52 - 89.35	<0.001	1.76
Functional balance assessment global score (%)	94.06 (2.49)	93.17 - 94.96	88.03 (3.41)	86.78 - 89.28	<0.001	2.03
Functional balance assessment global score interpretation, n (%)					<0.001	
Functionally impaired (≤ 79%)	0 (0.0%)		0 (0.0%)			
Slightly impaired (80-89%)	2 (6.3%)		21 (67.7%)			
Normal (90-100%)	30 (93.8%)		10 (32.3%)			

Abbreviations: ROA, Romberg Test with Eyes Open; ROC, Romberg Test with Eyes Closed; RGA, Romberg Test with Eyes Open on Foam Cushion; RGC, Romberg Test with Eyes Closed on Foam Cushion; ML, mediolateral; AP, anteroposterior; Avg., Average; MRP, study group (motor relearning program); CPT, control group (conventional physiotherapy program); SD, standard deviation; CI, confidence interval.

***** $p<0.05$ indicates a statistically significant difference between the groups, as determined by the Mann-Whitney U test.

Functional gait analysis

With regard to the instrumental gait analysis at 3-months follow-up, the results showed that there were statistically significant differences between the two groups in the gait speed as m/s and as percentage of normality. The mean gait speed was 0.81 m/s (SD=0.14; 95% CI=0.76–0.86) for the MRP group, while 0.66 m/s (SD=0.12; 95% CI=0.62–0.71) for the CPT group ($p<0.001$; d=1.14); and the mean gait speed as percentage of normality was 98.59% (SD=3.37; 95% CI=97.38–99.81) for the MRP group, while 92.42% (SD=10.61; 95% CI=88.53–96.31) for the CPT group (p=0.004; d=0.79). Also, there was statistically significant difference between the two groups in the difference in support time score, the mean of difference in support time score was 91.81% (SD=8.89; 95% CI=88.61–95.02) for the MRP group, compared to 75.71% (SD=18.55; 95% CI=68.91–82.51) for the CPT group ($p<0.001$; d=1.11) (see Table 6.11).

However, there were no statistically significant differences between the groups in the global scores of the AP braking force, vertical take-off force, and oscillation force. Specifically, the mean AP braking force global score was 99.06 (SD=2.34; 95% CI=98.22–99.91) for the MRP group, while 92.97 (SD=18.50; 95% CI=86.18–99.75) for the CPT group (p=0.076; d=0.47); the mean vertical take-off force global score was 99.50 (SD=1.44; 95% CI=98.98–100.02) for the MRP group, while 99.19 (SD=1.87; 95% CI=98.51–99.88) for the CPT group (p=0.616; d=0.18); and the mean oscillation force global score was 99.78 (SD=0.91; 95% CI=99.45–100.11) for the MRP group, while 99.87 (SD=0.56; 95% CI=99.66–100.08) for the CPT group (p=0.842; d=0.12). Nevertheless, there was a statistically significant difference between the two groups in the AP propulsion force global score, the mean AP propulsion force global score was 95.72 (SD=12.83; 95% CI=91.09–100.34) for the MRP group, compared to 86.42 (SD=22.78; 95% CI=78.07–94.77) for the CPT group (p=0.043; d=0.51) (see Table 6.11).

In terms of force morphology, there was a statistically significant difference between the two groups in AP force morphology global score. The mean AP force morphology global score was 73.25 (SD=10.71; 95% CI=69.39–77.11) for the MRP group, while 62.52 (SD=15.19; 95% CI=56.94–68.09) for the CPT group (p=0.003; d= 0.82). Moreover, the ML force morphology global score was statistically significantly different between both groups, the mean ML force morphology score was 44.81 (SD=23.03; 95% CI=36.51–53.12) for the MRP group, compared to 24.81

(SD=20.46; 95% CI=17.30–32.31) for the CPT group ($p<0.001$; d=0.92). On the contrary, there was no statistically significant difference between the two groups in the mean vertical force morphology global score, the mean vertical force morphology score was 78.56 (SD=14.76; 95% CI=73.24–83.88) for the MRP group, while 72.77 (SD=16.35; 95% CI=66.78– 78.77) for the CPT group (p=0.171; d=0.37) (see Table 6.11).

Lastly, the results showed that participants in the MRP group had a significantly higher mean scores in terms of functional gait analysis global score compared to the CPT group. the mean functional gait analysis global score was 87.88 (SD=5.39; 95% CI=85.93–89.82) for the MRP group, compared to 79.55 (SD=8.05; 95% CI=76.59–82.50) for the CPT group ($p<0.001$; d=1.22). Regarding the gait analysis global score global score interpretation, there was a statistically significant difference between the two groups ($p<0.001$). In the MRP group, 2 (6.3%) patients had functionally impaired gait, 15 (46.9%) patients had slightly impaired gait, and 15 (46.9%) patients had normal gait; while in the CPT group, 14 (45.2%) patients had functionally impaired gait, 13 (41.9%) patients had slightly impaired gait, and 4 (12.9%) patients had normal gait (see Table 6.11).

Additional parameters and data tables related to the functional gait analysis results at 3-months follow-up are presented in Appendix 11.14.

Table 6.11: Instrumental functional gait analysis of study participants at 3-months follow-up.

Functional Gait Analysis Parameters	MRP Group (n = 32)		CPT Group (n = 31)		*p*-Value*	Effect Size (*d*)
	Mean (SD)	**95% CI of Mean**	**Mean (SD)**	**95% CI of Mean**		
Gait speed (m/s)	0.81 (0.14)	0.76 - 0.86	0.66 (0.12)	0.62 - 0.71	<0.001	1.14
Average gait speed (%)	98.59 (3.37)	97.38 - 99.81	92.42 (10.61)	88.53 - 96.31	0.004	0.79
Difference in support time (%)	91.81 (8.89)	88.61 - 95.02	75.71 (18.55)	68.91 - 82.51	<0.001	1.11
AP braking force global score (%)	99.06 (2.34)	98.22 - 99.91	92.97 (18.50)	86.18 - 99.75	0.076	0.47
AP propulsion force global score (%)	95.72 (12.83)	91.09 - 100.34	86.42 (22.78)	78.07 - 94.77	0.043	0.51
Vertical take-off force global score (%)	99.50 (1.44)	98.98 - 100.02	99.19 (1.87)	98.51 - 99.88	0.616	0.18
Oscillation force global score (%)	99.78 (0.91)	99.45 - 100.11	99.87 (0.56)	99.66 - 100.08	0.842	0.12
AP force morphology (Fx Morphology) (%)	73.25 (10.71)	69.39 - 77.11	62.52 (15.19)	56.94 - 68.09	0.003	0.82
ML force morphology (Fy Morphology) (%)	44.81 (23.03)	36.51 - 53.12	24.81 (20.46)	17.30 - 32.31	<0.001	0.92
Vertical force morphology (Fz Morphology) (%)	78.56 (14.76)	73.24 - 83.88	72.77 (16.35)	66.78 - 78.77	0.171	0.37
Functional gait analysis global score (%)	87.88 (5.39)	85.93 - 89.82	79.55 (8.05)	76.59 - 82.50	<0.001	1.22
Functional gait analysis global score interpretation, n (%)					<0.001	
Functionally impaired (≤ 79%)	2 (6.3%)		14 (45.2%)			
Slightly impaired (80-89%)	15 (46.9%)		13 (41.9%)			
Normal (90-100%)	15 (46.9%)		4 (12.9%)			

Abbreviations: AP, anteroposterior; ML, mediolateral; MRP, study group (motor relearning program); CPT, control group (conventional physiotherapy program); SD, standard deviation; CI, confidence interval.
***** $p<0.05$ indicates a statistically significant difference between the groups, as determined by the Mann-Whitney U test.

6.5 Changes over time

6.5.1 Changes in clinical outcome measures

Changes from baseline to post-intervention

After the intervention, both groups showed a statistically significant improvement in the mean BBS score. The MRP group demonstrated a significantly higher improvement in mean BBS score, with a mean change of 13.78 (SD=2.85) ($p<0.001$; $d=4.84$), compared to 6.90 (SD=1.56) in the CPT group ($p<0.001$; $d=4.43$). The difference in the mean change of BBS score between the two groups was also statistically significant ($p<0.001$; $d=2.98$) (see Table 6.12 and Figure 6.1A).

For the TUG test, both groups showed a statistically significant improvement in mean TUG time. The MRP group exhibited a significantly greater reduction in mean TUG time, with a decrease of -7.39 seconds (SD=5.44) ($p<0.001$; $d=1.36$), compared to -2.54 seconds (SD=1.92) in the CPT group ($p<0.001$; $d=1.32$). The difference in the mean TUG time reduction between the two groups was also statistically significant ($p<0.001$; $d=1.18$) (see Table 6.12 and Figure 6.1B).

Both groups demonstrated a statistically significant improvement in mean self-selected gait velocity on the 10mWT. The MRP group had a significantly greater improvement in mean self-selected gait velocity on the 10mWT, with a mean change of 0.28 m/s (SD=0.10) ($p<0.001$; $d=2.90$), compared to 0.10 m/s (SD=0.05) in the CPT group ($p<0.001$; $d=1.92$). The difference in mean change between the two groups was also statistically significant ($p<0.001$; $d=2.23$) (see Table 6.12 and Figure 6.1C). Additionally, both groups showed a statistically significant improvement in mean fast gait velocity on the 10mWT. The MRP group exhibited a significantly larger improvement in mean fast gait velocity on the 10mWT, with a mean change of 0.35 m/s (SD=0.13) ($p<0.001$; $d=2.76$), compared to 0.11 m/s (SD=0.05) in the CPT group ($p<0.001$; $d=2.02$). The difference in mean change between the two groups was also statistically significant ($p<0.001$; $d=2.42$) (see Table 6.12 and Figure 6.1D).

For the BI, both groups demonstrated a statistically significant improvement in the mean BI score. The MRP group exhibited a significantly greater improvement in the mean BI score, with a mean change of 17.81 (SD=9.58) ($p<0.001$; $d=1.86$), compared to 8.23 (SD=5.09) in the CPT group ($p<0.001$; $d=1.62$). The difference in the mean change in BI score between the two groups was also statistically significant ($p<0.001$; d=1.24) (see Table 6.12 and Figure 6.1E).

Furthermore, both groups showed a statistically significant improvement in the mean SIS-16 score. The MRP group demonstrated a significantly higher improvement in the mean SIS-16 score, with a mean change of 14.59 (SD=4.76) ($p<0.001$; d=3.06), compared to 7.06 (SD=1.98) in the CPT group ($p<0.001$; d=3.56). The difference in the mean change in SIS-16 score between the two groups was also statistically significant ($p<0.001$; d=2.05) (see Table 6.12 and Figure 6.1F).

Table 6.12: Changes in clinical outcome measures from baseline to post-intervention in the two groups.

Clinical Outcome Measures	MRP Group (n = 32)			CPT Group (n = 31)			*p*-Value**	Effect Size (*d*)
	Mean Change (SD)	*p*-Value*	Effect Size (*d*)	Mean Change (SD)	*p*-Value*	Effect Size (*d*)		
BBS	13.78 (2.85)	<0.001	4.84	6.90 (1.56)	<0.001	4.43	<0.001	2.98
TUG (s)	-7.39 (5.44)	<0.001	1.36	-2.54 (1.92)	<0.001	1.32	<0.001	1.18
S-10mWT (m/s)	0.28 (0.10)	<0.001	2.90	0.10 (0.05)	<0.001	1.92	<0.001	2.23
F-10mWT (m/s)	0.35 (0.13)	<0.001	2.76	0.11 (0.05)	<0.001	2.02	<0.001	2.42
BI	17.81 (9.58)	<0.001	1.86	8.23 (5.09)	<0.001	1.62	<0.001	1.24
SIS-16	14.59 (4.76)	<0.001	3.06	7.06 (1.98)	<0.001	3.56	<0.001	2.05

Abbreviations: BBS, Berg Balance Scale; TUG, Timed Up and Go Test; S-10mWT, 10-meter Walk Test (self-selected gait velocity); F-10mWT, 10-meter Walk Test (fast gait velocity); BI, Barthel Index; SIS-16, Stroke Impact Scale-16; MRP, study group (motor relearning program); CPT, control group (conventional physiotherapy program); SD, standard deviation.

***** $p<0.05$ indicates a statistically significant difference within the group, as determined by the Wilcoxon signed-rank test.

****** $p<0.05$ indicates a statistically significant difference between the groups, as determined by the Mann-Whitney U test.

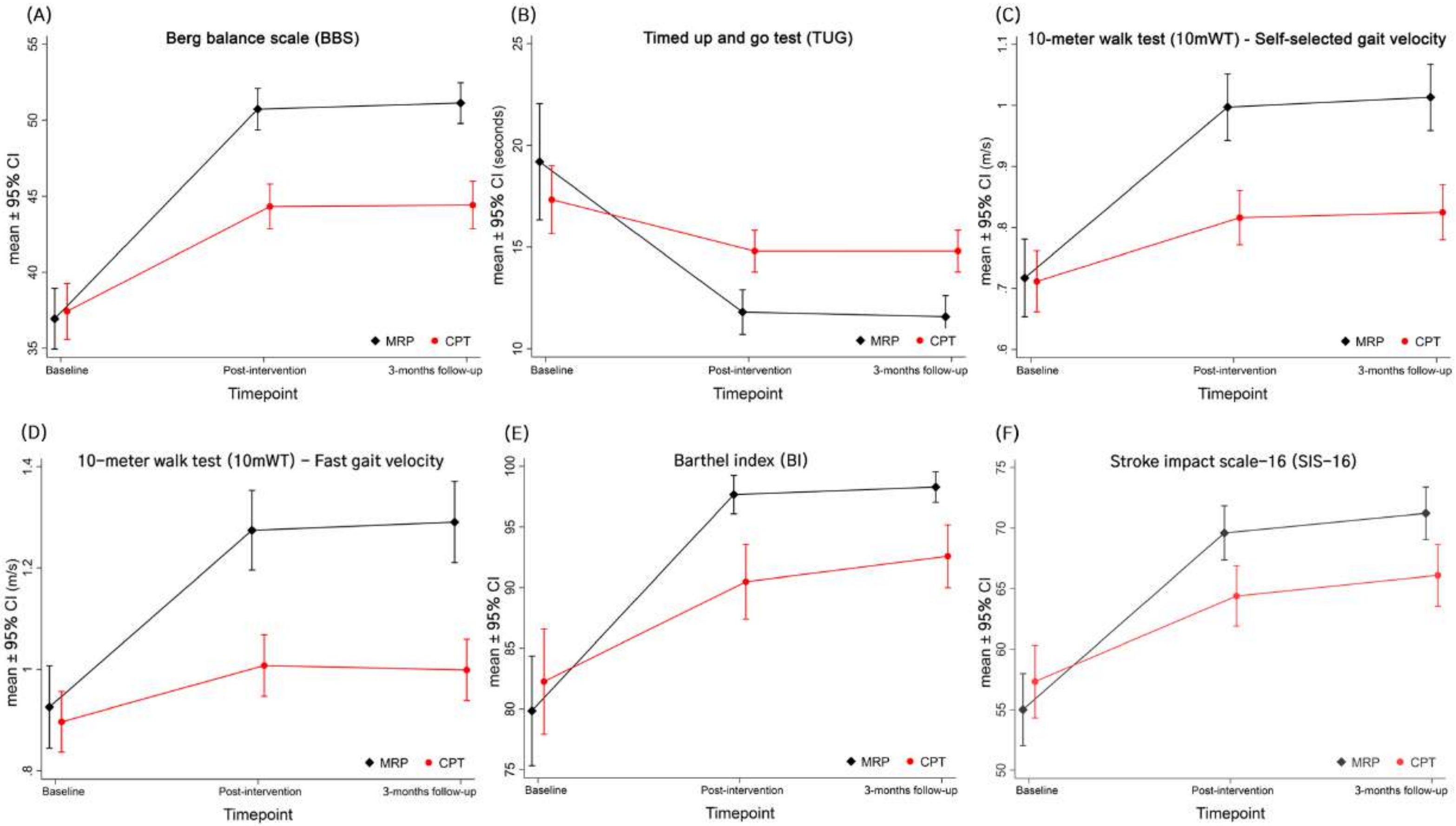


Figure 6.1: Profile plot of the mean changes in clinical outcomes for the two groups over time. The line graphs represent the compared changes in mean scores of the two groups at three time points: baseline, post-intervention, and at 3-months follow-up. Vertical bars represent the 95% confidence interval (CI). Abbreviations: MRP, study group (motor relearning program); CPT, control group (conventional physiotherapy program).

Changes from post-intervention to 3-months follow-up

Both the MRP and CPT groups exhibited an improvement in the mean BBS score from post-intervention to the 3-month follow-up. The MRP group displayed a significant mean change of 0.41 (SD=0.98) (p=0.024; d=0.41), while the CPT group showed a slight but non-significant mean change of 0.10 (SD=1.30) (p=0.765; d=0.07). However, there was no statistically significant difference in the mean change of BBS scores between the two groups (p=0.536; d=0.27) (see Table 6.13 and Figure 6.1A).

For the TUG test, the MRP group showed a significant reduction in mean TUG time of -0.23 seconds (SD=0.46) (p=0.012; d=0.49). In contrast, the CPT group showed no mean change in TUG time of 0.00 seconds (SD=0.65) (p=0.860; d=0.00). However, the difference in mean TUG time change between the two groups was not statistically significant (p=0.090; d=0.41) (see Table 6.13 and Figure 6.1B).

For the 10mWT, both groups demonstrated an improvement in mean self-selected gait velocity. The mean change in the MRP group was statistically significant, with a mean change of 0.02 m/s (SD=0.03) (p=0.007; d=0.50), while the CPT group had a non-significant mean change of 0.01 m/s (SD=0.02) (p=0.067; d=0.39). However, the difference in mean change between the two groups was not statistically significant (p=0.527; d=0.27) (see Table 6.13 and Figure 6.1C). In terms of the change in mean fast gait velocity on the 10mWT, the MRP group showed a significant increase in fast gait velocity with a mean change of 0.02 m/s (SD=0.04) (p=0.029; d=0.38), while the CPT group exhibited a small reduction with a mean change of -0.01 m/s (SD=0.03) (p=0.109; d=0.29). The difference in mean change between the two groups was statistically significant (p=0.008; d=0.67) (see Table 6.13 and Figure 6.1D).

For the BI, both groups demonstrated a slight but statistically significant improvement in the mean BI score. The CPT group exhibited a greater improvement in the mean BI score, with a mean change of 2.10 (SD=2.51) (p<0.001; d=0.84), whereas the MRP group had a mean change of 0.63 (SD=1.68) (p=0.046; d=0.37). The difference in the mean change in BI score between the two groups was also statistically significant (p=0.045; d=0.69) (see Table 6.13 and Figure 6.1E).

Furthermore, both groups showed a similar and statistically significant improvement in the mean SIS-16 score. The MRP group had a mean change of 1.63

(SD=1.21) ($p<0.001$; d=1.34), while the CPT group had a mean change of 1.71 (SD=2.04) ($p<0.001$; d=0.84). However, the difference in mean SIS-16 score change between the two groups was not statistically significant (p=0.645; d=0.05) (see Table 6.13 and Figure 6.1F).

Table 6.13: Changes in clinical outcome measures from post-intervention to 3-months follow-up in the two groups.

Clinical Outcome Measures	MRP Group (n = 32)			CPT Group (n = 31)			*p*-Value**	Effect Size (*d*)
	Mean Change (SD)	*p*-Value*	Effect Size (*d*)	Mean Change (SD)	*p*-Value*	Effect Size (*d*)		
BBS	0.41 (0.98)	0.024	0.41	0.10 (1.30)	0.765	0.07	0.536	0.27
TUG (s)	-0.23 (0.46)	0.012	0.49	0.00 (0.65)	0.860	0.00	0.090	0.41
S-10mWT (m/s)	0.02 (0.03)	0.007	0.50	0.01 (0.02)	0.067	0.39	0.527	0.27
F-10mWT (m/s)	0.02 (0.04)	0.029	0.38	-0.01 (0.03)	0.109	0.29	0.008	0.67
BI	0.63 (1.68)	0.046	0.37	2.10 (2.51)	<0.001	0.84	0.045	0.69
SIS-16	1.63 (1.21)	<0.001	1.34	1.71 (2.04)	<0.001	0.84	0.645	0.05

Abbreviations: BBS, Berg Balance Scale; TUG, Timed Up and Go Test; S-10mWT, 10-meter Walk Test (self-selected gait velocity); F-10mWT, 10-meter Walk Test (fast gait velocity); BI, Barthel Index; SIS-16, Stroke Impact Scale-16; MRP, study group (motor relearning program); CPT, control group (conventional physiotherapy program); SD, standard deviation.

***** $p<0.05$ indicates a statistically significant difference within the group, as determined by the Wilcoxon signed-rank test.

****** $p<0.05$ indicates a statistically significant difference between the groups, as determined by the Mann-Whitney U test.

Changes from baseline to 3-months follow-up

From baseline to 3-months follow-up, both groups showed a statistically significant improvement in the mean BBS score. The MRP group demonstrated a significantly higher mean change of 14.19 (SD=3.16) ($p<0.001$; d=4.49), compared to 7.00 (SD=2.02) in the CPT group ($p<0.001$; d=3.47). The difference in the mean change of BBS score between the two groups was also statistically significant ($p<0.001$; d=2.70) (see Table 6.14 and Figure 6.1A).

For the TUG test, both groups showed a statistically significant improvement in mean TUG time. The MRP group exhibited a significantly greater reduction in mean TUG time, with a decrease of -7.62 seconds (SD=5.58) ($p<0.001$; d=1.36), compared to -2.53 seconds (SD=1.98) in the CPT group ($p<0.001$; d=1.28). The difference in the mean TUG time reduction between the two groups was also statistically significant ($p<0.001$; d=1.21) (see Table 6.14 and Figure 6.1B).

Both groups demonstrated a statistically significant improvement in mean self-selected gait velocity on the 10mWT. The MRP group had a significantly greater improvement in mean self-selected gait velocity on the 10mWT, with a mean change of 0.30 m/s (SD=0.10) ($p<0.001$; d=3.09), compared to 0.11 m/s (SD=0.05) in the CPT group ($p<0.001$; d=2.15). The difference in mean change between the two groups was also statistically significant ($p<0.001$; d=2.36) (see Table 6.14 and 6.1C). Additionally, both groups showed a statistically significant improvement in mean fast gait velocity on the 10mWT. The MRP group exhibited a significantly larger improvement in mean fast gait velocity on the 10mWT, with a mean change of 0.36 m/s (SD=0.13) ($p<0.001$; d=2.79), compared to 0.10 m/s (SD=0.06) in the CPT group ($p<0.001$; d=1.84). The difference in mean change between the two groups was also statistically significant ($p<0.001$; d=2.60) (see Table 6.14 and Figure 6.1D).

For the BI, both groups demonstrated a statistically significant improvement in the mean BI score. The MRP group exhibited a significantly greater improvement in the mean BI score, with a mean change of 18.44 (SD=10.27) ($p<0.001$; d=1.79), compared to 10.32 (SD=6.32) in the CPT group ($p<0.001$; d=1.63). The difference in the mean change in BI score between the two groups was also statistically significant ($p=0.001$; d=0.95) (see Table 6.14 and Figure 6.1E).

Furthermore, both groups showed a statistically significant improvement in the mean SIS-16 score. The MRP group demonstrated a significantly higher improvement in mean SIS-16 score, with a mean change of 16.22 (SD=5.30) ($p<0.001$; $d=3.06$), compared to 8.77 (SD=2.85) in the CPT group ($p<0.001$; $d=3.08$). The difference in mean change in SIS-16 score between the two groups was also statistically significant ($p<0.001$; $d=1.74$) (see Table 6.14 and Figure 6.1F).

Table 6.14: Changes in clinical outcome measures from baseline to 3-months follow-up in the two groups.

Clinical Outcome Measures	MRP Group (n = 32)			CPT Group (n = 31)			*p*-Value**	Effect Size (*d*)
	Mean Change (SD)	*p*-Value*	Effect Size (*d*)	Mean Change (SD)	*p*-Value*	Effect Size (*d*)		
BBS	14.19 (3.16)	<0.001	4.49	7.00 (2.02)	<0.001	3.47	<0.001	2.70
TUG (s)	-7.62 (5.58)	<0.001	1.36	-2.53 (1.98)	<0.001	1.28	<0.001	1.21
S-10mWT (m/s)	0.30 (0.10)	<0.001	3.09	0.11 (0.05)	<0.001	2.15	<0.001	2.36
F-10mWT (m/s)	0.36 (0.13)	<0.001	2.79	0.10 (0.06)	<0.001	1.84	<0.001	2.60
BI	18.44 (10.27)	<0.001	1.79	10.32 (6.32)	<0.001	1.63	0.001	0.95
SIS-16	16.22 (5.30)	<0.001	3.06	8.77 (2.85)	<0.001	3.08	<0.001	1.74

Abbreviations: BBS, Berg Balance Scale; TUG, Timed Up and Go Test; S-10mWT, 10-meter Walk Test (self-selected gait velocity); F-10mWT, 10-meter Walk Test (fast gait velocity); BI, Barthel Index; SIS-16, Stroke Impact Scale-16; MRP, study group (motor relearning program); CPT, control group (conventional physiotherapy program); SD, standard deviation.

***** $p<0.05$ indicates a statistically significant difference within the group, as determined by the Wilcoxon signed-rank test.

****** $p<0.05$ indicates a statistically significant difference between the groups, as determined by the Mann-Whitney U test.

6.5.2 Changes in instrumental analysis of balance and gait

Changes from baseline to post-intervention

Functional balance assessment

After the intervention, both groups demonstrated a statistically significant improvement in the mean scores for all static posturography tests from baseline to post-intervention. Specifically, the mean change in the ROA score was slightly higher in the MRP group, with a mean change of 2.69 (SD=3.32) ($p<0.001$; d=0.83), compared to 2.26 (SD=2.58) in the CPT group ($p<0.001$; d=0.87); however, the difference between the two groups was not statistically significant (p=0.869; d=0.15) (see Table 6.15 and Figure 6.2A). The mean change in the ROC score was significantly larger in the MRP group, with a mean change of 5.13 (SD=4.51) ($p<0.001$; d=1.14), compared to 2.68 (SD=2.88) in the CPT group ($p<0.001$; d=0.93); the difference between the two groups was statistically significant (p=0.033; d=0.64) (see Table 6.15 and Figure 6.2B). The mean change in the RGA score was higher in the MRP group, with a mean change of 5.41 (SD=4.23) ($p<0.001$; d=1.28), compared to 3.35 (SD=2.89) in the CPT group ($p<0.001$; d=1.16); however, the difference between the two groups was not statistically significant (p=0.066; d=0.56) (see Table 6.15 and Figure 6.2C). Furthermore, the mean change in the RGC score was significantly greater in the MRP group, with a mean change of 14.31 (SD=5.79) ($p<0.001$; d=2.47), compared to 5.52 (SD=3.04) in the CPT group ($p<0.001$; d=1.81); the difference between the two groups was statistically significant ($p<0.001$; d=1.89) (see Table 6.15 and Figure 6.2D).

Table 6.15: Changes in instrumental functional balance assessment from baseline to post-intervention in the two groups

Functional Balance Assessment Tests	MRP Group (n = 32)			CPT Group (n = 31)			*p*-Value**	Effect Size (*d*)
	Mean Change (SD)	*p*-Value*	Effect Size (*d*)	Mean Change (SD)	*p*-Value*	Effect Size (*d*)		
Static posturography tests								
ROA (%)	2.69 (3.23)	<0.001	0.83	2.26 (2.58)	<0.001	0.87	0.869	0.15
ROC (%)	5.13 (4.51)	<0.001	1.14	2.68 (2.88)	<0.001	0.93	0.033	0.64
RGA (%)	5.41 (4.23)	<0.001	1.28	3.35 (2.89)	<0.001	1.16	0.066	0.56
RGC (%)	14.31 (5.79)	<0.001	2.47	5.52 (3.04)	<0.001	1.81	<0.001	1.89
Romberg test ML stability (%)	5.41 (2.76)	<0.001	1.96	2.58 (2.11)	<0.001	1.22	<0.001	1.15
Romberg test AP stability (%)	3.72 (3.81)	<0.001	0.98	1.81 (1.87)	<0.001	0.97	0.064	0.63
Somatosensory index (%)	5.25 (4.24)	<0.001	1.24	2.58 (2.28)	<0.001	1.13	0.012	0.78
Visual index (%)	2.88 (2.77)	<0.001	1.04	2.58 (2.22)	<0.001	1.16	0.789	0.12
Vestibular index (%)	14.81 (6.78)	<0.001	2.18	5.19 (3.54)	<0.001	1.47	<0.001	1.77
Dynamic index (%)	13.69 (6.71)	<0.001	2.04	5.97 (2.30)	<0.001	2.59	<0.001	1.53
Sensory-Dynamic total score (%)	8.72 (2.44)	<0.001	3.57	3.90 (1.83)	<0.001	2.13	<0.001	2.23
Postural control assessment								
Avg. score of maximum displacement (%)	17.56 (9.93)	<0.001	1.77	11.13 (4.54)	<0.001	2.45	<0.001	0.83
Avg. score of directional control (%)	16.69 (6.64)	<0.001	2.51	9.90 (4.85)	<0.001	2.04	<0.001	1.16
Avg. score of reaction time (s)	-0.40 (0.22)	<0.001	1.83	-0.21 (0.18)	<0.001	1.15	<0.001	0.94

Limits of stability (LOS) analysis score (%)	13.44 (6.59)	<0.001	2.04	6.45 (2.69)	<0.001	2.40	<0.001	1.38
ML rhythmic and directional control (%)	13.94 (5.19)	<0.001	2.68	4.39 (2.47)	<0.001	1.77	<0.001	2.34
AP rhythmic and directional control (%)	10.75 (4.62)	<0.001	2.33	4.45 (2.75)	<0.001	1.62	<0.001	1.65
Postural control assessment total score (%)	13.09 (4.87)	<0.001	2.69	5.52 (2.03)	<0.001	2.72	<0.001	2.02
Functional balance assessment global score (%)	11.19 (2.89)	<0.001	3.87	4.61 (1.52)	<0.001	3.03	<0.001	2.83

Abbreviations: ROA, Romberg Test with Eyes Open; ROC, Romberg Test with Eyes Closed; RGA, Romberg Test with Eyes Open on Foam Cushion; RGC, Romberg Test with Eyes Closed on Foam Cushion; ML, mediolateral; AP, anteroposterior; Avg., Average; MRP, study group (motor relearning program); CPT, control group (conventional physiotherapy program); SD, standard deviation.

***** $p<0.05$ indicates a statistically significant difference within the group, as determined by the Wilcoxon signed-rank test.

****** $p<0.05$ indicates a statistically significant difference between the groups, as determined by the Mann-Whitney U test.

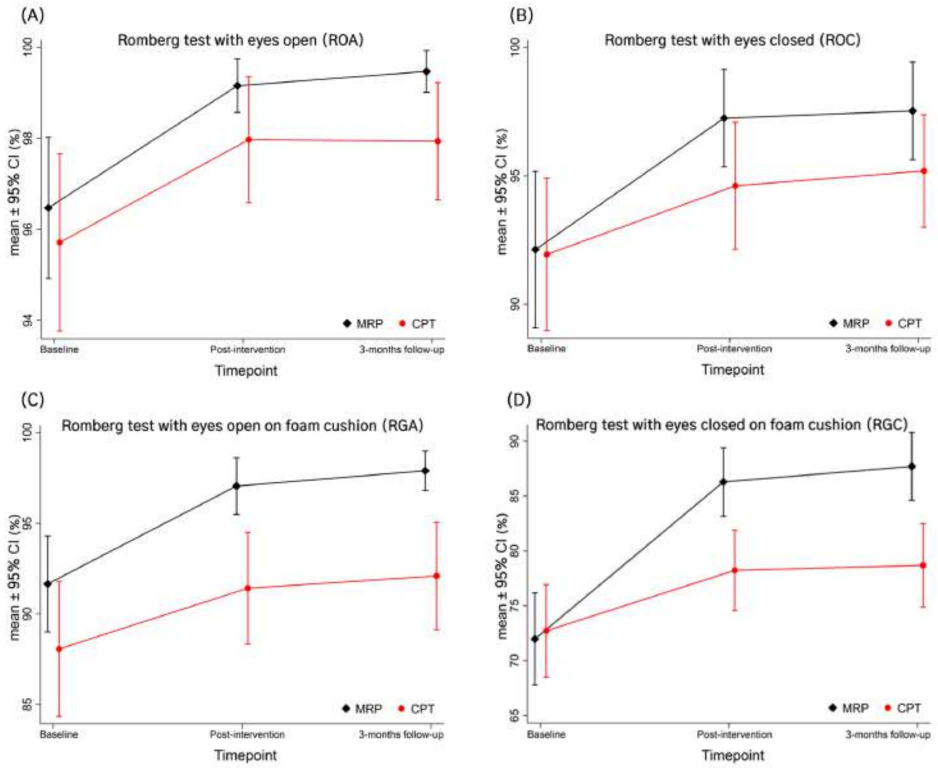


Figure 6.2: Profile plot of the mean changes in static posturography tests for the two groups over time. The line graphs represent the compared changes in mean scores of the two groups at three time points: baseline, post-intervention, and at 3-months follow-up. Vertical bars represent the 95% confidence interval (CI). Abbreviations: MRP, study group (motor relearning program); CPT, control group (conventional physiotherapy program).

For ML stability during the Romberg tests, both groups exhibited a statistically significant improvement in the mean ML stability score. The MRP group demonstrated a significantly higher mean change of 5.41 (SD=2.76) ($p<0.001$; d=1.96), compared to 2.58 (SD=2.11) in the CPT group ($p<0.001$; d=1.22); the difference between the two groups was statistically significant ($p<0.001$; d=1.15). Moreover, both groups displayed a statistically significant improvement in the mean AP stability score. The MRP group showed a mean change of 3.72 (SD=3.81) ($p<0.001$; d=0.98), compared to 1.81 (SD=1.87) in the CPT group ($p<0.001$; d=0.97); however, the difference between the two groups was not statistically significant ($p=0.064$; d=0.63) (see Table 6.15).

In terms of changes in the assessment indices for the contribution of sensory systems, both groups exhibited a statistically significant improvement in the mean scores from baseline to post-intervention for all indices. Regarding the somatosensory index, the MRP group demonstrated a significantly higher mean change of 5.25 (SD=4.24) ($p<0.001$; d=1.24), compared to 2.58 (SD=2.28) in the CPT group ($p<0.001$; d=1.13); the difference between the two groups was statistically significant (p=0.012; d=0.78) (see Table 6.15 and Figure 6.3A). The change in the mean visual index score was similar between the MRP group, with a mean change of 2.88 (SD=2.77) ($p<0.001$; d=1.04), and the CPT group, with a mean change of 2.58 (SD=2.22) ($p<0.001$; d=1.16); however, the difference between the two groups was not statistically significant (p=0.789; d=0.12) (see Table 6.15). The change in the mean vestibular index score was significantly greater in the MRP group, with a mean change of 14.81 (SD=6.78) ($p<0.001$; d=2.18), compared to 5.19 (SD=3.54) in the CPT group ($p<0.001$; d=1.47); the difference between the two groups was statistically significant ($p<0.001$; d=1.77) (see Table 6.15 and Figure 6.3B). The change in the mean dynamic index was also significantly larger in the MRP group, with a mean change of 13.69 (SD=6.71) ($p<0.001$; d=2.04), compared to 5.97 (SD=2.30) in the CPT group ($p<0.001$; d=2.59); the difference between the two groups was statistically significant ($p<0.001$; d=1.53) (see Table 6.15 and Figure 6.3C). Furthermore, both groups demonstrated a statistically significant improvement in the mean sensory-dynamic total score. The mean change was significantly higher in the MRP group, with a mean change of 8.72 (SD=2.44) ($p<0.001$; d=3.57), compared to 3.90 (SD=1.83) in the CPT group ($p<0.001$; d=2.13); the difference in mean score change between the two groups was statistically significant ($p<0.001$; d=2.23) (see Table 6.15 and Figure 6.3D).

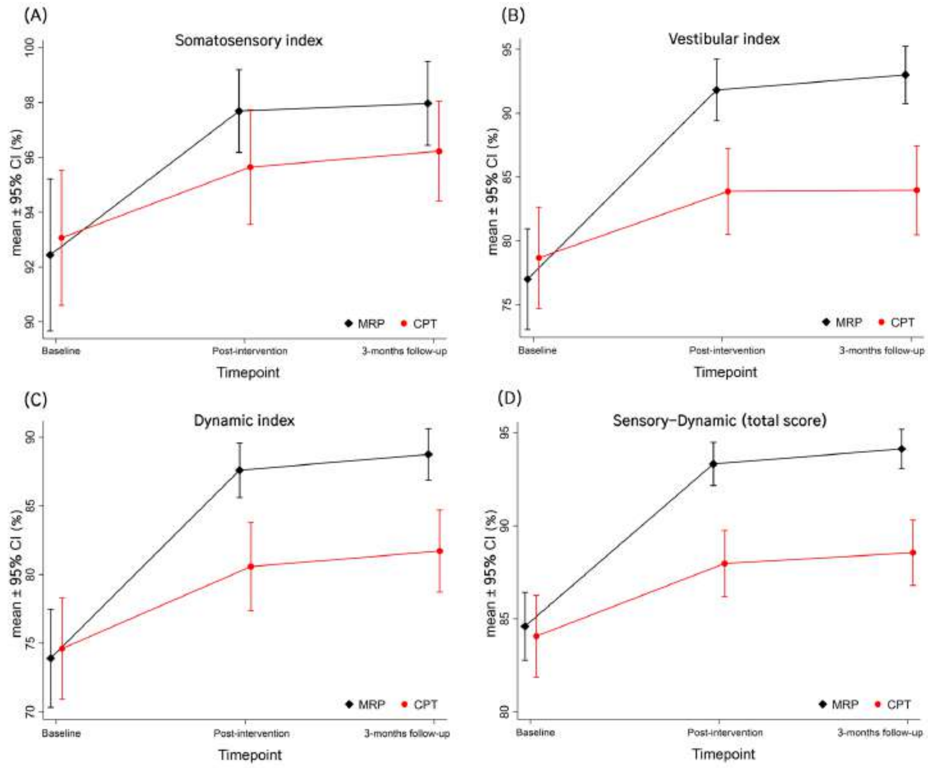


Figure 6.3: Profile plot of the mean changes in sensory systems and sensory-dynamic assessment scores for the two groups over time. The line graphs represent the compared changes in mean scores of the two groups at three time points: baseline, post-intervention, and at 3-months follow-up. Vertical bars represent the 95% confidence interval (CI). Abbreviations: MRP, study group (motor relearning program); CPT, control group (conventional physiotherapy program).

For the assessment of limits of stability, both groups demonstrated a statistically significant improvement in the mean scores from baseline to post-intervention for all parameters. Specifically, the mean maximum displacement score exhibited a significantly higher change in the MRP group, with a mean change of 17.56 (SD=9.93) ($p<0.001$; d=1.77), compared to 11.13 (SD=4.54) in the CPT group ($p<0.001$; d=2.45); the difference between the two groups was statistically significant ($p<0.001$; d=0.83) (see Table 6.15 and Figure 6.4A). The change in mean directional control score was also significantly larger in the MRP group, with a mean change of 16.69 (SD=6.64) ($p<0.001$; d=2.51), compared to 9.90 (SD=4.85) in the CPT group ($p<0.001$; d=2.04); the difference between the two groups was statistically significant ($p<0.001$; d=1.16) (see Table 6.15 and Figure 6.4B). In addition, the MRP group exhibited a significantly greater reduction in mean reaction time, with a mean change of -0.40 (SD=0.22) (p<0.001; d=1.83), compared to -0.21 (SD=0.18) in the CPT group (p<0.001; d=1.15); the difference between the two groups was statistically significant (p<0.001; d=0.94) (see Table 6.15 and Figure 6.4C). Moreover, the change in mean LOS total score was significantly higher in the MRP group, with a mean change of 13.44 (SD=6.59) (p<0.001; d=2.04), compared to 6.45 (SD=2.69) in the CPT group (p<0.001; d=2.40); and the difference in mean LOS score change between the two groups was statistically significant (p<0.001; d=1.38) (see Table 6.15 and Figure 6.4D).

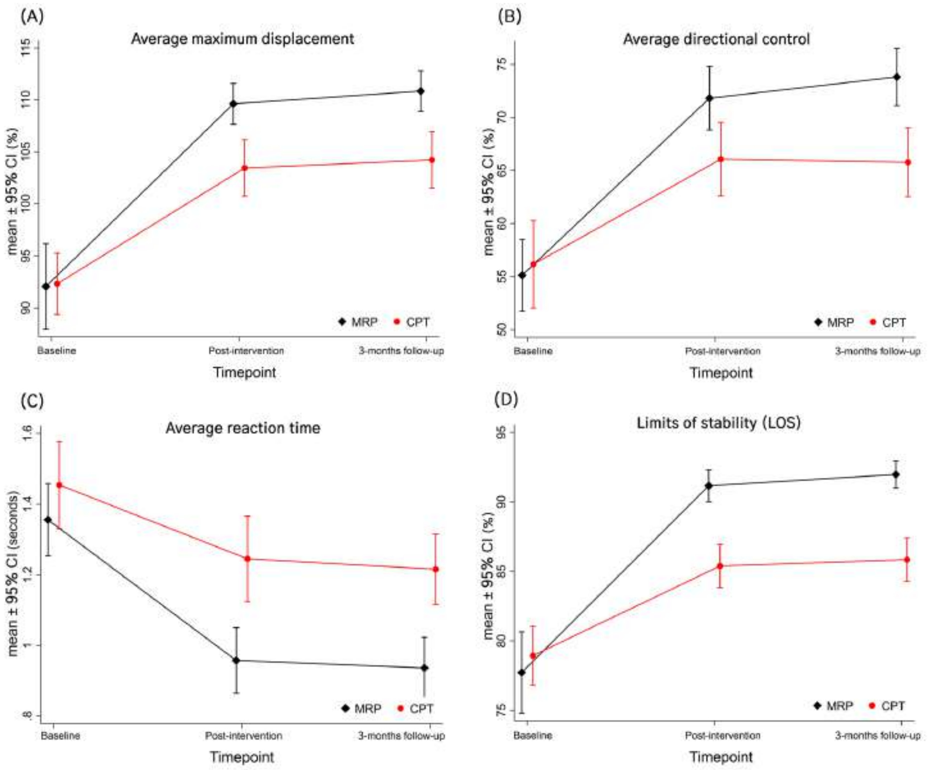


Figure 6.4: Profile plot of the mean changes in limits of stability assessment for the two groups over time. The line graphs represent the compared changes in mean scores of the two groups at three time points: baseline, post-intervention, and at 3-months follow-up. Vertical bars represent the 95% confidence interval (CI). Abbreviations: MRP, study group (motor relearning program); CPT, control group (conventional physiotherapy program).

Furthermore, both groups demonstrated a statistically significant improvement in mean ML rhythmic and directional control scores. The change in mean ML rhythmic and directional control score was significantly higher in the MRP group, with a mean change of 13.94 (SD=5.19) (p<0.001; d=2.68), compared to 4.39 (SD=2.47) in the CPT group ($p<0.001$; $d=1.77$); the difference between the two groups was statistically significant ($p<0.001$; $d=2.34$) (see Table 6.15 and Figure 6.5A). Similarly, both groups exhibited a statistically significant improvement in mean AP rhythmic and directional control scores. The change in mean AP rhythmic and directional control score was significantly larger in the MRP group, with a mean change of 10.75 (SD=4.62) ($p<0.001$; $d=2.33$), compared to 4.45 (SD=2.75) in the CPT group ($p<0.001$; $d=1.62$); the difference between the two groups was statistically significant ($p<0.001$; $d=1.65$) (see Table 6.15 and Figure 6.5B). Additionally, both groups demonstrated a statistically significant improvement in mean postural control assessment total scores. The MRP group exhibited a significantly higher change in mean postural control assessment total score, with a mean change of 13.09 (SD=4.87) ($p<0.001$; $d=2.69$), compared to 5.52 (SD=2.03) in the CPT group ($p<0.001$; $d=2.72$); the difference in mean score change between the two groups was statistically significant ($p<0.001$; $d=2.02$) (see Table 6.15 and Figure 6.5C).

In terms of the functional balance assessment global score, both groups demonstrated a statistically significant improvement in the mean functional balance global score. The change in the mean functional balance global score was significantly greater in the MRP group, with a mean change of 11.19 (SD=2.89) ($p<0.001$; $d=3.87$), compared to 4.61 (SD=1.52) in the CPT group ($p<0.001$; $d=3.03$). The difference in the mean functional balance assessment global score change between the two groups was statistically significant ($p<0.001$; $d=2.83$) (see Table 6.15 and Figure 6.5D).

Additional parameters and data tables related to the changes in instrumental functional balance assessment from baseline to post-intervention in the two groups are presented in Appendix 11.15.

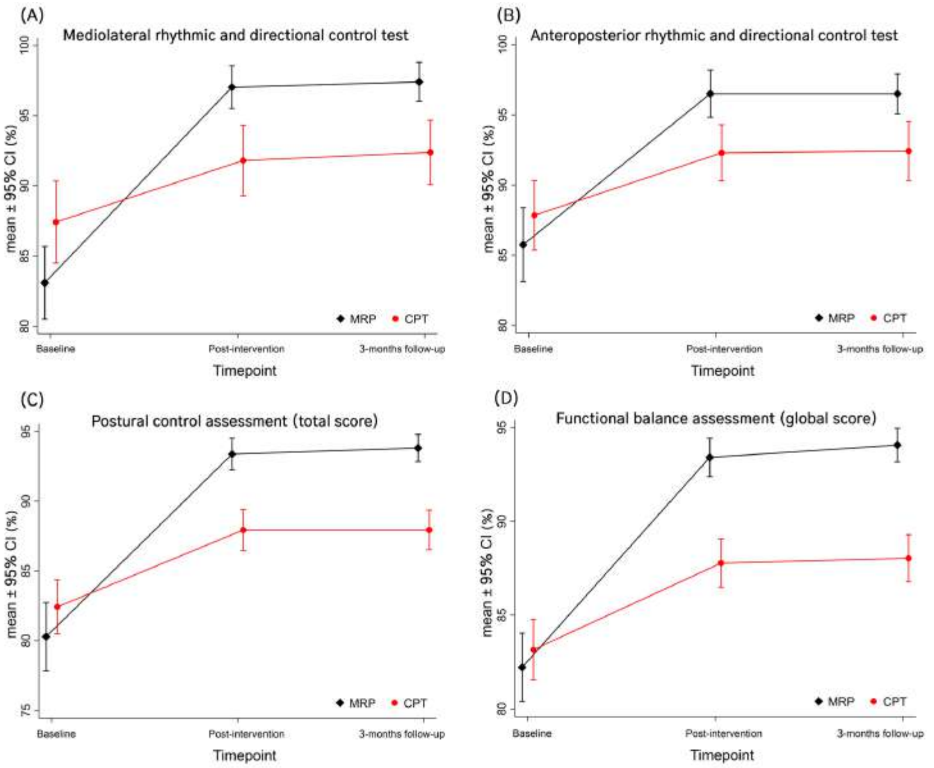


Figure 6.5: Profile plot of the mean changes in rhythmic and directional control, postural control, and functional balance assessment for the two groups over time. The line graphs represent the compared changes in mean scores of the two groups at three time points: baseline, post-intervention, and at 3-months follow-up. Vertical bars represent the 95% confidence interval (CI). Abbreviations: MRP, study group (motor relearning program); CPT, control group (conventional physiotherapy program).

Functional gait analysis

With regard to the instrumental gait analysis from baseline to post-intervention, both groups demonstrated a statistically significant improvement in the mean scores of gait speed, both in m/s and as a percentage of normality. Specifically, the change in the mean gait speed in m/s was significantly higher in the MRP group, with a mean change of 0.20 m/s (SD=0.10) ($p<0.001$; d=2.00), compared to 0.09 m/s (SD=0.04) in the CPT group ($p<0.001$; d=2.32); the difference between the two groups was statistically significant ($p<0.001$; d=1.46) (see Table 6.16 and Figure 6.6A). In addition, the change in the mean gait speed as a percentage of normality was numerically higher in the MRP group, with a mean change of 17.13% (SD=18.34) ($p<0.001$; d=0.93), compared to 9.29% (SD=7.61) in the CPT group ($p<0.001$; d=1.22); however, the difference between the two groups was not statistically significant (p=0.353; d=0.55) (see Table 6.16 and Figure 6.6B). Moreover, both groups exhibited a statistically significant improvement in the mean difference in support time score. The change in the mean difference in support time score was significantly greater in the MRP group, with a mean change of 29.31% (SD=19.69) ($p<0.001$; d=1.49), compared to 9.84% (SD=5.11) in the CPT group ($p<0.001$; d=1.92); the difference between the two groups was statistically significant ($p<0.001$; d=1.34) (see Table 6.16 and Figure 6.6C).

Table 6.16: Changes in instrumental functional gait analysis from baseline to post-intervention in the two groups.

Functional Gait Analysis Parameters	**MRP Group (n = 32)**			**CPT Group (n = 31)**			***p*-Value****	**Effect Size (*d*)**
	Mean Change (SD)	***p*-Value***	**Effect Size (*d*)**	**Mean Change (SD)**	***p*-Value***	**Effect Size (*d*)**		
Gait speed (m/s)	0.20 (0.10)	<0.001	2.00	0.09 (0.04)	<0.001	2.32	<0.001	1.46
Average gait speed (%)	17.13 (18.34)	<0.001	0.93	9.29 (7.61)	<0.001	1.22	0.353	0.55
Difference in support time (%)	29.31 (19.69)	<0.001	1.49	9.84 (5.11)	<0.001	1.92	<0.001	1.34
AP braking force global score (%)	14.13 (19.10)	<0.001	0.74	5.71 (7.16)	<0.001	0.80	0.187	0.58
AP propulsion force global score (%)	17.97 (20.02)	<0.001	0.90	5.19 (7.47)	<0.001	0.70	0.011	0.84
Vertical take-off force global score (%)	6.06 (11.76)	<0.001	0.52	1.61 (3.86)	0.002	0.42	0.075	0.50
Oscillation force global score (%)	3.47 (7.94)	0.003	0.44	0.65 (2.07)	0.083	0.31	0.173	0.48
AP force morphology (Fx Morphology) (%)	17.22 (8.93)	<0.001	1.93	10.16 (5.79)	<0.001	1.75	<0.001	0.93
ML force morphology (Fy Morphology) (%)	16.50 (16.86)	<0.001	0.98	5.19 (3.50)	<0.001	1.49	<0.001	0.92
Vertical force morphology (Fz Morphology) (%)	11.94 (10.88)	<0.001	1.10	7.90 (7.97)	<0.001	0.99	0.076	0.42
Functional gait analysis global score (%)	14.69 (6.62)	<0.001	2.22	6.35 (2.30)	<0.001	2.76	<0.001	1.67

Abbreviations: AP, anteroposterior; ML, mediolateral; MRP, study group (motor relearning program); CPT, control group (conventional physiotherapy program); SD, standard deviation.

***** $p<0.05$ indicates a statistically significant difference within the group, as determined by the Wilcoxon signed-rank test.

****** $p<0.05$ indicates a statistically significant difference between the groups, as determined by the Mann-Whitney U test.

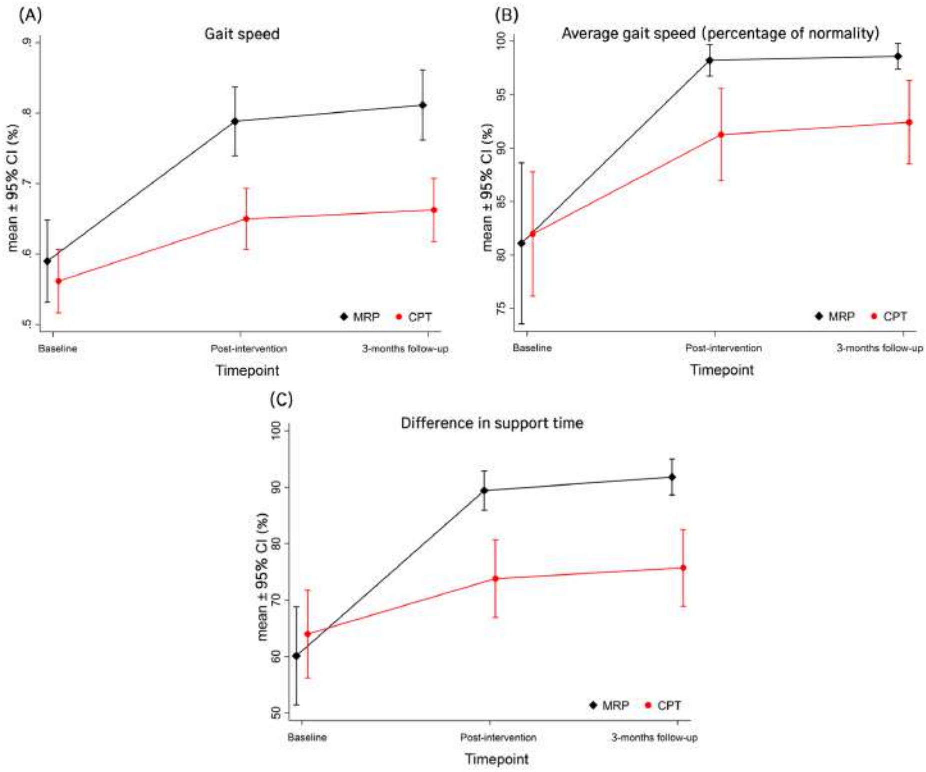


Figure 6.6: Profile plot of the mean changes in gait speed and support time difference for the two groups over time. The line graphs represent the compared changes in mean scores of the two groups at three time points: baseline, post-intervention, and at 3-months follow-up. Vertical bars represent the 95% confidence interval (CI). Abbreviations: MRP, study group (motor relearning program); CPT, control group (conventional physiotherapy program).

For the AP braking force global score, both groups exhibited a statistically significant improvement in the mean AP braking force global score. The MRP group demonstrated a higher mean change of 14.13 (SD=19.10) ($p<0.001$; d=0.74), compared to 5.71 (SD=7.16) in the CPT group ($p<0.001$; d=0.80); however, the difference between the two groups was not statistically significant ($p=0.187$; d=0.58) (see Table 6.16 and Figure 6.7A). Additionally, both groups displayed a statistically significant improvement in the mean AP propulsion force global score. The MRP group had a significantly greater mean change of 17.97 (SD=20.02) ($p<0.001$; d=0.90), compared to 5.19 (SD=7.47) in the CPT group ($p<0.001$; d=0.70); the difference between the two groups was statistically significant ($p=0.011$; d=0.84) (see Table 6.16 and Figure 6.7B). Furthermore, both groups demonstrated a statistically significant improvement in the mean vertical take-off force global score. The MRP group displayed a greater mean change of 6.06 (SD=11.76) ($p<0.001$; d=0.52), compared to 1.61 (SD=3.86) in the CPT group (p=0.002; d=0.42); however, the difference between the two groups was not statistically significant (p=0.075; d=0.50) (see Table 6.16 and Figure 6.7C). Moreover, both groups exhibited an improvement in the mean oscillation force global score. The MRP group demonstrated a significant mean change of 3.47 (SD=7.94) (p=0.003; d=0.44), while the CPT group showed a non-significant mean change of 0.65 (SD=2.07) (p=0.083; d=0.31); however, the difference between the two groups was not statistically significant (p=0.173; d=0.48) (see Table 6.16 and Figure 6.7D).

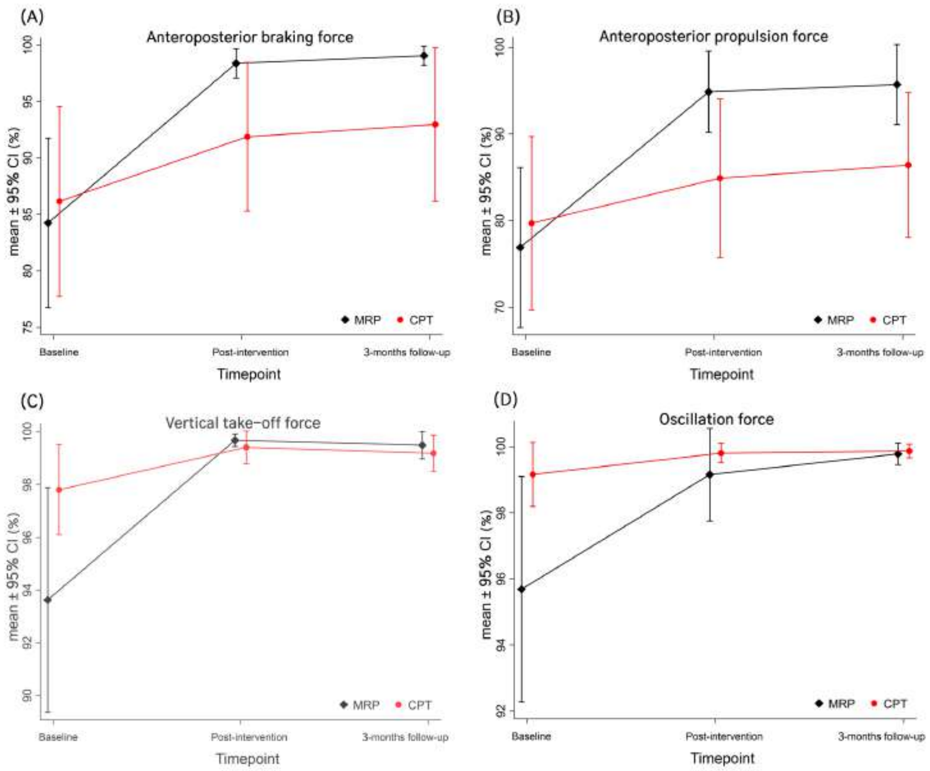


Figure 6.7: Profile plot of the mean changes in braking, propulsion, vertical take-off, and oscillation forces for the two groups over time. The line graphs represent the compared changes in mean scores of the two groups at three time points: baseline, post-intervention, and at 3-months follow-up. Vertical bars represent the 95% confidence interval (CI). Abbreviations: MRP, study group (motor relearning program); CPT, control group (conventional physiotherapy program).

In terms of force morphology, both groups demonstrated a statistically significant improvement in the mean scores from baseline to post-intervention for all force morphologies. Regarding the AP force morphology global score, the MRP group exhibited a significantly higher mean change of 17.22 (SD=8.93) ($p<0.001$; $d=1.93$), compared to 10.16 (SD=5.79) in the CPT group ($p<0.001$; $d=1.75$); the difference between the two groups was statistically significant ($p<0.001$; $d=0.93$) (see Table 6.16 and Figure 6.8A). Additionally, the change in the mean ML force morphology global score was significantly greater in the MRP group, with a mean change of 16.50 (SD=16.86) ($p<0.001$; $d=0.98$), compared to 5.19 (SD=3.50) in the CPT group ($p<0.001$; $d=1.49$); the difference between the two groups was statistically significant ($p<0.001$; $d=0.92$) (see Table 6.16 and Figure 6.8B). Moreover, the change in the mean vertical force morphology global score was larger in the MRP group, with a mean change of 11.94 (SD=10.88) ($p<0.001$; $d=1.10$), compared to 7.90 (SD=7.97) in the CPT group ($p<0.001$; $d=0.99$); however, the difference between the two groups was not statistically significant ($p=0.076$; $d=0.42$) (see Table 6.16 and Figure 6.8C).

Finally, the results indicated that participants in both groups exhibited a statistically significant improvement in the mean functional gait analysis global score from baseline to post-intervention. The MRP group demonstrated a significantly higher improvement in the mean functional gait analysis global score, with a mean change of 14.69 (SD=6.62) ($p<0.001$; $d=2.22$), compared to 6.35 (SD=2.30) in the CPT group ($p<0.001$; $d=2.76$). The difference in mean functional gait analysis global score change between the two groups was statistically significant ($p<0.001$; $d=1.67$) (see Table 6.16 and Figure 6.8D).

Additional parameters and data tables related to the changes in instrumental functional gait analysis from baseline to post-intervention in the two groups are presented in Appendix 11.16.

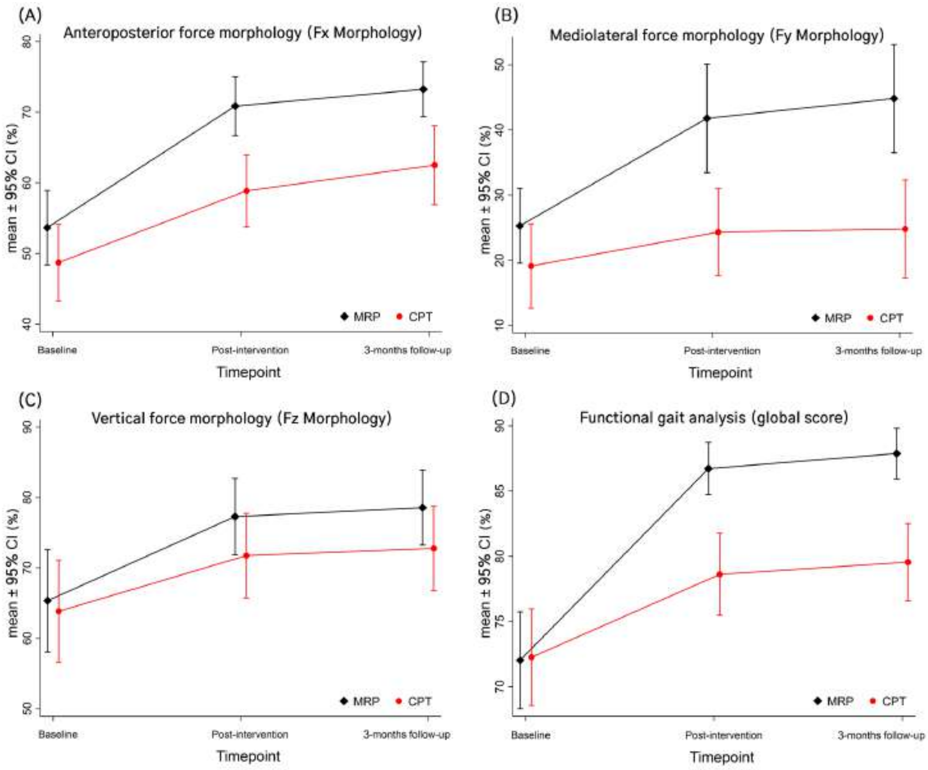


Figure 6.8: Profile plot of the mean changes in gait forces morphology and functional gait analysis for the two groups over time. The line graphs represent the compared changes in mean scores of the two groups at three time points: baseline, post-intervention, and at 3-months follow-up. Vertical bars represent the 95% confidence interval (CI). Abbreviations: MRP, study group (motor relearning program); CPT, control group (conventional physiotherapy program).

Changes from post-intervention to 3-months follow-up

Functional balance assessment

Regarding the static posturography tests from post-intervention to the 3-month follow-up, the change in the mean ROA score was not statistically significant in either group. The MRP group showed a minimal improvement in mean ROA score, with a mean change of 0.31 (SD=1.03) (p=0.087; d=0.30); on the other hand, the CPT group exhibited a minimal reduction in mean ROA score, with a mean change of -0.03 (SD=1.08) (p=0.835; d=0.03); however, the difference between the two groups was not statistically significant (p=0.322; d=0.33) (see Table 6.17 and Figure 6.2A). Both groups showed a slight improvement in the mean ROC score, but it was not statistically significant. The MRP group had a mean change of 0.28

(SD=1.02) (p=0.180; d=0.27), while the CPT group had a mean change of 0.58 (SD=1.91) (p=0.140; d=0.30); however, the difference between the two groups was not statistically significant (p=0.611; d=0.20) (see Table 6.17 and Figure 6.2B). In addition, the change in the mean RGA score significantly increased in the MRP group, with a mean change of 0.84 (SD=2.00) (p=0.017; d=0.42), while the CPT group showed a non-significant mean change of 0.68 (SD=2.55) (p=0.528; d=0.27); however, the difference between the two groups was not statistically significant (p=0.268; d=0.07) (see Table 6.17 and Figure 6.2C). Furthermore, the MRP group exhibited a significant change in the mean RGC score, with a mean change of 1.41 (SD=2.55) (p=0.003; d=0.55), compared to a non-significant mean change of 0.45 (SD=3.12) in the CPT group (p=0.745; d=0.14); however, the difference between the two groups was not statistically significant (p=0.060; d=0.34) (see Table 6.17 and Figure 6.2D).

Table 6.17: Changes in instrumental functional balance assessment from baseline to post-intervention in the two groups

Functional Balance Assessment Tests	MRP Group (n = 32)			CPT Group (n = 31)			*p*-Value**	Effect Size (*d*)
	Mean Change (SD)	*p*-Value*	Effect Size (*d*)	Mean Change (SD)	*p*-Value*	Effect Size (*d*)		
Static posturography tests								
ROA (%)	0.31 (1.03)	0.087	0.30	-0.03 (1.08)	0.835	0.03	0.322	0.33
ROC (%)	0.28 (1.02)	0.180	0.27	0.58 (1.91)	0.140	0.30	0.611	0.20
RGA (%)	0.84 (2.00)	0.017	0.42	0.68 (2.55)	0.528	0.27	0.268	0.07
RGC (%)	1.41 (2.55)	0.003	0.55	0.45 (3.12)	0.745	0.14	0.060	0.34
Romberg test ML stability (%)	0.81 (1.20)	<0.001	0.68	0.13 (1.31)	0.808	0.10	0.031	0.54
Romberg test AP stability (%)	0.16 (0.92)	0.669	0.17	0.16 (0.82)	0.376	0.20	0.747	0.01
Somatosensory index (%)	0.28 (0.73)	0.050	0.39	0.58 (1.52)	0.086	0.38	0.736	0.25
Visual index (%)	0.50 (1.41)	0.035	0.35	0.32 (1.38)	0.385	0.23	0.536	0.13
Vestibular index (%)	1.19 (2.40)	0.012	0.49	0.10 (2.41)	0.952	0.04	0.054	0.45
Dynamic index (%)	1.16 (1.05)	<0.001	1.10	1.13 (1.88)	0.002	0.60	0.940	0.02
Sensory-Dynamic total score (%)	0.81 (0.86)	<0.001	0.95	0.58 (1.39)	0.035	0.42	0.429	0.20
Postural control assessment								
Avg. score of maximum displacement (%)	1.22 (3.75)	0.073	0.33	0.77 (3.78)	0.315	0.20	0.582	0.12
Avg. score of directional control (%)	2.00 (4.33)	0.016	0.46	-0.29 (3.28)	0.256	0.09	0.014	0.60
Avg. score of reaction time (s)	-0.02 (0.19)	0.432	0.11	-0.03 (0.19)	0.450	0.16	0.837	0.04

Limits of stability (LOS) analysis score (%)	0.81 (1.60)	0.011	0.51	0.45 (1.36)	0.073	0.33	0.626	0.24
ML rhythmic and directional control (%)	0.38 (1.18)	0.130	0.32	0.58 (2.62)	0.647	0.22	0.559	0.10
AP rhythmic and directional control (%)	0.00 (1.59)	0.840	0.00	0.13 (1.98)	0.797	0.07	0.934	0.07
Postural control assessment total score (%)	0.44 (1.13)	0.052	0.39	0.00 (1.21)	0.885	0.00	0.199	0.37
Functional balance assessment global score (%)	0.66 (0.87)	<0.001	0.76	0.26 (1.00)	0.194	0.26	0.182	0.43

Abbreviations: ROA, Romberg Test with Eyes Open; ROC, Romberg Test with Eyes Closed; RGA, Romberg Test with Eyes Open on Foam Cushion; RGC, Romberg Test with Eyes Closed on Foam Cushion; ML, mediolateral; AP, anteroposterior; Avg., Average; MRP, study group (motor relearning program); CPT, control group (conventional physiotherapy program); SD, standard deviation.

***** $p<0.05$ indicates a statistically significant difference within the group, as determined by the Wilcoxon signed-rank test.

****** $p<0.05$ indicates a statistically significant difference between the groups, as determined by the Mann-Whitney U test.

For ML stability during the Romberg tests, the MRP group exhibited a significant increase in the mean ML stability score, with a mean change of 0.81 (SD=1.20) (p<0.001; d=0.68), while the CPT group showed a non-significant mean change of 0.13 (SD=1.31) (p=0.808; d=0.10); the difference between the two groups was statistically significant (p=0.031; d=0.54). However, there was no significant improvement in the mean AP stability score in either group. The mean change was similar for the MRP group, with a mean change of 0.16 (SD=0.92) (p=0.669; d=0.17), and 0.16 (SD=0.82) (p=0.376; d=0.20) in the CPT group; however, the difference between the two groups was not statistically significant (p=0.747; d=0.01) (see Table 6.17).

In terms of changes in the assessment indices for the contribution of sensory systems, both groups demonstrated a slight improvement in mean scores from post-intervention to the 3-month follow-up. Regarding the somatosensory index, both groups exhibited an increase in the mean score. The MRP group had a mean change of 0.28 (SD=0.73) (p=0.050; d=0.39), while the CPT group had a mean change of 0.58 (SD=1.52) (p=0.086; d=0.38); however, the difference between the two groups was not statistically significant (p=0.736; d=0.25) (see Table 6.17 and Figure 6.3A). The visual index mean score significantly increased in the MRP group, with a mean change of 0.50 (SD=1.41) (p=0.035; d=0.35), while the CPT group showed a non-significant mean change of 0.32 (SD=1.38) (p=0.385; d=0.23); however, the difference between the two groups was not statistically significant (p=0.536; d=0.13) (see Table 6.17). Similarly, the change in the vestibular index mean score was significant in the MRP group, with a mean change of 1.19 (SD=2.40) (p=0.012; d=0.49), compared to 0.10 (SD=2.41) in the CPT group (p=0.952; d=0.04); however, the difference between the two groups was not statistically significant (p=0.054; d=0.45) (see Table 6.17 and Figure 6.3B). In addition, the change in the dynamic index mean score was statistically significant for both groups. The mean change was similar in both groups, with a mean change of 1.16 (SD=1.05) (p<0.001; d=1.10) in the MRP group and 1.13 (SD=1.88) (p=0.002; d=0.60) in the CPT group; however, the difference between the two groups was not statistically significant (p=0.940; d=0.02) (see Table 6.17 and Figure 6.3C). Moreover, both groups demonstrated a statistically significant improvement in the mean sensory-dynamic total score. The mean change was numerically higher in the MRP group, with a mean change of 0.81 (SD=0.86) (p<0.001; d=0.95), compared to 0.58 (SD=1.39) in the CPT group (p=0.035; d=0.42); however, the difference between the two groups was not statistically significant (p=0.429; d=0.20) (see Table 6.17 and Figure 6.3D).

For the assessment of limits of stability, the change in the mean maximum displacement score was not statistically significant for either group. The mean change was slightly higher in the MRP group, with a mean change of 1.22 (SD=3.75) (p=0.073; d=0.33), compared to 0.77 (SD=3.78) in the CPT group (p=0.315; d=0.20); however, the difference between the two groups was not statistically significant (p=0.582; d=0.12) (see Table 6.17 and Figure 6.4A).). For the change in the mean directional control score, the MRP group showed a significant improvement in the mean score, with a mean change of 2.00 (SD=4.33) (p=0.016; d=0.46), while the CPT group exhibited a minimal reduction, with a mean change of -0.29 (SD=3.28) (p=0.256; d=0.09); the difference between the two groups was statistically significant (p=0.014; d=0.60) (see Table 6.17 and Figure 6.4B). Both groups exhibited a non-significant minimal reduction in mean reaction time. The MRP group had a mean change of -0.02 (SD=0.19) (p=0.432; d=0.11), and the CPT group had a mean change of -0.03 (SD=0.19) (p=0.450; d=0.16); however, the difference between the two groups was not statistically significant (p=0.837; d=0.04) (see Table 6.17 and Figure 6.4C). Furthermore, both groups demonstrated an improvement in the mean LOS total score. The MRP group had a significant increase in the mean score, with a mean change of 0.81 (SD=1.60) (p=0.011; d=0.51), while the CPT group exhibited a non-significant mean change of 0.45 (SD=1.36) (p=0.073; d=0.33) however, the difference between the two groups was not statistically significant (p=0.626; d=0.24) (see Table 6.17 and Figure 6.4D).

Besides, both groups exhibited a non-significant slight improvement in the mean ML rhythmic and directional control score. The MRP group had a mean change of 0.38 (SD=1.18) (p=0.130; d=0.32), and the CPT group had a mean change of 0.58 (SD=2.62) (p=0.647; d=0.22); however, the difference between the two groups was not statistically significant (p=0.559; d=0.10) (see Table 6.17 and Figure 6.5A). Similarly, the change in the mean AP rhythmic and directional control score was not statistically significant for either group. The MRP group showed no change with a mean of 0.00 (SD=1.59) (p=0.840; d=0.00), while the CPT group exhibited a mean change of 0.13 (SD=1.98) (p=0.797; d=0.07); however, the difference between the two groups was not statistically significant (p=0.934; d=0.07) (see Table 6.17 and Figure 6.5B). Additionally, the change in the mean postural control assessment total score was marginally significant in the MRP group, with a mean change of 0.44 (SD=1.13) (p=0.052; d=0.39), while the CPT group showed no change with a mean of 0.00 (SD=1.21) (p=0.885; d=0.00); however, the difference between the two groups was not statistically significant (p=0.199; d=0.37) (see Table 6.17 and Figure 6.5C).

In terms of the functional balance assessment global score, both groups demonstrated an improvement in the mean functional balance global score. The MRP group showed a significant increase in the mean score, with a mean change of 0.66 (SD=0.87) (p<0.001; d=0.76), while the CPT group exhibited a non-significant increase in the mean score, with a mean change of 0.26 (SD=1.00) (p=0.194; d=0.26). However, the difference in mean score change between the two groups was not statistically significant (p=0.182; d=0.43) (see Table 6.17 and Figure 6.5D).

Additional parameters and data tables related to the changes in instrumental functional balance assessment from post-intervention to 3-months follow-up in the two groups are presented in Appendix 11.17.

Functional gait analysis

With regard to the instrumental gait analysis from post-intervention to the 3-month follow-up, both groups demonstrated a statistically significant improvement in the mean scores of gait speed measured in m/s. The change in mean gait speed was slightly higher in the MRP group, with a mean change of 0.02 (SD=0.03) (p<0.001; d=0.80), compared to 0.01 (SD=0.03) in the CPT group (p=0.021; d=0.47); however, the difference between the two groups was not statistically significant (p=0.240; d=0.38) (see Table 6.18 and Figure 6.6A). On the other hand, both groups showed a non-significant improvement in the mean scores of gait speed as a percentage of normality. The MRP group had a mean change of 0.38 (SD=1.07) (p=0.081; d=0.35), and the CPT group had a mean change of 1.16 (SD=3.31) (p=0.112; d=0.35); however, the difference between the two groups was not statistically significant (p=0.559; d=0.32) (see Table 6.18 and Figure 6.6B). Moreover, both groups demonstrated a statistically significant improvement in the mean difference in support time score. The change in the mean difference in support time score was slightly higher in the MRP group, with a mean change of 2.41 (SD=2.67) (p<0.001; d=0.90), compared to 1.90 (SD=3.67) in the CPT group (p=0.013; d=0.52); however, the difference between the two groups was not statistically significant (p=0.815; d=0.16) (see Table 6.18 and Figure 6.6C).

Table 6.18: Changes in instrumental functional gait analysis from post-intervention to 3-month follow-up in the two groups.

Functional Gait Analysis Parameters	**MRP Group (n = 32)**			**CPT Group (n = 31)**			***p*-Value****	**Effect Size (*d*)**
	Mean Change (SD)	***p*-Value***	**Effect Size (*d*)**	**Mean Change (SD)**	***p*-Value***	**Effect Size (*d*)**		
Gait speed (m/s)	0.02 (0.03)	<0.001	0.80	0.01 (0.03)	0.021	0.47	0.240	0.38
Average gait speed (%)	0.38 (1.07)	0.081	0.35	1.16 (3.31)	0.112	0.35	0.559	0.32
Difference in support time (%)	2.41 (2.67)	<0.001	0.90	1.90 (3.67)	0.013	0.52	0.815	0.16
AP braking force global score (%)	0.69 (1.77)	0.096	0.39	1.10 (5.48)	0.322	0.20	0.940	0.10
AP propulsion force global score (%)	0.84 (2.27)	0.037	0.37	1.52 (5.30)	0.319	0.29	0.731	0.17
Vertical take-off force global score (%)	-0.19 (1.23)	0.658	0.15	-0.23 (1.78)	0.071	0.13	0.462	0.03
Oscillation force global score (%)	0.63 (3.02)	0.171	0.21	0.06 (1.00)	0.973	0.06	0.559	0.25
AP force morphology (Fx Morphology) (%)	2.38 (2.98)	<0.001	0.80	3.65 (6.26)	0.003	0.58	0.747	0.26
ML force morphology (Fy Morphology) (%)	3.03 (3.95)	<0.001	0.77	0.48 (5.77)	0.314	0.08	<0.001	0.52
Vertical force morphology (Fz Morphology) (%)	1.28 (3.53)	0.087	0.36	1.03 (3.49)	0.135	0.30	0.973	0.07
Functional gait analysis global score (%)	1.16 (0.95)	<0.001	1.21	0.94 (1.73)	0.006	0.54	0.336	0.16

Abbreviations: AP, anteroposterior; ML, mediolateral; MRP, study group (motor relearning program); CPT, control group (conventional physiotherapy program); SD, standard deviation.
***** $p<0.05$ indicates a statistically significant difference within the group, as determined by the Wilcoxon signed-rank test.
****** $p<0.05$ indicates a statistically significant difference between the groups, as determined by the Mann-Whitney U test.

For the AP braking force global score, both groups showed a non-significant slight improvement in the mean AP braking force global score. The MRP group had a mean change of 0.69 (SD=1.77) (p=0.096; d=0.39), and the CPT group had a mean change of 1.10 (SD=5.48) (p=0.322; d=0.20); however, the difference between the two groups was not statistically significant (p=0.940; d=0.10) (see Table 6.18 and Figure 6.7A). For the AP propulsion force global score, the MRP group showed a significant improvement in the mean score, with a mean change of 0.84 (SD=2.27) (p=0.037; d=0.37), while the CPT group had a non-significant mean change of 1.52 (SD=5.30) (p=0.319; d=0.29); however, the difference between the two groups was not statistically significant (p=0.731; d=0.17) (see Table 6.18 and Figure 6.7B). In addition, the change in the mean vertical take-off force global score showed a non-significant minimal reduction in both groups. The MRP group had a mean change of -0.19 (SD=1.23) (p=0.658; d=0.15), and the CPT group had a mean change of -0.23 (SD=1.78) (p=0.071; d=0.13); however, the difference between the two groups was not statistically significant (p=0.462; d=0.03) (see Table 6.18 and Figure 6.7C). Furthermore, the change in the mean oscillation force global score was not statistically significant in either group. The change in the mean oscillation force global score was slightly higher in the MRP group, with a mean change of 0.63 (SD=3.02) (p=0.171; d=0.21), compared to 0.06 (SD=1.00) in the CPT group (p=0.973; d=0.06); however, the difference in mean score change between the two groups was not statistically significant (p=0.559; d=0.25) (see Table 6.18 and Figure 6.7D).

In terms of force morphology, both groups demonstrated a statistically significant improvement in the mean AP force morphology global score. The MRP group had a mean change of 2.38 (SD=2.98) (p<0.001; d=0.80), and the CPT group had a mean change of 3.65 (SD=6.26) (p=0.003; d=0.58); however, the difference between the two groups was not statistically significant (p=0.747; d=0.26) (see Table 6.18 and Figure 6.8A). Both groups showed an improvement in the mean ML force morphology global score. The MRP group exhibited a significant increase in the mean score, with a mean change of 3.03 (SD=3.95) (p<0.001; d=0.77), compared to a non-significant mean change of 0.48 (SD=5.77) in the CPT group (p=0.314; d=0.08); the difference between the two groups was statistically significant (p<0.001; d=0.52) (see Table 6.18 and Figure 6.8B). Moreover, both groups showed a non-significant improvement in the mean vertical force morphology global score. The change in the mean vertical force morphology global score was similar in both groups, with a mean change of 1.28 (SD=3.53) (p=0.087; d=0.36) in the MRP group, and 1.03 (SD=3.49) (p=0.135; d=0.30) in the CPT group; however, the difference between the two groups was not statistically significant (p=0.973; d=0.07) (see Table 6.18 and Figure 6.8C).

Finally, the results showed that participants in both groups exhibited a statistically significant improvement in the mean functional gait analysis global score from post-intervention to the 3-month follow-up. The MRP group had a slightly higher improvement in the mean functional gait analysis global score, with a mean change of 1.16 (SD=0.95) (p<0.001; d=1.21), compared to 0.94 (SD=1.73) in the CPT group (p=0.006; d=0.54). However, the difference in mean score change between the two groups was not statistically significant (p=0.336; d=0.16) (see Table 6.18 and Figure 6.8D).

Additional parameters and data tables related to the changes in instrumental functional gait analysis from post-intervention to 3-months follow-up in the two groups are presented in Appendix 11.18.

Changes from baseline to 3-months follow-up

Functional balance assessment

Both groups demonstrated a statistically significant improvement in the mean scores for all static posturography tests from baseline to the 3-month follow-up. Specifically, the change in the mean ROA score was slightly higher in the MRP group, with a mean change of 3.00 (SD=3.60) (p<0.001; d=0.83), compared to 2.23 (SD=2.93) in the CPT group (p<0.001; d=0.76); however, the difference between the two groups was not statistically significant (p=0.564; d=0.24) (see Table 6.19 and Figure 6.2A). The change in the mean ROC score was larger in the MRP group, with a mean change of 5.41 (SD=4.71) (p<0.001; d=1.15), compared to 3.26 (SD=3.45) in the CPT group (p<0.001; d=0.94); but the difference between the two groups was not statistically significant (p=0.093; d=0.52) (see Table 6.19 and Figure 6.2B). Moreover, the change in the mean RGA score was higher in the MRP group, with a mean change of 6.25 (SD=4.98) (p<0.001; d=1.25), compared to 4.03 (SD=3.36) in the CPT group (p<0.001; d=1.20); however, the difference between the two groups was not statistically significant (p=0.080; d=0.52) (see Table 6.19 and Figure 6.2C). Furthermore, the change in the mean RGC score was significantly greater in the MRP group, with a mean change of 15.72 (SD=6.49) (p<0.001; d=2.42), compared to 5.97 (SD=4.13) in the CPT group ($p<0.001$; $d=1.45$); the difference between the two groups was statistically significant ($p<0.001$; $d=1.79$) (see Table 6.19 and Figure 6.2D).

Table 6.19: Changes in instrumental functional balance assessment from baseline to 3-month follow-up in the two groups.

Functional Balance Assessment Tests	MRP Group (n = 32)			CPT Group (n = 31)			*p*-Value**	Effect Size (*d*)
	Mean Change (SD)	*p*-Value*	Effect Size (*d*)	Mean Change (SD)	*p*-Value*	Effect Size (*d*)		
Static posturography tests								
ROA (%)	3.00 (3.60)	<0.001	0.83	2.23 (2.93)	<0.001	0.76	0.564	0.24
ROC (%)	5.41 (4.71)	<0.001	1.15	3.26 (3.45)	<0.001	0.94	0.093	0.52
RGA (%)	6.25 (4.98)	<0.001	1.25	4.03 (3.36)	<0.001	1.20	0.080	0.52
RGC (%)	15.72 (6.49)	<0.001	2.42	5.97 (4.13)	<0.001	1.45	<0.001	1.79
Romberg test ML stability (%)	6.22 (3.09)	<0.001	2.01	2.71 (2.52)	<0.001	1.08	<0.001	1.24
Romberg test AP stability (%)	3.88 (3.92)	<0.001	0.99	1.97 (2.18)	<0.001	0.90	0.083	0.60
Somatosensory index (%)	5.53 (4.34)	<0.001	1.27	3.16 (2.52)	<0.001	1.26	0.048	0.67
Visual index (%)	3.38 (3.38)	<0.001	1.00	2.90 (2.66)	<0.001	1.09	0.826	0.15
Vestibular index (%)	16.00 (7.12)	<0.001	2.25	5.29 (3.78)	<0.001	1.40	<0.001	1.87
Dynamic index (%)	14.84 (7.10)	<0.001	2.09	7.10 (3.60)	<0.001	1.97	<0.001	1.37
Sensory-Dynamic total score (%)	9.53 (2.86)	<0.001	3.33	4.48 (1.84)	<0.001	2.43	<0.001	2.09
Postural control assessment								
Avg. score of maximum displacement (%)	18.78 (10.71)	<0.001	1.75	11.90 (5.78)	<0.001	2.06	0.001	0.80
Avg. score of directional control (%)	18.69 (7.40)	<0.001	2.52	9.61 (5.54)	<0.001	1.74	<0.001	1.39
Avg. score of reaction time (s)	-0.42 (0.26)	<0.001	1.63	-0.24 (0.22)	<0.001	1.09	0.005	0.75

Limits of stability (LOS) analysis score (%)	14.25 (7.12)	<0.001	2.00	6.90 (3.05)	<0.001	2.26	<0.001	1.33
ML rhythmic and directional control (%)	14.31 (5.68)	<0.001	2.52	4.97 (3.61)	<0.001	1.38	<0.001	1.96
AP rhythmic and directional control (%)	10.75 (5.32)	<0.001	2.02	4.58 (3.12)	<0.001	1.47	<0.001	1.41
Postural control assessment total score (%)	13.53 (5.38)	<0.001	2.51	5.52 (2.43)	<0.001	2.27	<0.001	1.91
Functional balance assessment global score (%)	11.84 (3.42)	<0.001	3.46	4.87 (1.54)	<0.001	3.16	<0.001	2.62

Abbreviations: ROA, Romberg Test with Eyes Open; ROC, Romberg Test with Eyes Closed; RGA, Romberg Test with Eyes Open on Foam Cushion; RGC, Romberg Test with Eyes Closed on Foam Cushion; ML, mediolateral; AP, anteroposterior; Avg., Average; MRP, study group (motor relearning program); CPT, control group (conventional physiotherapy program); SD, standard deviation.

***** $p<0.05$ indicates a statistically significant difference within the group, as determined by the Wilcoxon signed-rank test.

****** $p<0.05$ indicates a statistically significant difference between the groups, as determined by the Mann-Whitney U test.

For ML stability during the Romberg tests, both groups exhibited a statistically significant improvement in the mean ML stability score. The MRP group had a significantly higher mean change of 6.22 (SD=3.09) ($p<0.001$; d=2.01), compared to 2.71 (SD=2.52) in the CPT group ($p<0.001$; d=1.08); the difference between the two groups was statistically significant ($p<0.001$; d=1.24). Additionally, both groups showed a statistically significant improvement in the mean AP stability score. The MRP group had a mean change of 3.88 (SD=3.92) ($p<0.001$; d=0.99), compared to 1.97 (SD=2.18) in the CPT group ($p<0.001$; d=0.90); however, the difference between the two groups was not statistically significant (p=0.083; d=0.60) (see Table 6.19).

In terms of changes in the assessment indices for the contribution of sensory systems, both groups demonstrated a statistically significant improvement in the mean scores from baseline to the 3-month follow-up for all indices. For the somatosensory index, the MRP group exhibited a significantly higher mean change of 5.53 (SD=4.34) ($p<0.001$; d=1.27), compared to 3.16 (SD=2.52) in the CPT group ($p<0.001$; d=1.26); the difference between the two groups was statistically significant (p=0.048; d=0.67) (see Table 6.19 and Figure 6.3A). Additionally, the change in the visual index mean score was higher in the MRP group, with a mean change of 3.38 (SD=3.38) ($p<0.001$; d=1.00), compared to 2.90 (SD=2.66) in the CPT group ($p<0.001$; d=1.09); but the difference between the two groups was not statistically significant (p=0.826; d=0.15) (see Table 6.19). Furthermore, the change in the vestibular index mean score was significantly greater in the MRP group, with a mean change of 16.00 (SD=7.12) ($p<0.001$; d=2.25), compared to 5.29 (SD=3.78) in the CPT group ($p<0.001$; d=1.40); the difference between the two groups was statistically significant ($p<0.001$; d=1.87) (see Table 6.19 and Figure 6.3B). The change in the dynamic index was also significantly larger in the MRP group, with a mean change of 14.84 (SD=7.10) ($p<0.001$; d=2.09), compared to 7.10 (SD=3.60) in the CPT group ($p<0.001$; d=1.97); the difference between the two groups was statistically significant ($p<0.001$; d=1.37) (see Table 6.19 and Figure 6.3C). Moreover, both groups displayed a statistically significant improvement in the mean sensory-dynamic total score. The mean change was significantly higher in the MRP group with a mean change of 9.53 (SD=2.86) ($p<0.001$; d=3.33), compared to 4.48 (SD=1.84) in the CPT group ($p<0.001$; d=2.43); the difference in mean score change between the two groups was statistically significant ($p<0.001$; d=2.09) (see Table 6.19 and Figure 6.3D).

For the assessment of limits of stability, both groups demonstrated a statistically significant improvement in the mean scores from baseline to the 3-month follow-up for all parameters. Specifically, the mean maximum displacement score showed a significantly higher change in the MRP group, with a mean change of 18.78 (SD=10.71) ($p<0.001$; d=1.75), compared to 11.90 (SD=5.78) in the CPT group ($p<0.001$; d=2.06); the difference between the two groups was statistically significant (p=0.001; d=0.80) (see Table 6.19 and Figure 6.4A). Additionally, the change in mean directional control score was also significantly larger in the MRP group, with a mean change of 18.69 (SD=7.40) ($p<0.001$; d=2.52), compared to 9.61 (SD=5.54) in the CPT group ($p<0.001$; d=1.74); the difference between the two groups was statistically significant ($p<0.001$; d=1.39) (see Table 6.19 and Figure 6.4B). Furthermore, the MRP group exhibited a significantly greater reduction in mean reaction time, with a mean change of -0.42 (SD=0.26) ($p<0.001$; d=1.63), compared to -0.24 (SD=0.22) in the CPT group ($p<0.001$; d=1.09); the difference between the two groups was statistically significant (p=0.005; d=0.75) (see Table 6.19 and Figure 6.4C). Moreover, the change in mean LOS total score was significantly higher in the MRP group, with a mean change of 14.25 (SD=7.12) ($p<0.001$; d=2.00), compared to 6.90 (SD=3.05) in the CPT group ($p<0.001$; d=2.26); and the difference in mean LOS score change between the two groups was statistically significant ($p<0.001$; d=1.33) (see Table 6.19 and Figure 5.46.4D).

Furthermore, both groups demonstrated a statistically significant improvement in mean ML rhythmic and directional control score. The change in mean ML rhythmic and directional control score was significantly higher in the MRP group, with a mean change of 14.31 (SD=5.68) ($p<0.001$; d=2.52), compared to 4.97 (SD=3.61) in the CPT group ($p<0.001$; d=1.38); the difference between the two groups was statistically significant ($p<0.001$; d=1.96) (see Table 6.19 and Figure 6.5A). Similarly, both groups showed a statistically significant improvement in mean AP rhythmic and directional control score. The change in mean AP rhythmic and directional control score was significantly larger in the MRP group, with a mean change of 10.75 (SD=5.32) ($p<0.001$; d=2.02), compared to 4.58 (SD=3.12) in the CPT group ($p<0.001$; d=1.47); the difference between the two groups was statistically significant ($p<0.001$; d=1.41) (see Table 6.19 and Figure 6.5B). Additionally, both groups demonstrated a statistically significant improvement in mean postural control assessment total score. The MRP group had a significantly higher change in mean postural control assessment total score, with a mean change of 13.53 (SD=5.38) (p<0.001; d=2.51), compared to 5.52 (SD=2.43) in the CPT group (p<0.001; d=2.27); the difference in mean score change between the two groups was statistically significant (p<0.001; d=1.91) (see Table 6.19 and Figure 6.5C).

In terms of the functional balance assessment global score, both groups showed a statistically significant improvement in mean functional balance global score. The change in mean functional balance global score was significantly greater in the MRP group, with a mean change of 11.84 (SD=3.42) (p<0.001; d=3.46), compared to 4.87 (SD=1.54) in the CPT group (p<0.001; d=3.16). The difference in mean functional balance assessment global score change between the two groups was statistically significant (p<0.001; d=2.62) (see Table 6.19 and Figure 6.5D).

Additional parameters and data tables related to the changes in instrumental functional balance assessment from baseline to 3-months follow-up in the two groups are presented in Appendix 11.19.

Functional gait analysis

With regard to the instrumental gait analysis from baseline to 3-months follow-up, both groups demonstrated a statistically significant improvement in the mean scores of gait speed as m/s and as percentage of normality. Specifically, the change in the mean gait speed as m/s was significantly higher in the MRP group, with a mean change of 0.22 m/s (SD=0.10) (p<0.001; d=2.11), compared to 0.10 m/s (SD=0.05) in the CPT group (p<0.001; d=2.13); the difference between the two groups was statistically significant (p<0.001; d=1.48) (see Table 6.20 and Figure 6.6A). In addition, the change in the mean gait speed as percentage of normality was numerically higher in the MRP group, with a mean change of 17.50% (SD=18.94) (p<0.001; d=0.92), compared to 10.45% (SD=8.86) in the CPT group (p<0.001; d=1.18); however, the difference between the two groups was not statistically significant (p=0.441; d=0.47) (see Table 6.20 and Figure 6.6B). Moreover, both groups showed a statistically significant improvement in the mean difference in support time score. The change in the mean difference in support time score was significantly greater in the MRP group, with a mean change of 31.72% (SD=20.73) (p<0.001; d=1.53), compared to 11.74% (SD=6.08) in the CPT group (p<0.001; d=1.93); the difference between the two groups was statistically significant (p<0.001; d=1.30) (see Table 6.20 and Figure 6.6C).

Table 6.20: Changes in instrumental functional gait analysis from baseline to 3-month follow-up in the two groups.

Functional Gait Analysis Parameters	**MRP Group (n = 32)**			**CPT Group (n = 31)**			***p*-Value****	**Effect Size (*d*)**
	Mean Change (SD)	***p*-Value***	**Effect Size (*d*)**	**Mean Change (SD)**	***p*-Value***	**Effect Size (*d*)**		
Gait speed (m/s)	0.22 (0.10)	<0.001	2.11	0.10 (0.05)	<0.001	2.13	<0.001	1.48
Average gait speed (%)	17.50 (18.94)	<0.001	0.92	10.45 (8.86)	<0.001	1.18	0.441	0.47
Difference in support time (%)	31.72 (20.73)	<0.001	1.53	11.74 (6.08)	<0.001	1.93	<0.001	1.30
AP braking force global score (%)	14.81 (19.91)	<0.001	0.74	6.81 (8.42)	<0.001	0.81	0.268	0.52
AP propulsion force global score (%)	18.81 (20.68)	<0.001	0.91	6.71 (8.91)	<0.001	0.75	0.019	0.76
Vertical take-off force global score (%)	5.88 (11.70)	<0.001	0.50	1.39 (4.36)	0.049	0.32	0.012	0.51
Oscillation force global score (%)	4.09 (9.00)	0.009	0.46	0.71 (2.73)	0.590	0.26	0.138	0.51
AP force morphology (Fx Morphology) (%)	19.59 (10.43)	<0.001	1.88	13.81 (9.72)	<0.001	1.42	0.003	0.57
ML force morphology (Fy Morphology) (%)	19.53 (15.95)	<0.001	1.22	5.68 (6.51)	<0.001	0.87	<0.001	1.13
Vertical force morphology (Fz Morphology) (%)	13.22 (11.24)	<0.001	1.18	8.94 (9.69)	<0.001	0.92	0.049	0.41
Functional gait analysis global score (%)	15.84 (7.03)	<0.001	2.26	7.29 (3.29)	<0.001	2.22	<0.001	1.55

Abbreviations: AP, anteroposterior; ML, mediolateral; MRP, study group (motor relearning program); CPT, control group (conventional physiotherapy program); SD, standard deviation.

***** $p<0.05$ indicates a statistically significant difference within the group, as determined by the Wilcoxon signed-rank test.

****** $p<0.05$ indicates a statistically significant difference between the groups, as determined by the Mann-Whitney U test.

For the AP braking force global score, both groups exhibited a statistically significant improvement in the mean AP braking force global score. The MRP group demonstrated a higher mean change of 14.81 (SD=19.91) ($p<0.001$; d=0.74), compared to 6.81 (SD=8.42) in the CPT group ($p<0.001$; d=0.81); however, the difference between the two groups was not statistically significant (p=0.268; d=0.52) (see Table 6.20 and Figure 6.7A). Both groups also displayed a statistically significant improvement in the mean AP propulsion force global score. The MRP group had a significantly greater mean change of 18.81 (SD=20.68) ($p<0.001$; d=0.91), compared to 6.71 (SD=8.91) in the CPT group ($p<0.001$; d=0.75); the difference between the two groups was statistically significant (p=0.019; d=0.76) (see Table 6.20 and Figure 6.7B). In addition, both groups demonstrated a statistically significant improvement in the mean vertical take-off force global score. The MRP group displayed a greater mean change of 5.88 (SD=11.70) ($p<0.001$; d=0.50), compared to 1.39 (SD=4.36) in the CPT group (p=0.049; d=0.32); the difference between the two groups was statistically significant (p=0.012; d=0.51) (see Table 6.20 and Figure 6.7C). Furthermore, both groups exhibited an improvement in the mean oscillation force global score. The MRP group demonstrated a significant mean change of 4.09 (SD=9.00) (p=0.009; d=0.46), while the CPT group showed a non-significant mean change of 0.71 (SD=2.73) (p=0.590; d=0.26); however, the difference between the two groups was not statistically significant (p=0.138; d=0.51) (see Table 6.20 and Figure 6.7D).

In terms of force morphology, both groups showed a statistically significant improvement in the mean scores from baseline to 3-months follow-up for all force morphologies. For the AP force morphology global score, the MRP group showed a significantly higher mean change of 19.59 (SD=10.43) ($p<0.001$; d=1.88), compared to 13.81 (SD=9.72) in the CPT group ($p<0.001$; d=1.42); the difference between the two groups was statistically significant (p=0.003; d=0.57) (see Table 6.20 and Figure 6.8A). The change in the mean ML force morphology global score was significantly greater in the MRP group, with a mean change of 19.53 (SD=15.95) ($p<0.001$; d=1.22), compared to 5.68 (SD=6.51) in the CPT group ($p<0.001$; d=0.87); the difference between the two groups was statistically significant ($p<0.001$; d=1.13) (see Table 6.20 and Figure 6.8B). Moreover, the change in the mean vertical force morphology global score was significantly larger in the MRP group, with a mean change of 13.22 (SD=11.24) ($p<0.001$; d=1.18), compared to 8.94 (SD=9.69) in the CPT group ($p<0.001$; d=0.92); the difference between the two groups was statistically significant ($p=0.049$; $d=0.41$) (see Table 6.20 and Figure 6.8C).

Finally, the results showed that participants in both groups exhibited a statistically significant improvement in the mean functional gait analysis global score from baseline to 3-months follow-up. The MRP group had significantly higher improvement in the mean functional gait analysis global score, with a mean change of 15.84 (SD=7.03) ($p<0.001$; $d=2.26$), compared to 7.29 (SD=3.29) in the CPT group ($p<0.001$; $d=2.22$). The difference in mean functional gait analysis global score change between the two groups was statistically significant ($p<0.001$; $d=1.55$) (see Table 6.20 and Figure 6.8D).

Additional parameters and data tables related to the changes in instrumental functional gait analysis from baseline to 3-months follow-up in the two groups are presented in Appendix 11.20.

Section 7

Discussion

The discussion chapter of this thesis critically examines and interprets the findings obtained from the current study, a randomized controlled clinical trial (RCT), which evaluated the efficacy and long-term outcomes of task-specific training based on the motor relearning program (MRP) for post-stroke patients. The primary objective of the study was to investigate the effects of this training approach on balance, mobility, and the performance of activities of daily living (ADL) in individuals who have experienced a stroke. By examining the outcomes of the RCT, this study aims to contribute to the existing body of knowledge on effective rehabilitation strategies for post-stroke patients.

The structure of this discussion chapter follows a logical progression, beginning with a concise summary of the main findings. This summary is followed by a thorough analysis of the results, highlighting the key outcomes and statistical results obtained from the study. Furthermore, the discussion draws connections between the study's results and existing literature on stroke rehabilitation and motor recovery. This comparative analysis enables us to assess the consistency or divergence of the study's results with the broader body of knowledge. Therefore, this synthesis helps identify areas of agreement as well as any novel contributions or contradictions the study may have made.

Finally, the study critically evaluates the limitations, recognizing potential biases, methodological constraints, or sample limitations that may have influenced the results. By acknowledging these limitations, the study offers a more nuanced interpretation of the findings and provides a realistic assessment of the generalizability and validity. This evaluation also helps identify areas for future research that may address these limitations and further enhance our understanding of stroke rehabilitation strategies.

7.1 Methodological considerations

The methodological considerations applied in the present study are designed to investigate the effectiveness of a MRP on balance, mobility, and performance of activities of daily living in sub-acute stroke patients. The study adopted a two-armed randomized controlled clinical trial (RCT) with parallel group design, which is considered the most reliable method for obtaining clinical evidence regarding the relative effectiveness of the intervention [339], thus making it an appropriate design choice for the study.

The study followed the Standard Protocol Items: Recommendations for Interventional Trials (SPIRIT) guidelines for developing the study protocol [338], ensuring that the research design and methodology adhered to established standards. This enhances the transparency and rigor of the study, facilitating replication and comparison with other similar studies. Additionally, the study protocol was published in the European Stroke Journal (ESJ) [430], the official journal of the European Stroke Organisation (ESO), indicating a level of peer review, validation of the methodology, and enhancing the credibility of the research.

In clinical research, the calculation of an appropriate sample size is critical to ensure the study's validity and statistical power. In this study, the sample size was determined by considering balance impairment as the primary indicator, using the Berg Balance Scale (BBS). This choice was well-founded due to its established relevance in previous research. The expected mean effect size, based on previous studies that used similar interventions, was approximately $d = 0.65$ [318, 321, 327]. To achieve a statistically significant level of $\alpha = 0.05$ and a power of $1–\beta = 0.80$, the power analysis suggested that 30 participants were needed in each group. To account for potential dropouts, the sample size was increased by 10%, resulting in a total of 66 participants who were randomly assigned to either the study group or the control group after completing the baseline assessment. The final analysis included 32 study and 31 control participants, after 2 drop-outs and 1 loss to follow-up. This approach ensured that the study had sufficient statistical power to detect significant differences between the treatment groups, producing accurate and reliable results, thus contributing meaningful insights to the field.

The randomized allocation of patients to either the MRP group or the conventional physical therapy program (CPT) group, was done with an allocation ratio of 1:1. Randomized allocation was performed to minimize selection bias by distributing the characteristics of patients that may impact the outcome randomly between the groups. This helps ensure that any observed differences in outcomes can be attributed to the treatment received rather than pre-existing differences in patient characteristics [340]. By reducing the imbalance of known and unknown characteristics such as age, gender, and disease duration, randomization increases the validity and generalizability of the study results [341].

The interventions in the study consisted of task-specific training based on the MRP for the study group, while the control group received a conventional physical therapy program (CPT) based on standard stroke rehabilitation. The intensity of interventions in this study involved both groups undergoing 1-hour exercise sessions, three sessions per week, over a duration of 8 weeks, resulting in a total of 24 sessions. This duration aligns with international guidelines for stroke rehabilitation [289, 344], ensuring that a significant improvement in the study outcomes could be achieved.

The study assessed changes in balance, gait, and performance of activities of daily living at two stages: post-intervention and at three months after the end of the intervention to determine the long-term outcome. Baseline assessments were conducted before randomization; post-intervention assessments were conducted after eight weeks of the intervention; and follow-up assessments were conducted three months after the post-intervention assessment. This longitudinal approach allowed for the evaluation of the immediate and sustained effects of the interventions.

Previous studies on stroke have widely used standardized outcome measures to evaluate motor deficits (i.e., balance and gait). In this respect, this study adopted instrumental balance and gait analysis as part of the approach for evaluating the results. This approach provides quantitative data, including kinetic and kinematic parameters, which reduce the interference of subjective factors in the evaluation process and provide more objective and reliable results. By using standardized and objective measures, the study increases the reliability and validity of its findings, ensures consistency, and facilitates comparison with previous studies.

Moreover, the methodological quality of the conducted study was assessed using the Physiotherapy Evidence Database (PEDro) Scale criteria, which is a valid and reliable widely used tool for rating the quality of randomized controlled trials in physiotherapy [431]. The study scored 7 out of 10 on the PEDro Scale, indicating good overall quality of evidence [432]. The study met the criteria for specified eligibility criteria, random allocation, concealed allocation, baseline comparability, adequate follow-up, intention-to-treat analysis, between-group comparisons, and point estimates and variability. These criteria ensure the internal validity and interpretability of the study results. However, the study did not meet the criterion for blinding, which includes three criteria related to blinding: blinding of participants, blinding of therapists, and blinding of assessors. This lack of blinding can be attributed to the nature of the study, which involved an exercise-based intervention where both the therapist and participants actively engaged in the intervention and thus could not be blinded to the assigned interventions. Additionally, the principal investigator who was in charge of assessments (the outcome assessor) was also involved in most of the interventions, making this an open-label trial with the exception of the individual conducting the data analysis.

Nevertheless, it is noteworthy that in exercise trials, a score of 7–8 out of 10 on the PEDro scale is considered indicative of high quality [433]. Considering the inherent difficulties in achieving blinding of therapists and participants in this type of intervention, despite this limitation, the study met other crucial criteria that ensure the robustness, rigor, and reliability of its methodology and findings. Therefore, the study's score of 7 on the PEDro scale suggests that it can be considered a high-quality study, albeit with limitations related to the blinding context duly acknowledged. However, it is important to acknowledge these limitations when interpreting the study's outcomes. By doing so, a comprehensive understanding of the study's strengths and weaknesses can be achieved, facilitating informed decision-making and future research endeavors.

7.2 Baseline profile: Demographic, clinical characteristics, and descriptive results

After completing the baseline assessment, the final analysis included data from a total of 63 participants who were randomly assigned to either the study group (MRP), which consisted of 32 participants, or the control group (CPT), which consisted of

31 participants. The baseline characteristics of the participants in the study were examined to assess whether there were any potential differences between the two groups, ensuring that the study could proceed under the condition of comparability.

In terms of age, the mean age of participants in the MRP group was 64.22 years (SD=10.18), while in the CPT group, the mean age was 66.29 years (SD=8.60). The mean age of all participants in both groups was around 65 years, which aligns with the average age of stroke survivors in Spain [15]. Although there was a small difference in mean age between the groups, it was not statistically significant and can be considered negligible. Therefore, it is unlikely that age would be a confounding factor influencing the outcomes of the study.

Regarding the type of stroke, the majority of participants in both groups had experienced an ischemic stroke, which is the most common type of stroke worldwide. In the MRP group, 71.9% of participants had experienced an ischemic stroke, while in the CPT group, this proportion was slightly higher at 74.2%. Despite a slightly higher number of participants with ischemic stroke in the CPT group, the difference in incidence rates between the two groups was not statistically significant. This similarity in stroke type distribution suggests that the groups were well-balanced in terms of the underlying stroke pathology. The comparable distribution of stroke types between the groups indicates that the randomization process was successful in ensuring a balanced representation of stroke subtypes. This is important as it reduces the potential confounding effect of stroke type on intervention outcomes.

The mean time since stroke onset was approximately 3 months in both groups, with a mean of 3.01 months (SD=1.21) in the MRP group and 3.19 months (SD=0.98) in the CPT group. This indicates that participants in both groups were recruited within a similar timeframe after their stroke. The small difference in mean time between the groups is not statistically significant, suggesting that the duration of time since stroke onset was comparable for participants in both groups at baseline. The relatively short time since stroke onset suggests that participants were in the early sub-acute stages of stroke recovery, which falls within the optimal window for motor recovery after stroke. This timeframe is appropriate for evaluating the effectiveness of the interventions [288].

Stroke severity was assessed using the National Institutes of Health Stroke Scale (NIHSS) score at discharge from inpatient care. The mean NIHSS score was 5.19 (SD=3.02) in the MRP group and 4.97 (SD=2.83) in the CPT group. These scores reflect a range of stroke severities, including both minor and moderate strokes in both groups. The distribution of stroke severity between the groups was similar, and there was no statistically significant difference observed. The similar mean NIHSS scores in both groups indicate that the severity of strokes was comparable at baseline. This suggests that the randomization process successfully distributed patients with similar levels of stroke severity between the two groups, further strengthening the internal validity of the study.

Importantly, the statistical analysis indicated that there were no statistically significant differences in demographic or clinical characteristics between the MRP and CPT groups at baseline ($p>0.05$). This finding further supports the assumption that the randomization process was successful in creating comparable groups and minimizing the potential for confounding variables to influence the results. It increases the internal validity of the study by reducing the likelihood of bias.

Overall, the baseline characteristics of the participants in the MRP and CPT groups appear to be well-balanced and comparable. The similarities in demographic and clinical characteristics between the two groups imply that the study groups were well-matched. This suggests that any observed differences in outcomes following the interventions are more likely to be attributed to the intervention received (MRP or CPT) rather than variations in baseline characteristics. These comparable findings provide a solid foundation for accurately evaluating the effects of the intervention (MRP) compared to the control (CPT) while controlling for potential confounders. As a result, this strengthens the validity of the study design and enhances the generalizability of the study findings.

7.2.1 Clinical outcome measures at baseline

The baseline results of the clinical outcome measures provide important insights into the initial status of the participants in the study. In order to understand the initial state of the patients and assess the comparability between the two groups, the baseline characteristics and functional abilities of the participants in both the MRP and CPT groups were examined. Several clinical outcome measures were evaluated, including the BBS score for balance, the TUG time for functional mobility, the self-selected and fast gait velocities on the 10mWT for gait speed, the BI score for functional independence, and the SIS-16 score for physical function following a stroke.

In terms of balance, as measured by the BBS score, there was no statistically significant difference between the MRP and CPT groups at baseline. The mean BBS scores were similar in both groups, indicating comparable levels of balance ability. The distribution of balance categories within each group further supported this finding, with a similar proportion of patients falling into each category across the two groups. The mean BBS scores indicate that participants in both groups had similar balance impairments. It also indicates that the participants had a high risk of falling prior to the interventions.

Similarly, the baseline results for functional mobility, as measured by the TUG test, showed no statistically significant difference between the two groups. Both groups had similar mean TUG times, indicating comparable functional mobility abilities at baseline. The distribution of functional mobility categories within each group further supported this finding, with a similar proportion of patients falling into each category across the two groups. The mean TUG times from these results indicate that participants in both groups had comparable levels of mobility and transfer ability. It was also found that there was no statistically significant difference between both groups in terms of predicting falls, indicating that participants in both groups had a high risk of falling before the interventions.

Regarding self-selected gait velocity on the 10mWT, there was no statistically significant difference between the MRP and CPT groups at baseline. The mean gait velocities were similar in both groups, indicating comparable walking speeds. The mean scores indicated that participants in both groups were limited community ambulators. The distribution of gait velocity categories within each group further supported this finding, with a similar proportion of patients falling into each category across the two groups. These results suggest that participants in both groups had similar walking abilities prior to the interventions. In addition, the mean scores for fast gait velocity on the 10mWT were similar for the two groups, and the difference in mean score between the groups was not statistically significant. This indicates that there was no significant difference in fast gait velocity between the two groups at baseline.

The baseline results for the BI of functional independence showed no statistically significant difference between the two groups. The mean BI scores were comparable, indicating similar levels of functional independence. The distribution of functional dependency categories within each group further supported this finding, with a similar proportion of patients falling into each category across the two groups. These results suggest that participants in both groups had similar levels of functional dependency before the interventions. However, the mean BI scores also indicated that the majority of participants in both groups were classified as moderately dependent, indicating a need for assistance with daily activities.

Furthermore, the baseline results for the SIS-16 of physical function following a stroke showed no statistically significant difference between the two groups. The mean scores were similar, indicating comparable levels of physical function following a stroke. These findings suggest that participants in both groups experienced similar levels of physical impairments related to stroke.

Overall, the baseline results indicate that the MRP and CPT groups were comparable in terms of clinical outcome measures. The lack of statistically significant differences in these measures suggests that the randomization process was successful in creating comparable groups, and indicates that any subsequent changes observed in these measures during the study can be attributed to the effects of the interventions (MRP or CPT) rather than baseline variations between the groups. These findings provide a solid foundation for evaluating the efficacy of the interventions and contribute to the overall validity of the study.

7.2.2 Instrumental analysis of balance and gait at baseline

The instrumental analysis of balance and gait offers valuable insights into the initial condition of the study participants from the MRP and CPT groups. This serves as a baseline reference point for evaluating the effects of the interventions on these aspects. These findings describe the participants' baseline characteristics and set the stage for further analysis of the intervention outcomes.

Functional balance assessment

In terms of static posturography tests, the Romberg test measures postural stability with eyes open (ROA), eyes closed (ROC), eyes open on foam cushion (RGA), and eyes closed on foam cushion (RGC). The baseline results showed that the study participants from both groups had slightly impaired to normal mean scores in ROA, ROC, and RGA tests. However, the most challenging test for all participants was the RGC, which assesses the ability to maintain balance while standing on an unstable surface with eyes closed. In this test, both groups demonstrated functionally impaired scores. Importantly, there were no significant differences between the two groups in any of the static posturography tests. The similar scores obtained by both groups indicate that they had comparable levels of postural stability in these specific conditions. The Romberg test provides valuable insights into participants' ability to maintain balance under various sensory conditions. The slightly impaired to normal mean scores in ROA, ROC, and RGA for both groups suggest that, at baseline, they were able to maintain stability under relatively stable conditions (with eyes open or on a foam cushion). However, the functionally impaired scores in RGC for both groups indicate difficulty in maintaining balance with eyes closed on an unstable surface. This reflects a more challenging sensory condition. The lack of significant differences between the two groups' scores suggests that, at baseline, both groups faced similar challenges in maintaining postural stability.

The baseline results of mediolateral (ML) and anteroposterior (AP) stability during the Romberg tests showed no statistically significant differences between the MRP and CPT groups. These measures assess the ability to maintain balance in a static position under different sensory conditions, where ML stability refers to the ability to maintain balance in the side-to-side direction and to control lateral sway, and AP stability represents balance control in the front-to-back direction and to control anteroposterior sway. Both groups demonstrated similar ML and AP stability, suggesting comparable baseline balance abilities. It is noteworthy that all study participants showed a limited ability to maintain ML stability, and this aspect was more affected than AP stability among the participants. This finding indicates that participants had greater difficulty maintaining balance in the mediolateral direction, which aligns with common observations in stroke survivors [152, 160].

The assessment of the contribution of sensory systems to balance did not reveal any significant differences between the MRP and CPT groups. This comprehensive assessment includes somatosensory, visual, vestibular, and dynamic indices, as well as a sensory-dynamic total score. These evaluations provide insights into how the somatosensory, visual, vestibular, and dynamic systems contribute to balance control. The comparable scores in these indices indicate that both groups had similar reliance on sensory systems for maintaining balance. Despite the stroke's impact, the results showed a slight impairment in the somatosensory index, indicating that participants in both groups experienced some challenges in processing sensory information from the body's proprioceptive receptors. On the other hand, the visual index was within the normal range for all study participants, implying that visual information played a relatively stable role in balance control. However, the vestibular and dynamic indices were more affected, which reflect the vestibular system's contribution to balance control and the participants' ability to adjust body posture during dynamic activities, respectively. The mean sensory-dynamic total score, which reflects their overall performance on the sensory integration scores, indicated that participants in both groups had impaired sensory-dynamic control of balance. These findings suggest that stroke survivors may face challenges in effectively integrating sensory inputs to maintain balance during static and dynamic tasks. These findings are in line with common observations in individuals after a stroke, as stroke can commonly affect the sensory organization and regulation of balance control [148]. Stroke can disrupt this integration, affecting the ability to select and rely on the most relevant sensory input for any given circumstance, which is known as sensory reweighting, leading to deficits in balance control and an increased risk of falling [166].

The results of the limits of stability (LOS) assessment indicate that there were no statistically significant differences between the two groups in any of the LOS tests. This suggests that, at the beginning of the study, both groups had similar abilities to control their stability and maintain balance during the LOS tasks. The mean maximum displacement score, which reflects the ability to move the center of gravity to the maximum distance reached by the participant within the base of support, was similar and comparable between the MRP and CPT groups. The mean maximum displacement scores for both groups indicated that the participants in both groups had slightly impaired abilities. Similarly, there were no significant differences between the groups in the mean directional control score, which reflects the ability to move the center of gravity towards a specified target direction during the LOS tasks. The similar scores indicate that both groups had comparable control over their movement direction during the tasks, with participants in both groups showing functionally impaired abilities to control their center of gravity during the LOS tasks. The mean reaction time, which measures the participant's response speed in initiating movement towards each of the stability limits to reach the target, was also similar between the two groups. The lack of statistical significance suggests that both groups had comparable reaction times, indicating similar abilities to initiate and execute movements in response to the LOS task demands. However, participants in both groups showed slow and delayed reaction time mean scores. Furthermore, the mean LOS total score, which combines various aspects of the LOS assessment, such as maximum displacement, directional control, and reaction time, did not show a significant difference between the groups. This indicates that, overall, both groups had similar performance in the LOS tasks at baseline, and the mean LOS total score for the participants in both groups indicates functionally impaired LOS control. These findings are in line with common observations after a stroke, as stroke can affect the LOS by reducing the ability to control body movements within the stability limits [163]. This can impair balance and increase the risk of falls.

There was no significant difference in AP rhythmic and directional control between the two groups. This measure evaluates the ability to control anteroposterior sway during rhythmic weight shifts. The similar scores obtained by both groups indicate that they had comparable levels of balance control in the AP direction. The mean AP rhythmic and directional control scores for both groups indicate that the participants had a limited ability to control their posture in the AP direction. On the other hand, there was a statistically significant difference in ML rhythmic and directional control between the two groups, with the MRP group demonstrating better performance at baseline. ML rhythmic and directional control assesses the ability to control lateral sway during rhythmic weight shifts. The mean ML rhythmic and directional control scores for both groups indicate that the participants had a similar limited ability to control their posture in the ML direction. However, this difference in ML control did not significantly affect the overall postural control assessment total score, which did not show a significant difference between the MRP and CPT groups at baseline. The total score was comparable between the two groups and indicated that participants in both groups had similar limited abilities to control their posture. These findings are consistent with the commonly observed postural control impairments among individuals who have experienced a stroke [29, 137]. The findings suggest that, at the baseline, both groups had comparable levels of postural control.

In terms of functional balance assessment, no significant difference was found between the MRP and CPT groups in the global score at baseline. The functional balance assessment evaluates the participants' overall functional balance performance, taking into account various static and dynamic tasks. The absence of a significant difference suggests that both groups' participants had similar functional balance abilities at the start of the study. The interpretation of the functional balance assessment global score reveals that a substantial proportion of participants in both groups had slightly impaired balance, while a smaller percentage had functionally impaired or normal balance. These findings indicate that the study participants, regardless of the intervention group, generally had some degree of balance impairment at baseline. Since both groups had similar functional balance abilities at baseline, the subsequent effects of the MRP and CPT interventions can be more accurately assessed and compared.

Overall, the functional balance assessment provides a valuable baseline reference for evaluating the effects of the MRP and CPT interventions on functional balance. The baseline results show no significant differences between the groups in most of the functional balance measures, indicating that they were well-balanced and equivalent in their initial performance. The similarity in functional balance abilities between the groups ensures that any changes observed in post-intervention or follow-up assessments can be confidently attributed to the interventions. This provides a valid basis for comparing the effectiveness of the interventions in improving functional balance over time.

Functional gait analysis

In terms of gait speed, both groups had comparable mean values and showed no significant differences in absolute gait speed (measured in m/s). The mean scores for participants from both groups indicated that they had similar slow gait speeds, which aligns with common observations in stroke survivors [209, 215]. These slow gait speeds suggest that the participants were limited community ambulators [214]. For the gait speed as a percentage of normality, which reflects the ability to approach a normal walking pace compared to healthy individuals, there were no significant differences between the groups. The mean gait speed values were similar in both groups, indicating that initial differences in gait speed were not present. The mean scores for both groups suggest that the participants had limited walking speed compared to healthy individuals.

Furthermore, the difference in the support time score, which measures the disparity between the support time (stance time) of each leg during the gait cycle, did not show a statistically significant difference between the groups. This suggests that the participants from both groups had similar stance periods during walking at baseline. The mean scores for participants from both groups indicate a limited ability to balance the support time between each leg, with less support time on the paretic leg. The absence of a significant difference in the support time score at baseline indicates that both groups demonstrated a comparable difference in the support time during walking. However, the limited ability to balance the support time between the legs, with greater reliance on the non-paretic leg, highlights a common asymmetry observed in stroke survivors [211, 221].

Regarding force parameters, ground reaction forces were assessed for various force parameters during gait, including AP braking force, AP propulsion force, vertical take-off force, and oscillation force. These parameters reflect the participants' ability to generate and control forces during gait. The results showed no significant differences between the groups, indicating that the overall forces exerted during gait were similar in both groups at baseline. The mean scores for all participants from both groups indicate that there was a reduction in the various force parameters during gait. The most affected force parameters were AP braking force and AP propulsion force, which is in line with common observations in individuals with stroke [236]. The reduction in these forces can contribute to difficulties in controlling forward propulsion and deceleration during walking. While the vertical take-off force and oscillation force were slightly impaired, indicating challenges in generating force during the push-off phase and maintaining stability during the swing phase of the affected limb. This is typically observed in hemiparetic patients and aligns with the specific gait characteristics commonly seen in stroke survivors [213].

In terms of force morphology, which assesses the shape and pattern of force application during gait, there was no significant difference between the groups in the AP force morphology global score. This indicates that the groups had similar patterns of force production in the anteroposterior direction during walking. Similarly, there was no significant difference between the groups in the vertical force morphology global score, indicating that the groups had similar patterns of force production in the vertical direction during gait. The only exception was the ML force morphology global score, which was significantly lower in the CPT group than in the MRP group. This suggests that the CPT group had less lateral stability and symmetry during gait, and there were differences in force distribution between the two groups in the ML plane. However, despite this difference, it did not affect the overall functional gait analysis global score, which remained comparable between the two groups. Participants from both groups exhibited impairment in all force morphologies, with the most affected being the ML force morphology, followed by the AP force morphology, and then the vertical force morphology. These findings align with common observations in individuals with stroke, who often experience challenges in generating and controlling forces in multiple planes during gait [211, 213]. The reduced ML force morphology indicates challenges in lateral stability and weight distribution, which are commonly observed in stroke survivors [211, 244].

Regarding functional gait analysis, there was no significant difference between the MRP and CPT groups in the global score. This suggests that both groups exhibited similar overall functional gait performance and characteristics at baseline. Additionally, when interpreting the gait analysis global score, no significant difference was found, indicating that the overall gait impairment levels were comparable between the two groups. The mean functional gait analysis global scores for both groups indicate functionally impaired gait performance in both groups. These findings suggest that the study participants, regardless of the intervention group, generally had functionally impaired gait at baseline. The lack of a significant difference in the functional gait analysis global score at baseline is an essential starting point for assessing the effects of the MRP and CPT interventions on gait performance. The similarity in baseline gait impairment levels ensures that any changes observed after the interventions can be attributed to the effects of the interventions.

Overall, the baseline results showed no significant differences between the MRP and CPT groups in most of the gait speed, kinetic gait parameters, and force morphology measures. This indicates that the participants from both groups had similar gait characteristics and force patterns before the interventions. The similar baseline gait performance between the groups ensures that any changes observed after the interventions can be confidently attributed to the effects of the interventions. This provides a valid basis for evaluating the effectiveness of the MRP and CPT interventions in improving gait and force control over time.

7.3 Changes from baseline to post-intervention

7.3.1 Changes in clinical outcome measures

In terms of balance, both groups exhibited statistically significant improvements in the mean BBS score. Nevertheless, the MRP group demonstrated a significantly higher improvement in the mean BBS score (13.78) compared to the CPT group (6.90). Notably, the mean changes in both groups exceeded the minimal detectable change for clinically important differences, which is 6 BBS points, providing 90% confidence in genuine change for stroke patients [367]. These findings strongly suggest that the MRP intervention is a superior for enhancing balance recovery after stroke. The effect sizes of both interventions were large, indicating clinically meaningful changes. Additionally, the difference in effect size between the two groups was also substantial, favoring the MRP intervention, which further signifies a meaningful difference between the groups and highlights the significant impact of the MRP intervention on participants' balance performance and fall risk reduction. The results suggest that the MRP intervention was more effective in improving balance control and stability compared to conventional physical therapy.

Similarly, for the TUG test, both groups showed statistically significant improvements in mean TUG time, indicating enhanced mobility. However, the MRP group exhibited a significantly greater reduction in mean TUG time (-7.39 seconds) compared to the CPT group (-2.54 seconds). It is noteworthy that the mean change in the MRP group surpassed the minimal detectable change for clinically important differences of the TUG test, which is 2.9 seconds for stroke patients [371]. Conversely, the mean change in the CPT group was less than the minimal detectable change of the TUG test. These results strongly suggest that the MRP intervention is a superior approach for enhancing mobility recovery after stroke. The effect sizes of both interventions were large, indicating that the observed changes were clinically meaningful. The large effect size between the two groups further supports the superiority of the MRP intervention, as it signifies a more significant impact on participants' functional mobility performance and fall risk reduction. This implies that the MRP intervention had a more pronounced impact on reducing the time taken to perform the TUG test, implying improved functional mobility.

In terms of gait velocity, both groups demonstrated statistically significant improvements in mean self-selected and fast gait velocities on the 10mWT, indicating that both MRP and CPT are effective interventions for improving gait speed in stroke survivors. However, the MRP group showed significantly greater improvements in both self-selected and fast gait velocities compared to the CPT group. The mean change in self-selected gait velocity in the MRP group (0.28 m/s) was higher than the minimal detectable change for clinically important differences of the 10mWT test, which is 0.16 m/s for stroke patients [434], while the mean change in the CPT group (0.10 m/s) fell below this threshold. These results strongly suggest that the MRP intervention is a superior for enhancing gait recovery after a stroke, leading to more substantial improvements in gait velocity. The effect size values for gait velocity changes were relatively high, indicating substantial differences between the two groups. The large effect sizes observed in the MRP group further support that the intervention had a significant impact on the participants' gait performance. This implies that the MRP intervention had a stronger effect on enhancing gait performance and increasing walking speeds compared to conventional physical therapy. These results highlight the importance of considering both self-selected and fast gait velocities when evaluating the impact of interventions on gait performance. Faster gait velocities are associated with improved functional mobility and can lead to enhanced independence for stroke survivors [435, 436].

Regarding functional independence, both groups demonstrated statistically significant improvements in the mean BI score, indicating that both interventions were effective in enhancing the functional independence of stroke survivors. However, the MRP group exhibited a significantly greater improvement in the mean BI score, with a mean change of 17.81, compared to 8.23 in the CPT group. Notably, both groups had a higher mean change than the minimal detectable change for clinically important differences of the BI, which is 6.84 [437], suggesting that the MRP intervention has a superior effect on enhancing functional independence after a stroke. The effect sizes of both interventions were large, indicating that the observed changes were clinically meaningful. The substantial difference in effect size between the two groups further reinforces the advantage of the MRP group, implying that the MRP intervention had a more significant impact on improving functional independence compared to CPT. These findings indicate that the MRP intervention was more effective in promoting functional independence and improving the ability to perform activities of daily living.

Furthermore, both the MRP and CPT interventions proved effective in improving the physical function of stroke survivors, as measured by the SIS-16. However, the

MRP group demonstrated a significantly higher improvement in the mean SIS-16 score compared to the CPT group. The mean change in the MRP group (14.59) exceeded the minimal detectable change for clinically important differences of the SIS-16, which is 13.2 [412], while the CPT group (7.06) had a mean change below the minimal detectable change. These results suggest that the MRP intervention has a superior effect on enhancing functional recovery after a stroke. The effect sizes of both interventions were large, indicating that the observed changes were clinically meaningful. Moreover, the substantial difference in effect size between the two groups further implies that MRP had a significant advantage over CPT in terms of physical function improvement following a stroke.

Overall, the results of this study demonstrated that both the MRP and CPT interventions led to significant improvements in various clinical outcome measures. However, the MRP group exhibited significantly greater improvements than the CPT group across all outcome measures, including balance, mobility, gait performance, functional independence, and physical function. These findings suggest that the MRP intervention is a superior approach for enhancing post-stroke recovery.

7.3.2 Changes in instrumental analysis of balance and gait

Functional balance assessment

In terms of static posturography tests, both interventions significantly improved the participants' static posturography for all measures after the intervention, reflecting their ability to maintain balance in a static position under different sensory conditions. However, it is noteworthy that the MRP intervention was more effective than the CPT intervention in improving static posturography. This is evident from the larger mean changes and effect sizes observed in the MRP group for most tests. Specifically, the MRP group showed significant improvements in their ROC and RGC scores, which reflect the ability to maintain balance and adapt to changing sensory conditions without visual input or while standing on an unstable surface, respectively. These tests are more challenging for the balance system, as they require greater reliance on proprioceptive and vestibular inputs. This suggests that the MRP intervention had a greater impact on enhancing the ability to improve static postural stability than CPT, particularly in conditions where visual input is absent or unreliable. Both groups also significantly improved their ROA and RGA scores, which reflect the ability to maintain balance on stable and unstable surfaces and the ability to use visual cues for balance, respectively. While the MRP group showed a higher improvement, the difference between the groups was not statistically significant, indicating that both MRP and CPT had a positive effect on enhancing postural stability and visual integration for balance. These findings suggest that the MRP intervention had a more substantial impact on enhancing static balance control under different sensory conditions and improving the ability to adapt to changing sensory conditions in patients with stroke, which are essential skills for maintaining balance in complex and dynamic environments.

Regarding ML and AP stability during the Romberg tests, both interventions improved the ML and AP stability of the participants, reflecting their ability to maintain balance in a static position under different sensory conditions. However, the MRP intervention was more effective than the CPT intervention in improving ML stability, which reflects the ability to control lateral sway. This is evident from the larger mean change and effect size observed in the MRP group. These findings suggest that the MRP intervention had a more substantial impact on the participants' ability to maintain lateral stability during standing tasks. Enhancing ML stability is essential for activities that require balance maintenance in the mediolateral direction. This difference could be attributed to the fact that the MRP intervention involved more ML movements that challenged the participants to control their ML sway, while the CPT intervention involved fewer ML movements that did not require as much ML stability. The significant difference between the two groups indicates that the direction and amplitude of movements may have a significant influence on ML stability outcomes. Both groups significantly improved their AP stability score, which reflects the ability to control anteroposterior sway. This is shown by the larger mean change and effect size observed in both groups, indicating that both interventions were effective in improving AP stability. This improvement could be attributed to the fact that both interventions involved similar amounts of AP movements, which required similar levels of AP stability. The difference between the two groups in AP stability score was marginally statistically significant, indicating that the MRP intervention was more effective in improving AP stability, which is important for maintaining balance during standing and reaching.

In terms of changes in the assessment indices for the contribution of sensory systems, both groups exhibited significant improvements in sensory system contributions to functional balance in stroke survivors, as indicated by changes in somatosensory, visual, vestibular, and dynamic indices. These changes suggest that both groups improved their sensory integration for balance control after the intervention, but the MRP group showed greater improvement than the CPT group in all indices. The MRP group significantly improved their somatosensory, vestibular, and dynamic indices, which reflect their ability to use somatosensory, vestibular, and multiple sensory cues to maintain static and dynamic balance, respectively. These results suggest that the MRP intervention had a greater effect on enhancing somatosensory-vestibular integration and dynamic balance performance, which are important skills for fall prevention and functional mobility. The CPT group also significantly improved their somatosensory, vestibular, and dynamic indices, indicating that their sensory integration and dynamic balance performance also improved after the intervention. However, the difference between the two groups was statistically significant in somatosensory, vestibular, and dynamic indices, which may indicate a specific effect of MRP on these aspects of balance performance. Both groups significantly improved their visual index, which reflects their ability to use visual cues to maintain balance. These results suggest that both MRP and CPT have a positive effect on enhancing visual integration for balance control, which is important for maintaining balance in complex and dynamic environments. However, the difference between the two groups in the visual index was not statistically significant. The effect sizes of both interventions were large for most of the sensory indices, indicating that the changes were clinically meaningful and not due to chance. The difference in effect size between the two groups was also large for some of the sensory indices, implying that MRP had a substantial advantage over CPT in terms of sensory integration for functional balance. This suggests that the MRP intervention had a superior impact on enhancing the integration of sensory information and sensory reweighting for balance control after a stroke.

Moreover, both groups significantly improved their sensory-dynamic total score, which reflects their overall performance on the sensory integration scores and their ability to utilize multiple sensory cues to maintain balance during dynamic tasks, such as walking and turning. However, the MRP intervention was more effective than the CPT intervention in enhancing sensory-dynamic balance performance, which is important for preventing falls and functional mobility. This is evidenced by the larger mean change and effect size in the MRP group. This difference could be explained by the fact that the MRP intervention involved more sensory stimulation and integration, requiring participants to use different sensory systems to maintain their balance, while the CPT intervention involved less sensory challenge and variation that did not activate different sensory systems as much. The significant differences between the two groups indicate that the level and diversity of sensory input may have a significant impact on the contribution of sensory systems to balance.

In terms of the assessment of limits of stability (LOS), both the MRP and CPT interventions were effective in improving the limits of stability. However, it is notable that the MRP group showed a greater improvement than the CPT group in all of the parameters, including the maximum displacement, directional control, reaction time, and LOS total score. These parameters reflect the ability to move the center of gravity as far as possible, the ability to move the center of gravity toward a target direction without losing balance, the speed of initiating a movement, and the overall performance on the limits of stability test, respectively. These results suggest that the MRP intervention had a greater impact on improving the limits of stability and enhancing the control of balance during weight shifting, which is crucial for preventing falls and performing functional tasks that require reaching and shifting weight. The effect sizes of both interventions were large for all of the parameters, indicating that the observed changes were clinically meaningful. Furthermore, the difference in effect size between the two groups was also large for all of the parameters, implying that MRP had a substantial advantage over CPT in terms of improving limits of stability after a stroke. This difference in improvement could be attributed to the fact that the MRP intervention involved more dynamic and complex balance tasks that challenged the participants to move their center of gravity closer to their limits of stability. On the other hand, the CPT intervention involved more static and simple balance tasks that did not require as much movement of the center of gravity.

Furthermore, both groups demonstrated significant improvements in both ML and AP rhythmic and directional postural control after the intervention, which reflect their ability to control lateral and anteroposterior sway during rhythmic weight shifts. However, it is evident that the MRP group showed significantly greater improvement in their ML and AP rhythmic and directional control scores. These results suggest that the MRP intervention was more effective in improving rhythmic control and direction-specific stability during dynamic tasks, which are important for performing activities that require changing direction and speed. Both groups significantly improved their postural control assessment total score, which reflects their overall performance on the postural control test. This result indicates that both

MRP and CPT have a positive effect on enhancing balance performance, which is essential for preventing falls and maintaining mobility. However, the difference between the two groups in the postural control assessment total score was statistically significant, suggesting that MRP has a superior effect on enhancing postural control after a stroke. The effect sizes of both interventions were large for all postural control parameters, indicating that the observed changes were clinically meaningful. Moreover, the difference in effect size between the two groups was also large for all postural control parameters, implying that MRP had a substantial advantage over CPT in terms of postural control improvement. This advantage of the MRP intervention could be explained by the fact that it involved more rhythmic and directional movements that required the participants to adjust their balance in different directions and at varying speeds. In contrast, the CPT intervention involved more static and linear movements that did not challenge the participants' rhythmic and directional control. The significant differences between the two groups indicate that the type and complexity of the movements may have a significant impact on the postural control outcomes.

In terms of the functional balance assessment global score, which is a composite score of all the functional balance tests, both the MRP and CPT interventions were effective in improving functional balance among the study participants. However, it is noteworthy that the MRP group showed a significantly greater improvement than the CPT group in the functional balance assessment global score. This finding strongly suggests that the MRP intervention has a superior effect on enhancing functional balance performance, which is crucial for performing daily activities and preventing falls. The effect sizes of both interventions were large, indicating that the observed changes were clinically meaningful and not due to chance. Moreover, the difference in effect size between the two groups was also large, implying that MRP had a substantial advantage over CPT in enhancing overall functional balance. This difference further suggests a specific effect of MRP on balance performance after a stroke. This advantage of the MRP intervention could be attributed to the fact that it involved more functional and task-oriented balance exercises that simulated real-life situations. In contrast, the CPT intervention involved more general and non-specific balance exercises that did not target specific functional tasks. The significant difference between the two groups suggests that the specificity and relevance of the balance exercises may have a significant influence on the functional balance outcomes.

Overall, the findings of this study revealed significant improvements in functional balance assessments for both the MRP group and the CPT group following the intervention. However, it is noteworthy that the MRP group consistently displayed more substantial mean changes and higher effect sizes compared to the CPT group across the majority of the measures. These results suggest that the MRP intervention proved to be more effective in enhancing functional balance.

Functional gait analysis

In terms of gait speed, the study observed that both the MRP and CPT groups showed statistically significant improvements in the gait speed of the participants. However, the MRP group exhibited a significantly greater improvement in gait speed, both in m/s and as a percentage of normality. These improvements reflect the ability to walk faster and more efficiently, as well as the ability to approach a normal walking pace compared to healthy individuals. These results suggest that the MRP intervention was highly effective in improving walking speed, which is essential for enhancing mobility in individuals post-stroke. The CPT group also experienced a significant improvement in gait speed, both in m/s and as a percentage of normality, indicating that their gait speed also improved after the intervention. However, the statistically significant difference between the two groups in gait speed (in m/s) indicates a specific and more pronounced effect of the MRP intervention on gait speed outcomes. The observed effect size values further support the meaningful difference between the groups, favoring the MRP intervention. This suggests that the MRP intervention was more effective in increasing the walking speed of the stroke survivors, indicating that the MRP intervention helped participants approach more normalized walking speeds. Gait speed is a critical indicator of functional mobility, and an improvement in this measure has practical implications for enhancing the independence and quality of life of individuals with gait deficits [435]. This difference in gait speed improvements could be attributed to the fact that the MRP intervention involved more focused gait training and re-learning, requiring the participants to practice walking at different speeds and distances, while the CPT intervention involved less specific gait training and more general exercises that did not target the same level of gait parameters. The significant difference between the two groups further indicates that the type and intensity of the gait training may have a significant impact on the gait speed outcomes.

Additionally, both interventions improved the difference in support time of the participants, which reflects the support time (stance time) of each leg during the gait cycle and their ability to balance their weight equally between their legs during walking. However, it is evident that the MRP intervention was more effective than the CPT intervention in improving the difference in support time. This is demonstrated by the larger mean change and effect size in favor of the MRP group, indicating that MRP can improve the gait symmetry of stroke patients more effectively than conventional therapy. This finding suggests that the MRP intervention was more successful in improving the distribution of weight and temporal aspects of gait, such as the timing of weight-bearing or stance phase, resulting in a more symmetrical distribution of support time during walking. This improvement is particularly important as proper support time distribution is essential for maintaining stability and efficient walking after a stroke. The effectiveness of the MRP intervention in improving support time distribution could be attributed to the fact that it involved more symmetrical and bilateral exercises, which required the participants to use both legs equally. In contrast, the CPT intervention included more unilateral and asymmetrical exercises that did not specifically address the weight distribution between the legs. The significant difference between the two groups suggests that the symmetry and balance of the exercises may have a substantial influence on the difference in support time outcomes.

Regarding force parameters, the results indicate that both the MRP and CPT interventions were effective in improving the ground reaction forces for various force parameters during gait, including AP braking force, AP propulsion force, vertical take-off force, and oscillation force. These parameters reflect the participants' ability to generate and control forces during walking, which are crucial for maintaining a stable and efficient gait pattern. Both the MRP and CPT groups demonstrated statistically significant improvements in the mean AP braking force global score, which reflects the ability to control forward deceleration during the gait cycle and is crucial for controlled and safe forward motion. While the MRP group displayed a higher mean change compared to the CPT group, this difference was not statistically significant. Both groups also showed statistically significant improvements in the mean AP propulsion force global score, which reflects the ability to generate forward momentum and is essential for propelling the body forward during the gait cycle. However, the MRP group exhibited a significantly greater mean change compared to the CPT group, and the difference between the two groups was statistically significant. Additionally, both groups displayed a statistically significant improvement in the mean vertical take-off force global score, which reflects the ability to generate optimal vertical force patterns and is related to the capacity to lift off the ground during the push-off phase of walking. Although the MRP group showed a greater mean change compared to the CPT group, this difference was not statistically significant. Furthermore, both groups demonstrated improvement in the mean oscillation force global score, which reflects the ability to control lateral oscillation or sway during walking, which is essential for the smoothness and stability of the gait pattern. The MRP group displayed a significant mean change, while the CPT group showed a non-significant mean change, and the difference between the two groups was also not statistically significant. The effect sizes of both interventions were moderate to large for some of the ground reaction force parameters, indicating that the changes were clinically meaningful. The difference in the effect size between the two groups was also moderate to large for some of the ground reaction force parameters, implying that the MRP intervention had a substantial advantage over CPT in terms of ground reaction force improvement. These results suggest that the MRP intervention had a more pronounced effect on enhancing the ground reaction forces that are crucial for gait control and mechanics, leading to improved walking efficiency, stability, and speed after a stroke. This difference could be attributed to the fact that the MRP intervention involved more dynamic and functional exercises that required the participants to produce and modulate forces in different directions and magnitudes. In contrast, the CPT intervention involved more static and passive exercises that did not challenge the participants' force generation and control effectively.

Furthermore, both the MRP and CPT interventions were effective in improving all force morphologies, reflecting the participants' ability to generate smooth and symmetrical force patterns during walking. However, the MRP group showed significantly higher mean changes and larger effect sizes in AP force morphology and ML force morphology compared to the CPT group. This indicates a more favorable shift towards normal force patterns during walking in the MRP group, particularly in terms of mediolateral and anteroposterior force control. These findings suggest that the MRP intervention had a greater impact on enhancing mediolateral and anteroposterior force control and modifying force patterns during gait, leading to more substantial improvements in the force distribution along the AP and ML axes. Additionally, both groups significantly improved their vertical force morphology global score, reflecting the ability to generate optimal vertical force patterns during walking. The difference between the two groups was not statistically significant in the vertical force morphology global score, suggesting that both MRP and CPT interventions were equally effective in improving the ability to produce smooth and symmetrical forces in the vertical direction. Overall, these findings indicate that the MRP intervention had a greater impact on improving force patterns in the sagittal and frontal planes but did not significantly differ from the CPT group in vertical force patterns. This implies that MRP had a substantial advantage over CPT in terms of force morphology improvement. The observed differences in force morphology are likely attributed to the fact that the MRP intervention involved more gait re-learning and feedback, emphasizing the improvement of gait quality and symmetry. In contrast, the CPT intervention involved less emphasis on gait re-learning and feedback. Force morphology plays a crucial role in maintaining stability and reducing the risk of falls during walking, making these improvements highly relevant for clinical practice.

In terms of the functional gait analysis global score, which represents a composite score of all the gait parameters and tests and reflects the participants' ability to walk with normal gait patterns and parameters, the results indicate that both the MRP and CPT interventions were effective in improving gait performance after the intervention. However, the MRP group showed a greater improvement than the CPT group in the functional gait analysis global score, suggesting that MRP had a superior effect on enhancing gait performance after a stroke. The effect sizes of both interventions were large, indicating that the changes were clinically meaningful and not due to chance. The difference in the effect size between the two groups was also large, implying that MRP had a significant advantage over CPT in terms of gait performance improvement, which is crucial for functional mobility. This difference in effectiveness could be attributed to the fact that the MRP intervention involved more targeted gait training and re-learning, which required the participants to practice walking with normal gait patterns and parameters. On the other hand, the CPT intervention involved more general exercises that did not specifically target gait patterns and parameters. The significant difference between the two groups suggests that the type and intensity of the gait training may have a significant impact on the functional gait analysis outcomes.

Overall, the results of the functional gait analysis in this study demonstrate that the MRP and CPT groups showed statistically significant improvements in various gait parameters after the intervention. Compared to the CPT intervention, the MRP intervention showed greater improvements and larger effects in most of the gait parameters. This suggests that MRP was more effective than CPT in improving the functional gait performance of stroke survivors with gait impairments. These findings support the importance of targeted and task-specific gait training in stroke rehabilitation. Interventions like MRP, which focus on gait re-learning and normalization, lead to more substantial improvements in gait performance than conventional physiotherapy. Enhancing gait performance is essential for promoting functional mobility and independence in individuals post-stroke [436].

7.4 Changes from post-intervention to 3-months follow-up

7.4.1 Changes in clinical outcome measures

Regarding the BBS, both the MRP and CPT groups were able to maintain their balance improvement at the 3-month follow-up. The MRP group demonstrated a statistically significant increase in the BBS score, while the increase in the CPT group was negligible and not statistically significant. However, there was no significant difference between the groups, and the effect size between the two groups was also small. These findings suggest that the MRP intervention was more effective in maintaining and promoting balance in stroke survivors at the 3-month follow-up.

For the TUG test, the MRP group demonstrated a significant reduction in mean TUG time at the 3-month follow-up, indicating that they were able to perform the task faster and more efficiently. In contrast, the CPT group showed no change in TUG time, suggesting that they did not experience any improvement or deterioration in their mobility. While the difference in TUG time change between the two groups was not statistically significant, the difference in effect size between the two groups was moderate. These findings suggest that both the MRP and CPT interventions were effective in maintaining functional mobility, with the MRP intervention being more effective in promoting improvement at the 3-month follow-up.

The results of the 10mWT indicated that both groups experienced an improvement in mean self-selected gait velocity. The MRP group showed a statistically significant increase in self-selected gait velocity, whereas the CPT group had a non-significant improvement. However, the difference in mean change between the two groups was not statistically significant. On the other hand, when assessing fast gait velocity on the 10mWT, the MRP group demonstrated a significant increase, while the CPT group exhibited a slight reduction. Notably, the difference in mean change between the two groups was statistically significant. The effect size for self-selected gait velocity was small, while for fast gait velocity, it was moderate. These findings suggest that MRP had a moderate advantage over CPT in maintaining and promoting gait speed during the follow-up period.

Regarding the BI, both groups showed a statistically significant improvement in the mean BI score. However, the CPT group exhibited a greater improvement in functional independence than the MRP group. The difference in the mean change of BI score between the two groups was also statistically significant, and the effect size of the difference was moderate, favoring the CPT group. This finding indicates that both interventions contributed to sustaining and promoting functional independence over the 3-month follow-up period.

Furthermore, both groups showed a similar and statistically significant improvement in physical function, as measured by the SIS-16. However, the difference in the mean change of SIS-16 score between the two groups was not statistically significant, and the effect size of the difference was negligible. This suggests that both interventions had a similar advantage in terms of maintaining the improvement in physical function at the follow-up period.

Overall, the results regarding the changes in clinical outcome measures from post-intervention to the 3-month follow-up provide valuable insights into the long-term effects of both the MRP and CPT interventions. It is evident that both groups successfully maintained the improvements in the clinical outcome measures of study participants during the post-intervention to the 3-month follow-up period. However, notable differences between the two groups were observed, with the MRP intervention showing more favorable outcomes. Importantly, the MRP intervention had a more pronounced impact on maintaining and promoting the achieved improvements in various outcome measures over the 3-month follow-up period. These findings underscore the potential benefits of MRP for stroke patients in terms of long-term effectiveness.

7.4.2 Changes in instrumental analysis of balance and gait

Functional balance assessment

Regarding static posturography tests, both groups maintained their improvements in static posturography scores at the 3-month follow-up. However, the MRP group exhibited a slightly greater enhancement than the CPT group in some aspects of static posturography scores, particularly the RGA and RGC scores. This suggests that MRP might have a superior effect on sustaining and promoting the improvements in static postural control after a stroke, reflecting the ability to maintain balance in various sensory conditions and adapt to changes in sensory inputs. Conversely, the CPT group did not exhibit any significant change in their static posturography scores, indicating that their balance performance remained stable but did not improve further after the intervention. Nevertheless, the difference between the two groups in terms of scores was not statistically significant, and the effect size difference between the groups was small to moderate for some of the static posturography scores. These findings suggest that both interventions were effective in maintaining the improvement achieved after the intervention, and the MRP had a more significant impact on promoting the ability to maintain balance in different sensory conditions in patients with stroke at the follow-up period. It's possible that the MRP group retained the sensory integration skills learned during the intervention phase, which could have improved their confidence and reduced their fear of falling.

During the Romberg tests, both MRP and CPT interventions were effective in maintaining or slightly improving ML and AP stability from post-intervention to the 3-month follow-up. Notably, the MRP group exhibited a significantly greater improvement in ML stability compared to the CPT group. The statistical significance of this difference and the moderate effect size between the two groups imply that MRP had a more substantial impact on enhancing ML stability in stroke patients. The results suggest that the MRP group likely retained the motor skills and strategies learned during the intervention phase, which could have contributed to improved balance control and a reduced risk of sideways falls. Conversely, both groups did not show significant improvements in their AP stability, indicating that the initial gains made during the interventions were maintained over the follow-up period.

The results of the assessment indices for the contribution of sensory systems, from post-intervention to the 3-month follow-up, indicate that both groups maintained and improved their sensory integration for balance control after the intervention. For the somatosensory index, both groups exhibited a slight, non-significant improvement, indicating that they sustained the improvement achieved after the intervention. However, the MRP group demonstrated significant increases in their visual and vestibular indices, which reflect their ability to effectively use visual and vestibular cues to maintain balance. These findings suggest that MRP had a positive effect on enhancing visual-vestibular integration, which is important for maintaining balance in complex and dynamic environments. In contrast, the CPT group did not show significant improvement in either visual or vestibular indices, indicating that their sensory integration remained stable but did not improve further after the intervention. It is worth noting that the difference between the two groups was not statistically significant in any of the sensory indices. However, both groups maintained and exhibited significant improvements in their dynamic index and sensory-dynamic total score. These findings suggest that both MRP and CPT interventions were effective in maintaining and promoting dynamic balance performance, which is a critical factor for functional mobility and fall prevention.

For the limits of stability (LOS) assessment, both groups maintained their improvements in balance performance after the intervention, but the MRP group showed greater enhancement in some aspects. Specifically, the MRP group showed a significant improvement in their directional control score, which reflects their ability to move the center of gravity towards a target direction without losing balance. This finding suggests that MRP had a positive effect on enhancing voluntary control of balance, which is crucial for performing functional tasks that require reaching and shifting weight. On the other hand, the CPT group did not show any significant improvement in directional control, indicating that their voluntary balance control remained stable but did not improve further after the intervention. The difference between the two groups in directional control was significant, and the effect size of the difference was moderate, suggesting a specific and advantageous effect of MRP on this aspect of balance performance.

Neither group showed any significant improvement in maximum displacement or reaction time, which reflect the ability to move the center of gravity as far as possible and the speed of initiating a movement, respectively. These results imply that both MRP and CPT interventions were effective in maintaining these aspects of balance performance. Both groups, however, showed an improvement in their LOS total score, which reflects their overall performance in the limits of stability test. Notably, the MRP group demonstrated a statistically significant improvement in their LOS total score. Although there was no significant difference between the groups in terms of LOS total score, the effect size between the two groups was also small. These findings suggest that MRP had a positive and beneficial effect on maintaining and promoting limits of stability during the follow-up period.

Furthermore, both the MRP and CPT groups exhibited similar improvements in most of the postural control parameters, including ML and AP rhythmic and directional control, which reflect their ability to control lateral and anteroposterior sway during rhythmic weight shifts. Neither group showed any significant change in their ML or AP rhythmic and directional control scores, and the effect size of the difference between the two groups was also small to moderate for the postural control parameters. This suggests that both MRP and CPT interventions were effective and had a similar advantage in maintaining the improvement in rhythmic and directional postural control at the follow-up.

Moreover, the result of the postural control assessment total score at the 3-month follow-up indicated that both groups maintained their improvements in postural control performance after the intervention. The MRP group showed a marginally significant improvement in their total score, suggesting that MRP had a positive and lasting effect on enhancing global postural control performance, which is important for preventing falls and maintaining mobility. The CPT group, on the other hand, did not show any significant improvement in their total score, indicating that they maintained but did not improve their postural control performance after the intervention. However, there was no significant difference between the two groups, and the effect size between the two groups was also small. This implies that both groups were effective in maintaining the improvements they achieved. Additionally, the MRP intervention had a more pronounced impact on maintaining and promoting postural control over the follow-up period.

Considering the functional balance assessment global score, the results from post-intervention to the 3-month follow-up indicate that both groups maintained and improved their functional balance performance after the intervention. Notably, the MRP group showed a statistically significant improvement in their global score, suggesting that MRP had a positive and beneficial effect on maintaining and promoting functional balance performance, a critical aspect for performing daily activities and preventing falls. On the other hand, the CPT group showed a non-significant improvement in their global score, indicating that their functional balance performance remained stable but did not improve further after the intervention. The difference between the two groups in their global score was not significant, and the effect size of the difference between the two groups was also small. These findings suggest that both interventions were effective in maintaining the improvements in functional balance achieved post-intervention. However, they also indicate that the MRP had a greater impact on maintaining and promoting functional balance encompassing various balance and postural control parameters over the 3-month follow-up period.

Overall, the results of the functional balance assessment from post-intervention to the 3-month follow-up provide valuable insights into the sustained improvements in balance and postural control following both the MRP and CPT interventions. The findings indicate that both groups maintained and demonstrated improvements in certain aspects of balance and postural control. Nevertheless, some notable differences between the two groups were observed, favoring the MRP intervention. It is noteworthy that the MRP had a more pronounced impact on maintaining and promoting functional balance over the 3-month follow-up period. These outcomes underscore the potential benefits of MRP for stroke patients in terms of long-term balance and postural control.

Functional gait analysis

Regarding gait speed measured in m/s, both groups exhibited significant improvements. The MRP group had a slightly higher mean change in gait speed than the CPT group, but the difference between the two groups was not significant, and the effect size difference between the two groups was also small. This suggests that both interventions were effective in maintaining and enhancing walk speed, which is a key indicator of functional mobility in stroke survivors. However, neither group showed any significant improvement in gait speed as a percentage of normality. These results indicate that both MRP and CPT interventions helped maintain the participants' gait speed at a stable level, but they did not reach a higher level of normality in walking speed beyond what was observed post-intervention.

Additionally, both groups showed significant improvements in the mean difference in support time score. The MRP group had a slightly higher mean change than the CPT group, but the difference between the two groups was not significant, and the effect size of the difference between the two groups was also negligible. This finding indicates that both interventions effectively sustained the improvement achieved in the difference in support time between the legs during the gait cycle at post-intervention.

In terms of force parameters, both groups did not show any significant changes in all the force parameters, including AP braking force, AP propulsion force, vertical take-off force, and oscillation force global scores. Although there were slight improvements in most of the force parameters in both groups, the MRP group exhibited a higher improvement. However, these changes were not significant between the two groups, and the effect size between the two groups was also small. These results indicate that both the MRP and CPT interventions were effective in maintaining the ground reaction forces. It is worth noting that the MRP had a greater impact in promoting the achieved improvements after the intervention at the 3-month follow-up.

Regarding force morphology, both groups showed improvements in the force morphology global scores. The MRP group significantly improved their AP and ML force morphology global scores, suggesting that MRP had a positive effect on maintaining and promoting force morphology, which is crucial for walking efficiency and stability. Similarly, the CPT group also showed a significant improvement in their AP force morphology global score, indicating a positive impact on their AP force pattern after the intervention. However, the CPT group did not show any significant improvement in their ML force morphology global score, suggesting that their ML force pattern remained stable and did not improve further after the intervention. The difference between the two groups in ML force morphology was significant, and the effect size difference between the two groups was moderate, implying a specific effect of MRP on this aspect of gait performance. On the other hand, neither group showed any significant improvement in their vertical force morphology global score. While this aspect did not show significant changes, the overall results suggest that both the MRP and CPT interventions were effective in maintaining the improvements in force morphology. Furthermore, it is notable that the MRP had a greater impact in promoting force morphology at the 3-month follow-up.

In terms of the functional gait analysis global score, both groups demonstrated significant improvements. The mean change observed in the MRP group was slightly higher than the CPT group, but the difference between the two groups was not significant. Additionally, the effect size of the difference between the two groups was negligible. These findings indicate that both interventions were effective in maintaining the improvements in gait achieved post-intervention. However, they also suggest that the MRP had a greater impact on maintaining and promoting gait function encompassing various gait parameters over the 3-month follow-up period.

Overall, the results of the functional gait analysis from post-intervention to the 3-month follow-up demonstrate sustained improvements in functional gait performance after both the MRP and CPT interventions. The findings indicate that both groups maintained the improvements in gait achieved post-intervention. However, it is noteworthy that the MRP had a more pronounced impact on promoting functional gait performance over the 3-month follow-up period. These outcomes emphasize the potential benefits of MRP for stroke patients in terms of long-term functional gait performance.

7.5 Comparison to previous research

The main findings of this study revealed that task-specific training based on MRP was more effective than conventional physical therapy in improving balance, mobility, and ADL performance among sub-acute stroke patients, leading to significant improvements in functional outcomes. Furthermore, the positive effects of MRP were sustained for three months after the intervention, indicating its potential for long-term benefits in stroke rehabilitation.

These results are consistent with previous studies that have also demonstrated the advantages of MRP compared to conventional physical therapy in stroke rehabilitation. For instance, Chan et al. [321] conducted a randomized controlled trial comparing MRP to conventional therapy over a 6-week period and found that MRP led to greater improvements in balance, mobility, and ADL performance, as measured by the BBS, TUG, Functional Independence Measure (FIM), and the modified Lawton Instrumental Activities of Daily Living (IADL) test. Their findings emphasized the efficacy of MRP in enhancing functional recovery for stroke patients.

Similar positive outcomes were observed in studies by Kanase [325] and Raval

[326], which also investigated the impact of MRP on functional balance and mobility compared to conventional therapy using the Motor Assessment Scale (MAS) and the Barthel index over a 6-week intervention period. These findings, in conjunction with the present study, suggest that MRP has a broader impact on multiple aspects of functional recovery.

Another randomized controlled trial conducted by Naz et al. [329] investigated the combination of MRP with routine physical therapy compared to routine physical therapy alone. The study found that combining MRP with routine therapy was more effective in enhancing balance and upright mobility among sub-acute stroke patients, as assessed by the BBS and the TUG test. This adds further support to the notion that MRP contributes more effectively to improving balance and mobility in post-stroke patients, consistent with the current study's observations.

Several previous studies have also compared MRP with other rehabilitation approaches, such as Bobath. Langhammer and Stanghelle [316] conducted a randomized trial comparing the effectiveness of Bobath therapy and MRP in stroke rehabilitation. Their study revealed that both approaches led to improvement in motor function and ADL, but the MRP group showed significantly better motor function outcomes as assessed by the Motor Assessment Scale (MAS) and the Sødring Motor Evaluation Scale (SMES). This suggests that MRP's task-oriented exercises are more effective than the facilitation/inhibition strategies used in the Bobath concept for stroke rehabilitation, supporting the current study's findings.

Bhalerao et al. [322] also supported the superiority of MRP over the Bobath approach in improving ADL and ambulation in acute stroke rehabilitation. Their study found that the MRP group exhibited significantly higher scores than the Bobath group in the Functional Independence Measure, Barthel Index, Functional Ambulation Category, and Dynamic Gait Index after a 6-week intervention. These results highlight the benefits of MRP's task-specific and goal-oriented training in enhancing functional recovery and mobility compared to the facilitation and inhibition strategies of the Bobath approach.

Furthermore, Mufidah et al. [327] compared the effects of MRP and the Bobath Method on the standing balance of stroke patients. Their quasi-experimental study demonstrated that both methods improved standing balance, but MRP was significantly more effective than the Bobath Method. The study attributed this effectiveness to MRP's involvement of cognitive, associative, and autonomic processes that enhance standing balance in stroke patients.

Singha [323] conducted a randomized controlled trial comparing the effects of MRP and the proprioceptive neuromuscular facilitation (PNF) technique on basic mobility among chronic stroke patients. The results showed that MRP was significantly more effective than PNF in improving and maintaining basic mobility in chronic stroke patients as measured by the TUG test and the Sit to Stand item of the Motor Assessment Scale.

While the long-term effects of MRP have not been widely studied, Langhammer et al. [317] found that MRP was more effective than Bobath in various outcomes for stroke patients, including motor function and postural control, even at a 4-year follow-up. Additionally, the study by Singha [323] observed lasting effects of MRP on basic mobility, as significant improvements were still evident in the MRP group at the one-month follow-up.

The long-term maintenance of intervention effects observed in the MRP group can be attributed to its emphasis on cognitive, associative, and autonomic processes that facilitate motor learning, leading to the consolidation and retention of motor skills after practice. Consolidation refers to the stabilization and integration of newly acquired motor skills into existing motor representations, while retention is the ability to recall and reproduce a motor skill after a period of no practice. These processes depend on factors such as the amount, intensity, variability, and specificity of practice, as well as the type, timing, and frequency of feedback [286, 438]. MRP incorporates these factors into its design, ensuring that patients practice sufficiently, intensely, variably, and specifically, and receive appropriate feedback at optimal intervals. As a result, MRP enhances the consolidation and retention of motor skills in stroke patients, leading to long-lasting functional improvements. Consequently, the MRP emerges as a preferable approach for stroke rehabilitation, effectively enhancing the functional recovery and quality of life of stroke patients.

Despite the promising outcomes of the MRP in improving balance, mobility, and ADL performance among post-stroke patients, the current body of evidence primarily relies on traditional clinical outcome measures. However, there is a research gap when it comes to evaluating the effectiveness of the MRP using biomechanical balance and gait variables, as well as posturography. Currently, no studies have been conducted in this area. To address this research gap, the current study explored the efficacy and long-term outcomes of task-specific training based on the MRP, while incorporating instrumental evaluation tools such as biomechanical balance and gait variables (kinematic and kinetic gait analysis) and posturography. These objective measures provide a more comprehensive assessment of the intervention's effects, offering valuable insights into the biomechanical changes and adaptations that occur after MRP intervention. Therefore, this study provides more comprehensive evidence supporting the effectiveness and value of MRP as a rehabilitation approach for stroke patients.

The findings from this study, in conjunction with previous research, contribute to robust evidence supporting the efficacy of task-specific training based on the MRP in improving balance, mobility, and ADL performance in stroke rehabilitation. The MRP stands out as a promising and enduring rehabilitation strategy that can significantly contribute to the functional recovery of stroke patients, highlighting its potential as a valuable addition to stroke rehabilitation protocols. Future research may further explore the specific biomechanical and neurophysiological aspects of MRP to deepen our understanding of its underlying mechanisms and optimize its application in stroke rehabilitation.

7.6 Implications for clinical practice

The study's findings have important clinical implications for stroke rehabilitation practices and patient outcomes. They indicate that task-specific training based on the MRP is a superior approach to conventional physical therapy in improving balance, mobility (i.e., gait), and performance of daily living activities among stroke patients. By targeting functional tasks relevant to daily life, the MRP addresses the specific impairments and challenges faced by stroke survivors, leading to more substantial functional improvements across multiple domains. MRP also allows stroke survivors to practice movements in context, facilitating more efficient and meaningful recovery. Therefore, MRP can be recommended as an effective approach to address the functional impairments of stroke patients in a goal-oriented and task-specific manner. Healthcare professionals should consider incorporating task-specific training based on MRP into their clinical practice and stroke rehabilitation protocols to optimize functional outcomes and achieve better long-term results for stroke patients.

The study's clinical implications extend beyond immediate effectiveness, as task-specific training based on MRP also proves advantageous in maintaining the achieved improvements over the long term. The retention of gains observed in balance, mobility (i.e., gait), and activities of daily living performance at the 3-month follow-up highlights the enduring impact of MRP in stroke rehabilitation. The MRP reinforces learned motor patterns and functional skills, leading to enhanced retention and transfer of these skills to daily life. Integrating MRP into rehabilitation clinical practice can lead to not only short-term benefits but also better long-term functional outcomes and more lasting functional gains. This allows stroke survivors to maintain and build upon their achievements, leading to improved independence and overall quality of life during the post-stroke period. Healthcare professionals should also consider that regular follow-up assessments are essential components of a successful rehabilitation program, ensuring sustained improvements and minimizing the risk of functional decline in the later stages of stroke recovery.

Furthermore, this study contributes to the existing literature by providing additional evidence supporting the benefits of the MRP intervention in improving functional balance, mobility (i.e., gait), and performance of daily life activities. The statistically significant differences and large effect sizes observed between the MRP and CPT groups indicate that the MRP intervention yielded superior outcomes compared to conventional physical therapy. These findings reinforce the growing body of evidence supporting the effectiveness of MRP in stroke rehabilitation. Healthcare professionals should consider these findings when designing stroke rehabilitation programs, as they highlight the potential of MRP-based training to significantly enhance stroke patients' functional outcomes and overall quality of life.

7.7 Study limitations

The study acknowledges several limitations that should be considered. To begin with, the inclusion criteria limit the sample to first-ever stroke patients in the subacute phase who had mild to moderate lower limb weakness and could stand and walk independently. The study also excluded patients with communication impairments, such as aphasia. Consequently, these restrictions may limit the generalizability of the findings to a broader population of post-stroke patients with different characteristics, such as those with acute and chronic stroke, severe impairment, or dependence on others for mobility.

Additionally, a limitation of this study is that the participants who took part were patients with mild and moderate stroke severity. Moreover, the study is an open-label trial, lacking blinding. Both the participants and the therapist, who also serves as the outcome assessor, are aware of the intervention received.

Furthermore, a limitation of the study was that the duration of the intervention was only 8 weeks, which might not be long enough to capture the full effects of the intervention on the participants' outcomes. Also, the study has a limited follow-up duration, with an assessment conducted only three months after the interventions. This relatively short follow-up period may not capture the long-term effects of the interventions or the possible changes over time.

Another possible limitation of this study could be the concomitant rehabilitation interventions, such as occupational therapy, which may contribute to the observed functional improvements in activities of daily living within both study groups. This coexisting factor could potentially provide a partial explanation for the observed outcomes, impacting the ability to isolate the specific effects of the interventions being investigated.

Lastly, the study does not account for other potential factors that may influence the recovery of post-stroke patients. Variables such as age, comorbidities, social and family support, and medication use, among others, could confound the results and pose additional limitations to the study's findings by making it difficult to isolate the specific effects of the interventions.

Despite these limitations, this study provides valuable insights and offers novel evidence on the effects of task-specific training based on the Motor Relearning Program (MRP) on balance, mobility, and the performance of activities of daily living among post-stroke patients who meet the specified inclusion criteria.

Section 8

Conclusions

This study aimed to compare the effectiveness of task-specific training based on a motor relearning program (MRP) with conventional physical therapy in improving balance, mobility (i.e., gait), and activities of daily living (ADL) performance in sub-acute stroke patients. It also evaluated the long-term retention of gains in both intervention groups three months after the post-intervention assessment. The study's conclusions are as follows:

1. The study examined the effect of MRP on balance and postural control. The results indicate that task-specific training based on MRP demonstrated superior effectiveness in improving balance and postural control compared to conventional physical therapy in sub-acute stroke patients. Participants who underwent MRP showed significant and clinically relevant improvements in their ability to maintain balance and control posture, which are crucial for functional recovery and independence in stroke patients.

2. The study assessed the effect of MRP on mobility, specifically the gait. The results show that task-specific training based on MRP led to substantial improvements in gait and overall mobility compared to conventional physical therapy. This highlights the potential of MRP to enhance gait function and contribute to better overall functional mobility outcomes in sub-acute stroke patients, thereby indicating its value in stroke rehabilitation.

3. The study explored the impact of MRP on ADL performance. The findings indicate that MRP had a more substantial positive effect on enhancing ADL performance and independence compared to conventional physical therapy. This suggests that MRP can effectively address the challenges faced by stroke

patients in carrying out essential daily tasks, leading to enhanced independence, increased social participation, and ultimately, an improved quality of life.

4. The study assessed the long-term maintenance of intervention effects by conducting a 3-month follow-up assessment after the intervention. The analysis reveals that task-specific training based on MRP maintained a higher level of improvement compared to conventional physical therapy. Participants who received MRP maintained their achieved improvements in balance, mobility, and ADL performance. This suggests that task-specific training based on MRP provides more lasting benefits and better retention of functional improvements for sub-acute stroke patients compared to conventional physical therapy.

Overall, this study provides compelling evidence supporting the effectiveness of task-specific training based on a MRP in improving balance, mobility, and activities of daily living performance among sub-acute stroke patients. Furthermore, the long-term maintenance of treatment effects observed in the MRP group highlights its potential as a valuable rehabilitation approach in promoting functional recovery for individuals in the sub-acute stage of stroke recovery. These findings provide evidence-based guidance and valuable insights for clinicians and researchers in implementing MRP in clinical practice and designing effective rehabilitation protocols to optimize functional outcomes and enhance quality of life in stroke rehabilitation.

Section 9

Recommendations and future research

The study provides evidence for the effectiveness of task-specific training based on the motor relearning program (MRP) in improving balance, mobility, and performance of daily activities among post-stroke patients in the subacute phase. However, the study has some limitations that warrant further research to solidify and expand upon these findings. In light of these limitations, several recommendations and directions for future research can be suggested:

Diversify the sample: To enhance the generalizability of the study findings, future research should consider expanding the inclusion criteria to include a broader and more diverse spectrum of post-stroke patients. This could involve recruiting individuals with different phases of recovery and severities of stroke, including those in the acute and chronic phases or with severe impairments. Also, future research should consider including patients with communication impairments, such as aphasia, and explore alternative methods for assessing outcomes in these patients, such as utilizing proxy-reported measures or incorporating technology-assisted communication tools. By including a wider and more diverse sample of stroke patients, the study can provide insights into the effectiveness of the interventions across different subgroups.

Implement blinding: To reduce potential biases and enhance the internal validity of the study, future research should consider implementing a double-blind design, where neither the participants nor the therapist or outcome assessor are aware of the intervention allocation. Alternatively, an independent assessor who is blinded to the intervention allocation could be used to conduct the outcome measurements. Blinding would help ensure that the assessments are conducted objectively and reduce the potential for bias.

Extend the follow-up duration: To evaluate the long-term effects and sustainability of the interventions, future studies should extend the follow-up period beyond three months and conduct multiple assessments at different time points, such as six months, one year, and even longer, to capture the potential changes and sustained benefits over time. This will provide a more comprehensive understanding of the intervention's impact on the recovery of post-stroke patients and can provide valuable insights into the durability of the intervention's effects.

Control for confounding variables: To control for confounding factors and isolate the specific effects of the interventions, future studies should collect and analyze data on relevant variables that may influence the recovery of post-stroke patients, such as age, comorbidities, social and family support, and medication use. Statistical methods such as multivariate regression analysis or propensity score matching could be used to adjust for these factors and account for their potential impact on the results. Moreover, implementing a stratified randomization process based on relevant confounders could strengthen the study's internal validity.

Consider a multicenter or multinational approach: Collaboration across multiple centers or countries can enhance the generalizability and external validity of the findings. Future studies could involve multiple sites to increase the sample size, diversity of participants, and variability of healthcare settings. This would provide a more robust foundation for drawing conclusions and making recommendations applicable to a broader stroke population.

Technology integration: Exploring the integration of technology, such as wearable devices, smartphone applications, or telerehabilitation, into the exercises of the intervention may enhance accessibility and adherence to the intervention. Investigating the feasibility and effectiveness of such technology-based interventions would help identify innovative strategies for improving post-stroke rehabilitation and could have significant implications for post-stroke recovery.

Mechanisms of recovery: Further research into the underlying neurobiological mechanisms that contribute to the observed improvements in balance, mobility, and activities of daily living following the exercises of the intervention would advance our understanding of stroke recovery and rehabilitation. Neuroimaging studies and biomarker analyses could shed light on the neural pathways involved in the process.

By addressing these recommendations and conducting further research, the study's limitations can be mitigated, leading to a more comprehensive understanding of the interventions' effectiveness in post-stroke rehabilitation. This knowledge can guide evidence-based clinical practices and contribute to improved patient care and quality of life.

Section 10

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Section 11

Appendices

11.1 Training program for study group (MRP) exercises

Appendix A: Training Program for Study Group (Motor Relearning Program) Exercises

Task-specific training were performed for study group (MRP) based on the motor relearning program for 8 weeks (3 sessions per week; 1 hr. per session; 24 sessions). Each MRP rehabilitation session includes the following exercises:

(1) Bed Mobility and Sitting Up Over the Side of The Bed

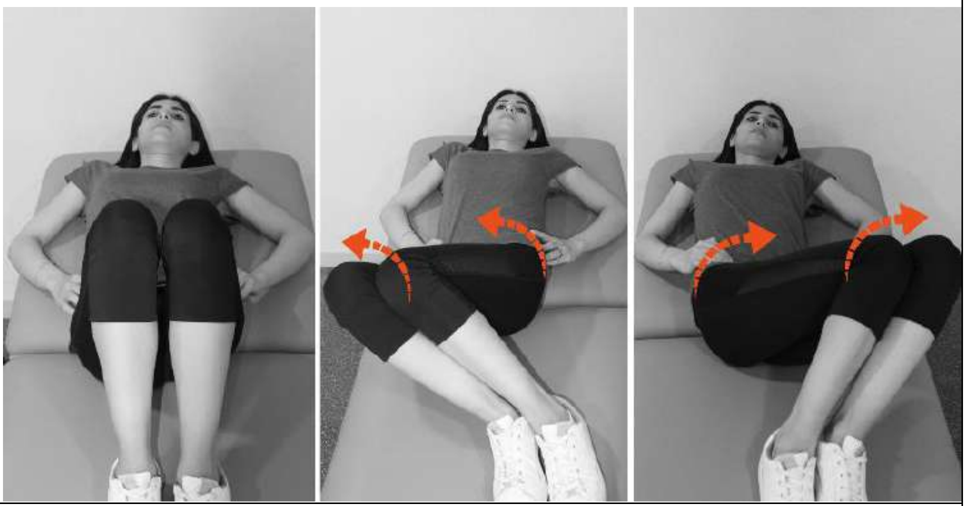
Supine Trunk Rotation

REPS: 10 | SETS: 3 | HOLD: 5-10 sec.

Starting position:
The patient should lie on their back in a supine position, with their knees flexed at a 90-degrees and the feet flat on the bed.

Exercise:
The patient should slowly rotate their knees and hips to one side while keeping the upper body flat on the bed. They should aim to rotate as far as they comfortably can without causing any pain or discomfort, until they feel a stretch in the trunk. Hold this position for 5-10 seconds. Then, slowly rotate the knees and hips back to the starting position. Repeat the same movement on the other side, keeping the upper body still while rotating the lower body. This completes one repetition. The patient should perform a total of 3 sets of 10 repetitions, with a short rest period between sets.

The patient should start with a small range of motion and gradually increase the rotation as they become more comfortable with the exercise. They should keep the neck and shoulders relaxed throughout the exercise and avoid tensing up or straining the neck.



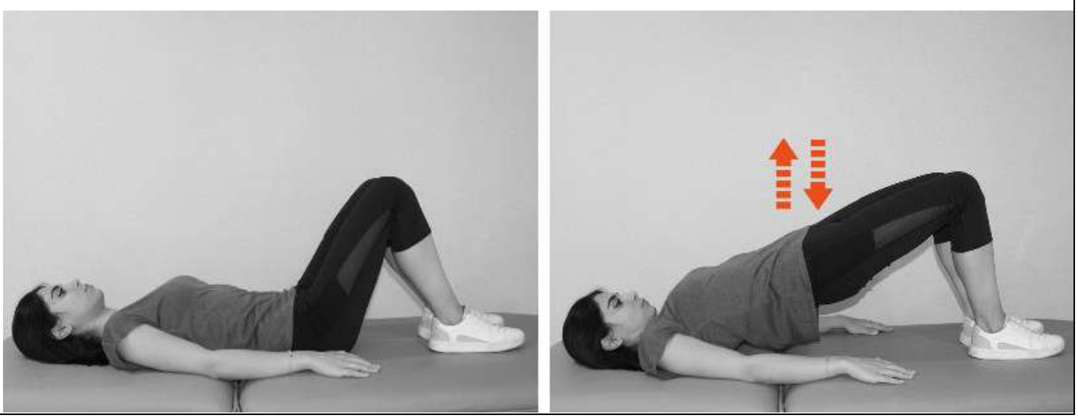
Bridging Exercise

REPS: 10 | SETS: 3 | HOLD: 2-3 sec.

Starting position:
The patient should lie on their back in a supine position, with their hips flexed at 45-degrees, knees flexed at a 90-degrees, and the feet flat on the bed. They should place their arms at the sides with palms facing down and keep their feet hip-width apart, ensuring they are aligned with the knees and hips.

Exercise:
The patient should begin by contracting their core muscles to stabilize the spine and slowly raise their hips/pelvis from the bed until their hips are extended (0-degrees or slightly less) and the pelvis is level. This motion is called a concentric contraction. During the elevation, they should make sure the lumbar spine is in a neutral position, and the pelvis does not rotate. They should hold this position for 2-3 seconds and focus on squeezing their glutes to maintain the elevated position. Then, they should slowly lower the hips/pelvis back down to the bed in a controlled manner. This motion is called an eccentric contraction. They should make sure not to let the pelvis rotate during the lowering motion.

The patient should perform a total of 3 sets of 10 repetitions, with a short rest period between sets. They should keep the neck and shoulders relaxed throughout the exercise and avoid tensing up or straining the neck.



Single-Leg Bridge Exercise (Bridging Exercise Progression)

REPS: 10 | SETS: 3 | HOLD: 2-3 sec.

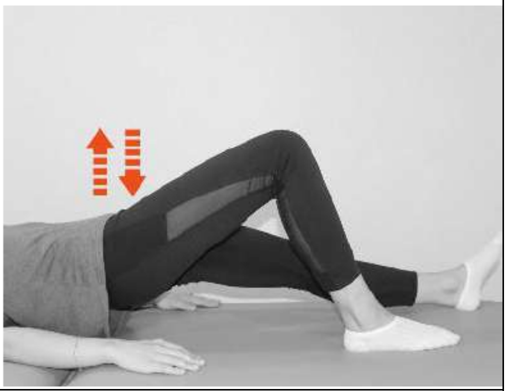
Starting position:

The patient should lie on their back in a supine position, with their arms at your sides and palms facing down. Keep the leg on the affected side pressed on the bed, with a 45 degrees hip joint flexion and a 90 degrees knee flexion. The leg on the unaffected side should be fully extended and comfortably laid down.

Exercise:

The patient should begin by contracting their core muscles to stabilize the spine and slowly raise their affected side hips/pelvis from the bed until their hips are extended (0-degrees or slightly less) and the pelvis is level. During the elevation, they should make sure the lumbar spine is in a neutral position, and the pelvis does not rotate. They should hold this position for 2-3 seconds and focus on squeezing their glutes to maintain the elevated position. Then, they should slowly lower the hips/pelvis back down to the bed in a controlled manner. After completing the exercise on the affected side, they should alternate legs and repeat the same exercise on the unaffected side.

The patient should perform a total of 3 sets of 10 repetitions for each leg or side, with a short rest period between sets. They should keep the neck and shoulders relaxed throughout the exercise and avoid tensing up or straining the neck.



Sitting Up Over the Side of Bed

REPS: 5 both sides | SETS: 1

Starting position:

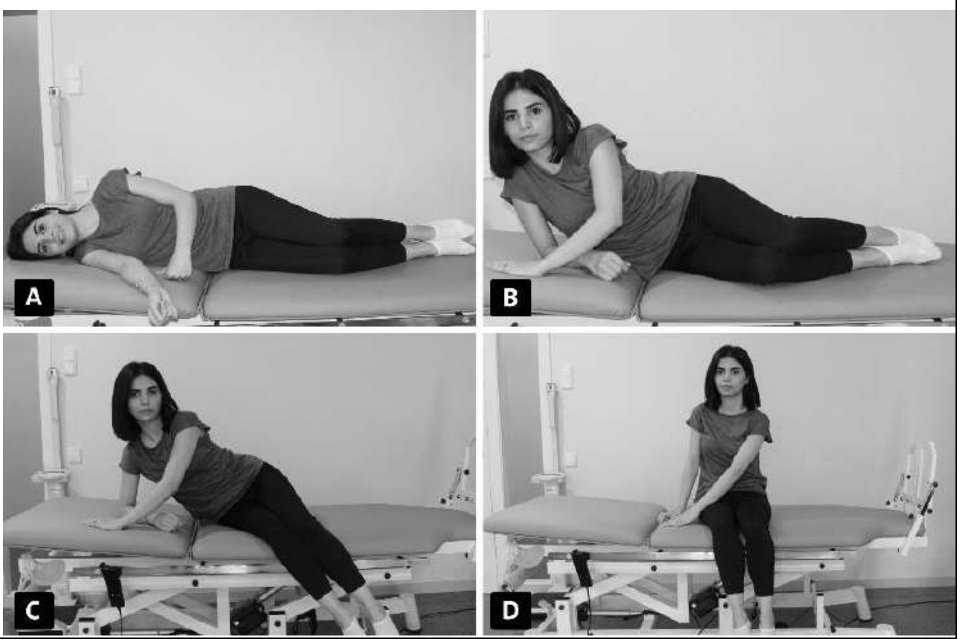
The patient should lie on their back in a supine position, with their arms at their sides.

Exercise:

The patient should turn onto the affected side by first rotating and flexing the neck to the side, followed by flexion of the hip and knee, flexion of the shoulder, and protraction of the shoulder girdle, and then rotation within the trunk to face the edge of the bed. From this position, the patient should prepare to sit up by first laterally flexing the neck, then laterally flexing the trunk (abducting the lower arm across), and then lifting and lowering the legs over the side of the bed. Next, the patient should sit up over the side of the bed, keeping the affected arm close to the body and using the intact arm to push themselves up. They should try to keep their head and trunk aligned as they sit up.

Return to the lying position by lowering the legs back onto the bed and then lying back down on their side. Repeat this exercise for 5 repetitions on the affected side, and then repeat the entire sequence on the unaffected side for another 5 repetitions.

While performing the exercise, it is important to avoid rotating the neck and flexing it forward instead of laterally. It's also important to avoid pulling with the unaffected hand or hooking the affected leg with the unaffected leg in order to get the legs over the side of the bed. The therapist can assist with the movement as needed to ensure proper form and safety, but they should also encourage the patient to progress without assistance as they become more comfortable and stable with the exercise.



(2) Balanced Sitting

Seated Lateral Trunk Flexion

REPS: 10 **|** SETS: 3 **|** HOLD: 2-3 sec.

Starting position:
The patient should sit at the edge of the bed with their feet flat on the ground, positioned hip-width apart and their knees bent at a 90-degrees. The patient should maintain a straight back and relaxed shoulders.

Exercise:
The patient should slowly shift their weight to the right side and place their right elbow on the bed, keeping the forearm perpendicular to the body. The left arm should be relaxed and resting on the left thigh. Hold this position for 2-3 seconds, then tighten the core muscles and slowly push back up to the center. Repeat the same movement on the left side.

The patient should alternate between the left and right sides, performing a total of 3 sets of 10 repetitions on each side, with a short rest period between sets.

The patient should control the movement with their core muscles, particularly the obliques, rather than using momentum or gravity to move up and down. Avoid arching the lower back or rounding the shoulders.

Sitting Trunk Rotation

REPS: 10 **|** SETS: 3 **|** HOLD: 5-10 sec.

Starting position:
The patient should sit at the edge of the bed with their feet flat on the ground, positioned hip-width apart and their knees bent at a 90-degrees. They should place their hands on the thighs or on the side of the bed for support.

Exercise:
The patient should slowly twist their torso to the left, using their hands to gradually deepen the stretch and attempting to look behind at the therapist, without over-rotating or twisting the neck too much. They should keep their hips facing forward and avoid overstretching. Hold the stretch for 5-10 seconds, then return to the center. Repeat the stretch on the other side by twisting the torso to the right.

The patient should alternate between the left and right sides, performing a total of 3 sets of 10 repetitions on each side, with a short rest period between sets.

Sitting Multidirectional Reaching

REPS: 5 | SETS: 1

Starting position:

The patient should sit upright on a chair or bench with their feet flat on the ground. The therapist should place a small object, such as a small weight, at different heights and positions in front of the patient.

Exercise:

The patient should slowly reach forward with one arm to pick up the object. The therapist should assist by guiding the affected upper limb to reach out and pick up the object from the designated location. Then, return the object to its location and repeat the exercise, but this time reach out with the other arm to pick up the object. Repeat the exercise again, but this time reach out to the side to pick up the object from a different location. Finally, repeat the exercise one more time, this time reaching down to pick up the object from the ground.

The patient should alternate between these three reaching directions, performing one set of 5 repetitions in each direction with each arm. As the patient progresses, the therapist should reduce their assistance until the patient is performing the exercise without any assistance.

(3) Standing Up and Sitting Down

Standing Up and Sitting Down

REPS: 10 | SETS: 3

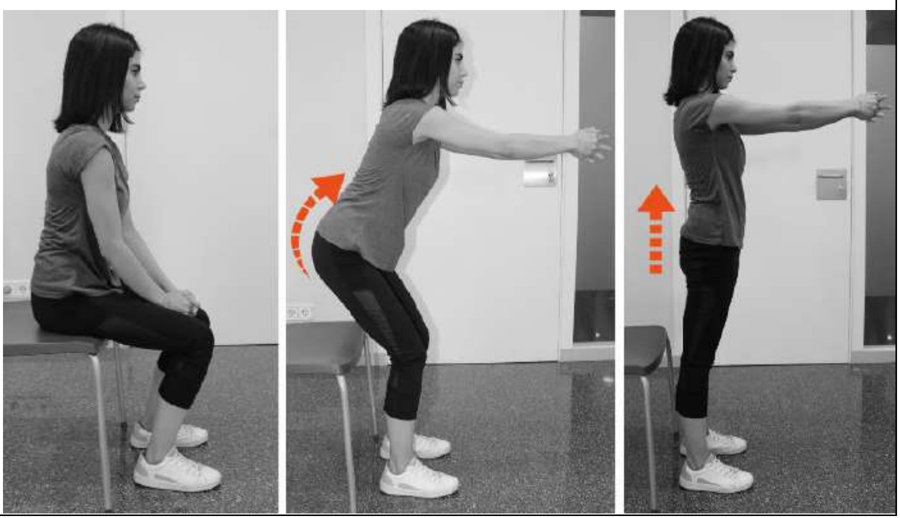
Starting position:

The patient should sit upright near the front of a sturdy chair with a flat seat and a backrest, with their feet positioned slightly behind the knees and shoulder-width apart.

Exercise:

The patient should clasp their hands together or interlock their fingers in front of the chest. The patient should maintain equal weight on both legs and slowly lean forward, shifting their weight forward, and push up through their feet until they are fully extended and the back is straight. They should keep their hands clasped together in front of the chest throughout the movement. Then, the patient should slowly lower themselves back down onto the chair by bending the knees and hips. They should keep their back straight and their hands clasped in front of the chest.

The patient should repeat the standing up and sitting down movement for 3 sets of 10 repetitions, resting for 30-60 seconds between each set.



(4) Balanced Standing

Standing Multidirectional Reaching

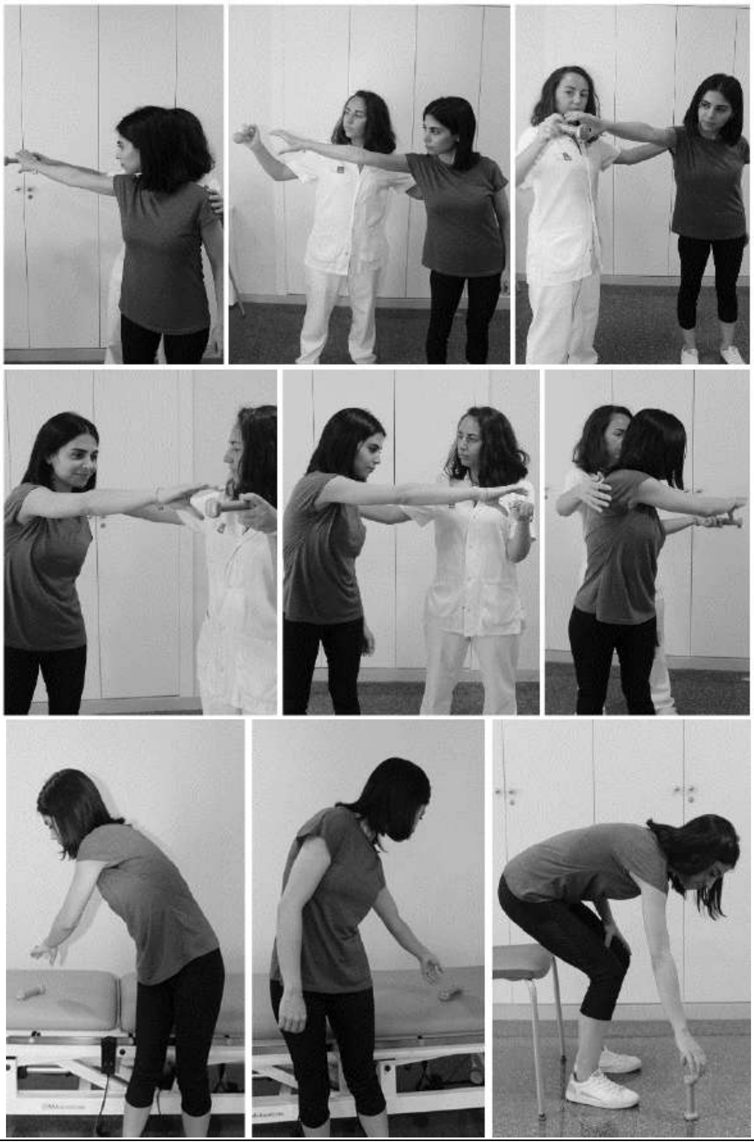
REPS: 5 | SETS: 1

Starting position:
The patient should stand in front of the therapist with their feet shoulder-width apart and their arms at the sides. The therapist should hold a small object at different heights and positions in front of the patient.

Exercise:
The patient should slowly reach forward with one arm to pick up the object from the therapist's hand while maintaining balance and stability. Then, they should return to the starting position and repeat the exercise by reaching out to the side to pick up the object from the therapist's hand. They should repeat the exercise again by reaching backward to pick up the object from the therapist's hand. Finally, they should repeat the exercise by reaching downward to pick up an object from the floor. When reaching downward, they should make sure to bend their knees and keep their back straight to avoid straining the lower back.

The patient should alternate between these four reaching directions, performing one set of 5 repetitions in each direction with each arm.

To progress, narrow the patient's base of support, which means bringing their feet closer together to make it more challenging to maintain balance. The patient should start the exercise progression by standing with their feet hip-width apart instead of shoulder-width apart. Then, continue to narrow the base of support by bringing their feet even closer together until they are together, which will further challenge their balance and stability.



Standing Heel and Toe Raises

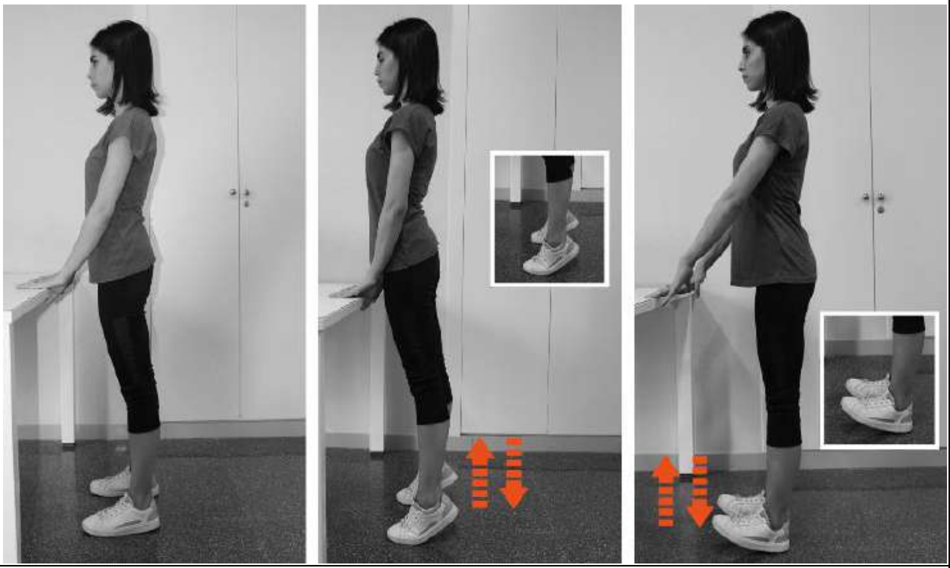
REPS: 10 **|** SETS: 3 **|** HOLD: 2-3 sec.

Starting position:

The patient should stand upright with both feet flat on the ground, about hip-width apart, and hold onto a sturdy countertop or the back of a sturdy chair for balance and stability.

Exercise:

The patient should slowly raise their heels off the ground (rise up onto their toes) as high as they are comfortable while keeping the upper body and knees straight. Hold for 2-3 seconds, and then slowly return to the starting position. Next, they should slowly raise their toes as high as they are comfortable while maintaining good posture, taking their weight on their heels. Hold for 2-3 seconds, and then return to the starting position.



The patient should perform a total of 3 sets of 10 repetitions for each movement, with a short rest period between sets.

The patient should begin by using both hands to maintain balance, then progress to just using one hand, and finally no hands. Additionally, as the patient progresses, they should move back and forth a bit faster and hold for a few seconds in the toe and heel positions.

Single Leg Standing

REPS: 5 **|** SETS: 3 **|** HOLD: 10 sec.

Starting position:

The patient should stand upright nearby a sturdy countertop or the back of a sturdy chair and hold it with one hand to help with balance and stability, with both feet flat on the ground, about shoulder-width apart.

Exercise:

The patient should slowly lift one leg off the ground until they are balanced on the other leg. They should maintain balance standing on one leg for a count of 10 seconds, and then slowly lower the leg back down to the starting position. The patient should repeat the same exercise with the other leg. The patient should alternate between the left and right legs, performing a total of 3 sets of 5 repetitions on each leg, with a short rest period between sets.

The patient should start by holding onto a support with one hand for balance, and then progress to performing the exercise without any support. Additionally, as the patient progresses, they can try doing the exercise with their eyes closed for an extra challenge.

Standing Knee Extension with Heel Strike

REPS: 10 | SETS: 3 | HOLD: 2-3 sec.

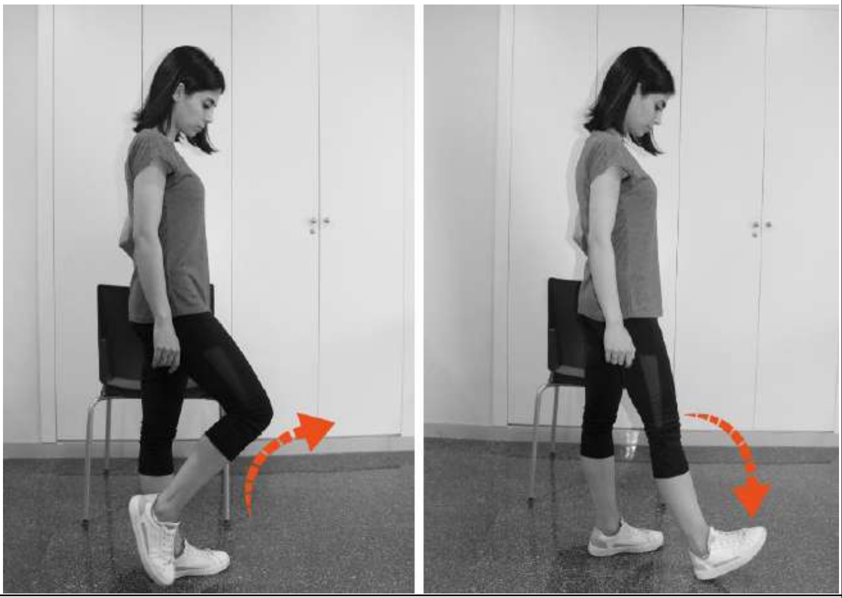
Starting position:

The patient should stand upright nearby a sturdy countertop or the back of a sturdy chair and hold it with one hand to help with balance and stability, with both feet flat on the ground, about shoulder-width apart.

Exercise:

The patient should start by shifting their weight onto one leg and slightly lifting the other leg off the ground. Next, they should slowly extend the lifted leg forward while keeping the knee straight and simultaneously strike the ground with the heel. They should hold this position for 2-3 seconds, and then slowly lower the leg back down to the starting position. The patient should repeat the same exercise with the other leg. The patient should alternate between the left and right legs, performing a total of 3 sets of 5 repetitions on each leg, with a short rest period between sets.

The patient should start by holding onto a support with one hand for balance, and then progress to performing the exercise without any support.



(5) Practice of Walking

Practice of Walking Components

REPS: 3 | 1 REP = 10 meters

Starting position:

In a safe, flat, and level surface room free from obstacles, the patient should wear appropriate footwear. The therapist should be close to the patient to guide them through the movement by providing physical assistance, verbal and visual cues to ensure proper form and technique to maintain a proper gait pattern, and to avoid compensating with other body parts during the exercise.

Exercise:

Practice of walking components: Break down the walking cycle into its two main phases: stance and swing.

Step 1: Stance phase practice

The stance phase is the part of the walking cycle when the foot is in contact with the ground. To practice this phase, the patient should start by standing with feet hip-width apart, with weight evenly distributed between both feet. Then, the patient should practice shifting their weight from one foot to the other, paying attention to their balance and weight distribution. The exercise should be repeated with both legs.

Step 2: Swing phase practice

The swing phase is the part of the walking cycle when the foot is off the ground and swinging forward. To practice this phase, the patient should start by standing with feet hip-width apart, with weight evenly distributed between both feet. Then, the patient should practice lifting one foot off the ground and swinging it forward and backward in a smooth, controlled motion, as if taking a step. Encourage the patient to maintain good posture and use their hip muscles to control the movement and maintain balance throughout the exercise. The exercise should be repeated with both legs, gradually increasing the range of motion and speed of the swing until they can take full steps forward and backward.

Step 3: Practice of walking itself

Once the patient has demonstrated good control and coordination of the stance and swing phases, as well as an integrated walking pattern, begin practicing walking itself. The patient should start with short distances, slow speeds, and assisted walking, where the therapist provides support and guidance as needed. Gradually increase both walking distances and speeds, as well as decrease the amount of assistance as the patient's ability improves. Encourage the patient to focus on their foot placement, weight distribution, posture, and balance as they walk.

Backwards Walking

REPS: 3 **|** 1 REP = 10 meters

Starting position:

In a safe, flat, and level surface room free from obstacles, the patient should stand upright with their feet shoulder-width apart and their arms at their sides. The therapist should stand behind the patient for safety and to guide them through the movement by providing physical assistance, as well as verbal and visual cues to ensure proper technique to maintain a proper gait pattern.

Exercise:

The patient should slowly start walking backwards, taking small and controlled steps. Keep the head and neck in a neutral position and avoid looking over the shoulder or down at the feet, as this can disrupt the balance. Instead, use the sense of balance and body awareness to maintain stability. Try to maintain a slow and steady pace while walking backwards. If the patient feels unsteady or unsure, they can start by holding onto something close by, like a wall or countertop. This can help them maintain balance and build confidence as they get used to the exercise. Walk backwards for a distance of 10 meters. Once the patient reaches the end of the 10-meter distance, they should stop and turn around slowly, taking a moment to reorient themselves before starting the exercise again.

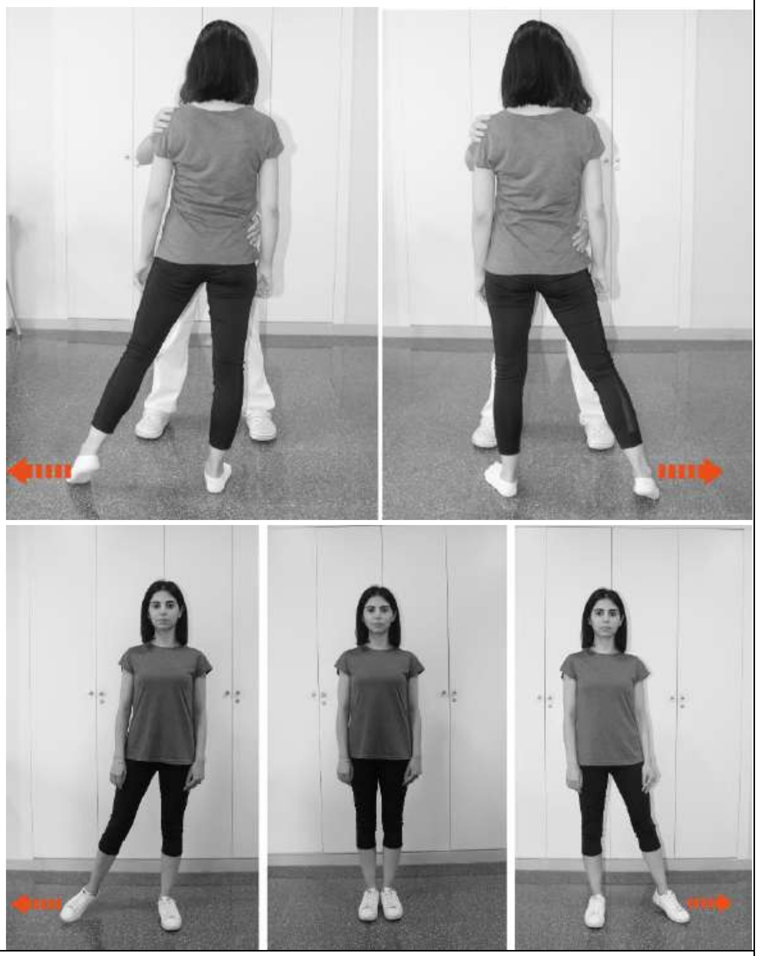
Repeat the exercise for a total of 3 repetitions, with a short rest period in between each repetition. As the patient becomes more confident and stable, they can try doing the exercise without holding onto anything for support.

Sideways Walking

REPS: 3 **|** 1 REP = 10 steps both sides

Starting position:

In a safe, flat, and level surface room free from obstacles, the patient should stand upright with their feet shoulder-width apart and their arms at their sides. The therapist should stand in front of the patient for safety, providing physical assistance, verbal and visual cues, and ensuring proper technique. The therapist should also ensure that the patient avoids compensating with other body parts during the exercise.



Exercise:

The patient should step sideways in a slow and controlled manner, starting by moving one foot to the side, followed by the other foot. It's important to avoid dropping the hips as the patient steps. After taking 10 steps in one direction, the patient should change directions and repeat the same steps in the other direction. The exercise should be performed for 3 repetitions of 10 steps each direction, with a short rest period in between each repetition.

The goal of the exercise is to increase glute activation and dynamic balance and stability with lateral weight shifting. As the patient becomes more confident and stable, the therapist can gradually step away and provide only supervision.

Braiding Walking

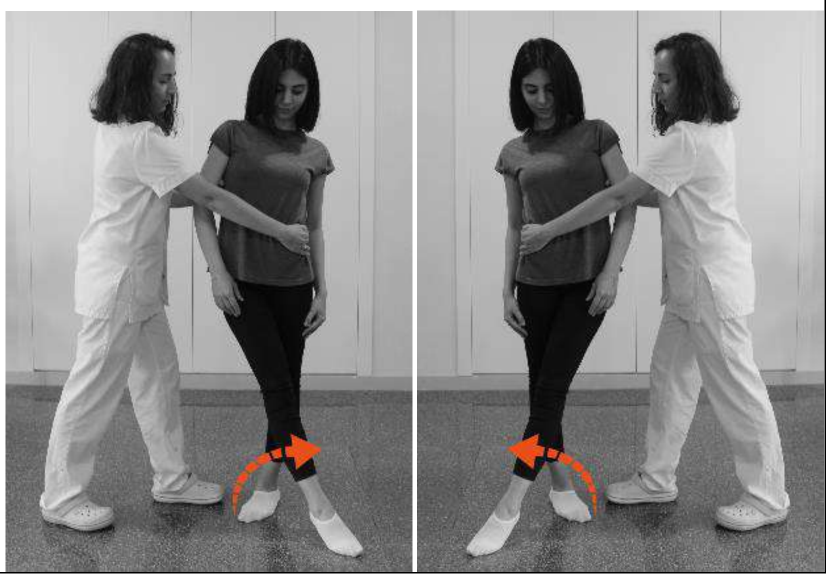
REPS: 3 **|** 1 REP = 10 steps both sides

Starting position:

In a safe, flat, and level surface room free from obstacles, the patient should stand upright with their arms at their sides. The therapist should stand behind and to the side of the patient for safety, providing physical assistance, verbal and visual cues, and ensuring proper technique. The therapist should also ensure that the patient avoids compensating with other body parts during the exercise.

Exercise:

The patient should begin the exercise by taking a side step to the left, shifting their weight onto the left leg. Next, cross the right leg up and across in front of the left leg, as if braiding the legs. Again, shift their weight onto the right leg, making sure to maintain a stable center of gravity. Take another side step to the left, shifting their weight back onto the left leg. Cross the left leg backward and behind the right leg, again as if braiding the legs. Then, shift their weight back onto the right leg, maintaining a stable center of gravity. After taking 10 steps in one direction, the patient should change directions and repeat the same steps in the other direction.



The exercise should be performed for 3 repetitions of 10 steps each direction, with a short rest period in between each repetition.

Make sure to maintain a slow and controlled pace throughout the exercise, focusing on maintaining balance and stability. As the patient becomes more confident and stable, the therapist can gradually step away and provide only supervision. Additionally, the therapist should ensure that the patient avoids compensating with other body parts during the exercise.

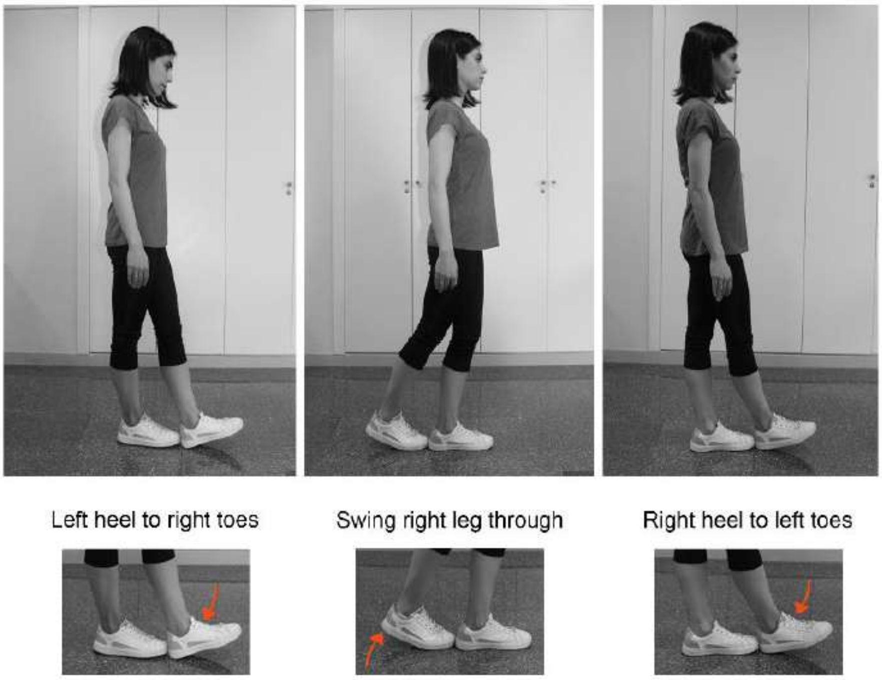
Heel-to-Toe Walking (Tandem Walking)

REPS: 3 | 1 REP = 10 meters

Starting position:
In a safe, flat, and level surface room free from obstacles, the patient should stand upright with their feet together and arms at their sides. The therapist should stand close to the patient for safety, providing physical assistance, verbal and visual cues, and ensuring proper technique.

Exercise:
The patient should lift one foot and place it directly in front of the other foot so that the heel touches the toe of the other foot. Then, take a step forward, placing the other foot in front of the one they just moved. Continue to walk heel-to-toe for a distance of 10 meters while keeping their eyes fixed on a spot in front of them to help with balance. Once the patient reaches the end of the 10-meter distance, they should stop and turn around slowly, taking a moment to reorient themselves before starting the exercise again. Repeat the exercise for a total of 3 repetitions, with a short rest period in between each repetition.

As the patient becomes more confident and stable, they should try not to rely on arm support to maintain their balance, and the therapist can gradually step away and provide only supervision.

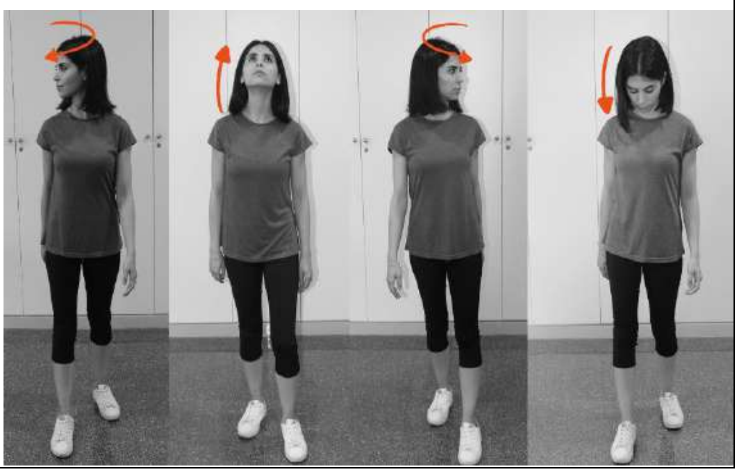


Walking with Head Turns and Tilts

REPS: 3 | 1 REP = 10 meters

Starting position:
In a safe, flat, and level surface room free from obstacles, the patient should stand upright with their shoulder-width apart and arms at their sides. The therapist should stand close to the patient for safety, providing physical assistance, verbal and visual cues, and ensuring proper technique.

Exercise:
The patient should start walking slowly, taking small and controlled steps while turning their head to the right and left, then tilting their head up and down. They should make sure to maintain their balance and focus on their breathing. If the patient feels dizzy, they should stop and take a deep inhale and exhale. Walk for a distance of 10 meters. Once the patient reaches the end of the 10-meter distance, they should stop and turn around slowly, taking a moment to reorient themselves before starting the exercise again. Repeat the exercise for a total of 3 repetitions, with a short rest period in between each repetition. As the patient becomes more confident and stable, the therapist can gradually step away and provide only supervision.



11.2 Training program for control group (CPT) exercise

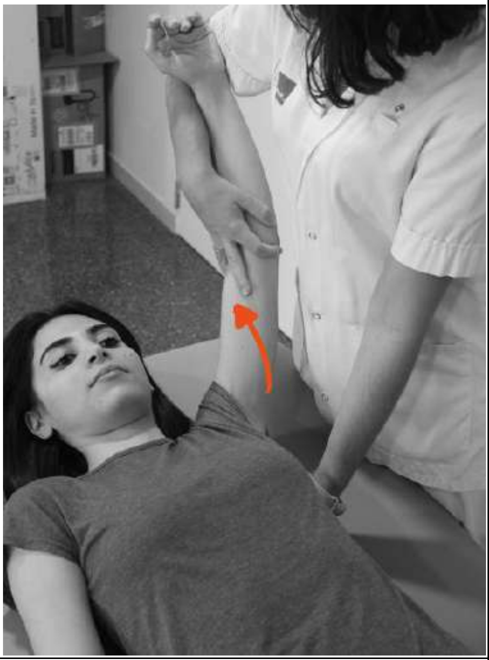
Appendix B - Training Program for Control Group (Conventional Physiotherapy Program) Exercises

The conventional physical therapy exercises were performed for control group (CPT) following a standard stroke rehabilitation program for 8 weeks (3 sessions per week; 1 hr. per session; 24 sessions). Each CPT rehabilitation session includes the following exercises:

(1) Gradual Progressive Stretching

Shoulder Flexion-Extension Stretching

REPS: 10 | HOLD: 15-30 sec.



Position the patient comfortably in the supine position on a bed or table, with their affected arm by their side. The therapist should stand at the head of the patient and gently grasp the affected arm at the elbow with one hand and stabilize the upper edge of the shoulder blade with the other hand. Slowly and gently raise the arm straight up towards the ceiling, until the point where the patient experiences discomfort or a mild stretch. The therapist should ensure that the patient's shoulder blade remains in a stable position during this movement. Hold the stretch for 15-30 seconds. Then, slowly release the stretch and lower the arm back down to the starting position.

Next, slowly and gently extend the affected arm backward towards the floor until the point of discomfort is reached. Again, hold the stretch for 15-30 seconds. Then, slowly release the stretch and return the arm to its starting position.

Avoid applying excessive force. Repeat the shoulder flexion-extension stretch cycle for a total of 10 repetitions for each movement, gradually increasing the range of motion and duration of the stretch.

Shoulder Abduction-Adduction Stretching

REPS: 10 | HOLD: 15-30 sec.

Position the patient comfortably in the supine position on a bed or table, with their elbow flexed to 90-degrees. Stand at the side of the patient and grasp the affected arm just above the wrist with one hand, ensuring that the patient's hand is relaxed. Use your other hand to support the patient's elbow and gently lift and move the patient's arm laterally away from the body to perform shoulder abduction, stopping at the point where the patient experiences discomfort or a mild stretch. Stabilize the scapula by using the table on which the patient is lying to prevent it from moving during the stretch. Hold this stretch for 15-30 seconds. Then, slowly release the stretch and return the patient's arm medially toward the body to perform shoulder adduction.

Avoid applying excessive force. Repeat the shoulder abduction-adduction stretch cycle for a total of 10 repetitions for each movement, gradually increasing the range of motion and duration of the stretch.

Shoulder Internal-External Rotation Stretching

REPS: 10 | HOLD: 15-30 sec.

Position the patient comfortably in the supine position on a bed or table. Begin by abducting the shoulder to a comfortable position, initially 45-degrees and later to 90-degrees if the glenohumeral joint is stable, or place a rolled towel at the patient's side for support. Flex the elbow to 90-degrees so the forearm can be used as a lever. Grasp the affected arm from the volar surface of the mid-forearm with one hand. Use your other hand to support the patient's elbow and gently begin to externally rotate the patient's arm, moving it away from the body by bringing the patient's forearm closer to the table while keeping their elbow bent. Stop at the point where the patient experiences discomfort or a mild stretch. Hold the stretch for 15-30 seconds. Then, slowly release the stretch and return the arm to its starting position.

Next, repeat the same process for internal rotation, rotating the arm internally towards the midline of their body while keeping their elbow bent until the point of discomfort is reached. Again, hold the stretch for 15-30 seconds. Then, slowly release the stretch and return the arm to its starting position.

Avoid applying excessive force. Repeat the shoulder internal-external rotation stretch cycle for a total of 10 repetitions for each movement, gradually increasing the range of motion and duration of the stretch.

Elbow Flexion-Extension Stretching

REPS: 10 | HOLD: 15-30 sec.

Position the patient comfortably in the supine position on a bed or table, with their affected elbow in a neutral position by their side. The therapist should stand on the affected side of the patient and gently grasp the patient's wrist with one hand while supporting the patient's elbow with the other hand. Slowly and gently extend the patient's arm at the elbow joint, moving it away from the body until the point where the patient experiences discomfort or a mild stretch. Hold the stretch for 15-30 seconds. Then, slowly release the stretch and return the elbow to its starting position.

Next, slowly and gently flex the arm at the elbow joint, bringing their hand towards their shoulder until the point where the patient experiences discomfort or a mild stretch. Again, hold the stretch for 15-30 seconds. Then, slowly release the stretch and return the forearm to its starting position.

Avoid applying excessive force. Repeat the elbow flexion-extension stretch cycle for a total of 10 repetitions for each movement, gradually increasing the range of motion and duration of the stretch.

Forearm Pronation-Supination Stretching

REPS: 10 | HOLD: 15-30 sec.

Position the patient comfortably in the supine position on a bed or table, with their affected arm placed on the table with the elbow flexed at 90-degrees and the shoulder in a neutral position. The therapist should stand on the affected side of the patient and gently grasp the patient's wrist and hand with one hand while supporting the patient's elbow with the other hand. Slowly and gently rotate the patient's palm in a pronation movement until the point where the patient experiences discomfort or a mild stretch. Hold the stretch for 15-30 seconds. Then, slowly release the stretch and return the forearm to its starting position.

Next, slowly and gently rotate the patient's palm in the opposite direction in a supination movement until the point of discomfort is reached. Again, hold the stretch for 15-30 seconds. Then, slowly release the stretch and return the forearm to its starting position.

Avoid applying excessive force. Repeat the forearm pronation-supination stretch cycle for a total of 10 repetitions for each movement, gradually increasing the range of motion and duration of the stretch.

Wrist Flexion-Extension Stretching

REPS: 10 | HOLD: 15-30 sec.

Position the patient comfortably in the supine position on a bed or table, with their affected arm placed on the table with the elbow flexed at a 90-degrees and the shoulder in a neutral position, and fingers straight. The therapist should gently use one hand to grasp the patient's forearm near the wrist to stabilize it, and with the other hand, hold the patient's hand in a loose fist with their palm facing down. Slowly and gently flex the patient's wrist by pushing the back of the patient's hand down towards their forearm while keeping the forearm stable. Stop at the point where the patient experiences discomfort or a mild stretch in the wrist and forearm muscles. Hold the stretch for 15-30 seconds. Then, slowly release the stretch and return the wrist to the neutral position.

Next, slowly and gently extend the patient's wrist towards the ceiling, lifting the back of their hand while keeping the forearm in a stable position until a gentle stretch is felt in the wrist and forearm muscles. Again, hold the stretch for 15-30 seconds. Then, slowly release the stretch and return the wrist to the neutral position.

Avoid applying excessive force. Repeat the wrist flexion-extension stretch cycle for a total of 10 repetitions for each movement, gradually increasing the range of motion and duration of the stretch.

Hamstring Stretch

REPS: 10 **|** HOLD: 15-30 sec.

Position the patient comfortably in the supine position on a bed or table, with their legs extended straight out. The therapist should stand at the side of the bed and grasp the patient's affected leg with both hands, placing one hand behind the knee and the other hand behind the ankle. Gently lift the affected leg up off the bed and rest it on the therapist's shoulder, supporting the leg with both hands. Apply a gentle stretch to the hamstring muscle by gradually straightening the knee and elevating the leg until the patient experiences discomfort or a mild stretch in the back of the thigh. Hold the stretch for 15-30 seconds. Then, slowly release the stretch and allow the patient to relax for a few seconds.

Avoid applying excessive force. Repeat the stretch for a total of 10 repetitions, gradually increasing the range of motion and duration of the stretch.

Heel-Cord Stretching

REPS: 10 **|** HOLD: 15-30 sec.

Position the patient comfortably in a supine position on a bed or table. The therapist should stand at the end of the table on the side of the affected leg. Grasp the affected foot with both hands, placing one hand under the heel and using the forearm of the same hand to support the plantar aspect of the foot and be used for pushing. The other hand should be placed over the leg for stabilization. Slowly and gradually dorsiflex the patient's ankle joint by pushing the foot towards the head while maintaining the knee in full extension. Stop at the point where the patient experiences discomfort or a mild stretch in the calf muscles, and hold the stretch for 15-30 seconds. Then slowly release the stretch and return the foot to its starting position.

Avoid applying excessive force. Repeat the stretch for a total of 10 repetitions, gradually increasing the range of motion and duration of the stretch.

(2) Active-Assisted Range of Motion Exercises for the Upper and Lower Extremities

Hip and Knee Flexion in Supine

REPS: 10 | SETS: 3

Starting position:
The patient should lie on their back in a supine position, with their legs extended, and their arms by their sides. The therapist should stand at the affected side of the patient, close enough to guide and assist the patient through the movement if necessary.

Exercise:
Ask the patient to slide the heel of their affected leg towards their chest to bend their hip and knee. Then slide the heel back down to the starting position. The patient should perform the movement slowly and smoothly, without jerking or bouncing. Repeat and perform 3 sets of 10 repetitions.

As the patient gains strength and mobility, the therapist can gradually decrease their level of assistance and encourage the patient to perform the movement independently.

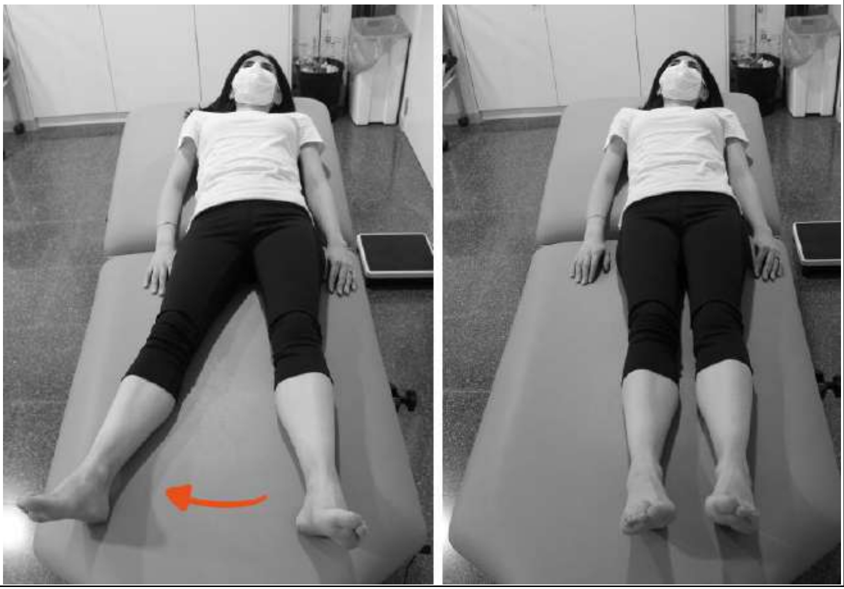
Hip Abduction-Adduction in Supine

REPS: 10 | SETS: 3

Starting position:
The patient should lie on their back in a supine position, with their legs extended, and their arms by their sides. The therapist should stand at the affected side of the patient, close enough to guide and assist the patient through the movement if necessary.

Exercise:
The patient should slightly lift their affected leg off the bed, keeping the knee straight. The patient should then slowly move the leg away from the other leg while keeping the knee straight, performing the abduction movement. Once they have moved their leg as far as they can in this direction, the patient should slowly bring the leg back towards the midline of the body, performing the adduction movement. This completes one repetition. The patient should perform a total of 3 sets of 10 repetitions, with a short rest period between sets.

As the patient gains strength and mobility, the therapist can gradually decrease their level of assistance and encourage the patient to perform the movement independently.



Ankle Dorsiflexion-Plantarflexion in Supine

REPS: 10 **|** SETS: 3

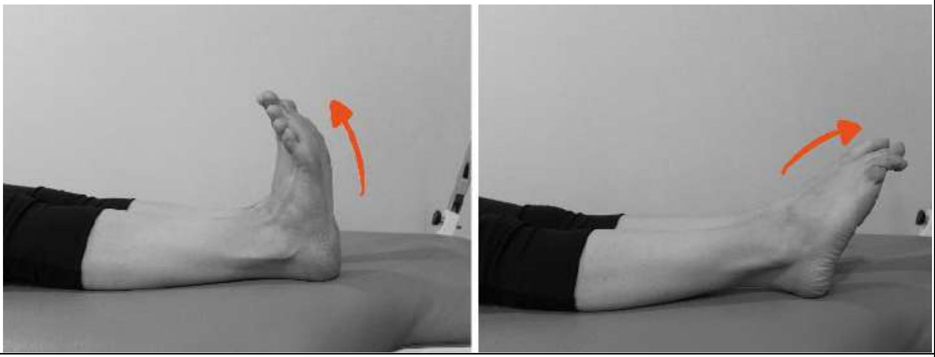
Starting position:

The patient should lie on their back in a supine position, with their legs extended, and their arms by their sides. The therapist should stand at the affected side of the patient, close enough to guide and assist the patient through the movement if necessary.

Exercise:

The patient should start with their ankle in a neutral position, pointing straight up towards the ceiling. Then the patient should lift their toes up towards their shin, performing dorsiflexion. Once they have reached their limit, the patient should then slowly point their toes down towards the floor, performing plantarflexion. This completes one repetition. The patient should perform a total of 3 sets of 10 repetitions, with a short rest period between sets.

As the patient gains strength and mobility, the therapist can gradually decrease their level of assistance and encourage the patient to perform the movement independently.



Shoulder Flexion-Extension, Abduction-Adduction, and Horizontal Abduction-Adduction

REPS: 10 **|** SETS: 3

Starting position:

The patient should sit in a comfortable position on a chair, with their back straight and their feet flat on the ground, and the affected arm resting comfortably at the side. The therapist should stand at the affected side of the patient, close enough to guide and assist the patient through the movement if necessary.

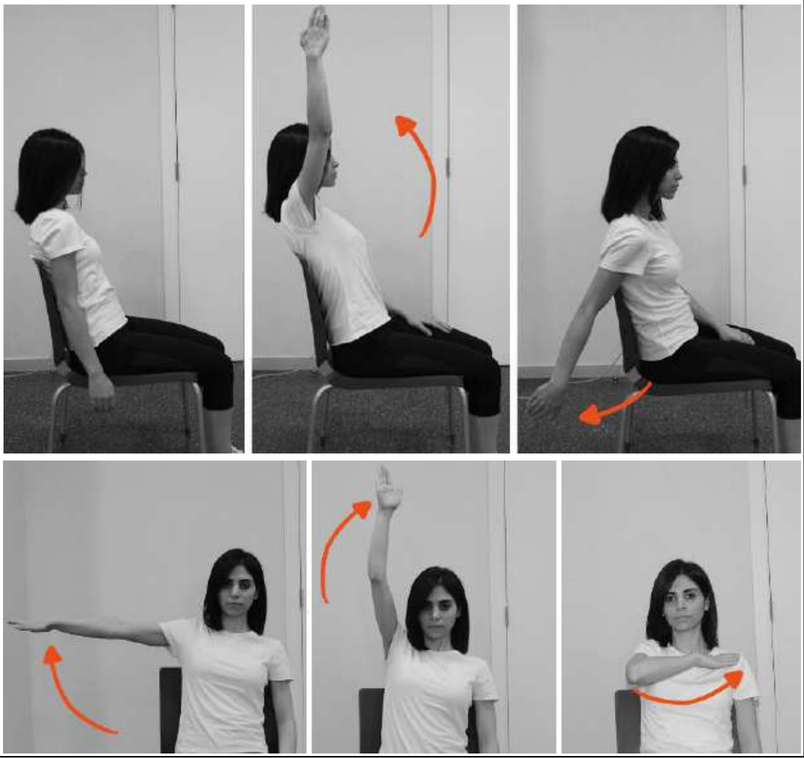
Exercise:

To perform shoulder flexion-extension, the patient should start with their affected arm hanging loosely at their side. They should then slowly lift their arm up towards the ceiling, keeping their elbow straight (shoulder flexion), and then slowly lower their arm back down and backwards (shoulder extension). This completes one repetition.

To perform shoulder abduction-adduction, the patient should start with their affected arm hanging loosely at their side, with the palm facing inwards. They should then slowly lift their arm out to the side, away from their body, until they feel a stretch in their shoulder (shoulder abduction), and then slowly lower their arm back down to their side (shoulder adduction). This completes one repetition.

To perform shoulder horizontal abduction-adduction, the patient should start with their affected arm out in front of them, parallel to the ground, palm facing down. They should then slowly move their arm out to the side, away from their body, until their arm is perpendicular to their body (horizontal abduction), and then slowly move their arm back in front of them (horizontal adduction). This completes one repetition.

The patient should perform a total of 3 sets of 10 repetitions for each movement cycle, with a short rest period between sets. As the patient gains strength and mobility, the therapist can gradually decrease their level of assistance and encourage the patient to perform the movement independently.



Elbow Flexion-Extension

REPS: 10 | SETS: 3

Starting position:

The patient should sit in a comfortable position on a chair, with their back straight and their feet flat on the ground, and the affected arm resting comfortably at the side. The therapist should stand at the affected side of the patient, close enough to guide and assist the patient through the movement if necessary.

Exercise:

The patient should slowly bend their elbow, bringing their hand towards their shoulder. Once the patient has lifted their hand as high as they can, they should then slowly straighten their elbow, pushing their hand away from their shoulder until their arm is fully extended, completing one repetition. The patient should perform a total of 3 sets of 10 repetitions, with a short rest period between sets.

As the patient gains strength and mobility, the therapist can gradually decrease their level of assistance and encourage the patient to perform the movement independently.

Forearm Supination-Pronation

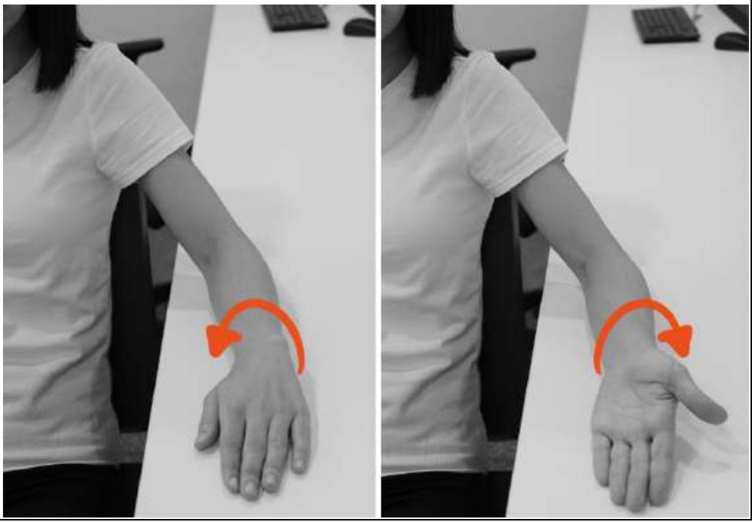
REPS: 10 | SETS: 3

Starting position:

The patient should sit in a comfortable position on a chair, with their back straight and their feet flat on the ground. The affected arm should be placed on a table with the palm facing down and the elbow bent at a 90-degrees. The therapist should stand at the affected side of the patient, close enough to guide and assist the patient through the movement if necessary.

Exercise:

The patient should slowly rotate their forearm so that their palm faces up, keeping their elbow stationary and their wrist straight (forearm supination), and then slowly rotate their forearm back to the starting position, with their palm facing down (forearm pronation). This completes one repetition. The patient should perform a total of 3 sets of 10 repetitions, taking a short rest period between sets.



As the patient gains strength and mobility, the therapist can gradually decrease their level of assistance and encourage the patient to perform the movement independently.

Wrist Flexion-Extension, and Radial-Ulnar Deviation

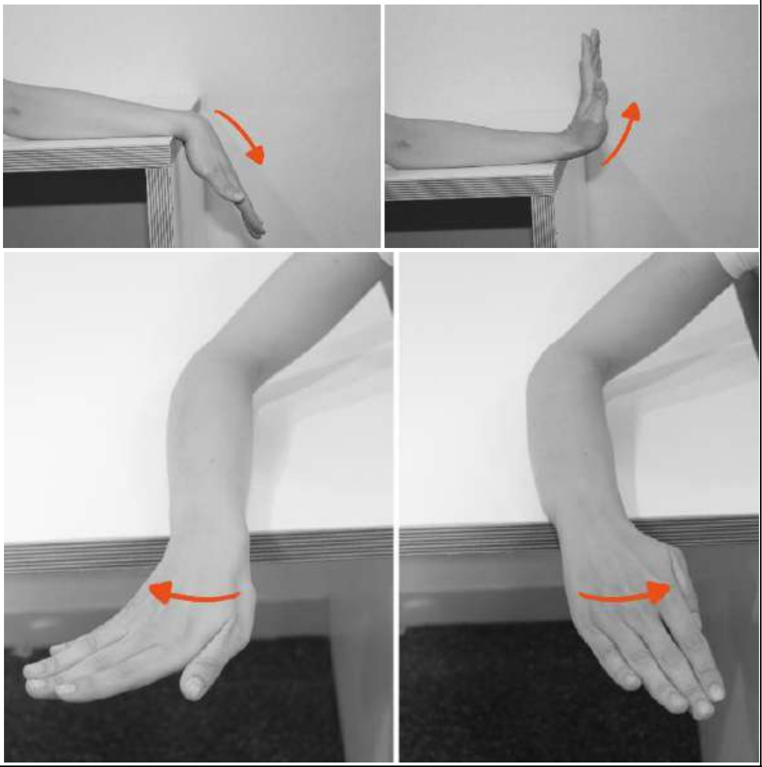
REPS: 10 **|** SETS: 3

Starting position:

The patient should sit in a comfortable position on a chair, with their back straight and their feet flat on the ground. The affected arm should be placed on a table with the forearm resting on the table and the elbow bent at a 90-degrees. The therapist should stand at the affected side of the patient, close enough to guide and assist the patient through the movement if necessary.

Exercise:

To perform wrist flexion-extension, the patient should start with their affected wrist hanging off the edge of the table, with the hand facing down. The patient should then slowly bend their wrist downward towards the palm (wrist flexion), and then slowly bend it backwards towards their forearm (wrist extension). This completes one repetition.



To perform radial-ulnar deviation, the patient should start with their affected wrist in a neutral position, with the hand facing down. The patient should then slowly tilt their wrist towards the thumb side (radial deviation), and then towards the little finger side (ulnar deviation). This completes one repetition. The patient should perform a total of 3 sets of 10 repetitions for each movement, with a short rest period between sets.

As the patient gains strength and mobility, the therapist can gradually decrease their level of assistance and encourage the patient to perform the movement independently.

(3) Strengthening Exercises

Seated Knee Extension

REPS: 10 **|** SETS: 3 **|** HOLD: 2-3 sec.

Starting position:

The patient should sit with their back straight and their feet flat on the ground, shoulder-width apart, and knees bent at a 90-degrees. Attach and secure an ankle weight to the patient's ankle.

Exercise:

The patient should slowly straighten the leg, lifting the foot off the ground and extending the knee as possible, and point the toes up (ankle at a 90-degrees). Hold this position for 2-3 seconds, then slowly lower the leg back down to return to the starting position. Repeat with the other leg. Alternate between the right and left legs, performing a total of 3 sets of 10 repetitions of the movement, slowly and with control, for each leg, with a short rest period between sets.

The patient should start with 1kg of ankle weight and progress to 1.5kg and 2kg as strength and tolerance improves. The therapist should monitor the patient's progress and adjust the weight accordingly.

Standing Knee Flexion (Hamstring Curl)

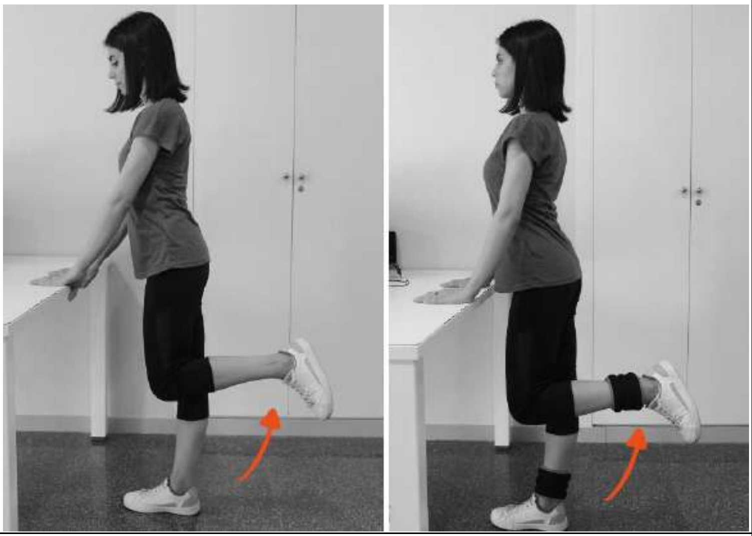
REPS: 10 **|** SETS: 3 **|** HOLD: 2-3 sec.

Starting position:

The patient should stand upright, holding onto a sturdy countertop or the back of a sturdy chair for support and balance, with their feet shoulder-width apart. Attach and secure an ankle weight to the patient's ankle.

Exercise:

The patient should start the exercise by slowly bending one knee, lifting and bringing the heel towards the buttocks, while keeping the thigh stationary. Hold this position for 2-3 seconds, then slowly lower the leg back down to return to the starting position. Repeat with the other leg. Alternate between the right and left legs, performing a total of 3 sets of 10 repetitions of the movement, slowly and with control, for each leg, with a short rest period between sets.



The patient should start with 1kg of ankle weight and progress to 1.5kg and 2kg as strength and tolerance improves. The therapist should monitor the patient's progress and adjust the weight accordingly.

Standing Hip Abduction

REPS: 10 **|** SETS: 3 **|** HOLD: 2-3 sec.

Starting position:

The patient should stand upright near a sturdy countertop or the back of a sturdy chair and hold it with one hand for support and balance, with their feet shoulder-width apart. Attach and secure an ankle weight to the patient's ankle.

Exercise:

The patient should shift their weight to one leg and slowly lift the other leg out to the side, keeping the knee straight and toes pointing forward. Hold for 2-3 seconds and then slowly lower the leg back down. Repeat with the other leg. Alternate between the right and left legs, performing a total of 3 sets of 10 repetitions of the movement, slowly and with control, for each leg, with a short rest period between sets.

The patient should start with 1kg of ankle weight and progress to 1.5kg and 2kg as strength and tolerance improves. The therapist should monitor the patient's progress and adjust the weight accordingly. The therapist should ensure that the patient maintains a good and stable posture and avoid leaning to one side or forward/backward during the exercise.

(4) Sitting and Standing Balance Training

Forward Reach in Sitting

REPS: 10 | SETS: 3 | HOLD: 2-3 sec.

Starting position:
The patient should be sitting upright in a chair with the feet flat on the ground and the arms relaxed at the sides. The patient should sit close to the edge of the chair.

Exercise:
The patient should start by reaching forward with the affected arm as far as possible. This movement should be slow and controlled. The patient should hold this position for 2-3 seconds, and then slowly return the arm to the starting position. The patient should repeat this movement for 10 repetitions. Once the patient's ability improves with the movement using the affected arm, the therapist can progress the exercise by having the patient perform the movement bilaterally, reaching forward with both arms simultaneously. The patient should perform 3 sets of 10 repetitions, with a short rest period between sets.

The therapist should ensure that the patient is not overreaching or leaning too far forward while performing the exercise. As the patient progresses, they can increase the range of reaching and holding duration.

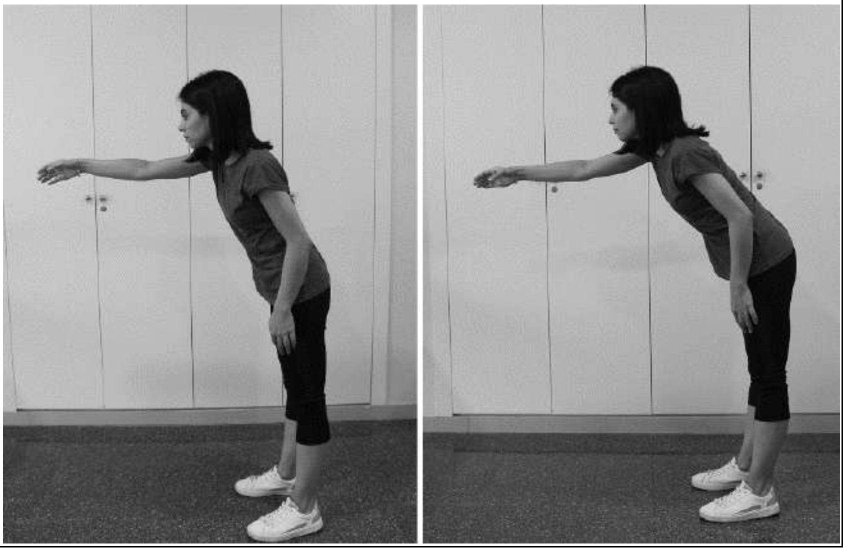
Forward Reach in Standing

REPS: 10 | SETS: 3 | HOLD: 2-3 sec.

Starting position:
The patient should stand upright with their feet shoulder-width apart and their arms relaxed at their sides.

Exercise:
The patient should start by reaching forward with the affected arm as far as possible. Hold the forward reach for 2-3 seconds, and then slowly return the arm to the side. Next, reach forward with the unaffected arm as far as possible. Again, hold for 2-3 seconds, and then slowly return the arm to the side. The reaching movement should be slow and controlled. Repeat this sequence of movements for 3 sets of 10 repetitions for each arm, with a short rest period between sets.

The therapist should monitor the patient during the exercise to ensure it is being performed correctly and safely. As the patient progresses, they can increase the range of reaching and holding duration.



(5) Walking Training

Gait Training with Parallel Bars Progress to Overground Walking

REPS: 3 | 1 REP = 10 meters

Starting position:

The patient is positioned at the parallel bars and instructed to grip the bars firmly while standing upright with their feet shoulder-width apart. The therapist should adjust the height of the bars to the patient's waist level, allowing them to maintain a comfortable and upright posture.

Exercise:

The therapist should begin by demonstrating how to use the parallel bars for gait training. Then, the therapist should instruct the patient to shift their weight from one leg to another and take steps forward while maintaining balance with the support of the bars. Initially, the therapist may provide physical assistance, such as holding onto the patient's waist or providing cues and feedback for step length, weight-bearing, and to encourage proper posture and gait pattern.

Once the patient becomes able to walk independently and has mastered walking with the parallel bars, the therapist should progress them to overground walking. The patient should perform three repetitions of 10 meters of overground walking. The therapist should provide physical assistance or cues if necessary to maintain a proper gait pattern.

Stepping Over a Series of Obstacles

REPS: 5 | SETS: 3

Starting position:

The therapist should set up a series of obstacles (e.g., small hurdles) along the pathway of the parallel bars. The distance between the obstacles should be such that it allows the patient to walk with a comfortable stride length. The patient should stand upright with their feet shoulder-width apart in front of the obstacles while holding onto the parallel bars for support. The therapist should be close by to provide support and ensure safety.

Exercise:

The patient is instructed to begin walking and step over each obstacle, one foot at a time, taking care not to trip or lose balance. The patient should lift their foot high enough to clear the obstacle and then bring it down to the ground on the other side, maintaining a natural walking motion without stopping or hesitating. Once the patient has stepped over all the obstacles, they should turn around and repeat the exercise in the opposite direction, stepping over the same obstacles again. This completes one repetition of the exercise. The patient should perform 3 sets of 5 repetitions, with a short rest period between each set.

11.3 Berg balance scale (BBS)

BERG BALANCE SCALE (BBS)

Balance Item	Score (0-4)
1. Sitting unsupported	________
2. Change of position: sitting to standing	________
3. Change of position: standing to sitting	________
4. Transfers	________
5. Standing unsupported	________
6. Standing with eyes closed	________
7. Standing with feet together	________
8. Tandem standing	________
9. Standing on one leg	________
10. Turning trunk (feet fixed)	________
11. Retrieving objects from floor	________
12. Turning 360 degrees	________
13. Stool stepping	________
14. Reaching forward while standing	________

TOTAL (0–56): ________

11.4 Barthel index (BI)

THE BARTHEL INDEX (BI)

Activity	Score
FEEDING 0 = Dependent: needs to be fed by another person 5 = Needs help to cut meat, bread, etc. but he is able to eat alone 10 = Totally independent	______
BATHING 0 = Dependent: needs some kind of help or supervision 5 = Independent (or in shower)	______
GROOMING 0 = Dependent: needs to help with personal care 5 = Independent to wash face, hands, comb hair, shave, put on makeup, etc.	______
DRESSING 0 = Dependent 5 = Needs help but can do about half unaided 10 = Independent: able to put on and take off clothes, button, tie shoes	______
BOWELS 0 = Incontinent 5 = Occasionally an episode of incontinence, or needs to be given enemas 10 = Continent	______
BLADDER 0 = Incontinent, or catheterized and unable to manage alone 5 = Occasional an episode of incontinence, or needs help to take care of the catheter 10 = Continent, or able to care for the catheter if one is in place	______
TOILET USE 0 = Dependent 5 = Needs some help, but can do something alone 10 = Independent (on and off, dressing, wiping)	______
TRANSFERS (BED TO CHAIR AND BACK) 0 = Unable, no sitting balance 5 = Major help (one or two people, physical), can sit alone 10 = Minor help (verbal, supervision or physical) 15 = Independent	______
MOBILITY (ON LEVEL SURFACES) 0 = Immobile or < 50 meters 5 = Wheelchair independent, including corners, > 50 meters 10 = Walks with help of one person (verbal or physical) > 50 meters 15 = Independent (but may use any aid; for example, stick) > 50 meters	______
STAIRS 0 = Unable 5 = Needs help (verbal, physical, carrying aid or supervision) 10 = Independent to go down and up stairs	______

TOTAL (0–100): ______

11.5 Stroke impact scale-16 (SIS-16)

ESCALA DE IMPACTO DEL ICTUS (SIS-16) (Castellà)

Durante las últimas 2 semanas, ¿hasta qué punto le ha sido difícil...	No la pudo realizar en absolute (Incapaz de Hacerlo)	La realizó con mucha dificultad (Muy Difícil)	La realizó con bastante dificultad (Bastante Difícil)	La realizó con ligera dificultad (Un poco Difícil)	La realizó sin dificultad alguna (Nada Difícil)
1) vestirse la parte superior de su cuerpo?	1	2	3	4	5
2) lavarse (bañarse, ducharse...)?	1	2	3	4	5
3) llegar al baño a tiempo?	1	2	3	4	5
4) controlar su vejiga (no sufrir un "accidente")?	1	2	3	4	5
5) controlar su intestino (no sufrir un "accidente")?	1	2	3	4	5
6) estar de pie sin perder el equilibrio?	1	2	3	4	5
7) ir de compras?	1	2	3	4	5
8) realizar tareas domésticas que supongan esfuerzo (p.e. usar la aspiradora, lavar la ropa o arreglar su jardín)?	1	2	3	4	5
9) estar sentado/a sin perder el equilibrio?	1	2	3	4	5
10) caminar (andar) sin perder el equilibrio?	1	2	3	4	5
11) trasladarse sólo de la cama a una silla?	1	2	3	4	5
12) caminar (andar) de prisa?	1	2	3	4	5
13) subir por las escaleras una planta?	1	2	3	4	5
14) caminar una manzana (unos 100 metros)?	1	2	3	4	5
15) entrar y salir de un coche (o carro)?	1	2	3	4	5
16) llevar objetos pesados con la mano afectada (p.e. una bolsa con la compra de alimentos)?	1	2	3	4	5
Total de puntos:					

STROKE IMPACT SCALE-16 (SIS-16) (English)

In the last two weeks, how difficult was it for you to…	**Couldn't do it at all**	**Did it with great difficulty**	**Did it with a lot of difficulty**	**Did it with slight difficulty**	**Did it without any difficulty**
1) Dress your upper body?	1	2	3	4	5
2) Take a bath by yourself?	1	2	3	4	5
3) Get to the bathroom on time?	1	2	3	4	5
4) Control your urinary bladder (not have an "accident")?	1	2	3	4	5
5) Control your bowel (not have an "accident")?	1	2	3	4	5
6) Stand up without losing balance?	1	2	3	4	5
7) Go shopping?	1	2	3	4	5
8) Carry out heavy household chores (e.g., vacuuming, doing laundry or gardening)?	1	2	3	4	5
9) Stay seated without losing balance?	1	2	3	4	5
10) Walk without losing balance?	1	2	3	4	5
11) Transfer from bed to chair alone?	1	2	3	4	5
12) Walk fast?	1	2	3	4	5
13) Climb the stairs one floor?	1	2	3	4	5
14) Walk around a block (or block) of houses?	1	2	3	4	5
15) Get in and out of a car (or cart)?	1	2	3	4	5
16) Carry heavy objects (e.g., a grocery bag) with your affected hand?	1	2	3	4	5
Total points:					

11.6 Ethical approval

Informe del Comité de Ética de la Investigación con medicamentos del Parc de Salut Mar

Doña Cristina Llop Julià, secretaria técnica del **Comité de Ética de la Investigación con medicamentos del Parc de Salut MAR**,

CERTIFICA

Que este Comité, de acuerdo a la Ley 14/2007 de Investigación Biomédica, Principios éticos de la Declaración de Helsinki, y resto de principios éticos aplicables, ha evaluado la propuesta para que se realice el proyecto de investigación núm. 2021/9986/I, promovido por Consorci Mar Parc de Salut de Barcelona y titulado: "El efecto del programa de reaprendizaje motor sobre el equilibrio, la movilidad y el desempeño de las actividades de la vida diaria en pacientes que han sufrido un ictus".

Versión de los documentos:

- **Protocolo versión 2 de fecha 16/07/2021**
- **HIP/CI versión 2 de fecha 16/07/2021**

Y considera que:

- Se cumplen los requisitos necesarios de idoneidad del protocolo en relación con los objetivos del estudio y están justificados los riesgos y molestias previsibles para el sujeto.
- La capacidad del investigador y sus colaboradores, y las instalaciones y medios disponibles, tal y como ha sido informado, son apropiados para llevar a cabo el estudio.
- Son adecuados los procedimientos para obtener el consentimiento informado y el modo de reclutamiento previsto, así como la compensación prevista para los sujetos por daños que pudieran derivarse de su participación en el estudio.
- El alcance de las compensaciones económicas previstas no interfiere con el respeto a los postulados éticos.

Y que este Comité aprueba que dicho proyecto de investigación sea realizado en el Servicio de Medicina Física y Rehabilitación del Centre Fòrum por el Dr. Amer Ghrouz como investigador principal, tal como recoge el ACTA de reunión del día 07/09/2021.

Lo que firmo en Barcelona a 17 de septiembre de 2021

COMITÈ ÈTIC D'INVESTIGACIÓ
CEIC - PARC DE SALUT MAR

Firmado digitalmente por LLOP JULIA CRISTINA - 53314050G
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Secretaria técnica CEIm-PSMAR

11.7 Participant information sheet

HOJA DE INFORMACIÓN AL PACIENTE

TÍTULO DEL ESTUDIO: El efecto del programa de reaprendizaje motor sobre el equilibrio, la movilidad y el desempeño de las actividades de la vida diaria en pacientes que han sufrido un ictus

INVESTIGADOR PRINCIPAL: Amer Ghrouz, Servicio de Medicina Física y Rehabilitación, Tel: 933268500

CENTRO: Centre Fòrum, Parc de Salut Mar

INTRODUCCION

Nos dirigimos a usted para informarle sobre un estudio de investigación en el que se le invita a participar. El estudio ha sido aprobado por el Comité Ético de Investigación Clínica correspondiente.

Nuestra intención es tan solo que usted reciba la información correcta y suficiente para que pueda evaluar y juzgar si quiere o no participar en este estudio. Para ello lea esta hoja informativa con atención y nosotros le aclararemos las dudas que le puedan surgir después de la explicación. Además, puede consultar con las personas que considere oportuno.

PARTICIPACIÓN VOLUNTARIA

Debe saber que su participación en este estudio es voluntaria y que puede decidir no participar o cambiar su decisión y retirar el consentimiento en cualquier momento, sin que por ello se altere la relación con su médico ni se produzca perjuicio alguno en su tratamiento.

DESCRIPCIÓN GENERAL DEL ESTUDIO

Objeto del estudio de investigación

El objetivo de este estudio es investigar la efectividad del entrenamiento específico de tareas de reaprendizaje motor sobre el equilibrio, la movilidad y el desempeño de las actividades de la vida diaria entre los supervivientes después de un ictus. Los resultados del estudio pueden arrojar luz sobre nuevas formas de abordar y comprender la rehabilitación del ictus. Además, el presente estudio tiene como objetivo ayudar a cerrar la brecha de conocimiento actual en las recomendaciones de rehabilitación física y ejercicio en la población con ictus.

¿Qué implica mi participación en el estudio de investigación? (¿Qué debo considerar?)

Después de leer esta hoja de información y tomarse el tiempo para hacer preguntas, se le pedirá que decida si está dispuesto a participar en este estudio. Si acepta participar, una computadora lo asignará al azar a uno de los 2 grupos de tratamiento. La aleatorización se realiza para asegurarse de que los resultados del ensayo no se vean afectados por el sesgo del investigador, por lo tanto, no podremos elegir a qué grupo ingresará. Un grupo (Grupo 1) recibirá una práctica específica de la tarea del programa de reaprendizaje motor, mientras que el otro grupo (Grupo 2) recibirá un programa de fisioterapia convencional (rehabilitación estándar del ictus).

El estudio se realizará en tres fases:

Fase I: Evaluación e intervención

La primera fase comenzará con actividades de detección para averiguar si califica para participar en este estudio. Es posible que muchas de estas actividades ya hayan ocurrido, ya que son parte de su atención de rutina.

Se evaluará lo siguiente para los participantes elegibles de los dos grupos:

- Escala de equilibrio de Berg (BBS)
- Prueba Timed Up and Go (TUG)
- Prueba de caminata de 10 metros (10mWT)
- Índice de Barthel (BI)
- Evaluación funcional del equilibrio y control postural mediante herramienta de posturografía computarizada - Plataforma NedSVE/IBV® (Valoración funcional del equilibrio)
- Evaluación funcional de la marcha utilizando el sistema NedAMH/IBV® (Valoración funcional de la marcha)

Los individuos de un grupo (Grupo 1) completarán 8 semanas (3 sesiones por semana; 1 hora por sesión; 24 sesiones) de práctica de tareas específicas del programa de reaprendizaje motor. Mientras que, los individuos del otro grupo (Grupo 2) recibirán un programa de fisioterapia convencional (rehabilitación estándar del ictus) durante 8 semanas (3 sesiones por semana; 1 hora por sesión; 24 sesiones).

Fase II: Evaluación posterior a la intervención

Las personas de los dos grupos serán reevaluadas para los mismos componentes que en la Fase I utilizando las mismas herramientas de evaluación después de completar la intervención. La retroalimentación de los resultados y el desempeño se dará al final de esta fase.

Fase III: Evaluación de seguimiento a los 3 meses

En esta fase, los participantes de ambos grupos serán reevaluados después de tres meses de la sesión de evaluación posterior a la intervención de cada participante para investigar qué grupo de tratamiento mantuvo la mejora a largo plazo.

El procedimiento de aleatorización

Los participantes elegibles serán asignados al azar a uno de los dos grupos (grupo de estudio o grupo de control) con una proporción de asignación de 1:1, utilizando una herramienta basada en la web (www.sealedenvelope.com).

Los códigos generados serán distribuidos y almacenados en sobres sellados y mantenidos en forma confidencial por un miembro del equipo de investigación que realizó el procedimiento de aleatorización; esta persona estará ciega a las identidades de los participantes hasta que los participantes hayan completado todas las evaluaciones de referencia. Para la asignación en grupos, cada participante a ciegas levantará un sobre sellado que indica uno de los grupos de intervención. Se informará a los participantes sobre su grupo de intervención asignado.

BENEFICIOS Y RIESGOS DERIVADOS DE SU PARTICIPACIÓN EN EL ESTUDIO

Beneficios derivados de su participación en el estudio

No podemos garantizarle que obtendrá mayor beneficio con un tipo u otro de fisioterapia, aunque ambos han demostrado mejorar los resultados funcionales en pacientes con ictus. Sin embargo, el programa lo ayudará a comprender mejor sus habilidades potenciales como sobreviviente de un ictus. Aprenderá algunos ejercicios motores y de equilibrio diseñados específicamente para la población con ictus, así como algunas estrategias de afrontamiento para realizar actividades de la vida diaria en el hogar y en la comunidad. La información que obtenemos de este estudio ayudará a mejorar la recuperación y rehabilitación del ictus en la comunidad en general, en el futuro.

Riesgos derivados de su participación en el estudio

El reaprendizaje motor se ha utilizado en la rehabilitación de muchos supervivientes de ictus, ninguno de los cuales ha sufrido efectos secundarios dañinos relacionados con esta terapia. Sin embargo, las personas que han sufrido un ictus pueden presentar con frecuencia fatiga asociada a esfuerzos moderados, lo que no comporta ningún riesgo médico y se resuelve generalmente con el reposo. Existe también la posibilidad de sentir “rigidez muscular” o “espasticidad” asociada con el esfuerzo, lo que también es común después de sufrir un ictus y se resuelve generalmente con el reposo. Su fisioterapeuta registrará estos efectos al terminar cada sesión.

CONFIDENCIALIDAD

El tratamiento, la comunicación y la cesión de los datos de carácter personal de todos los sujetos participantes se ajustará a lo dispuesto en la Ley Orgánica 3/2018, de 5 de diciembre, de Protección de Datos Personales y garantía de los derechos digitales. De acuerdo a lo que establece la legislación mencionada, usted puede ejercer los derechos de acceso, modificación, oposición y cancelación de datos, para lo cual deberá dirigirse a su médico del estudio.

Los datos recogidos para el estudio estarán identificados mediante un código y solo su médico del estudio/colaboradores podrán relacionar dichos datos con usted y con su historia clínica. Por lo tanto, su identidad no será revelada a persona alguna salvo excepciones, en caso de urgencia médica o requerimiento legal.

Sólo se transmitirán a terceros y a otros países los datos recogidos para el estudio que en ningún caso contendrán información que le pueda identificar directamente, como nombre y apellidos, iniciales, dirección, nº de la seguridad social, etc. En el caso de que se produzca esta cesión, será para los mismos fines del estudio descrito y garantizando la confidencialidad como mínimo con el nivel de protección de la legislación vigente en nuestro país.

El acceso a su información personal quedará restringido al médico del estudio/colaboradores, autoridades sanitarias (Agencia Española del Medicamento y Productos Sanitarios), al Comité Ético de Investigación Clínica y personal autorizado por el promotor, cuando lo precisen para comprobar los datos y procedimientos del estudio, pero siempre manteniendo la confidencialidad de los mismos de acuerdo a la legislación vigente.

COMPENSACIÓN ECONÓMICA

El promotor del estudio es el responsable de gestionar la financiación del mismo. Para la realización del estudio el promotor del mismo ha firmado un contrato con el centro donde se va a realizar y con el médico del estudio.

Su participación en el estudio no le supondrá ningún gasto y le serán reintegrados los gastos extraordinarios (p. ejem. comidas y traslados). Usted no tendrá que pagar por las intervenciones del estudio.

OTRA INFORMACIÓN RELEVANTE

Cualquier nueva información referente a las intervenciones utilizados en el estudio y que pueda afectar a su disposición para participar en el estudio, que se descubra durante su participación, le será comunicada por su médico lo antes posible.

Si usted decide retirar el consentimiento para participar en este estudio, ningún dato nuevo será añadido a la base de datos y, puede exigir la destrucción de todas las muestras identificables previamente retenidas para evitar la realización de nuevos análisis.

También debe saber que puede ser excluido del estudio si el promotor los investigadores del estudio lo consideran oportuno, ya sea por motivos de seguridad, por cualquier acontecimiento adverso que se produzca por las intervenciones en estudio o porque consideren que no está cumpliendo con los procedimientos establecidos. En cualquiera de los casos, usted recibirá una explicación adecuada del motivo que ha ocasionado su retirada del estudio.

Al firmar la hoja de consentimiento adjunta, se compromete a cumplir con los procedimientos del estudio que se le han expuesto.

Cuando acabe su participación recibirá el mejor tratamiento disponible y que su médico considere el más adecuado para su enfermedad, pero es posible que no se le pueda seguir administrando las intervenciones del estudio. Por lo tanto, ni el investigador ni el promotor adquieren compromiso alguno de mantener dicho tratamiento fuera de este estudio.

Datos de contacto del equipo de investigación:

Investigador

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Parc de Salut Mar, Barcelona
Telf +34933674214. FAX +34933674276
Eduarte@parcdesalutmar.cat

Gracias por considerar participar

Gracias por tomarse el tiempo de leer esta información

11.8 Consent form

Consentiment Informat (Català)

"CONSENTIMENT INFORMAT PER ESCRIT"

Títol de l'estudi: L'efecte del programa de reaprenentatge motor sobre l'equilibri, la mobilitat i el rendiment de les activitats de la vida diària entre els pacients post-ictus

Jo …………………………………………………………………………………….
(nom i cognoms del participant)

He llegit el full d'informació que m'ha estat lliurat.
He pogut fer preguntes sobre l'estudi.
He rebut suficient informació sobre l 'estudi.

He parlat amb ………………………………………………………………………..
(nom i cognom de l'investigador)

Entenc que la meva participació és voluntària.

Entenc que puc retirar-me de l'estudi:
1º Quan vulgui.
2º Sense donar explicacions.
3º Sense que això repercuteixi en la meva atenció mèdica.

Dono lliurement la meva conformitat per participar en aquest estudi i dono lliurament el meu consentiment per l'accés i utilització de les meves dades en les condicions detallades en el full d'informació.

Si ☐ NO ☐

Nom i cognoms del **participant:**
Data:
Signatura

Nom i cognoms de l'**investigador:**
Data:
Signatura

Consentiment Informat (Castellà)

"CONSENTIMIENTO INFORMADO"

Título del estudio: El efecto del programa de reaprendizaje motor sobre el equilibrio, la movilidad y el desempeño de las actividades de la vida diaria en pacientes que han sufrido un ictus.

Yo ………………………………………………………………………………….
(nombre y apellidos del participante)

He leído la hoja de información que me han proporcionado.
He podido hacer preguntas sobre el estudio.
He recibido suficiente información sobre el estudio.

He hablado con ……………………………………………………………………..
(nombre y apellidos del investigador)

Comprendo que mi participación es voluntaria.

Comprendo que puedo retirarme del estudio:
1º Cuando quiera.
2º Sin dar explicaciones.
3º Sin que esto repercuta en mi atención médica.

Doy libremente mi conformidad para participar en este estudio y mi consentimiento para el acceso y la utilización de mis datos en la condiciones detalladas en la hoja de información.

Si ☐ NO ☐

Nombre y apellidos del **participante**:
Fecha:
Firma

Nombre y apellidos del **investigador:**
Fecha:
Firma

11.9 Results of instrumental functional balance assessment at baseline

Appendix I: Results of instrumental functional balance assessment of study participants at baseline.

Functional Balance Assessment Tests	MRP Group (n = 32)		CPT Group (n = 31)		All Participants (n = 63)	*P* Value	Effect Size *d* (95% CI)
	Mean (SD)	95% CI of Mean	Mean (SD)	95% CI of Mean	Mean (SD)		
Static Posturography Tests							
Romberg Test with Eyes Open (ROA)							
ROA Total Displacement (mm)	11.24 (4.39)	9.65 ;12.82	8.72 (3.79)	7.33 ; 10.11	10.00 (4.27)	0.009	0.61 (0.10; 1.12)
ROA Displacement Angle (º)	226.85 (83.87)	196.61 ; 257.09	213.60 (59.00)	191.96 ; 235.24	220.33 (72.43)	0.458	0.18 (0.31; 0.68)
ROA Mediolateral (ML) Dispersed X (mm)	4.26 (1.55)	3.71 ; 4.82	4.53 (1.38)	4.02 ; 5.03	4.39 (1.46)	0.429	0.18 (0.67; 0.32)
ROA Anteroposterior (AP) Dispersed Y (mm)	5.88 (2.75)	4.88 ; 6.87	5.82 (2.79)	4.80 ; 6.84	5.85 (2.75)	0.853	0.02 (0.47; 0.51)
ROA Average Speed (m/s)	0.02 (0.01)	0.01 ; 0.02	0.02 (0.01)	0.01 ; 0.02	0.02 (0.01)	0.479	0.07 (0.56; 0.42)
ROA Mediolateral (ML) Displacement (mm)	23.41 (11.17)	19.39 ; 27.44	23.37 (8.77)	20.16 ; 26.59	23.39 (9.98)	0.821	0.00 (0.49; 0.50)
ROA Anteroposterior (AP) Displacement (mm)	29.98 (13.20)	25.22 ; 34.74	29.83 (14.30)	24.58 ; 35.07	29.91 (13.64)	0.789	0.01 (0.48; 0.51)
ROA Mediolateral (ML) Maximal Force (N)	10.95 (6.59)	8.58 ; 13.33	10.28 (5.38)	8.31 ; 12.25	10.62 (5.99)	0.837	0.11 (0.38; 0.61)
ROA Anteroposterior (AP) Maximal Force (N)	6.36 (3.68)	5.03 ; 7.68	6.44 (3.82)	5.04 ; 7.84	6.40 (3.72)	0.912	0.02 (0.52; 0.47)
ROA Assessment Score (%)	96.47 (4.30)	94.92 ; 98.02	95.71 (5.32)	93.76 ; 97.66	96.10 (4.80)	0.597	0.16 (0.34; 0.65)
Romberg Test with Eyes Closed (ROC)							
ROC Total Displacement (mm)	13.95 (6.73)	11.52 ; 16.37	11.37 (4.57)	9.69 ; 13.04	12.68 (5.87)	0.149	0.45 (0.06; 0.95)
ROC Displacement Angle (º)	273.83 (71.33)	248.11 ; 299.55	233.70 (69.91)	208.05 ; 259.34	254.08 (72.93)	0.024	0.57 (0.06; 1.07)
ROC Mediolateral (ML) Dispersed X (mm)	6.70 (3.33)	5.50 ; 7.90	6.75 (2.91)	5.68 ; 7.81	6.72 (3.10)	0.768	0.02 (0.51; 0.48)
ROC Anteroposterior (AP) Dispersed Y (mm)	7.51 (4.01)	6.07 ; 8.96	7.60 (3.29)	6.39 ; 8.80	7.55 (3.64)	0.747	0.02 (0.52; 0.47)
ROC Average Speed (m/s)	0.03 (0.03)	0.02 ; 0.04	0.03 (0.02)	0.02 ; 0.04	0.03 (0.02)	0.675	0.06 (0.44; 0.55)
ROC Mediolateral (ML) Displacement (mm)	35.21 (16.61)	29.22 ; 41.20	35.63 (16.05)	29.74 ; 41.51	35.41 (16.20)	0.891	0.03 (0.52; 0.47)
ROC Anteroposterior (AP) Displacement (mm)	41.44 (21.94)	33.53 ; 49.35	41.55 (19.19)	34.51 ; 48.59	41.49 (20.47)	0.716	0.01 (0.50; 0.49)
ROC Mediolateral (ML) Maximal Force (N)	14.47 (7.13)	11.89 ; 17.04	14.82 (6.91)	12.29 ; 17.36	14.64 (6.97)	0.869	0.05 (0.54; 0.44)
ROC Anteroposterior (AP) Maximal Force (N)	10.37 (7.78)	7.56 ; 13.17	10.62 (5.68)	8.54 ; 12.70	10.49 (6.77)	0.466	0.04 (0.53; 0.46)
ROC Assessment Score (%)	92.13 (8.45)	89.08 ; 95.17	91.94 (8.11)	88.96 ; 94.91	92.03 (8.21)	0.731	0.02 (0.47; 0.52)
Romberg Test with Eyes Open on Foam Cushion (RGA)							
RGA Total Displacement (mm)	17.75 (7.49)	15.06 ; 20.45	17.62 (6.93)	15.08 ; 20.16	17.69 (7.16)	0.956	0.02 (0.48; 0.51)
RGA Displacement Angle (º)	244.05 (64.30)	220.87 ; 267.23	237.07 (54.74)	216.99 ; 257.15	240.62 (59.41)	0.611	0.12 (0.38; 0.61)
RGA Mediolateral (ML) Dispersed X (mm)	8.34 (3.26)	7.16 ; 9.51	9.79 (4.27)	8.23 ; 11.36	9.05 (3.83)	0.268	0.38 (0.88; 0.12)
RGA Anteroposterior (AP) Dispersed Y (mm)	10.77 (3.89)	9.37 ; 12.17	11.42 (3.84)	10.01 ; 12.82	11.09 (3.85)	0.536	0.17 (0.66; 0.33)
RGA Average Speed (m/s)	0.04 (0.02)	0.04 ; 0.05	0.04 (0.02)	0.04 ; 0.05	0.04 (0.02)	0.573	0.01 (0.48; 0.50)
RGA Mediolateral (ML) Displacement (mm)	44.19 (13.99)	39.15 ; 49.23	51.93 (20.96)	44.24 ; 59.62	48.00 (18.05)	0.199	0.44 (0.93; 0.07)
RGA Anteroposterior (AP) Displacement (mm)	57.12 (17.14)	50.94 ; 63.29	59.61 (17.24)	53.29 ; 65.93	58.34 (17.10)	0.747	0.15 (0.64; 0.35)

RGA Mediolateral (ML) Maximal Force (N)	19.90 (7.79)	17.10 ; 22.71	21.21 (8.50)	18.09 ; 24.33	20.55 (8.10)	0.386	0.16 (0.65; 0.33)
RGA Anteroposterior (AP) Maximal Force (N)	14.20 (8.45)	11.15 ; 17.24	15.46 (8.02)	12.52 ; 18.40	14.82 (8.20)	0.492	0.15 (0.65; 0.34)
RGA Assessment Score (%)	91.66 (7.36)	89.00 ; 94.31	88.06 (10.13)	84.35 ; 91.78	89.89 (8.95)	0.216	0.41 (0.09; 0.90)
Romberg Test with Eyes Closed on Foam Cushion (RGC)							
RGC Total Displacement (mm)	26.75 (12.87)	22.11 ; 31.39	22.73 (7.04)	20.15 ; 25.31	24.77 (10.53)	0.582	0.39 (0.11; 0.88)
RGC Displacement Angle (º)	264.69 (76.33)	237.17 ; 292.21	292.83 (59.42)	271.03 ; 314.63	278.54 (69.45)	0.157	0.41 (0.91; 0.09)
RGC Mediolateral (ML) Dispersed X (mm)	23.66 (6.55)	21.29 ; 26.02	22.88 (5.35)	20.92 ; 24.84	23.28 (5.95)	0.559	0.13 (0.37; 0.62)
RGC Anteroposterior (AP) Dispersed Y (mm)	22.20 (5.37)	20.27 ; 24.14	21.32 (4.14)	19.80 ; 22.84	21.77 (4.79)	0.675	0.18 (0.31; 0.68)
RGC Average Speed (m/s)	0.10 (0.03)	0.09 ; 0.11	0.09 (0.02)	0.08 ; 0.10	0.10 (0.03)	0.630	0.24 (0.26; 0.73)
RGC Mediolateral (ML) Displacement (mm)	119.17 (26.04)	109.78 ; 128.56	113.45 (16.20)	107.51 ; 119.40	116.36 (21.78)	0.343	0.26 (0.23; 0.76)
RGC Anteroposterior (AP) Displacement (mm)	102.25 (19.08)	95.37 ; 109.13	100.57 (16.48)	94.53 ; 106.61	101.42 (17.72)	0.853	0.09 (0.40; 0.59)
RGC Mediolateral (ML) Maximal Force (N)	43.92 (13.00)	39.23 ; 48.61	40.63 (11.45)	36.43 ; 44.83	42.30 (12.28)	0.260	0.27 (0.23; 0.76)
RGC Anteroposterior (AP) Maximal Force (N)	38.58 (14.97)	33.18 ; 43.97	36.80 (11.62)	32.54 ; 41.07	37.70 (13.35)	0.747	0.13 (0.36; 0.63)
RGC Assessment Score (%)	71.97 (11.64)	67.77 ; 76.16	72.71 (11.49)	68.49 ; 76.93	72.33 (11.48)	0.815	0.06 (0.56; 0.43)
Romberg Test Stability Assessment							
ROA Mediolateral (ML) Stability (%)	97.47 (4.36)	95.90 ; 99.04	97.90 (3.92)	96.47 ; 99.34	97.68 (4.12)	0.773	0.10 (0.60; 0.39)
ROC Mediolateral (ML) Stability (%)	95.03 (5.90)	92.90 ; 97.16	95.42 (6.27)	93.12 ; 97.72	95.22 (6.04)	0.660	0.06 (0.56; 0.43)
RGA Mediolateral (ML) Stability (%)	92.69 (7.61)	89.94 ; 95.43	91.00 (8.11)	88.03 ; 93.97	91.86 (7.84)	0.336	0.21 (0.28; 0.71)
RGC Mediolateral (ML) Stability (%)	74.13 (11.73)	69.90 ; 78.35	78.00 (12.35)	73.47 ; 82.53	76.03 (12.10)	0.185	0.32 (0.82; 0.18)
Romberg Test ML Stability Assessment (%)	89.63 (5.53)	87.63 ; 91.62	90.61 (6.51)	88.22 ; 93.00	90.11 (6.01)	0.322	0.16 (0.66; 0.33)
ROA Anteroposterior (AP) Stability (%)	98.63 (2.56)	97.70 ; 99.55	98.55 (2.99)	97.45 ; 99.64	98.59 (2.76)	0.773	0.03 (0.47; 0.52)
ROC Anteroposterior (AP) Stability (%)	96.66 (6.71)	94.24 ; 99.08	97.32 (4.04)	95.84 ; 98.80	96.98 (5.53)	0.929	0.12 (0.61; 0.38)
RGA Anteroposterior (AP) Stability (%)	97.38 (5.77)	95.29 ; 99.46	96.10 (6.61)	93.67 ; 98.52	96.75 (6.18)	0.429	0.21 (0.29; 0.70)
RGC Anteroposterior (AP) Stability (%)	87.59 (13.02)	82.90 ; 92.29	90.71 (10.72)	86.78 ; 94.64	89.13 (11.95)	0.409	0.26 (0.76; 0.24)
Romberg Test AP Stability Assessment (%)	94.66 (5.61)	92.63 ; 96.68	95.55 (4.74)	93.81 ; 97.29	95.10 (5.18)	0.695	0.17 (0.67; 0.32)
Somatosensory Index (%)	92.44 (7.70)	89.66 ; 95.21	93.06 (6.70)	90.61 ; 95.52	92.75 (7.17)	0.896	0.09 (0.58; 0.41)
Visual Index (%)	94.50 (5.90)	92.37 ; 96.63	92.61 (5.78)	90.49 ; 94.73	93.57 (5.87)	0.171	0.32 (0.18; 0.82)
Vestibular Index (%)	77.00 (10.95)	73.05 ; 80.95	78.68 (10.82)	74.71 ; 82.65	77.83 (10.83)	0.716	0.15 (0.65; 0.34)
Dynamic Index (%)	73.91 (9.90)	70.34 ; 77.47	74.61 (10.06)	70.92 ; 78.30	74.25 (9.90)	0.789	0.07 (0.56; 0.42)
Sensory-Dynamic Total Score (%)	84.59 (5.05)	82.77 ; 86.41	84.06 (5.97)	81.88 ; 86.25	84.33 (5.48)	0.705	0.10 (0.40; 0.59)
Postural Control Assessment							
Limits of Stability (LOS) Analysis							
Forward (F) Maximum Displacement (%)	90.28 (17.28)	84.05 ; 96.51	94.61 (14.70)	89.22 ; 100.01	92.41 (16.08)	0.248	0.27 (0.76; 0.23)
Forward (F) Directional Control (%)	67.97 (16.91)	61.87 ; 74.07	61.61 (12.21)	57.13 ; 66.09	64.84 (15.02)	0.069	0.43 (0.07; 0.93)
Forward (F) Reaction Time (s)	1.52 (0.62)	1.30 ; 1.74	1.86 (0.71)	1.60 ; 2.12	1.69 (0.68)	0.127	0.52 (1.02; 0.01)
Forward (F) Assessment Score (%)	79.19 (12.23)	74.78 ; 83.60	81.29 (9.49)	77.81 ; 84.77	80.22 (10.93)	0.630	0.19 (0.69; 0.30)

Right-Forward (RF) Maximum Displacement (%)	85.72 (14.70)	80.42 ; 91.02	84.06 (13.77)	79.01 ; 89.12	84.90 (14.16)	0.505	0.12 (0.38; 0.61)
Right-Forward (RF) Directional Control (%)	51.81 (19.32)	44.85 ; 58.78	53.65 (15.92)	47.81 ; 59.49	52.71 (17.61)	0.778	0.10 (0.60; 0.39)
Right-Forward (RF) Reaction Time (s)	1.26 (0.56)	1.06 ; 1.46	1.41 (0.51)	1.22 ; 1.60	1.34 (0.53)	0.386	0.27 (0.77; 0.22)
Right-Forward (RF) Assessment Score (%)	72.34 (10.69)	68.49 ; 76.20	72.52 (9.23)	69.13 ; 75.90	72.43 (9.92)	0.929	0.02 (0.51; 0.48)
Right (R) Maximum Displacement (%)	88.97 (20.39)	81.62 ; 96.32	89.13 (14.73)	83.73 ; 94.53	89.05 (17.69)	0.973	0.01 (0.50; 0.48)
Right (R) Directional Control (%)	53.22 (20.01)	46.00 ; 60.43	57.26 (17.17)	50.96 ; 63.56	55.21 (18.63)	0.611	0.22 (0.71; 0.28)
Right (R) Reaction Time (s)	1.59 (0.60)	1.38 ; 1.81	1.49 (0.66)	1.25 ; 1.74	1.54 (0.63)	0.731	0.16 (0.34; 0.65)
Right (R) Assessment Score (%)	75.03 (13.11)	70.30 ; 79.76	77.19 (11.52)	72.97 ; 81.42	76.10 (12.30)	0.616	0.18 (0.67; 0.32)
Right-Backward (RB) Maximum Displacement (%)	97.84 (24.68)	88.94 ; 106.74	97.29 (14.11)	92.11 ; 102.47	97.57 (20.03)	0.956	0.03 (0.47; 0.52)
Right-Backward (RB) Directional Control (%)	52.47 (13.85)	47.47 ; 57.46	52.74 (16.65)	46.64 ; 58.85	52.60 (15.17)	0.940	0.02 (0.51; 0.48)
Right-Backward (RB) Reaction Time (s)	1.43 (0.60)	1.21 ; 1.64	1.46 (0.54)	1.26 ; 1.65	1.44 (0.56)	0.700	0.05 (0.55; 0.44)
Right-Backward (RB) Assessment Score (%)	80.53 (12.77)	75.93 ; 85.14	81.16 (7.76)	78.31 ; 84.01	80.84 (10.53)	0.458	0.06 (0.55; 0.43)
Backward (B) Maximum Displacement (%)	108.91 (16.85)	102.83 ; 114.98	105.39 (12.92)	100.65 ; 110.13	107.17 (15.03)	0.248	0.23 (0.26; 0.73)
Backward (B) Directional Control (%)	58.75 (18.95)	51.92 ; 65.58	62.45 (18.72)	55.59 ; 69.32	60.57 (18.78)	0.532	0.20 (0.69; 0.30)
Backward (B) Reaction Time (s)	1.15 (0.50)	0.97 ; 1.33	1.32 (0.45)	1.16 ; 1.49	1.23 (0.48)	0.149	0.37 (0.87; 0.13)
Backward (B) Assessment Score (%)	86.97 (10.16)	83.31 ; 90.63	88.03 (6.93)	85.49 ; 90.57	87.49 (8.67)	0.789	0.12 (0.62; 0.37)
Left-Backward (LB) Maximum Displacement (%)	95.78 (19.85)	88.62 ; 102.94	95.90 (16.66)	89.79 ; 102.01	95.84 (18.20)	0.501	0.01 (0.50; 0.49)
Left-Backward (LB) Directional Control (%)	52.03 (17.26)	45.81 ; 58.25	54.58 (16.89)	48.38 ; 60.78	53.29 (16.99)	0.559	0.15 (0.64; 0.35)
Left-Backward (LB) Reaction Time (s)	1.34 (0.48)	1.17 ; 1.51	1.45 (0.73)	1.18 ; 1.72	1.39 (0.61)	0.630	0.18 (0.67; 0.32)
Left-Backward (LB) Assessment Score (%)	79.59 (14.10)	74.51 ; 84.68	80.39 (10.78)	76.43 ; 84.34	79.98 (12.49)	0.762	0.06 (0.56; 0.43)
Left (L) Maximum Displacement (%)	88.81 (19.78)	81.68 ; 95.94	86.29 (17.78)	79.77 ; 92.81	87.57 (18.71)	0.505	0.13 (0.36; 0.63)
Left (L) Directional Control (%)	53.63 (15.19)	48.15 ; 59.10	54.71 (15.25)	49.12 ; 60.30	54.16 (15.10)	0.885	0.07 (0.57; 0.42)
Left (L) Reaction Time (s)	1.43 (0.53)	1.24 ; 1.62	1.25 (0.57)	1.04 ; 1.46	1.34 (0.55)	0.322	0.32 (0.18; 0.82)
Left (L) Assessment Score (%)	76.22 (15.79)	70.53 ; 81.91	76.35 (13.24)	71.50 ; 81.21	76.29 (14.47)	0.815	0.01 (0.50; 0.48)
Left-Forward (LF) Maximum Displacement (%)	84.00 (15.53)	78.40 ; 89.60	84.16 (14.98)	78.67 ; 89.66	84.08 (15.14)	0.815	0.01 (0.50; 0.48)
Left-Forward (LF) Directional Control (%)	48.91 (18.00)	42.42 ; 55.40	50.74 (17.99)	44.14 ; 57.34	49.81 (17.87)	0.778	0.10 (0.60; 0.39)
Left-Forward (LF) Reaction Time (s)	1.16 (0.51)	0.97 ; 1.34	1.48 (0.59)	1.26 ; 1.70	1.32 (0.57)	0.017	0.59 (1.09; 0.08)
Left-Forward (LF) Assessment Score (%)	72.09 (12.01)	67.76 ; 76.42	72.65 (11.42)	68.46 ; 76.83	72.37 (11.63)	0.934	0.05 (0.54; 0.45)
Average Score of Maximum Displacement (%)	92.06 (11.39)	87.96 ; 96.17	92.32 (8.04)	89.37 ; 95.27	92.19 (9.81)	0.902	0.03 (0.52; 0.47)
Average Score of Directional Control (%)	55.13 (9.37)	51.75 ; 58.50	56.16 (11.21)	52.05 ; 60.27	55.63 (10.24)	0.621	0.10 (0.59; 0.39)
Average Score of Reaction Time (s)	1.36 (0.28)	1.25 ; 1.46	1.45 (0.34)	1.33 ; 1.58	1.40 (0.31)	0.284	0.32 (0.81; 0.18)
Limits of Stability (LOS) Analysis Score (%)	77.72 (8.12)	74.79 ; 80.65	78.94 (5.76)	76.82 ; 81.05	78.32 (7.03)	0.810	0.17 (0.67; 0.32)
Rhythmic and Directional Control Assessment							
Mediolateral (ML) Ability (%)	80.38 (12.12)	76.01 ; 84.74	84.97 (10.65)	81.06 ; 88.87	82.63 (11.56)	0.159	0.40 (0.90; 0.10)
Mediolateral (ML) Control and Efficacy (%)	86.34 (15.12)	80.89 ; 91.80	92.84 (12.43)	88.28 ; 97.40	89.54 (14.14)	0.041	0.47 (0.97; 0.03)
ML Rhythmic and Directional Control Assessment (%)	83.09 (7.20)	80.50 ; 85.69	87.42 (7.96)	84.50 ; 90.34	85.22 (7.83)	0.041	0.57 (1.07; 0.06)

Anteroposterior (AP) Ability (%)	95.78 (7.03)	93.25 ; 98.32	97.32 (6.28)	95.02 ; 99.63	96.54 (6.67)	0.293	0.23 (0.73; 0.27)
Anteroposterior (AP) Control and Efficacy (%)	63.50 (16.70)	57.48 ; 69.52	67.52 (15.72)	61.75 ; 73.28	65.48 (16.22)	0.326	0.25 (0.74; 0.25)
AP Rhythmic and Directional Control Assessment (%)	85.75 (7.31)	83.11 ; 88.39	87.84 (6.76)	85.36 ; 90.32	86.78 (7.07)	0.173	0.30 (0.79; 0.20)
Postural Control Assessment (Total Score) (%)	80.28 (6.79)	77.83 ; 82.73	82.42 (5.26)	80.49 ; 84.35	81.33 (6.13)	0.326	0.35 (0.85; 0.15)
Functional Balance Assessment - Global Score (%)	82.22 (5.04)	80.40 ; 84.04	83.16 (4.37)	81.56 ; 84.77	82.68 (4.71)	0.621	0.20 (0.69; 0.30)
Functional Balance Assessment - Global Score Interpretation, n (%)						0.701	
Functionally impaired (≤ 79%)	8 (25.0%)		8 (25.8%)		16 (25.4%)		
Slightly impaired (80-89%)	23 (71.9%)		20 (64.5%)		43 (68.3%)		
Normal (90-100%)	1 (3.1%)		3 (9.7%)		4 (6.3%)		

11.10 Results of instrumental functional gait analysis at baseline

Appendix J: Results of instrumental functional gait analysis of study participants at baseline.

Functional Gait Analysis Parameters	MRP Group (n = 32)		CPT Group (n = 31)		All Participants (n = 63)	*p*-Value	Effect Size *d* (95% CI)
	Mean (SD)	95% CI of Mean	Mean (SD)	95% CI of Mean	Mean (SD)		
Gait speed (m/s)	0.59 (0.16)	0.53 ; 0.65	0.56 (0.12)	0.52 ; 0.61	0.58 (0.14)	0.417	0.20 (0.30 ; 0.69)
Average gait speed (%)	81.09 (20.90)	73.56 ; 88.63	81.97 (15.81)	76.17 ; 87.77	81.52 (18.43)	0.831	0.05 (0.54 ; 0.45)
Lt. foot support time (s)	1.00 (0.21)	0.93 ; 1.08	1.00 (0.18)	0.94 ; 1.07	1.00 (0.19)	0.752	0.01 (0.50 ; 0.49)
Rt. foot support time (s)	0.98 (0.19)	0.91 ; 1.05	0.99 (0.17)	0.93 ; 1.05	0.98 (0.18)	0.891	0.03 (0.52 ; 0.46)
Difference in support time (%)	60.09 (24.21)	51.37 ; 68.82	63.97 (21.15)	56.21 ; 71.72	62.00 (22.65)	0.501	0.17 (0.66 ; 0.33)
Anteroposterior braking force							
Lt. AP braking force (N)	55.11 (25.14)	46.04 ; 64.17	50.77 (16.24)	44.82 ; 56.73	52.97 (21.18)	0.858	0.20 (0.29 ; 0.70)
Lt. AP braking force (Normalized)	0.08 (0.03)	0.07 ; 0.09	0.07 (0.02)	0.06 ; 0.08	0.07 (0.02)	0.645	0.24 (0.26 ; 0.73)
Lt. AP braking force assessment (%)	92.34 (24.07)	83.67 ; 101.02	91.32 (21.78)	83.33 ; 99.31	91.84 (22.79)	0.956	0.04 (0.45 ; 0.54)
Rt. AP braking force (N)	51.05 (23.67)	42.52 ; 59.59	46.24 (23.80)	37.51 ; 54.98	48.69 (23.67)	0.441	0.20 (0.29 ; 0.70)
Rt. AP braking force (Normalized)	0.07 (0.03)	0.06 ; 0.08	0.06 (0.03)	0.05 ; 0.08	0.07 (0.03)	0.299	0.17 (0.32 ; 0.67)
Rt. AP braking force assessment (%)	83.13 (36.44)	69.99 ; 96.26	84.94 (32.46)	73.03 ; 96.84	84.02 (34.27)	0.597	0.05 (0.55 ; 0.44)
AP braking force global score (%)	84.25 (20.81)	76.75 ; 91.75	86.16 (22.93)	77.75 ; 94.57	85.19 (21.72)	0.805	0.09 (0.58 ; 0.41)
Anteroposterior propulsion force							
Lt. AP propulsion force (N)	53.95 (24.83)	45.00 ; 62.90	50.47 (16.91)	44.27 ; 56.68	52.24 (21.20)	0.645	0.16 (0.33 ; 0.66)
Lt. AP propulsion force (Normalized)	0.07 (0.03)	0.06 ; 0.08	0.07 (0.03)	0.06 ; 0.08	0.07 (0.03)	0.847	0.00 (0.50 ; 0.49)
Lt. AP propulsion force assessment (%)	77.25 (32.74)	65.45 ; 89.05	74.87 (34.67)	62.15 ; 87.59	76.08 (33.45)	0.918	0.07 (0.42 ; 0.56)
Rt. AP propulsion force (N)	58.38 (28.07)	48.25 ; 68.50	58.77 (21.51)	50.88 ; 66.66	58.57 (24.86)	0.721	0.02 (0.51 ; 0.48)
Rt. AP propulsion force (Normalized)	0.08 (0.03)	0.07 ; 0.09	0.08 (0.03)	0.07 ; 0.09	0.08 (0.03)	0.912	0.02 (0.52 ; 0.47)
Rt. AP propulsion force assessment (%)	78.59 (31.92)	67.08 ; 90.10	85.74 (29.15)	75.05 ; 96.43	82.11 (30.56)	0.425	0.23 (0.73 ; 0.26)
AP propulsion force global score (%)	76.91 (25.61)	67.67 ; 86.14	79.71 (27.29)	69.70 ; 89.72	78.29 (26.28)	0.409	0.11 (0.60 ; 0.39)
Vertical take-off force							
Lt. vertical take-off force (N)	706.18 (153.43)	650.86 ; 761.50	710.66 (153.40)	654.39; 766.93	708.39 (152.19)	0.799	0.03 (0.52 ; 0.46)
Lt. vertical take-off force (Normalized)	0.98 (0.05)	0.96 ; 1.00	0.99 (0.05)	0.97 ; 1.01	0.99 (0.05)	0.650	0.18 (0.67 ; 0.32)
Lt. vertical take-off force assessment (%)	93.38 (17.91)	86.92 ; 99.83	99.35 (7.45)	96.62 ; 102.09	96.32 (14.01)	0.219	0.43 (0.93 ; 0.07)
Rt. vertical take-off force (N)	714.03 (156.57)	657.58 ; 770.48	720.07 (164.17)	659.85 ; 780.29	717.00 (159.08)	0.799	0.04 (0.53 ; 0.46)
Rt. vertical take-off force (Normalized)	0.99 (0.05)	0.97 ; 1.01	0.99 (0.05)	0.97 ; 1.01	0.99 (0.05)	0.601	0.05 (0.44 ; 0.54)
Rt. vertical take-off force assessment (%)	96.38 (20.95)	88.82 ; 103.93	100.13 (16.12)	94.22 ; 106.04	98.22 (18.67)	0.831	0.20 (0.69 ; 0.30)
Vertical take-off force global score (%)	93.63 (11.83)	89.36 ; 97.89	97.81 (4.66)	96.10 ; 99.51	95.68 (9.22)	0.073	0.46 (0.96 ; 0.04)

Oscillation force							
Lt. oscillation force (N)	643.46 (163.68)	584.45 ; 702.47	628.61 (166.96)	567.36 ; 689.85	636.15 (164.13)	0.962	0.09 (0.40 ; 0.58)
Lt. oscillation force (Normalized)	0.89 (0.09)	0.86 ; 0.93	0.88 (0.13)	0.83 ; 0.92	0.89 (0.11)	0.568	0.15 (0.35 ; 0.64)
Lt. oscillation force assessment (%)	104.63 (28.71)	94.27 ; 114.98	121.06 (37.74)	107.22 ; 134.91	112.71 (34.20)	0.031	0.49 (0.99 ; 0.01)
Rt. oscillation force (N)	643.72 (163.28)	584.85 ; 702.59	628.48 (165.16)	567.89 ; 689.06	636.22 (163.06)	0.815	0.09 (0.40 ; 0.59)
Rt. oscillation force (Normalized)	0.89 (0.08)	0.86 ; 0.92	0.87 (0.09)	0.84 ; 0.91	0.88 (0.08)	0.372	0.20 (0.30 ; 0.70)
Rt. oscillation force assessment (%)	107.88 (34.68)	95.37 ; 120.38	123.74 (41.21)	108.62 ; 138.86	115.68 (38.57)	0.069	0.42 (0.91 ; 0.08)
Oscillation force global score (%)	95.69 (9.46)	92.28 ; 99.10	99.16 (2.63)	98.20 ; 100.13	97.40 (7.15)	0.176	0.50 (1.00 ; 0.01)
AP force morphology (Fx Morphology)							
Lt. AP force morphology (%)	55.50 (16.26)	49.64 ; 61.36	49.55 (15.35)	43.92 ; 55.18	52.57 (15.98)	0.114	0.38 (0.12 ; 0.87)
Rt. AP force morphology (%)	51.88 (17.80)	45.46 ; 58.29	48.55 (19.02)	41.57 ; 55.53	50.24 (18.34)	0.409	0.18 (0.32 ; 0.67)
AP force morphology global score (%)	53.66 (14.58)	48.40 ; 58.91	48.71 (14.78)	43.29 ; 54.13	51.22 (14.77)	0.251	0.34 (0.16 ; 0.83)
ML force morphology (Fy Morphology)							
Lt. ML force morphology (%)	24.59 (17.06)	18.44 ; 30.74	17.94 (17.77)	11.42 ; 24.45	21.32 (17.59)	0.053	0.38 (0.12 ; 0.88)
Rt. ML force morphology (%)	25.91 (17.68)	19.53 ; 32.28	20.39 (18.29)	13.68 ; 27.10	23.19 (18.05)	0.129	0.31 (0.19 ; 0.80)
ML force morphology global score (%)	25.28 (15.89)	19.55 ; 31.01	19.13 (17.63)	12.66 ; 25.60	22.25 (16.92)	0.043	0.37 (0.13 ; 0.86)
Vertical force morphology (Fz Morphology)							
Lt. vertical force morphology (%)	66.38 (21.04)	58.79 ; 73.96	65.35 (20.63)	57.79 ; 72.92	65.87 (20.68)	0.956	0.05 (0.45 ; 0.54)
Rt. vertical force morphology (%)	64.31 (21.03)	56.73 ; 71.89	62.23 (20.95)	54.54 ; 69.91	63.29 (20.85)	0.685	0.10 (0.40 ; 0.59)
Vertical force morphology global score (%)	65.34 (20.20)	58.06 ; 72.62	63.84 (19.71)	56.61 ; 71.07	64.60 (19.81)	0.907	0.08 (0.42 ; 0.57)
Lt. foot global assessment (%)	73.97 (10.25)	70.27 ; 77.66	72.32 (10.27)	68.56 ; 76.09	73.16 (10.21)	0.496	0.16 (0.33 ; 0.65)
Rt. foot global assessment (%)	71.63 (10.80)	67.73 ; 75.52	71.77 (10.70)	67.85 ; 75.70	71.70 (10.67)	0.995	0.01 (0.51 ; 0.48)
Functional gait analysis global score (%)	72.03 (10.28)	68.32 ; 75.74	72.26 (10.11)	68.55 ; 75.96	72.14 (10.12)	0.967	0.02 (0.52 ; 0.47)
Functional gait analysis global score interpretation, n (%)						1.000	
Functionally impaired (≤ 79%)	25 (78.1%)		24 (77.4%)		49 (77.8%)		
Slightly impaired (80-89%)	7 (21.9%)		7 (22.6%)		14 (22.2%)		
Normal (90-100%)	0 (0.0%)		0 (0.0%)		0 (0.0%)		

11.11 Results of instrumental functional balance assessment at post-intervention

Appendix K: Results of instrumental functional balance assessment of study participants at post-intervention.

Functional Balance Assessment Tests	MRP Group (n = 32)		CPT Group (n = 31)		All Participants (n = 63)	*P* Value	Effect Size *d* (95% CI)
	Mean (SD)	95% CI of Mean	Mean (SD)	95% CI of Mean	Mean (SD)		
Static Posturography Tests							
Romberg Test with Eyes Open (ROA)							
ROA Total Displacement (mm)	5.58 (2.27)	4.77 ; 6.40	7.37 (2.69)	6.38 ; 8.36	6.46 (2.62)	0.005	0.72 (1.23; 0.21)
ROA Displacement Angle (º)	114.83 (65.56)	91.19 ; 138.47	199.29 (55.48)	178.94 ; 219.64	156.39 (73.83)	<0.001	1.39 (1.94; 0.83)
ROA Mediolateral (ML) Dispersed X (mm)	3.39 (1.20)	2.96 ; 3.83	3.84 (1.27)	3.38 ; 4.31	3.61 (1.24)	0.185	0.36 (0.86; 0.14)
ROA Anteroposterior (AP) Dispersed Y (mm)	4.13 (1.17)	3.70 ; 4.55	4.80 (1.66)	4.19 ; 5.41	4.46 (1.46)	0.130	0.47 (0.97; 0.03)
ROA Average Speed (m/s)	0.01 (0.00)	0.01 ; 0.01	0.02 (0.01)	0.01 ; 0.02	0.01 (0.01)	0.025	0.56 (1.06; 0.05)
ROA Mediolateral (ML) Displacement (mm)	17.11 (6.15)	14.89 ; 19.33	19.52 (6.78)	17.03 ; 22.01	18.30 (6.53)	0.219	0.37 (0.87; 0.13)
ROA Anteroposterior (AP) Displacement (mm)	20.71 (5.40)	18.77 ; 22.66	24.44 (9.91)	20.80 ; 28.07	22.54 (8.10)	0.268	0.47 (0.97; 0.03)
ROA Mediolateral (ML) Maximal Force (N)	7.68 (3.56)	6.39 ; 8.96	8.51 (4.09)	7.01 ; 10.01	8.09 (3.82)	0.554	0.22 (0.71; 0.28)
ROA Anteroposterior (AP) Maximal Force (N)	4.67 (2.92)	3.62 ; 5.73	5.79 (4.13)	4.28 ; 7.31	5.23 (3.58)	0.103	0.31 (0.81; 0.18)
ROA Assessment Score (%)	99.16 (1.63)	98.57 ; 99.74	97.97 (3.78)	96.58 ; 99.35	98.57 (2.93)	0.224	0.41 (0.09; 0.91)
Romberg Test with Eyes Closed (ROC)							
ROC Total Displacement (mm)	7.35 (3.33)	6.15 ; 8.55	10.31 (3.80)	8.92 ; 11.71	8.81 (3.84)	0.002	0.83 (1.34; 0.31)
ROC Displacement Angle (º)	146.47 (66.71)	122.42 ; 170.52	212.26 (64.89)	188.46 ; 236.07	178.85 (73.22)	0.001	1.00 (1.52; 0.47)
ROC Mediolateral (ML) Dispersed X (mm)	5.01 (2.16)	4.23 ; 5.79	5.94 (2.36)	5.08 ; 6.81	5.47 (2.29)	0.099	0.41 (0.91; 0.09)
ROC Anteroposterior (AP) Dispersed Y (mm)	5.50 (2.25)	4.69 ; 6.31	6.93 (2.73)	5.93 ; 7.93	6.20 (2.58)	0.041	0.57 (1.08; 0.07)
ROC Average Speed (m/s)	0.02 (0.02)	0.02 ; 0.03	0.03 (0.02)	0.02 ; 0.03	0.02 (0.02)	0.112	0.16 (0.66; 0.33)
ROC Mediolateral (ML) Displacement (mm)	26.63 (12.41)	22.16 ; 31.11	30.83 (12.80)	26.14 ; 35.53	28.70 (12.68)	0.096	0.33 (0.83; 0.17)
ROC Anteroposterior (AP) Displacement (mm)	28.89 (12.97)	24.21 ; 33.57	37.29 (15.84)	31.48 ; 43.10	33.02 (14.95)	0.037	0.58 (1.08; 0.07)
ROC Mediolateral (ML) Maximal Force (N)	11.25 (5.38)	9.31 ; 13.19	12.54 (5.49)	10.52 ; 14.55	11.88 (5.43)	0.343	0.24 (0.73; 0.26)
ROC Anteroposterior (AP) Maximal Force (N)	7.35 (4.86)	5.60 ; 9.10	8.60 (4.69)	6.88 ; 10.32	7.96 (4.78)	0.083	0.26 (0.76; 0.24)
ROC Assessment Score (%)	97.25 (5.25)	95.36 ; 99.14	94.61 (6.75)	92.14 ; 97.09	95.95 (6.13)	0.037	0.44 (0.06; 0.94)
Romberg Test with Eyes Open on Foam Cushion (RGA)							
RGA Total Displacement (mm)	9.81 (4.81)	8.07 ; 11.55	15.91 (6.66)	13.47 ; 18.36	12.81 (6.52)	<0.001	1.05 (1.58; 0.52)
RGA Displacement Angle (º)	140.53 (53.39)	121.28 ; 159.77	212.11 (47.17)	194.81 ; 229.42	175.75 (61.67)	<0.001	1.42 (1.97; 0.86)
RGA Mediolateral (ML) Dispersed X (mm)	6.78 (2.68)	5.81 ; 7.74	8.83 (3.28)	7.62 ; 10.03	7.79 (3.14)	0.007	0.69 (1.19; 0.17)
RGA Anteroposterior (AP) Dispersed Y (mm)	7.98 (2.34)	7.13 ; 8.82	10.67 (4.01)	9.20 ; 12.15	9.30 (3.52)	0.006	0.83 (1.34; 0.31)
RGA Average Speed (m/s)	0.03 (0.01)	0.03 ; 0.04	0.04 (0.01)	0.03 ; 0.04	0.04 (0.01)	0.030	0.39 (0.89; 0.11)
RGA Mediolateral (ML) Displacement (mm)	36.29 (13.58)	31.40 ; 41.19	46.27 (15.33)	40.65 ; 51.90	41.20 (15.20)	0.009	0.69 (1.20; 0.18)
RGA Anteroposterior (AP) Displacement (mm)	42.98 (11.70)	38.77 ; 47.20	54.49 (16.24)	48.54 ; 60.45	48.65 (15.15)	0.010	0.82 (1.33; 0.30)

RGA Mediolateral (ML) Maximal Force (N)	15.73 (5.80)	13.64 ; 17.82	19.25 (8.66)	16.07 ; 22.43	17.46 (7.50)	0.103	0.48 (0.98; 0.02)
RGA Anteroposterior (AP) Maximal Force (N)	11.33 (7.13)	8.76 ; 13.90	14.97 (7.60)	12.19 ; 17.76	13.12 (7.53)	0.019	0.49 (0.99; 0.01)
RGA Assessment Score (%)	97.06 (4.35)	95.50 ; 98.63	91.42 (8.41)	88.34 ; 94.50	94.29 (7.19)	0.003	0.85 (0.33; 1.36)
Romberg Test with Eyes Closed on Foam Cushion (RGC)							
RGC Total Displacement (mm)	13.93 (6.17)	11.70 ; 16.15	21.40 (6.61)	18.98 ; 23.83	17.61 (7.37)	<0.001	1.17 (1.70; 0.63)
RGC Displacement Angle (º)	160.97 (59.62)	139.48 ; 182.47	264.08 (58.55)	242.61 ; 285.56	211.71 (78.33)	<0.001	1.74 (2.32; 1.16)
RGC Mediolateral (ML) Dispersed X (mm)	18.43 (4.61)	16.76 ; 20.09	19.96 (3.64)	18.62 ; 21.29	19.18 (4.20)	0.088	0.37 (0.86; 0.13)
RGC Anteroposterior (AP) Dispersed Y (mm)	17.95 (3.24)	16.78 ; 19.12	19.96 (4.15)	18.43 ; 21.48	18.94 (3.82)	0.078	0.54 (1.04; 0.03)
RGC Average Speed (m/s)	0.08 (0.02)	0.07 ; 0.09	0.09 (0.02)	0.08 ; 0.09	0.08 (0.02)	0.139	0.24 (0.73; 0.26)
RGC Mediolateral (ML) Displacement (mm)	94.31 (19.64)	87.23 ; 101.39	104.03 (16.78)	97.87 ; 110.18	99.09 (18.79)	0.017	0.53 (1.03; 0.03)
RGC Anteroposterior (AP) Displacement (mm)	87.35 (11.76)	83.11 ; 91.59	97.48 (15.97)	91.63 ; 103.34	92.34 (14.79)	0.009	0.72 (1.23; 0.21)
RGC Mediolateral (ML) Maximal Force (N)	36.04 (8.47)	32.99 ; 39.09	37.90 (8.88)	34.64 ; 41.16	36.96 (8.65)	0.483	0.21 (0.71; 0.28)
RGC Anteroposterior (AP) Maximal Force (N)	29.46 (10.48)	25.68 ; 33.24	34.03 (11.42)	29.84 ; 38.22	31.71 (11.11)	0.082	0.42 (0.91; 0.08)
RGC Assessment Score (%)	86.28 (8.64)	83.17 ; 89.40	78.23 (9.93)	74.58 ; 81.87	82.32 (10.08)	0.002	0.87 (0.35; 1.38)
Romberg Test Stability Assessment							
ROA Mediolateral (ML) Stability (%)	99.44 (2.00)	98.72 ; 100.16	98.81 (3.37)	97.57 ; 100.04	99.13 (2.76)	0.726	0.23 (0.27; 0.72)
ROC Mediolateral (ML) Stability (%)	98.13 (3.47)	96.87 ; 99.38	97.29 (4.41)	95.67 ; 98.91	97.71 (3.95)	0.322	0.21 (0.29; 0.71)
RGA Mediolateral (ML) Stability (%)	96.72 (4.31)	95.16 ; 98.27	93.55 (7.72)	90.72 ; 96.38	95.16 (6.38)	0.082	0.51 (0.01; 1.01)
RGC Mediolateral (ML) Stability (%)	85.59 (8.45)	82.55 ; 88.64	83.26 (9.17)	79.89 ; 86.62	84.44 (8.82)	0.390	0.26 (0.23; 0.76)
Romberg Test ML Stability Assessment (%)	95.03 (3.54)	93.75 ; 96.31	93.19 (5.33)	91.24 ; 95.15	94.13 (4.57)	0.199	0.41 (0.09; 0.91)
ROA Anteroposterior (AP) Stability (%)	99.66 (1.49)	99.12 ; 100.19	99.29 (2.21)	98.48 ; 100.10	99.48 (1.87)	0.645	0.19 (0.30; 0.69)
ROC Anteroposterior (AP) Stability (%)	98.94 (3.54)	97.66 ; 100.21	98.71 (2.70)	97.72 ; 99.70	98.83 (3.13)	0.375	0.07 (0.42; 0.57)
RGA Anteroposterior (AP) Stability (%)	98.84 (4.10)	97.37 ; 100.32	97.39 (4.96)	95.57 ; 99.21	98.13 (4.57)	0.450	0.32 (0.18; 0.82)
RGC Anteroposterior (AP) Stability (%)	95.78 (7.38)	93.12 ; 98.44	94.13 (7.92)	91.23 ; 97.03	94.97 (7.63)	0.206	0.22 (0.28; 0.71)
Romberg Test AP Stability Assessment (%)	98.38 (3.10)	97.26 ; 99.49	97.35 (3.42)	96.10 ; 98.61	97.87 (3.27)	0.069	0.31 (0.19; 0.81)
Somatosensory Index (%)	97.69 (4.18)	96.18 ; 99.19	95.65 (5.69)	93.56 ; 97.73	96.68 (5.04)	0.024	0.41 (0.09; 0.91)
Visual Index (%)	97.38 (4.15)	95.88 ; 98.87	95.19 (4.48)	93.55 ; 96.84	96.30 (4.42)	0.028	0.51 (0.00; 1.01)
Vestibular Index (%)	91.81 (6.69)	89.40 ; 94.22	83.87 (9.16)	80.51 ; 87.23	87.90 (8.89)	0.001	0.99 (0.46; 1.51)
Dynamic Index (%)	87.59 (5.48)	85.62 ; 89.57	80.58 (8.76)	77.37 ; 83.79	84.14 (8.04)	<0.001	0.96 (0.44; 1.48)
Sensory-Dynamic Total Score (%)	93.31 (3.21)	92.16 ; 94.47	87.97 (4.83)	86.19 ; 89.74	90.68 (4.87)	<0.001	1.31 (0.76; 1.85)
Postural Control Assessment							
Limits of Stability (LOS) Analysis							
Forward (F) Maximum Displacement (%)	110.38 (9.14)	107.08 ; 113.67	112.06 (13.40)	107.15 ; 116.98	111.21 (11.38)	0.532	0.15 (0.64; 0.35)
Forward (F) Directional Control (%)	80.56 (12.72)	75.98 ; 85.15	72.77 (10.80)	68.81 ; 76.74	76.73 (12.36)	0.003	0.66 (0.15; 1.16)
Forward (F) Reaction Time (s)	1.03 (0.47)	0.86 ; 1.20	1.55 (0.57)	1.33 ; 1.76	1.28 (0.58)	0.001	0.99 (1.51; 0.46)
Forward (F) Assessment Score (%)	93.75 (4.31)	92.20 ; 95.30	90.42 (5.17)	88.52 ; 92.32	92.11 (5.00)	0.001	0.70 (0.19; 1.21)

Right-Forward (RF) Maximum Displacement (%)	104.81 (10.70)	100.95 ; 108.67	95.55 (11.52)	91.32 ; 99.78	100.25 (11.97)	0.001	0.83 (0.32; 1.35)
Right-Forward (RF) Directional Control (%)	68.97 (16.37)	63.07 ; 74.87	65.61 (15.30)	60.00 ; 71.22	67.32 (15.82)	0.306	0.21 (0.28; 0.71)
Right-Forward (RF) Reaction Time (s)	0.93 (0.47)	0.76 ; 1.10	1.25 (0.54)	1.05 ; 1.44	1.09 (0.53)	0.025	0.62 (1.12; 0.11)
Right-Forward (RF) Assessment Score (%)	88.53 (5.90)	86.40 ; 90.66	82.45 (8.60)	79.30 ; 85.61	85.54 (7.91)	0.004	0.83 (0.31; 1.34)
Right (R) Maximum Displacement (%)	105.66 (11.92)	101.36 ; 109.95	99.58 (15.91)	93.74 ; 105.42	102.67 (14.24)	0.050	0.43 (0.07; 0.93)
Right (R) Directional Control (%)	71.09 (12.63)	66.54 ; 75.65	65.74 (15.92)	59.90 ; 71.58	68.46 (14.48)	0.169	0.37 (0.13; 0.87)
Right (R) Reaction Time (s)	1.11 (0.51)	0.93 ; 1.29	1.33 (0.55)	1.13 ; 1.53	1.22 (0.53)	0.090	0.41 (0.91; 0.09)
Right (R) Assessment Score (%)	90.06 (5.84)	87.96 ; 92.17	83.71 (10.22)	79.96 ; 87.46	86.94 (8.82)	0.006	0.77 (0.25; 1.28)
Right-Backward (RB) Maximum Displacement (%)	112.59 (10.95)	108.65 ; 116.54	106.68 (11.91)	102.31 ; 111.05	109.68 (11.72)	0.056	0.52 (0.01; 1.02)
Right-Backward (RB) Directional Control (%)	67.88 (11.52)	63.72 ; 72.03	60.55 (13.92)	55.44 ; 65.65	64.27 (13.18)	0.032	0.57 (0.07; 1.08)
Right-Backward (RB) Reaction Time (s)	0.90 (0.40)	0.76 ; 1.04	1.36 (0.58)	1.15 ; 1.57	1.13 (0.54)	0.001	0.93 (1.45; 0.41)
Right-Backward (RB) Assessment Score (%)	91.84 (3.29)	90.66 ; 93.03	85.90 (6.36)	83.57 ; 88.24	88.92 (5.83)	<0.001	1.18 (0.64; 1.71)
Backward (B) Maximum Displacement (%)	119.94 (12.43)	115.46 ; 124.42	119.00 (16.87)	112.81 ; 125.19	119.48 (14.67)	0.805	0.06 (0.43; 0.56)
Backward (B) Directional Control (%)	78.56 (11.76)	74.32 ; 82.80	70.61 (15.86)	64.80 ; 76.43	74.65 (14.38)	0.055	0.57 (0.06; 1.07)
Backward (B) Reaction Time (s)	0.97 (0.49)	0.79 ; 1.15	1.06 (0.53)	0.86 ; 1.25	1.01 (0.51)	0.475	0.18 (0.67; 0.32)
Backward (B) Assessment Score (%)	94.59 (2.79)	93.59 ; 95.60	91.68 (5.61)	89.62 ; 93.73	93.16 (4.61)	0.069	0.66 (0.15; 1.17)
Left-Backward (LB) Maximum Displacement (%)	112.88 (12.99)	108.19 ; 117.56	104.03 (12.91)	99.30 ; 108.77	108.52 (13.60)	0.008	0.68 (0.17; 1.19)
Left-Backward (LB) Directional Control (%)	69.97 (17.47)	63.67 ; 76.27	65.55 (13.39)	60.64 ; 70.46	67.79 (15.63)	0.226	0.28 (0.21; 0.78)
Left-Backward (LB) Reaction Time (s)	1.00 (0.46)	0.83 ; 1.16	1.18 (0.72)	0.92 ; 1.45	1.09 (0.60)	0.611	0.31 (0.81; 0.19)
Left-Backward (LB) Assessment Score (%)	91.19 (7.05)	88.64 ; 93.73	86.65 (7.74)	83.81 ; 89.48	88.95 (7.69)	0.007	0.61 (0.11; 1.12)
Left (L) Maximum Displacement (%)	107.16 (10.86)	103.24 ; 111.07	98.77 (14.47)	93.46 ; 104.08	103.03 (13.35)	0.021	0.66 (0.15; 1.16)
Left (L) Directional Control (%)	71.28 (12.49)	66.78 ; 75.78	65.90 (13.76)	60.86 ; 70.95	68.63 (13.30)	0.138	0.41 (0.09; 0.91)
Left (L) Reaction Time (s)	0.93 (0.40)	0.78 ; 1.07	1.11 (0.58)	0.90 ; 1.32	1.02 (0.50)	0.245	0.36 (0.86; 0.14)
Left (L) Assessment Score (%)	90.16 (5.17)	88.29 ; 92.02	83.94 (9.18)	80.57 ; 87.30	87.10 (8.00)	0.002	0.84 (0.32; 1.35)
Left-Forward (LF) Maximum Displacement (%)	104.56 (8.69)	101.43 ; 107.69	95.58 (14.95)	90.10 ; 101.07	100.14 (12.90)	0.005	0.74 (0.22; 1.25)
Left-Forward (LF) Directional Control (%)	67.78 (14.99)	62.38 ; 73.19	64.35 (15.00)	58.85 ; 69.86	66.10 (14.97)	0.433	0.23 (0.27; 0.72)
Left-Forward (LF) Reaction Time (s)	0.85 (0.43)	0.70 ; 1.01	1.13 (0.51)	0.95 ; 1.32	0.99 (0.49)	0.034	0.60 (1.10; 0.09)
Left-Forward (LF) Assessment Score (%)	89.53 (5.18)	87.66 ; 91.40	81.13 (10.67)	77.22 ; 85.04	85.40 (9.30)	0.002	1.01 (0.48; 1.53)
Average Score of Maximum Displacement (%)	109.63 (5.46)	107.66 ; 111.59	103.45 (7.37)	100.75 ; 106.16	106.59 (7.13)	0.001	0.95 (0.43; 1.47)
Average Score of Directional Control (%)	71.81 (8.32)	68.81 ; 74.81	66.06 (9.43)	62.60 ; 69.52	68.98 (9.28)	0.013	0.65 (0.14; 1.15)
Average Score of Reaction Time (s)	0.96 (0.26)	0.86 ; 1.05	1.25 (0.33)	1.12 ; 1.37	1.10 (0.33)	<0.001	0.98 (1.49; 0.45)
Limits of Stability (LOS) Analysis Score (%)	91.16 (3.17)	90.01 ; 92.30	85.39 (4.23)	83.83 ; 86.94	88.32 (4.71)	<0.001	1.55 (0.98; 2.11)
Rhythmic and Directional Control Assessment							
Mediolateral (ML) Ability (%)	96.25 (5.93)	94.11 ; 98.39	89.81 (9.42)	86.35 ; 93.26	93.08 (8.43)	0.003	0.82 (0.30; 1.33)
Mediolateral (ML) Control and Efficacy (%)	98.00 (5.11)	96.16 ; 99.84	95.03 (12.54)	90.43 ; 99.63	96.54 (9.56)	0.421	0.31 (0.19; 0.81)
ML Rhythmic and Directional Control Assessment (%)	97.03 (4.22)	95.51 ; 98.55	91.81 (6.85)	89.29 ; 94.32	94.46 (6.21)	0.001	0.92 (0.40; 1.44)

Anteroposterior (AP) Ability (%)	99.63 (2.12)	98.86 ; 100.39	98.74 (4.18)	97.21 ; 100.27	99.19 (3.30)	0.514	0.27 (0.23; 0.76)
Anteroposterior (AP) Control and Efficacy (%)	89.44 (14.19)	84.32 ; 94.55	77.84 (14.94)	72.36 ; 83.32	83.73 (15.58)	<0.001	0.80 (0.28; 1.31)
AP Rhythmic and Directional Control Assessment (%)	96.50 (4.66)	94.82 ; 98.18	92.29 (5.46)	90.29 ; 94.29	94.43 (5.46)	<0.001	0.83 (0.31; 1.34)
Postural Control Assessment (Total Score) (%)	93.38 (3.16)	92.24 ; 94.51	87.94 (4.01)	86.47 ; 89.41	90.70 (4.50)	<0.001	1.51 (0.94; 2.07)
Functional Balance Assessment - Global Score (%)	93.41 (2.84)	92.38 ; 94.43	87.77 (3.50)	86.49 ; 89.06	90.63 (4.24)	<0.001	1.77 (1.18; 2.35)
Functional Balance Assessment - Global Score Interpretation, n (%)						<0.001	
Functionally impaired (≤ 79%)	0 (0.0%)		0 (0.0%)		0 (0.0%)		
Slightly impaired (80-89%)	3 (9.4%)		21 (67.7%)		24 (38.1%)		
Normal (90-100%)	29 (90.6%)		10 (32.3%)		39 (61.9%)		

11.12 Results of instrumental functional gait analysis at post-intervention

Appendix L: Results of instrumental functional gait analysis of study participants at post-intervention.

Functional Gait Analysis Parameters	MRP Group (n = 32)		CPT Group (n = 31)		All Participants (n = 63)	*p*-Value	Effect Size *d* (95% CI)
	Mean (SD)	95% CI of Mean	Mean (SD)	95% CI of Mean	Mean (SD)		
Gait speed (m/s)	0.79 (0.13)	0.74 ; 0.84	0.65 (0.12)	0.61 ; 0.69	0.72 (0.14)	<0.001	1.09 (0.56 ; 1.62)
Average gait speed (%)	98.22 (4.07)	96.75 ; 99.69	91.26 (11.76)	86.94 ; 95.57	94.79 (9.36)	0.004	0.80 (0.28 ; 1.31)
Lt. foot support time (s)	0.83 (0.11)	0.79 ; 0.87	0.91 (0.14)	0.85 ; 0.96	0.87 (0.13)	0.023	0.58 (1.08 ; 0.07)
Rt. foot support time (s)	0.82 (0.11)	0.78 ; 0.86	0.90 (0.13)	0.85 ; 0.94	0.86 (0.12)	0.051	0.62 (1.13 ; 0.11)
Difference in support time (%)	89.41 (9.64)	85.93 ; 92.88	73.81 (18.77)	66.92 ; 80.69	81.73 (16.70)	<0.001	1.05 (0.52 ; 1.57)
Anteroposterior braking force							
Lt. AP braking force (N)	66.92 (20.18)	59.65 ; 74.20	61.00 (17.07)	54.74 ; 67.26	64.01 (18.80)	0.296	0.32 (0.18 ; 0.81)
Lt. AP braking force (Normalized)	0.09 (0.02)	0.09 ; 0.10	0.09 (0.02)	0.08 ; 0.09	0.09 (0.02)	0.268	0.39 (0.11 ; 0.89)
Lt. AP braking force assessment (%)	101.19 (11.83)	96.92 ; 105.45	101.13 (21.38)	93.29 ; 108.97	101.16 (17.06)	0.778	0.00 (0.49 ; 0.50)
Rt. AP braking force (N)	67.11 (19.14)	60.21 ; 74.01	51.05 (21.51)	43.16 ; 58.94	59.21 (21.74)	0.002	0.79 (0.27 ; 1.30)
Rt. AP braking force (Normalized)	0.09 (0.02)	0.09 ; 0.10	0.07 (0.03)	0.06 ; 0.08	0.08 (0.03)	0.003	0.80 (0.28 ; 1.31)
Rt. AP braking force assessment (%)	102.13 (13.42)	97.29 ; 106.96	93.00 (35.50)	79.98 ; 106.02	97.63 (26.85)	0.037	0.34 (0.16 ; 0.84)
AP braking force global score (%)	98.38 (3.60)	97.08 ; 99.67	91.87 (17.93)	85.29 ; 98.45	95.17 (13.14)	0.060	0.51 (0.00 ; 1.01)
Anteroposterior propulsion force							
Lt. AP propulsion force (N)	74.08 (24.14)	65.38 ; 82.78	58.90 (19.80)	51.64 ; 66.16	66.61 (23.23)	0.004	0.69 (0.18 ; 1.19)
Lt. AP propulsion force (Normalized)	0.10 (0.03)	0.09 ; 0.11	0.09 (0.03)	0.07 ; 0.10	0.09 (0.03)	0.026	0.57 (0.07 ; 1.08)
Lt. AP propulsion force assessment (%)	96.19 (17.61)	89.84 ; 102.54	81.81 (32.61)	69.84 ; 93.77	89.11 (26.87)	0.093	0.55 (0.05 ; 1.05)
Rt. AP propulsion force (N)	78.07 (25.34)	68.93 ; 87.20	64.25 (20.64)	56.68 ; 71.83	71.27 (23.99)	0.018	0.60 (0.09 ; 1.10)
Rt. AP propulsion force (Normalized)	0.11 (0.03)	0.10 ; 0.12	0.09 (0.03)	0.08 ; 0.10	0.10 (0.03)	0.022	0.58 (0.08 ; 1.09)
Rt. AP propulsion force assessment (%)	96.19 (19.77)	89.06 ; 103.31	89.77 (26.65)	80.00 ; 99.55	93.03 (23.44)	0.309	0.27 (0.22 ; 0.77)
AP propulsion force global score (%)	94.88 (13.04)	90.18 ; 99.57	84.90 (24.93)	75.76 ; 94.05	89.97 (20.27)	0.167	0.50 (0.00 ; 1.00)
Vertical take-off force							
Lt. vertical take-off force (N)	735.28 (148.49)	681.74 ; 788.82	729.45 (161.74)	670.13 ; 788.78	732.41 (153.92)	0.847	0.04 (0.46 ; 0.53)
Lt. vertical take-off force (Normalized)	1.02 (0.04)	1.01 ; 1.04	1.01 (0.04)	1.00 ; 1.02	1.02 (0.04)	0.141	0.35 (0.15 ; 0.84)
Lt. vertical take-off force assessment (%)	103.09 (10.94)	99.15 ; 107.04	101.84 (10.42)	98.02 ; 105.66	102.48 (10.62)	0.690	0.12 (0.38 ; 0.61)
Rt. vertical take-off force (N)	742.45 (148.52)	688.91 ; 796.00	717.92 (150.66)	662.65 ; 773.18	730.38 (148.88)	0.554	0.16 (0.33 ; 0.66)
Rt. vertical take-off force (Normalized)	1.03 (0.04)	1.02 ; 1.05	1.01 (0.04)	1.00 ; 1.02	1.02 (0.04)	0.008	0.66 (0.15 ; 1.17)
Rt. vertical take-off force assessment (%)	101.59 (7.31)	98.96 ; 104.23	101.48 (11.13)	97.40 ; 105.57	101.54 (9.31)	0.332	0.01 (0.48 ; 0.51)
Vertical take-off force global score (%)	99.69 (0.64)	99.46 ; 99.92	99.42 (1.69)	98.80 ; 100.04	99.56 (1.27)	0.773	0.21 (0.29 ; 0.71)

Oscillation force							
Lt. oscillation force (N)	643.80 (150.23)	589.64 ; 697.96	644.06 (144.78)	590.95 ; 697.17	643.93 (146.38)	0.842	0.00 (0.50 ; 0.49)
Lt. oscillation force (Normalized)	0.89 (0.05)	0.87 ; 0.91	0.90 (0.05)	0.89 ; 0.92	0.90 (0.05)	0.087	0.29 (0.78 ; 0.21)
Lt. oscillation force assessment (%)	101.88 (10.50)	98.09 ; 105.66	111.90 (31.47)	100.36 ; 123.45	106.81 (23.66)	0.293	0.43 (0.93 ; 0.07)
Rt. oscillation force (N)	645.26 (145.06)	592.96 ; 697.56	638.48 (150.89)	583.13 ; 693.83	641.92 (146.80)	0.923	0.05 (0.45 ; 0.54)
Rt. oscillation force (Normalized)	0.89 (0.03)	0.88 ; 0.90	0.89 (0.05)	0.88 ; 0.91	0.89 (0.04)	0.573	0.02 (0.51 ; 0.48)
Rt. oscillation force assessment (%)	102.28 (14.15)	97.18 ; 107.38	115.55 (33.93)	103.10 ; 127.99	108.81 (26.49)	0.316	0.51 (1.01 ; 0.01)
Oscillation force global score (%)	99.16 (3.89)	97.76 ; 100.56	99.81 (0.79)	99.52 ; 100.10	99.48 (2.82)	0.554	0.23 (0.72 ; 0.27)
AP force morphology (Fx Morphology)							
Lt. AP force morphology (%)	73.22 (12.92)	68.56 ; 77.88	62.10 (14.59)	56.75 ; 67.45	67.75 (14.76)	0.004	0.81 (0.29 ; 1.32)
Rt. AP force morphology (%)	68.34 (14.32)	63.18 ; 73.51	55.48 (18.76)	48.60 ; 62.36	62.02 (17.74)	0.007	0.77 (0.26 ; 1.28)
AP force morphology global score (%)	70.88 (11.53)	66.72 ; 75.03	58.87 (13.96)	53.75 ; 63.99	64.97 (14.05)	<0.001	0.94 (0.41 ; 1.46)
ML force morphology (Fy Morphology)							
Lt. ML force morphology (%)	40.78 (23.55)	32.29 ; 49.27	23.13 (18.59)	16.31 ; 29.95	32.10 (22.89)	0.001	0.83 (0.31 ; 1.34)
Rt. ML force morphology (%)	42.84 (24.73)	33.93 ; 51.76	25.55 (18.80)	18.65 ; 32.45	34.33 (23.51)	0.004	0.79 (0.27 ; 1.30)
ML force morphology global score (%)	41.78 (23.14)	33.44 ; 50.12	24.32 (18.19)	17.65 ; 31.00	33.19 (22.48)	0.001	0.84 (0.32 ; 1.35)
Vertical force morphology (Fz Morphology)							
Lt. vertical force morphology (%)	78.59 (15.55)	72.99 ; 84.20	72.81 (18.12)	66.16 ; 79.45	75.75 (16.98)	0.206	0.34 (0.16 ; 0.84)
Rt. vertical force morphology (%)	75.94 (16.30)	70.06 ; 81.81	70.16 (17.98)	63.57 ; 76.76	73.10 (17.26)	0.169	0.34 (0.16 ; 0.83)
Vertical force morphology global score (%)	77.28 (15.08)	71.84 ; 82.72	71.74 (16.36)	65.74 ; 77.74	74.56 (15.84)	0.187	0.35 (0.15 ; 0.85)
Lt. foot global assessment (%)	86.09 (5.82)	83.99 ; 88.19	78.29 (8.72)	75.09 ; 81.49	82.25 (8.32)	<0.001	1.06 (0.52 ; 1.58)
Rt. foot global assessment (%)	84.63 (6.99)	82.10 ; 87.15	77.16 (9.63)	73.63 ; 80.69	80.95 (9.14)	0.001	0.89 (0.37 ; 1.40)
Functional gait analysis global score (%)	86.72 (5.55)	84.72 ; 88.72	78.61 (8.58)	75.47 ; 81.76	82.73 (8.23)	<0.001	1.13 (0.59 ; 1.65)
Functional gait analysis global score interpretation, n (%)						<0.001	
Functionally impaired (≤ 79%)	3 (9.4%)		16 (51.6%)		19 (30.2%)		
Slightly impaired (80-89%)	17 (53.1%)		13 (41.9%)		30 (47.6%)		
Normal (90-100%)	12 (37.5%)		2 (6.5%)		14 (22.2%)		

11.13 Results of instrumental functional balance assessment at 3-months follow-up

Appendix M: Results of instrumental functional balance assessment of study participants at 3-months follow-up.

Functional Balance Assessment Tests	MRP Group (n = 32)		CPT Group (n = 31)		All Participants (n = 63)	*P* Value	Effect Size *d* (95% CI)
	Mean (SD)	95% CI of Mean	Mean (SD)	95% CI of Mean	Mean (SD)		
Static Posturography Tests							
Romberg Test with Eyes Open (ROA)							
ROA Total Displacement (mm)	6.38 (2.41)	5.51 ; 7.25	7.15 (2.99)	6.05 ; 8.25	6.76 (2.72)	0.379	0.28 (0.78; 0.21)
ROA Displacement Angle (º)	139.77 (74.85)	112.79 ; 166.76	184.81 (53.10)	165.34 ; 204.29	161.93 (68.41)	0.003	0.69 (1.20; 0.18)
ROA Mediolateral (ML) Dispersed X (mm)	3.44 (1.20)	3.00 ; 3.87	4.02 (1.23)	3.57 ; 4.47	3.72 (1.24)	0.056	0.48 (0.98; 0.02)
ROA Anteroposterior (AP) Dispersed Y (mm)	4.05 (1.12)	3.65 ; 4.45	4.70 (1.63)	4.10 ; 5.30	4.37 (1.42)	0.080	0.47 (0.97; 0.04)
ROA Average Speed (m/s)	0.01 (0.00)	0.01 ; 0.01	0.01 (0.01)	0.01 ; 0.02	0.01 (0.01)	0.005	0.53 (1.03; 0.03)
ROA Mediolateral (ML) Displacement (mm)	17.41 (5.05)	15.59 ; 19.23	20.55 (6.66)	18.10 ; 22.99	18.95 (6.06)	0.053	0.53 (1.03; 0.03)
ROA Anteroposterior (AP) Displacement (mm)	20.48 (5.37)	18.55 ; 22.42	24.54 (10.44)	20.71 ; 28.36	22.48 (8.44)	0.106	0.49 (0.99; 0.01)
ROA Mediolateral (ML) Maximal Force (N)	7.38 (2.59)	6.44 ; 8.31	8.56 (3.72)	7.20 ; 9.93	7.96 (3.22)	0.243	0.37 (0.87; 0.13)
ROA Anteroposterior (AP) Maximal Force (N)	4.63 (1.98)	3.91 ; 5.34	5.66 (3.39)	4.41 ; 6.90	5.13 (2.79)	0.182	0.37 (0.87; 0.13)
ROA Assessment Score (%)	99.47 (1.27)	99.01 ; 99.93	97.94 (3.52)	96.64 ; 99.23	98.71 (2.72)	0.012	0.58 (0.08; 1.09)
Romberg Test with Eyes Closed (ROC)							
ROC Total Displacement (mm)	8.09 (3.05)	6.99 ; 9.19	10.47 (4.13)	8.95 ; 11.98	9.26 (3.78)	0.025	0.66 (1.16; 0.15)
ROC Displacement Angle (º)	165.53 (65.99)	141.74 ; 189.32	201.08 (66.60)	176.65 ; 225.51	183.02 (68.15)	0.045	0.54 (1.04; 0.03)
ROC Mediolateral (ML) Dispersed X (mm)	5.17 (2.95)	4.10 ; 6.23	5.72 (2.45)	4.82 ; 6.62	5.44 (2.71)	0.208	0.21 (0.70; 0.29)
ROC Anteroposterior (AP) Dispersed Y (mm)	5.50 (2.14)	4.72 ; 6.27	6.75 (2.84)	5.70 ; 7.79	6.11 (2.57)	0.075	0.50 (1.00; 0.01)
ROC Average Speed (m/s)	0.02 (0.02)	0.02 ; 0.03	0.02 (0.01)	0.02 ; 0.03	0.02 (0.02)	0.081	0.08 (0.58; 0.41)
ROC Mediolateral (ML) Displacement (mm)	25.35 (12.10)	20.99 ; 29.72	29.41 (12.53)	24.82 ; 34.01	27.35 (12.38)	0.105	0.33 (0.83; 0.17)
ROC Anteroposterior (AP) Displacement (mm)	29.54 (13.65)	24.62 ; 34.46	36.11 (14.67)	30.73 ; 41.49	32.78 (14.43)	0.044	0.46 (0.96; 0.04)
ROC Mediolateral (ML) Maximal Force (N)	10.44 (5.13)	8.59 ; 12.29	13.05 (5.72)	10.95 ; 15.15	11.72 (5.54)	0.059	0.48 (0.98; 0.02)
ROC Anteroposterior (AP) Maximal Force (N)	7.29 (4.78)	5.57 ; 9.02	8.65 (4.50)	7.00 ; 10.30	7.96 (4.66)	0.102	0.29 (0.79; 0.21)
ROC Assessment Score (%)	97.53 (5.28)	95.63 ; 99.43	95.19 (5.99)	93.00 ; 97.39	96.38 (5.71)	0.039	0.41 (0.09; 0.91)
Romberg Test with Eyes Open on Foam Cushion (RGA)							
RGA Total Displacement (mm)	9.05 (3.71)	7.72 ; 10.39	14.43 (5.84)	12.28 ; 16.57	11.70 (5.54)	<0.001	1.10 (1.63; 0.57)
RGA Displacement Angle (º)	149.12 (65.14)	125.64 ; 172.61	206.38 (56.44)	185.67 ; 227.08	177.30 (67.05)	<0.001	0.94 (1.46; 0.41)
RGA Mediolateral (ML) Dispersed X (mm)	6.38 (2.15)	5.60 ; 7.16	8.82 (3.73)	7.45 ; 10.19	7.58 (3.25)	0.003	0.81 (1.32; 0.29)
RGA Anteroposterior (AP) Dispersed Y (mm)	7.84 (2.20)	7.05 ; 8.63	10.42 (4.07)	8.93 ; 11.92	9.11 (3.48)	0.007	0.79 (1.30; 0.28)
RGA Average Speed (m/s)	0.03 (0.01)	0.03 ; 0.03	0.04 (0.01)	0.03 ; 0.04	0.03 (0.01)	0.049	0.58 (1.08; 0.07)
RGA Mediolateral (ML) Displacement (mm)	33.69 (9.53)	30.26 ; 37.13	45.18 (16.98)	38.95 ; 51.41	39.35 (14.78)	0.003	0.84 (1.35; 0.32)
RGA Anteroposterior (AP) Displacement (mm)	42.36 (9.15)	39.06 ; 45.66	53.15 (15.93)	47.31 ; 58.99	47.67 (13.93)	0.004	0.83 (1.35; 0.32)

RGA Mediolateral (ML) Maximal Force (N)	14.73 (4.90)	12.96 ; 16.50	18.36 (7.84)	15.48 ; 21.23	16.52 (6.72)	0.060	0.56 (1.06; 0.05)
RGA Anteroposterior (AP) Maximal Force (N)	10.54 (3.93)	9.13 ; 11.96	14.14 (6.93)	11.59 ; 16.68	12.31 (5.85)	0.056	0.64 (1.14; 0.13)
RGA Assessment Score (%)	97.91 (3.01)	96.82 ; 98.99	92.10 (8.06)	89.14 ; 95.05	95.05 (6.68)	0.003	0.96 (0.43; 1.48)
Romberg Test with Eyes Closed on Foam Cushion (RGC)							
RGC Total Displacement (mm)	13.00 (4.89)	11.24 ; 14.76	20.11 (7.91)	17.21 ; 23.01	16.50 (7.42)	<0.001	1.09 (1.61; 0.55)
RGC Displacement Angle (º)	181.06 (81.61)	151.64 ; 210.49	264.34 (56.51)	243.61 ; 285.06	222.04 (81.47)	<0.001	1.18 (1.72; 0.64)
RGC Mediolateral (ML) Dispersed X (mm)	17.93 (3.98)	16.50 ; 19.37	20.57 (3.70)	19.22 ; 21.93	19.23 (4.04)	0.007	0.69 (1.19; 0.18)
RGC Anteroposterior (AP) Dispersed Y (mm)	18.33 (3.99)	16.89 ; 19.77	30.01 (52.92)	10.60 ; 49.42	24.08 (37.38)	0.013	0.31 (0.81; 0.18)
RGC Average Speed (m/s)	0.08 (0.02)	0.07 ; 0.09	0.09 (0.02)	0.08 ; 0.09	0.08 (0.02)	0.018	0.44 (0.94; 0.06)
RGC Mediolateral (ML) Displacement (mm)	91.00 (16.88)	84.92 ; 97.09	103.93 (14.29)	98.69 ; 109.17	97.36 (16.84)	0.001	0.83 (1.34; 0.31)
RGC Anteroposterior (AP) Displacement (mm)	87.42 (14.67)	82.13 ; 92.71	96.13 (15.53)	90.43 ; 101.82	91.71 (15.60)	0.009	0.58 (1.08; 0.07)
RGC Mediolateral (ML) Maximal Force (N)	34.74 (10.17)	31.07 ; 38.40	37.45 (8.86)	34.20 ; 40.69	36.07 (9.57)	0.257	0.28 (0.78; 0.21)
RGC Anteroposterior (AP) Maximal Force (N)	29.23 (10.70)	25.37 ; 33.09	33.12 (9.32)	29.70 ; 36.54	31.14 (10.16)	0.087	0.39 (0.88; 0.11)
RGC Assessment Score (%)	87.69 (8.56)	84.60 ; 90.77	78.68 (10.37)	74.87 ; 82.48	83.25 (10.45)	0.001	0.95 (0.42; 1.47)
Romberg Test Stability Assessment							
ROA Mediolateral (ML) Stability (%)	99.75 (0.67)	99.51 ; 99.99	99.00 (2.73)	98.00 ; 100.00	99.38 (2.00)	0.536	0.38 (0.12; 0.88)
ROC Mediolateral (ML) Stability (%)	98.44 (2.96)	97.37 ; 99.51	97.26 (4.13)	95.74 ; 98.77	97.86 (3.60)	0.375	0.33 (0.17; 0.83)
RGA Mediolateral (ML) Stability (%)	97.72 (3.39)	96.50 ; 98.94	93.94 (7.21)	91.29 ; 96.58	95.86 (5.88)	0.017	0.67 (0.16; 1.18)
RGC Mediolateral (ML) Stability (%)	87.75 (7.89)	84.90 ; 90.60	83.26 (9.66)	79.72 ; 86.80	85.54 (9.02)	0.072	0.51 (0.01; 1.01)
Romberg Test ML Stability Assessment (%)	95.84 (2.94)	94.78 ; 96.90	93.32 (4.98)	91.49 ; 95.15	94.60 (4.24)	0.051	0.62 (0.11; 1.12)
ROA Anteroposterior (AP) Stability (%)	99.75 (0.92)	99.42 ; 100.08	99.29 (2.02)	98.55 ; 100.03	99.52 (1.56)	0.741	0.29 (0.20; 0.79)
ROC Anteroposterior (AP) Stability (%)	98.97 (3.22)	97.81 ; 100.13	98.58 (3.12)	97.44 ; 99.72	98.78 (3.15)	0.541	0.12 (0.37; 0.62)
RGA Anteroposterior (AP) Stability (%)	99.34 (2.70)	98.37 ; 100.32	97.55 (4.30)	95.97 ; 99.12	98.46 (3.66)	0.155	0.50 (0.00; 1.00)
RGC Anteroposterior (AP) Stability (%)	96.09 (7.12)	93.53 ; 98.66	94.58 (7.52)	91.82 ; 97.34	95.35 (7.30)	0.268	0.21 (0.29; 0.70)
Romberg Test AP Stability Assessment (%)	98.53 (2.75)	97.54 ; 99.52	97.52 (3.21)	96.34 ; 98.69	98.03 (3.01)	0.187	0.34 (0.16; 0.84)
Somatosensory Index (%)	97.97 (4.23)	96.44 ; 99.49	96.23 (4.96)	94.41 ; 98.04	97.11 (4.65)	0.017	0.38 (0.12; 0.88)
Visual Index (%)	97.88 (3.35)	96.67 ; 99.08	95.52 (4.24)	93.96 ; 97.07	96.71 (3.97)	0.026	0.62 (0.11; 1.12)
Vestibular Index (%)	93.00 (6.23)	90.75 ; 95.25	83.97 (9.51)	80.48 ; 87.45	88.56 (9.16)	<0.001	1.13 (0.59; 1.66)
Dynamic Index (%)	88.75 (5.19)	86.88 ; 90.62	81.71 (8.15)	78.72 ; 84.70	85.29 (7.63)	<0.001	1.03 (0.50; 1.56)
Sensory-Dynamic Total Score (%)	94.13 (2.92)	93.07 ; 95.18	88.55 (4.78)	86.79 ; 90.30	91.38 (4.82)	<0.001	1.41 (0.86; 1.96)
Postural Control Assessment							
Limits of Stability (LOS) Analysis							
Forward (F) Maximum Displacement (%)	112.38 (12.27)	107.95 ; 116.80	108.58 (13.13)	103.76 ; 113.40	110.51 (12.74)	0.125	0.30 (0.20; 0.79)
Forward (F) Directional Control (%)	78.06 (9.30)	74.71 ; 81.41	74.13 (10.07)	70.43 ; 77.82	76.13 (9.81)	0.251	0.41 (0.09; 0.90)
Forward (F) Reaction Time (s)	0.85 (0.45)	0.69 ; 1.01	1.57 (0.56)	1.37 ; 1.78	1.21 (0.62)	<0.001	1.42 (1.97; 0.87)
Forward (F) Assessment Score (%)	93.41 (4.15)	91.91 ; 94.90	90.58 (5.58)	88.53 ; 92.63	92.02 (5.07)	0.009	0.58 (0.07; 1.08)

Right-Forward (RF) Maximum Displacement (%)	104.34 (9.22)	101.02 ; 107.67	97.61 (11.17)	93.52 ; 101.71	101.03 (10.69)	0.013	0.66 (0.15; 1.16)
Right-Forward (RF) Directional Control (%)	75.72 (11.55)	71.55 ; 79.88	64.19 (15.32)	58.57 ; 69.81	70.05 (14.63)	0.002	0.85 (0.33; 1.36)
Right-Forward (RF) Reaction Time (s)	0.88 (0.46)	0.71 ; 1.04	1.17 (0.61)	0.95 ; 1.40	1.02 (0.55)	0.045	0.56 (1.06; 0.05)
Right-Forward (RF) Assessment Score (%)	91.34 (5.42)	89.39 ; 93.30	83.26 (7.65)	80.45 ; 86.06	87.37 (7.72)	<0.001	1.22 (0.68; 1.76)
Right (R) Maximum Displacement (%)	107.47 (9.77)	103.95 ; 110.99	99.45 (10.70)	95.53 ; 103.38	103.52 (10.93)	0.007	0.78 (0.27; 1.29)
Right (R) Directional Control (%)	71.56 (13.16)	66.82 ; 76.31	66.74 (14.83)	61.30 ; 72.18	69.19 (14.10)	0.224	0.34 (0.15; 0.84)
Right (R) Reaction Time (s)	1.06 (0.48)	0.89 ; 1.23	1.25 (0.45)	1.08 ; 1.41	1.15 (0.47)	0.091	0.40 (0.90; 0.10)
Right (R) Assessment Score (%)	91.47 (4.09)	90.00 ; 92.94	84.68 (8.55)	81.54 ; 87.81	88.13 (7.44)	<0.001	1.02 (0.49; 1.54)
Right-Backward (RB) Maximum Displacement (%)	111.75 (12.63)	107.20 ; 116.30	106.42 (11.67)	102.14 ; 110.70	109.13 (12.36)	0.132	0.44 (0.06; 0.94)
Right-Backward (RB) Directional Control (%)	71.75 (11.71)	67.53 ; 75.97	61.32 (10.78)	57.37 ; 65.28	66.62 (12.35)	0.001	0.93 (0.40; 1.44)
Right-Backward (RB) Reaction Time (s)	0.96 (0.40)	0.82 ; 1.11	1.31 (0.51)	1.12 ; 1.50	1.13 (0.49)	0.009	0.75 (1.26; 0.24)
Right-Backward (RB) Assessment Score (%)	92.56 (3.76)	91.21 ; 93.92	86.32 (5.99)	84.13 ; 88.52	89.49 (5.86)	<0.001	1.25 (0.71; 1.79)
Backward (B) Maximum Displacement (%)	126.97 (18.54)	120.28 ; 133.65	122.97 (20.91)	115.30 ; 130.64	125.00 (19.69)	0.541	0.20 (0.29; 0.70)
Backward (B) Directional Control (%)	78.59 (12.68)	74.02 ; 83.16	69.16 (16.03)	63.28 ; 75.04	73.95 (15.08)	0.024	0.65 (0.14; 1.16)
Backward (B) Reaction Time (s)	1.02 (0.39)	0.88 ; 1.16	1.00 (0.40)	0.85 ; 1.15	1.01 (0.39)	0.794	0.05 (0.44; 0.55)
Backward (B) Assessment Score (%)	94.72 (2.93)	93.66 ; 95.78	91.58 (4.60)	89.90 ; 93.27	93.17 (4.13)	0.004	0.82 (0.30; 1.33)
Left-Backward (LB) Maximum Displacement (%)	114.97 (12.55)	110.44 ; 119.49	105.10 (15.24)	99.51 ; 110.69	110.11 (14.69)	0.006	0.71 (0.20; 1.22)
Left-Backward (LB) Directional Control (%)	71.63 (14.91)	66.25 ; 77.00	64.00 (15.55)	58.30 ; 69.70	67.87 (15.59)	0.066	0.50 (0.00; 1.00)
Left-Backward (LB) Reaction Time (s)	1.00 (0.42)	0.85 ; 1.16	1.22 (0.73)	0.95 ; 1.49	1.11 (0.60)	0.564	0.36 (0.86; 0.14)
Left-Backward (LB) Assessment Score (%)	92.53 (3.52)	91.26 ; 93.80	86.32 (7.65)	83.52 ; 89.13	89.48 (6.66)	<0.001	1.05 (0.52; 1.57)
Left (L) Maximum Displacement (%)	106.16 (7.91)	103.31 ; 109.01	97.71 (12.50)	93.12 ; 102.30	102.00 (11.18)	0.006	0.81 (0.29; 1.32)
Left (L) Directional Control (%)	71.44 (12.14)	67.06 ; 75.82	66.35 (13.05)	61.57 ; 71.14	68.94 (12.75)	0.103	0.40 (0.10; 0.90)
Left (L) Reaction Time (s)	0.78 (0.43)	0.62 ; 0.93	1.11 (0.46)	0.94 ; 1.27	0.94 (0.47)	0.011	0.74 (1.25; 0.23)
Left (L) Assessment Score (%)	90.50 (5.85)	88.39 ; 92.61	85.32 (8.62)	82.16 ; 88.48	87.95 (7.73)	0.005	0.71 (0.19; 1.21)
Left-Forward (LF) Maximum Displacement (%)	103.81 (8.30)	100.82 ; 106.81	96.61 (13.14)	91.79 ; 101.43	100.27 (11.46)	0.019	0.66 (0.15; 1.16)
Left-Forward (LF) Directional Control (%)	73.28 (11.76)	69.04 ; 77.52	61.97 (12.37)	57.43 ; 66.50	67.71 (13.25)	0.002	0.94 (0.41; 1.46)
Left-Forward (LF) Reaction Time (s)	0.94 (0.46)	0.78 ; 1.11	1.09 (0.50)	0.91 ; 1.28	1.02 (0.48)	0.240	0.31 (0.81; 0.19)
Left-Forward (LF) Assessment Score (%)	90.59 (4.68)	88.91 ; 92.28	82.32 (9.38)	78.88 ; 85.76	86.52 (8.42)	<0.001	1.12 (0.59; 1.65)
Average Score of Maximum Displacement (%)	110.84 (5.36)	108.91 ; 112.78	104.23 (7.40)	101.51 ; 106.94	107.59 (7.21)	0.001	1.03 (0.50; 1.55)
Average Score of Directional Control (%)	73.81 (7.45)	71.12 ; 76.50	65.77 (8.79)	62.55 ; 69.00	69.86 (9.03)	<0.001	0.99 (0.46; 1.51)
Average Score of Reaction Time (s)	0.94 (0.24)	0.85 ; 1.02	1.22 (0.27)	1.12 ; 1.31	1.07 (0.29)	<0.001	1.09 (1.62; 0.56)
Limits of Stability (LOS) Analysis Score (%)	91.97 (2.69)	91.00 ; 92.94	85.84 (4.25)	84.28 ; 87.40	88.95 (4.68)	<0.001	1.73 (1.14; 2.30)
Rhythmic and Directional Control Assessment							
Mediolateral (ML) Ability (%)	96.47 (5.51)	94.48 ; 98.45	90.26 (9.08)	86.93 ; 93.59	93.41 (8.05)	0.006	0.83 (0.31; 1.34)
Mediolateral (ML) Control and Efficacy (%)	98.69 (3.28)	97.51 ; 99.87	95.61 (8.12)	92.63 ; 98.59	97.17 (6.30)	0.187	0.50 (0.00; 1.00)
ML Rhythmic and Directional Control Assessment (%)	97.41 (3.84)	96.02 ; 98.79	92.39 (6.26)	90.09 ; 94.68	94.94 (5.72)	0.001	0.97 (0.44; 1.49)

Anteroposterior (AP) Ability (%)	99.72 (1.25)	99.27 ; 100.17	98.90 (3.83)	97.50 ; 100.31	99.32 (2.84)	0.778	0.29 (0.21; 0.78)
Anteroposterior (AP) Control and Efficacy (%)	89.31 (12.86)	84.68 ; 93.95	78.13 (15.03)	72.62 ; 83.64	83.81 (14.96)	0.001	0.80 (0.28; 1.31)
AP Rhythmic and Directional Control Assessment (%)	96.50 (3.94)	95.08 ; 97.92	92.42 (5.73)	90.32 ; 94.52	94.49 (5.28)	0.001	0.83 (0.31; 1.34)
Postural Control Assessment (Total Score) (%)	93.81 (2.72)	92.83 ; 94.79	87.94 (3.86)	86.52 ; 89.35	90.92 (4.44)	<0.001	1.76 (1.17; 2.34)
Functional Balance Assessment - Global Score (%)	94.06 (2.49)	93.17 ; 94.96	88.03 (3.41)	86.78 ; 89.28	91.10 (4.24)	<0.001	2.03 (1.41; 2.63)
Functional Balance Assessment - Global Score Interpretation, n (%)						<0.001	
Functionally impaired (≤ 79%)	0 (0.0%)		0 (0.0%)		0 (0.0%)		
Slightly impaired (80-89%)	2 (6.3%)		21 (67.7%)		23 (36.5%)		
Normal (90-100%)	30 (93.8%)		10 (32.3%)		40 (63.5%)		

11.14 Results of instrumental functional gait analysis at 3-months follow-up

Appendix N: Results of instrumental functional gait analysis of study participants at 3-months follow-up.

Functional Gait Analysis Parameters	MRP Group (n = 32)		CPT Group (n = 31)		All Participants (n = 63)	*p*-Value	Effect Size *d* (95% CI)
	Mean (SD)	95% CI of Mean	Mean (SD)	95% CI of Mean	Mean (SD)		
Gait speed (m/s)	0.81 (0.14)	0.76 ; 0.86	0.66 (0.12)	0.62 ; 0.71	0.74 (0.15)	<0.001	1.14 (0.60 ; 1.67)
Average gait speed (%)	98.59 (3.37)	97.38 ; 99.81	92.42 (10.61)	88.53 ; 96.31	95.56 (8.36)	0.004	0.79 (0.27 ; 1.30)
Lt. foot support time (s)	0.81 (0.10)	0.78 ; 0.85	0.90 (0.12)	0.85 ; 0.94	0.85 (0.12)	0.002	0.77 (1.28 ; 0.26)
Rt. foot support time (s)	0.81 (0.09)	0.77 ; 0.84	0.89 (0.12)	0.84 ; 0.93	0.85 (0.11)	0.009	0.78 (1.29 ; 0.27)
Difference in support time (%)	91.81 (8.89)	88.61 ; 95.02	75.71 (18.55)	68.91 ; 82.51	83.89 (16.49)	<0.001	1.11 (0.58 ; 1.64)
Anteroposterior braking force							
Lt. AP braking force (N)	68.90 (19.38)	61.91 ; 75.89	61.63 (16.19)	55.69 ; 67.56	65.32 (18.11)	0.199	0.41 (0.09 ; 0.90)
Lt. AP braking force (Normalized)	0.10 (0.02)	0.09 ; 0.10	0.09 (0.02)	0.08 ; 0.10	0.09 (0.02)	0.182	0.34 (0.15 ; 0.84)
Lt. AP braking force assessment (%)	100.56 (6.14)	98.35 ; 102.78	101.10 (24.81)	92.00 ; 110.20	100.83 (17.80)	0.962	0.03 (0.52 ; 0.46)
Rt. AP braking force (N)	68.33 (21.27)	60.66 ; 76.00	53.88 (19.81)	46.62 ; 61.15	61.22 (21.66)	0.016	0.70 (0.19 ; 1.21)
Rt. AP braking force (Normalized)	0.10 (0.02)	0.09 ; 0.10	0.08 (0.03)	0.07 ; 0.09	0.09 (0.03)	0.002	0.75 (0.24 ; 1.26)
Rt. AP braking force assessment (%)	105.44 (18.76)	98.67 ; 112.20	93.23 (27.24)	83.23 ; 103.22	99.43 (23.93)	0.037	0.52 (0.02 ; 1.02)
AP braking force global score (%)	99.06 (2.34)	98.22 ; 99.91	92.97 (18.50)	86.18 ; 99.75	96.06 (13.33)	0.076	0.47 (0.04 ; 0.96)
Anteroposterior propulsion force							
Lt. AP propulsion force (N)	77.46 (25.57)	68.24 ; 86.68	62.30 (18.00)	55.70 ; 68.91	70.00 (23.28)	0.006	0.68 (0.17 ; 1.19)
Lt. AP propulsion force (Normalized)	0.11 (0.03)	0.10 ; 0.12	0.09 (0.03)	0.08 ; 0.10	0.10 (0.03)	0.014	0.64 (0.13 ; 1.14)
Lt. AP propulsion force assessment (%)	96.44 (16.93)	90.33 ; 102.54	86.97 (32.18)	75.16 ; 98.77	91.78 (25.83)	0.350	0.37 (0.13 ; 0.87)
Rt. AP propulsion force (N)	79.31 (26.51)	69.75 ; 88.87	66.01 (21.41)	58.15 ; 73.86	72.76 (24.86)	0.035	0.55 (0.05 ; 1.05)
Rt. AP propulsion force (Normalized)	0.11 (0.03)	0.10 ; 0.12	0.09 (0.03)	0.08 ; 0.11	0.10 (0.03)	0.019	0.54 (0.03 ; 1.04)
Rt. AP propulsion force assessment (%)	96.25 (18.48)	89.59 ; 102.91	91.61 (30.88)	80.29 ; 102.94	93.97 (25.25)	0.406	0.18 (0.31 ; 0.68)
AP propulsion force global score (%)	95.72 (12.83)	91.09 ; 100.34	86.42 (22.78)	78.07 ; 94.77	91.14 (18.85)	0.043	0.51 (0.00 ; 1.01)
Vertical take-off force							
Lt. vertical take-off force (N)	730.14 (144.58)	678.01 ; 782.26	718.24 (150.82)	662.92 ; 773.56	724.28 (146.61)	0.842	0.08 (0.41 ; 0.57)
Lt. vertical take-off force (Normalized)	1.02 (0.04)	1.01 ; 1.04	1.01 (0.04)	0.99 ; 1.02	1.02 (0.04)	0.082	0.44 (0.06 ; 0.94)
Lt. vertical take-off force assessment (%)	100.28 (2.08)	99.53 ; 101.03	100.81 (6.69)	98.35 ; 103.26	100.54 (4.89)	0.226	0.11 (0.60 ; 0.39)
Rt. vertical take-off force (N)	735.48 (143.51)	683.74 ; 787.22	717.59 (149.01)	662.94 ; 772.25	726.68 (145.34)	0.645	0.12 (0.37 ; 0.62)
Rt. vertical take-off force (Normalized)	1.03 (0.04)	1.02 ; 1.05	1.01 (0.03)	0.99 ; 1.02	1.02 (0.04)	0.006	0.71 (0.20 ; 1.22)
Rt. vertical take-off force assessment (%)	100.47 (4.57)	98.82 ; 102.12	100.10 (7.47)	97.36 ; 102.84	100.29 (6.12)	0.260	0.06 (0.43 ; 0.55)
Vertical take-off force global score (%)	99.50 (1.44)	98.98 ; 100.02	99.19 (1.87)	98.51 ; 99.88	99.35 (1.66)	0.616	0.18 (0.31 ; 0.68)

Oscillation force							
Lt. oscillation force (N)	638.22 (135.46)	589.38 ; 687.06	644.09 (145.83)	590.60 ; 697.58	641.11 (139.55)	0.705	0.04 (0.54 ; 0.45)
Lt. oscillation force (Normalized)	0.89 (0.04)	0.88 ; 0.91	0.90 (0.05)	0.88 ; 0.92	0.90 (0.04)	0.243	0.13 (0.62 ; 0.37)
Lt. oscillation force assessment (%)	101.66 (7.33)	99.01 ; 104.30	112.87 (28.65)	102.36 ; 123.38	107.17 (21.35)	0.092	0.54 (1.04 ; 0.03)
Rt. oscillation force (N)	639.92 (134.30)	591.49 ; 688.34	646.30 (147.52)	592.19 ; 700.41	643.06 (139.85)	0.789	0.05 (0.54 ; 0.45)
Rt. oscillation force (Normalized)	0.89 (0.03)	0.88 ; 0.90	0.90 (0.03)	0.89 ; 0.91	0.90 (0.03)	0.326	0.24 (0.73 ; 0.26)
Rt. oscillation force assessment (%)	101.91 (6.06)	99.72 ; 104.09	112.77 (30.98)	101.41 ; 124.14	107.25 (22.65)	0.559	0.49 (0.99 ; 0.01)
Oscillation force global score (%)	99.78 (0.91)	99.45 ; 100.11	99.87 (0.56)	99.66 ; 100.08	99.83 (0.75)	0.842	0.12 (0.61 ; 0.38)
AP force morphology (Fx Morphology)							
Lt. AP force morphology (%)	76.31 (11.44)	72.19 ; 80.44	63.06 (14.91)	57.60 ; 68.53	69.79 (14.75)	0.001	1.00 (0.47 ; 1.52)
Rt. AP force morphology (%)	70.34 (14.30)	65.19 ; 75.50	59.23 (16.73)	53.09 ; 65.36	64.87 (16.40)	0.008	0.72 (0.20 ; 1.22)
AP force morphology global score (%)	73.25 (10.71)	69.39 ; 77.11	62.52 (15.19)	56.94 ; 68.09	67.97 (14.08)	0.003	0.82 (0.30 ; 1.33)
ML force morphology (Fy Morphology)							
Lt. ML force morphology (%)	44.03 (23.44)	35.58 ; 52.48	23.23 (19.11)	16.22 ; 30.24	33.79 (23.69)	<0.001	0.97 (0.44 ; 1.49)
Rt. ML force morphology (%)	45.50 (24.48)	36.67 ; 54.33	27.42 (22.01)	19.35 ; 35.49	36.60 (24.84)	0.003	0.78 (0.26 ; 1.29)
ML force morphology global score (%)	44.81 (23.03)	36.51 ; 53.12	24.81 (20.46)	17.30 ; 32.31	34.97 (23.86)	<0.001	0.92 (0.39 ; 1.43)
Vertical force morphology (Fz Morphology)							
Lt. vertical force morphology (%)	79.97 (15.15)	74.51 ; 85.43	73.55 (18.30)	66.84 ; 80.26	76.81 (16.95)	0.139	0.38 (0.12 ; 0.88)
Rt. vertical force morphology (%)	76.97 (16.16)	71.14 ; 82.79	71.97 (16.96)	65.75 ; 78.19	74.51 (16.62)	0.232	0.30 (0.20 ; 0.80)
Vertical force morphology global score (%)	78.56 (14.76)	73.24 ; 83.88	72.77 (16.35)	66.78 ; 78.77	75.71 (15.71)	0.171	0.37 (0.13 ; 0.87)
Lt. foot global assessment (%)	87.16 (5.67)	85.11 ; 89.20	78.68 (8.55)	75.54 ; 81.81	82.98 (8.35)	<0.001	1.17 (0.63 ; 1.70)
Rt. foot global assessment (%)	85.78 (7.05)	83.24 ; 88.32	78.26 (9.18)	74.89 ; 81.62	82.08 (8.94)	<0.001	0.92 (0.40 ; 1.44)
Functional gait analysis global score (%)	87.88 (5.39)	85.93 ; 89.82	79.55 (8.05)	76.59 ; 82.50	83.78 (7.97)	<0.001	1.22 (0.68 ; 1.75)
Functional gait analysis global score interpretation, n (%)						<0.001	
Functionally impaired (≤ 79%)	2 (6.3%)		14 (45.2%)		16 (25.4%)		
Slightly impaired (80-89%)	15 (46.9%)		13 (41.9%)		28 (44.4%)		
Normal (90-100%)	15 (46.9%)		4 (12.9%)		19 (30.2%)		

11.15 Results of changes in instrumental functional balance assessment from baseline to post-intervention

Appendix O: Results of changes in instrumental functional balance assessment from baseline to post-intervention in the two groups.

Functional Balance Assessment Tests	MRP Group (n = 32)			CPT Group (n = 31)			Paired *p*-Value	Between-Group *p*-Value	Effect Size *d* (95% CI)
	Mean Change (SD)	*p* Value	Effect Size *d*	Mean Change (SD)	*p* Value	Effect Size *d*			
Static Posturography Tests									
Romberg Test with Eyes Open (ROA)									
ROA Total Displacement (mm)	-5.65 (3.73)	<0.001	1.52	-1.35 (1.80)	0.001	0.75	<0.001	<0.001	1.46 (2.01; 0.90)
ROA Displacement Angle (º)	-112.02 (68.83)	<0.001	1.63	-14.31 (29.88)	0.010	0.48	<0.001	<0.001	1.83 (2.42; 1.24)
ROA Mediolateral (ML) Dispersed X (mm)	-0.87 (1.37)	0.001	0.64	-0.68 (0.79)	<0.001	0.86	<0.001	0.826	0.17 (0.66; 0.33)
ROA Anteroposterior (AP) Dispersed Y (mm)	-1.75 (2.41)	<0.001	0.73	-1.02 (1.97)	0.004	0.52	<0.001	0.194	0.33 (0.83; 0.17)
ROA Average Speed (m/s)	-0.00 (0.00)	<0.001	0.97	-0.00 (0.00)	<0.001	0.60	<0.001	0.003	0.71 (1.21; 0.19)
ROA Mediolateral (ML) Displacement (mm)	-6.30 (8.98)	<0.001	0.70	-3.85 (5.23)	0.001	0.74	<0.001	0.621	0.33 (0.83; 0.17)
ROA Anteroposterior (AP) Displacement (mm)	-9.27 (10.73)	<0.001	0.86	-5.39 (8.71)	0.001	0.62	<0.001	0.114	0.40 (0.89; 0.10)
ROA Mediolateral (ML) Maximal Force (N)	-3.27 (4.53)	<0.001	0.72	-1.77 (2.72)	0.001	0.65	<0.001	0.287	0.40 (0.90; 0.10)
ROA Anteroposterior (AP) Maximal Force (N)	-1.68 (2.71)	<0.001	0.62	-0.65 (2.34)	0.183	0.28	<0.001	0.063	0.41 (0.90; 0.09)
ROA Assessment Score (%)	2.69 (3.23)	<0.001	0.83	2.26 (2.58)	<0.001	0.87	<0.001	0.869	0.15 (0.35; 0.64)
Romberg Test with Eyes Closed (ROC)									
ROC Total Displacement (mm)	-6.60 (5.28)	<0.001	1.25	-1.05 (2.01)	0.042	0.53	<0.001	<0.001	1.38 (1.93; 0.82)
ROC Displacement Angle (º)	-127.36 (88.90)	<0.001	1.43	-21.43 (41.31)	0.006	0.52	<0.001	<0.001	1.52 (2.08; 0.95)
ROC Mediolateral (ML) Dispersed X (mm)	-1.69 (2.08)	<0.001	0.81	-0.80 (1.63)	0.011	0.49	<0.001	0.114	0.47 (0.97; 0.03)
ROC Anteroposterior (AP) Dispersed Y (mm)	-2.02 (2.62)	<0.001	0.77	-0.67 (1.49)	0.021	0.45	<0.001	0.009	0.63 (1.13; 0.12)
ROC Average Speed (m/s)	-0.01 (0.01)	<0.001	0.61	-0.00 (0.01)	0.021	0.47	<0.001	0.003	0.44 (0.94; 0.06)
ROC Mediolateral (ML) Displacement (mm)	-8.57 (8.73)	<0.001	0.98	-4.79 (8.40)	0.004	0.57	<0.001	0.102	0.44 (0.94; 0.06)
ROC Anteroposterior (AP) Displacement (mm)	-12.55 (13.29)	<0.001	0.94	-4.26 (8.68)	0.005	0.49	<0.001	0.016	0.74 (1.24; 0.22)
ROC Mediolateral (ML) Maximal Force (N)	-3.22 (3.41)	<0.001	0.94	-2.28 (3.84)	0.001	0.59	<0.001	0.208	0.26 (0.75; 0.24)
ROC Anteroposterior (AP) Maximal Force (N)	-3.02 (3.99)	<0.001	0.76	-2.02 (3.28)	0.002	0.62	<0.001	0.375	0.27 (0.77; 0.23)
ROC Assessment Score (%)	5.13 (4.51)	<0.001	1.14	2.68 (2.88)	<0.001	0.93	<0.001	0.033	0.64 (0.13; 1.15)
Romberg Test with Eyes Open on Foam Cushion (RGA)									
RGA Total Displacement (mm)	-7.94 (5.39)	<0.001	1.47	-1.71 (2.96)	0.001	0.58	<0.001	<0.001	1.43 (1.98; 0.87)
RGA Displacement Angle (º)	-103.53 (58.29)	<0.001	1.78	-24.96 (39.02)	<0.001	0.64	<0.001	<0.001	1.58 (2.14; 1.01)
RGA Mediolateral (ML) Dispersed X (mm)	-1.56 (1.71)	<0.001	0.91	-0.96 (1.78)	0.004	0.54	<0.001	0.271	0.34 (0.84; 0.16)
RGA Anteroposterior (AP) Dispersed Y (mm)	-2.79 (2.41)	<0.001	1.16	-0.74 (1.89)	0.010	0.39	<0.001	<0.001	0.95 (1.46; 0.42)
RGA Average Speed (m/s)	-0.01 (0.01)	<0.001	1.40	-0.00 (0.00)	<0.001	0.69	<0.001	<0.001	1.00 (1.52; 0.47)
RGA Mediolateral (ML) Displacement (mm)	-7.90 (7.45)	<0.001	1.06	-5.66 (9.46)	0.005	0.60	<0.001	0.257	0.26 (0.76; 0.23)

RGA Anteroposterior (AP) Displacement (mm)	-14.13 (10.26)	<0.001	1.38	-5.12 (7.71)	0.001	0.66	<0.001	<0.001	0.99 (1.51; 0.46)
RGA Mediolateral (ML) Maximal Force (N)	-4.17 (4.23)	<0.001	0.99	-1.96 (3.80)	0.007	0.52	<0.001	0.149	0.55 (1.05; 0.04)
RGA Anteroposterior (AP) Maximal Force (N)	-2.87 (4.21)	0.001	0.68	-0.48 (4.14)	0.674	0.12	0.004	0.019	0.57 (1.07; 0.06)
RGA Assessment Score (%)	5.41 (4.23)	<0.001	1.28	3.35 (2.89)	<0.001	1.16	<0.001	0.066	0.56 (0.06; 1.07)
Romberg Test with Eyes Closed on Foam Cushion (RGC)									
RGC Total Displacement (mm)	-12.82 (9.76)	<0.001	1.31	-1.32 (2.73)	0.006	0.48	<0.001	<0.001	1.59 (2.16; 1.02)
RGC Displacement Angle (º)	-103.71 (64.86)	<0.001	1.60	-28.75 (37.34)	<0.001	0.77	<0.001	<0.001	1.41 (1.96; 0.85)
RGC Mediolateral (ML) Dispersed X (mm)	-5.23 (4.09)	<0.001	1.28	-2.93 (3.95)	<0.001	0.74	<0.001	0.013	0.57 (1.07; 0.07)
RGC Anteroposterior (AP) Dispersed Y (mm)	-4.26 (4.10)	<0.001	1.04	-1.36 (2.62)	0.013	0.52	<0.001	0.001	0.84 (1.35; 0.32)
RGC Average Speed (m/s)	-0.02 (0.01)	<0.001	1.32	-0.01 (0.01)	<0.001	0.73	<0.001	<0.001	1.00 (1.52; 0.47)
RGC Mediolateral (ML) Displacement (mm)	-24.86 (14.82)	<0.001	1.68	-9.43 (12.25)	0.001	0.77	<0.001	<0.001	1.13 (1.66; 0.60)
RGC Anteroposterior (AP) Displacement (mm)	-14.90 (15.23)	<0.001	0.98	-3.09 (10.98)	0.170	0.28	<0.001	0.002	0.89 (1.40; 0.37)
RGC Mediolateral (ML) Maximal Force (N)	-7.88 (8.63)	<0.001	0.91	-2.73 (8.50)	0.092	0.32	<0.001	0.003	0.60 (1.10; 0.09)
RGC Anteroposterior (AP) Maximal Force (N)	-9.11 (9.85)	<0.001	0.93	-2.78 (8.77)	0.081	0.32	<0.001	0.015	0.68 (1.18; 0.17)
RGC Assessment Score (%)	14.31 (5.79)	<0.001	2.47	5.52 (3.04)	<0.001	1.81	<0.001	<0.001	1.89 (1.29; 2.48)
Romberg Test Stability Assessment									
ROA Mediolateral (ML) Stability (%)	1.97 (3.31)	<0.001	0.60	0.90 (1.60)	0.001	0.56	<0.001	0.402	0.41 (0.09; 0.91)
ROC Mediolateral (ML) Stability (%)	3.09 (3.14)	<0.001	0.99	1.87 (3.62)	0.004	0.52	<0.001	0.060	0.36 (0.14; 0.86)
RGA Mediolateral (ML) Stability (%)	4.03 (4.60)	<0.001	0.88	2.55 (2.14)	<0.001	1.19	<0.001	0.458	0.41 (0.09; 0.91)
RGC Mediolateral (ML) Stability (%)	11.47 (6.95)	<0.001	1.65	5.26 (7.77)	<0.001	0.68	<0.001	<0.001	0.84 (0.32; 1.36)
Romberg Test ML Stability Assessment (%)	5.41 (2.76)	<0.001	1.96	2.58 (2.11)	<0.001	1.22	<0.001	<0.001	1.15 (0.61; 1.68)
ROA Anteroposterior (AP) Stability (%)	1.03 (1.89)	0.001	0.55	0.74 (1.48)	0.002	0.50	<0.001	0.670	0.17 (0.33; 0.66)
ROC Anteroposterior (AP) Stability (%)	2.28 (3.82)	<0.001	0.60	1.39 (2.39)	0.002	0.58	<0.001	0.578	0.28 (0.22; 0.77)
RGA Anteroposterior (AP) Stability (%)	1.47 (3.73)	0.003	0.39	1.29 (2.10)	0.001	0.61	<0.001	0.492	0.06 (0.44; 0.55)
RGC Anteroposterior (AP) Stability (%)	8.19 (8.64)	<0.001	0.95	3.42 (3.81)	<0.001	0.90	<0.001	0.060	0.71 (0.20; 1.22)
Romberg Test AP Stability Assessment (%)	3.72 (3.81)	<0.001	0.98	1.81 (1.87)	<0.001	0.97	<0.001	0.064	0.63 (0.12; 1.14)
Somatosensory Index (%)	5.25 (4.24)	<0.001	1.24	2.58 (2.28)	<0.001	1.13	<0.001	0.012	0.78 (0.26; 1.29)
Visual Index (%)	2.88 (2.77)	<0.001	1.04	2.58 (2.22)	<0.001	1.16	<0.001	0.789	0.12 (0.38; 0.61)
Vestibular Index (%)	14.81 (6.78)	<0.001	2.18	5.19 (3.54)	<0.001	1.47	<0.001	<0.001	1.77 (1.18; 2.35)
Dynamic Index (%)	13.69 (6.71)	<0.001	2.04	5.97 (2.30)	<0.001	2.59	<0.001	<0.001	1.53 (0.96; 2.09)
Sensory-Dynamic Total Score (%)	8.72 (2.44)	<0.001	3.57	3.90 (1.83)	<0.001	2.13	<0.001	<0.001	2.23 (1.59; 2.85)
Postural Control Assessment									
Limits of Stability (LOS) Analysis									
Forward (F) Maximum Displacement (%)	20.09 (17.78)	<0.001	1.13	17.45 (14.04)	<0.001	1.24	<0.001	0.616	0.16 (0.33; 0.66)
Forward (F) Directional Control (%)	12.59 (14.20)	<0.001	0.89	11.16 (6.45)	<0.001	1.73	<0.001	0.429	0.13 (0.37; 0.62)

Forward (F) Reaction Time (s)	-0.49 (0.76)	0.001	0.64	-0.32 (0.83)	0.013	0.38	<0.001	0.129	0.22 (0.71; 0.28)
Forward (F) Assessment Score (%)	14.56 (11.78)	<0.001	1.24	9.13 (7.01)	<0.001	1.30	<0.001	0.106	0.56 (0.05; 1.06)
Right-Forward (RF) Maximum Displacement (%)	19.09 (16.86)	<0.001	1.13	11.48 (12.83)	<0.001	0.90	<0.001	0.083	0.51 (0.00; 1.01)
Right-Forward (RF) Directional Control (%)	17.16 (13.35)	<0.001	1.28	11.97 (16.63)	<0.001	0.72	<0.001	0.072	0.34 (0.15; 0.84)
Right-Forward (RF) Reaction Time (s)	-0.33 (0.60)	0.003	0.55	-0.16 (0.54)	0.134	0.31	0.001	0.165	0.29 (0.79; 0.21)
Right-Forward (RF) Assessment Score (%)	16.19 (9.52)	<0.001	1.70	9.94 (8.25)	<0.001	1.20	<0.001	0.007	0.70 (0.19; 1.21)
Right (R) Maximum Displacement (%)	16.69 (20.06)	<0.001	0.83	10.45 (10.15)	<0.001	1.03	<0.001	0.049	0.39 (0.11; 0.89)
Right (R) Directional Control (%)	17.88 (19.65)	<0.001	0.91	8.48 (10.25)	<0.001	0.83	<0.001	0.067	0.60 (0.09; 1.10)
Right (R) Reaction Time (s)	-0.48 (0.73)	0.001	0.66	-0.16 (0.67)	0.115	0.24	<0.001	0.049	0.45 (0.95; 0.05)
Right (R) Assessment Score (%)	15.03 (11.04)	<0.001	1.36	6.52 (4.50)	<0.001	1.45	<0.001	0.002	1.00 (0.48; 1.53)
Right-Backward (RB) Maximum Displacement (%)	14.75 (24.56)	<0.001	0.60	9.39 (9.90)	<0.001	0.95	<0.001	0.108	0.28 (0.21; 0.78)
Right-Backward (RB) Directional Control (%)	15.41 (13.10)	<0.001	1.18	7.81 (10.48)	<0.001	0.74	<0.001	0.007	0.64 (0.13; 1.14)
Right-Backward (RB) Reaction Time (s)	-0.53 (0.66)	<0.001	0.80	-0.10 (0.61)	0.086	0.16	<0.001	0.013	0.68 (1.19; 0.17)
Right-Backward (RB) Assessment Score (%)	11.31 (11.68)	<0.001	0.97	4.74 (3.58)	<0.001	1.33	<0.001	0.050	0.76 (0.24; 1.26)
Backward (B) Maximum Displacement (%)	11.03 (13.79)	<0.001	0.80	13.61 (13.40)	<0.001	1.02	<0.001	0.805	0.19 (0.68; 0.31)
Backward (B) Directional Control (%)	19.81 (17.88)	<0.001	1.11	8.16 (10.59)	<0.001	0.77	<0.001	0.005	0.79 (0.27; 1.30)
Backward (B) Reaction Time (s)	-0.18 (0.54)	0.032	0.33	-0.26 (0.38)	0.001	0.70	<0.001	0.475	0.18 (0.31; 0.68)
Backward (B) Assessment Score (%)	7.63 (9.65)	<0.001	0.79	3.65 (3.77)	<0.001	0.97	<0.001	0.055	0.54 (0.03; 1.04)
Left-Backward (LB) Maximum Displacement (%)	17.09 (16.14)	<0.001	1.06	8.13 (11.04)	<0.001	0.74	<0.001	0.042	0.65 (0.14; 1.15)
Left-Backward (LB) Directional Control (%)	17.94 (15.83)	<0.001	1.13	10.97 (15.79)	<0.001	0.69	<0.001	0.106	0.44 (0.06; 0.94)
Left-Backward (LB) Reaction Time (s)	-0.34 (0.58)	0.002	0.59	-0.27 (0.54)	0.004	0.50	<0.001	0.329	0.14 (0.63; 0.36)
Left-Backward (LB) Assessment Score (%)	11.59 (11.16)	<0.001	1.04	6.26 (6.31)	<0.001	0.99	<0.001	0.070	0.59 (0.08; 1.09)
Left (L) Maximum Displacement (%)	18.34 (18.09)	<0.001	1.01	12.48 (11.05)	<0.001	1.13	<0.001	0.206	0.39 (0.11; 0.89)
Left (L) Directional Control (%)	17.66 (15.61)	<0.001	1.13	11.19 (10.97)	<0.001	1.02	<0.001	0.017	0.48 (0.03; 0.98)
Left (L) Reaction Time (s)	-0.50 (0.56)	<0.001	0.90	-0.14 (0.43)	0.060	0.34	<0.001	0.003	0.72 (1.22; 0.20)
Left (L) Assessment Score (%)	13.94 (13.55)	<0.001	1.03	7.58 (6.95)	<0.001	1.09	<0.001	0.047	0.59 (0.08; 1.09)
Left-Forward (LF) Maximum Displacement (%)	20.56 (15.36)	<0.001	1.34	11.42 (9.48)	<0.001	1.20	<0.001	0.008	0.71 (0.20; 1.22)
Left-Forward (LF) Directional Control (%)	18.88 (17.99)	<0.001	1.05	13.61 (13.55)	<0.001	1.00	<0.001	0.109	0.33 (0.17; 0.83)
Left-Forward (LF) Reaction Time (s)	-0.30 (0.51)	0.002	0.59	-0.35 (0.45)	<0.001	0.77	<0.001	0.907	0.09 (0.40; 0.59)
Left-Forward (LF) Assessment Score (%)	17.44 (11.68)	<0.001	1.49	8.48 (6.89)	<0.001	1.23	<0.001	0.004	0.93 (0.41; 1.45)
Average Score of Maximum Displacement (%)	17.56 (9.93)	<0.001	1.77	11.13 (4.54)	<0.001	2.45	<0.001	<0.001	0.83 (0.31; 1.34)
Average Score of Directional Control (%)	16.69 (6.64)	<0.001	2.51	9.90 (4.85)	<0.001	2.04	<0.001	<0.001	1.16 (0.62; 1.70)
Average Score of Reaction Time (s)	-0.40 (0.22)	<0.001	1.83	-0.21 (0.18)	<0.001	1.15	<0.001	<0.001	0.94 (1.46; 0.42)
Limits of Stability (LOS) Analysis Score (%)	13.44 (6.59)	<0.001	2.04	6.45 (2.69)	<0.001	2.40	<0.001	<0.001	1.38 (0.82; 1.93)

Rhythmic and Directional Control Assessment									
Mediolateral (ML) Ability (%)	15.88 (8.58)	<0.001	1.85	4.84 (3.22)	<0.001	1.50	<0.001	<0.001	1.69 (1.11; 2.27)
Mediolateral (ML) Control and Efficacy (%)	11.66 (14.46)	<0.001	0.81	2.19 (6.87)	0.002	0.32	<0.001	0.006	0.83 (0.31; 1.34)
ML Rhythmic and Directional Control Assessment (%)	13.94 (5.19)	<0.001	2.68	4.39 (2.47)	<0.001	1.77	<0.001	<0.001	2.34 (1.69; 2.97)
Anteroposterior (AP) Ability (%)	3.84 (6.15)	<0.001	0.62	1.42 (3.72)	0.008	0.38	<0.001	0.138	0.47 (0.03; 0.97)
Anteroposterior (AP) Control and Efficacy (%)	25.94 (12.94)	<0.001	2.00	10.32 (6.92)	<0.001	1.49	<0.001	<0.001	1.50 (0.93; 2.05)
AP Rhythmic and Directional Control Assessment (%)	10.75 (4.62)	<0.001	2.33	4.45 (2.75)	<0.001	1.62	<0.001	<0.001	1.65 (1.07; 2.22)
Postural Control Assessment (Total Score) (%)	13.09 (4.87)	<0.001	2.69	5.52 (2.03)	<0.001	2.72	<0.001	<0.001	2.02 (1.40; 2.62)
Functional Balance Assessment - Global Score (%)	11.19 (2.89)	<0.001	3.87	4.61 (1.52)	<0.001	3.03	<0.001	<0.001	2.83 (2.12; 3.53)

11.16 Results of changes in instrumental functional gait analysis from baseline to post-intervention

Appendix P: Results of changes in instrumental functional gait analysis from baseline to post-intervention in the two groups.

Functional Gait Analysis Parameters	MRP Group (n = 32)			CPT Group (n = 31)			Paired *p*-Value	Between-Group *p*-Value	Effect Size *d* (95% CI)
	Mean Change (SD)	*p* Value	Effect Size *d*	Mean Change (SD)	*p* Value	Effect Size *d*			
Gait speed (m/s)	0.20 (0.10)	<0.001	2.00	0.09 (0.04)	<0.001	2.32	<0.001	<0.001	1.46 (0.89; 2.01)
Average gait speed (%)	17.13 (18.34)	<0.001	0.93	9.29 (7.61)	<0.001	1.22	<0.001	0.353	0.55 (0.05; 1.06)
Lt. foot support time (s)	-0.17 (0.14)	<0.001	1.26	-0.10 (0.08)	<0.001	1.19	<0.001	0.005	0.66 (1.16; 0.15)
Rt. foot support time (s)	-0.16 (0.13)	<0.001	1.23	-0.09 (0.08)	<0.001	1.11	<0.001	0.005	0.63 (1.14; 0.12)
Difference in support time (%)	29.31 (19.69)	<0.001	1.49	9.84 (5.11)	<0.001	1.92	<0.001	<0.001	1.34 (0.79; 1.89)
Anteroposterior braking force									
Lt. AP braking force (N)	11.82 (12.75)	<0.001	0.93	10.23 (9.55)	<0.001	1.07	<0.001	0.248	0.14 (0.35; 0.63)
Lt. AP braking force (Normalized)	0.02 (0.02)	<0.001	1.07	0.01 (0.01)	<0.001	1.15	<0.001	0.206	0.14 (0.35; 0.64)
Lt. AP braking force assessment (%)	8.84 (17.50)	0.003	0.51	9.81 (18.88)	<0.001	0.52	<0.001	0.918	0.05 (0.55; 0.44)
Rt. AP braking force (N)	16.05 (11.59)	<0.001	1.39	4.81 (9.15)	0.003	0.53	<0.001	<0.001	1.08 (0.54; 1.60)
Rt. AP braking force (Normalized)	0.02 (0.02)	<0.001	1.40	0.01 (0.01)	0.002	0.68	<0.001	<0.001	1.07 (0.53; 1.59)
Rt. AP braking force assessment (%)	19.00 (29.78)	<0.001	0.64	8.06 (10.58)	<0.001	0.76	<0.001	0.837	0.49 (0.02; 0.99)
AP braking force global score (%)	14.13 (19.10)	<0.001	0.74	5.71 (7.16)	<0.001	0.80	<0.001	0.187	0.58 (0.07; 1.08)
Anteroposterior propulsion force									
Lt. AP propulsion force (N)	20.13 (19.75)	<0.001	1.02	8.43 (8.71)	<0.001	0.97	<0.001	0.002	0.76 (0.25; 1.27)
Lt. AP propulsion force (Normalized)	0.03 (0.03)	<0.001	1.04	0.01 (0.01)	<0.001	1.00	<0.001	0.003	0.81 (0.29; 1.32)
Lt. AP propulsion force assessment (%)	18.94 (29.15)	<0.001	0.65	6.94 (9.26)	<0.001	0.75	<0.001	0.319	0.55 (0.05; 1.05)
Rt. AP propulsion force (N)	19.69 (14.42)	<0.001	1.37	5.49 (8.16)	0.001	0.67	<0.001	<0.001	1.21 (0.67; 1.74)
Rt. AP propulsion force (Normalized)	0.03 (0.02)	<0.001	1.30	0.01 (0.01)	<0.001	0.72	<0.001	<0.001	1.05 (0.52; 1.57)
Rt. AP propulsion force assessment (%)	17.59 (24.01)	<0.001	0.73	4.03 (9.98)	0.001	0.40	<0.001	0.115	0.73 (0.22; 1.24)
AP propulsion force global score (%)	17.97 (20.02)	<0.001	0.90	5.19 (7.47)	<0.001	0.70	<0.001	0.011	0.84 (0.32; 1.35)
Vertical take-off force									
Lt. vertical take-off force (N)	29.10 (45.40)	<0.001	0.64	18.79 (63.60)	0.196	0.30	<0.001	0.072	0.19 (0.31; 0.68)
Lt. vertical take-off force (Normalized)	0.04 (0.05)	<0.001	0.78	0.02 (0.05)	0.002	0.42	<0.001	0.006	0.47 (0.04; 0.97)
Lt. vertical take-off force assessment (%)	9.72 (19.22)	<0.001	0.51	2.48 (7.97)	0.005	0.31	<0.001	0.048	0.49 (0.01; 0.99)
Rt. vertical take-off force (N)	28.42 (40.93)	<0.001	0.69	-2.15 (56.56)	0.906	0.04	0.006	0.008	0.62 (0.11; 1.12)
Rt. vertical take-off force (Normalized)	0.04 (0.05)	<0.001	0.83	0.02 (0.03)	0.001	0.55	<0.001	0.008	0.52 (0.02; 1.02)
Rt. vertical take-off force assessment (%)	5.22 (21.57)	0.017	0.24	1.35 (6.29)	0.025	0.22	0.001	0.350	0.24 (0.26; 0.74)
Vertical take-off force global score (%)	6.06 (11.76)	<0.001	0.52	1.61 (3.86)	0.002	0.42	<0.001	0.075	0.50 (0.00; 1.00)

Oscillation force									
Lt. oscillation force (N)	0.34 (50.59)	0.550	0.01	15.45 (72.96)	0.645	0.21	0.748	0.224	0.24 (0.74; 0.26)
Lt. oscillation force (Normalized)	-0.00 (0.07)	0.174	0.05	0.03 (0.10)	0.201	0.26	0.687	0.047	0.35 (0.85; 0.14)
Lt. oscillation force assessment (%)	-2.75 (29.62)	0.717	0.09	-9.16 (32.51)	0.081	0.28	0.331	0.165	0.21 (0.29; 0.70)
Rt. oscillation force (N)	1.54 (59.81)	0.466	0.03	10.00 (50.30)	0.761	0.20	0.624	0.182	0.15 (0.65; 0.34)
Rt. oscillation force (Normalized)	0.00 (0.08)	0.151	0.02	0.02 (0.07)	0.240	0.29	0.675	0.038	0.24 (0.74; 0.26)
Rt. oscillation force assessment (%)	-5.59 (27.62)	0.873	0.20	-8.19 (33.48)	0.245	0.24	0.517	0.357	0.08 (0.41; 0.58)
Oscillation force global score (%)	3.47 (7.94)	0.003	0.44	0.65 (2.07)	0.083	0.31	0.001	0.173	0.48 (0.02; 0.98)
AP force morphology (Fx Morphology)									
Lt. AP force morphology (%)	17.72 (9.52)	<0.001	1.86	12.55 (11.14)	<0.001	1.13	<0.001	0.016	0.50 (0.00; 1.00)
Rt. AP force morphology (%)	16.47 (10.89)	<0.001	1.51	6.94 (9.68)	<0.001	0.72	<0.001	<0.001	0.92 (0.40; 1.44)
AP force morphology global score (%)	17.22 (8.93)	<0.001	1.93	10.16 (5.79)	<0.001	1.75	<0.001	<0.001	0.93 (0.41; 1.45)
ML force morphology (Fy Morphology)									
Lt. ML force morphology (%)	16.19 (17.73)	<0.001	0.91	5.19 (3.51)	<0.001	1.48	<0.001	<0.001	0.85 (0.33; 1.37)
Rt. ML force morphology (%)	16.94 (16.51)	<0.001	1.03	5.16 (3.81)	<0.001	1.35	<0.001	<0.001	0.98 (0.45; 1.50)
ML force morphology global score (%)	16.50 (16.86)	<0.001	0.98	5.19 (3.50)	<0.001	1.49	<0.001	<0.001	0.92 (0.40; 1.44)
Vertical force morphology (Fz Morphology)									
Lt. vertical force morphology (%)	12.22 (12.70)	<0.001	0.96	7.45 (9.89)	<0.001	0.75	<0.001	0.065	0.42 (0.08; 0.92)
Rt. vertical force morphology (%)	11.63 (11.42)	<0.001	1.02	7.94 (7.48)	<0.001	1.06	<0.001	0.072	0.38 (0.12; 0.88)
Vertical force morphology global score (%)	11.94 (10.88)	<0.001	1.10	7.90 (7.97)	<0.001	0.99	<0.001	0.076	0.42 (0.08; 0.92)
Lt. foot global assessment (%)	12.13 (7.84)	<0.001	1.55	5.97 (3.53)	<0.001	1.69	<0.001	<0.001	1.01 (0.48; 1.53)
Rt. foot global assessment (%)	13.00 (6.61)	<0.001	1.97	5.39 (1.89)	<0.001	2.85	<0.001	<0.001	1.55 (0.98; 2.11)
Functional gait analysis global score (%)	14.69 (6.62)	<0.001	2.22	6.35 (2.30)	<0.001	2.76	<0.001	<0.001	1.67 (1.09; 2.24)

11.17 Results of changes in instrumental functional balance assessment from post-intervention to 3-month follow-up

Appendix Q: Results of changes in instrumental functional balance assessment from post-intervention to 3-month follow-up in the two groups.

Functional Balance Assessment Tests	MRP Group (n = 32)			CPT Group (n = 31)			Paired *p*-Value	Between-Group *p*-Value	Effect Size *d* (95% CI)
	Mean Change (SD)	*p* Value	Effect Size *d*	Mean Change (SD)	*p* Value	Effect Size *d*			
Static Posturography Tests									
Romberg Test with Eyes Open (ROA)									
ROA Total Displacement (mm)	0.80 (2.66)	0.161	0.30	-0.22 (2.27)	0.631	0.10	0.489	0.248	0.41 (0.09; 0.91)
ROA Displacement Angle (º)	24.95 (63.84)	0.043	0.39	-14.48 (53.71)	0.183	0.27	0.561	0.019	0.67 (0.16; 1.17)
ROA Mediolateral (ML) Dispersed X (mm)	0.04 (1.00)	0.640	0.04	0.18 (0.92)	0.260	0.20	0.304	0.731	0.14 (0.64; 0.35)
ROA Anteroposterior (AP) Dispersed Y (mm)	-0.07 (0.92)	0.918	0.08	-0.09 (0.96)	0.674	0.10	0.727	0.951	0.02 (0.47; 0.51)
ROA Average Speed (m/s)	0.00 (0.00)	0.837	0.01	-0.00 (0.00)	0.806	0.09	0.766	0.907	0.09 (0.40; 0.59)
ROA Mediolateral (ML) Displacement (mm)	0.30 (4.44)	0.765	0.07	1.02 (5.06)	0.206	0.20	0.231	0.458	0.15 (0.65; 0.34)
ROA Anteroposterior (AP) Displacement (mm)	-0.23 (4.18)	0.830	0.06	0.10 (5.29)	0.837	0.02	0.753	0.951	0.07 (0.56; 0.42)
ROA Mediolateral (ML) Maximal Force (N)	-0.30 (2.12)	0.772	0.14	0.05 (1.97)	0.695	0.03	0.984	0.559	0.17 (0.67; 0.32)
ROA Anteroposterior (AP) Maximal Force (N)	-0.05 (2.39)	0.073	0.02	-0.14 (1.44)	0.992	0.09	0.242	0.353	0.04 (0.45; 0.54)
ROA Assessment Score (%)	0.31 (1.03)	0.087	0.30	-0.03 (1.08)	0.835	0.03	0.407	0.322	0.33 (0.17; 0.82)
Romberg Test with Eyes Closed (ROC)									
ROC Total Displacement (mm)	0.74 (2.78)	0.145	0.27	0.16 (2.99)	0.829	0.05	0.220	0.372	0.20 (0.29; 0.70)
ROC Displacement Angle (º)	19.06 (79.18)	0.501	0.24	-11.19 (48.22)	0.206	0.23	0.624	0.081	0.46 (0.04; 0.96)
ROC Mediolateral (ML) Dispersed X (mm)	0.15 (2.24)	0.660	0.07	-0.22 (1.03)	0.244	0.21	0.298	0.479	0.21 (0.28; 0.71)
ROC Anteroposterior (AP) Dispersed Y (mm)	0.00 (1.17)	0.793	0.00	-0.18 (1.35)	0.487	0.14	0.476	0.700	0.15 (0.35; 0.64)
ROC Average Speed (m/s)	0.00 (0.01)	0.449	0.01	-0.00 (0.00)	0.170	0.28	0.142	0.660	0.27 (0.23; 0.76)
ROC Mediolateral (ML) Displacement (mm)	-1.28 (6.80)	0.432	0.19	-1.42 (5.72)	0.244	0.25	0.171	0.896	0.02 (0.47; 0.52)
ROC Anteroposterior (AP) Displacement (mm)	0.65 (5.91)	0.416	0.11	-1.18 (6.55)	0.624	0.18	0.837	0.353	0.29 (0.20; 0.79)
ROC Mediolateral (ML) Maximal Force (N)	-0.81 (2.11)	0.061	0.38	0.51 (2.49)	0.170	0.20	0.782	0.019	0.57 (1.07; 0.07)
ROC Anteroposterior (AP) Maximal Force (N)	-0.06 (1.92)	0.701	0.03	0.05 (2.19)	0.899	0.02	0.701	0.962	0.05 (0.55; 0.44)
ROC Assessment Score (%)	0.28 (1.02)	0.180	0.27	0.58 (1.91)	0.140	0.30	0.047	0.611	0.20 (0.69; 0.30)
Romberg Test with Eyes Open on Foam Cushion (RGA)									
RGA Total Displacement (mm)	-0.76 (4.73)	0.640	0.16	-1.49 (4.43)	0.096	0.34	0.170	0.437	0.16 (0.34; 0.65)
RGA Displacement Angle (º)	8.60 (63.57)	0.751	0.14	-5.73 (49.98)	0.264	0.11	0.646	0.433	0.25 (0.25; 0.75)
RGA Mediolateral (ML) Dispersed X (mm)	-0.40 (1.70)	0.112	0.23	-0.01 (1.71)	0.984	0.00	0.383	0.353	0.23 (0.73; 0.27)
RGA Anteroposterior (AP) Dispersed Y (mm)	-0.13 (1.43)	0.513	0.09	-0.25 (1.67)	0.327	0.15	0.228	0.700	0.08 (0.42; 0.57)
RGA Average Speed (m/s)	-0.00 (0.01)	0.519	0.23	-0.00 (0.01)	0.969	0.10	0.608	0.695	0.17 (0.66; 0.33)
RGA Mediolateral (ML) Displacement (mm)	-2.60 (8.31)	0.125	0.31	-1.09 (9.45)	0.739	0.12	0.227	0.383	0.17 (0.66; 0.33)

RGA Anteroposterior (AP) Displacement (mm)	-0.62 (7.22)	0.640	0.09	-1.34 (7.29)	0.252	0.18	0.244	0.601	0.10 (0.40; 0.59)
RGA Mediolateral (ML) Maximal Force (N)	-1.00 (3.35)	0.118	0.30	-0.89 (3.86)	0.285	0.23	0.065	0.945	0.03 (0.53; 0.46)
RGA Anteroposterior (AP) Maximal Force (N)	-0.79 (4.57)	0.888	0.17	-0.84 (3.81)	0.252	0.22	0.338	0.488	0.01 (0.48; 0.51)
RGA Assessment Score (%)	0.84 (2.00)	0.017	0.42	0.68 (2.55)	0.528	0.27	0.040	0.268	0.07 (0.42; 0.57)
Romberg Test with Eyes Closed on Foam Cushion (RGC)									
RGC Total Displacement (mm)	-0.93 (4.15)	0.153	0.22	-1.30 (5.16)	0.264	0.25	0.071	0.891	0.08 (0.42; 0.57)
RGC Displacement Angle (º)	20.09 (63.58)	0.184	0.32	0.25 (35.44)	0.875	0.01	0.295	0.402	0.38 (0.12; 0.88)
RGC Mediolateral (ML) Dispersed X (mm)	-0.49 (2.55)	0.313	0.19	0.62 (1.99)	0.088	0.31	0.730	0.074	0.49 (0.98; 0.02)
RGC Anteroposterior (AP) Dispersed Y (mm)	0.38 (2.35)	0.322	0.16	10.05 (53.11)	0.108	0.19	0.073	0.736	0.26 (0.75; 0.24)
RGC Average Speed (m/s)	-0.00 (0.01)	0.046	0.38	0.00 (0.01)	0.604	0.12	0.247	0.049	0.54 (1.04; 0.04)
RGC Mediolateral (ML) Displacement (mm)	-3.31 (10.46)	0.067	0.32	-0.10 (10.96)	0.977	0.01	0.175	0.187	0.30 (0.80; 0.20)
RGC Anteroposterior (AP) Displacement (mm)	0.07 (10.16)	0.963	0.01	-1.36 (8.34)	0.378	0.16	0.634	0.554	0.15 (0.34; 0.65)
RGC Mediolateral (ML) Maximal Force (N)	-1.30 (5.52)	0.067	0.24	-0.45 (4.95)	0.462	0.09	0.067	0.194	0.16 (0.66; 0.33)
RGC Anteroposterior (AP) Maximal Force (N)	-0.23 (7.54)	0.633	0.03	-0.91 (7.87)	0.531	0.12	0.435	0.853	0.09 (0.41; 0.58)
RGC Assessment Score (%)	1.41 (2.55)	0.003	0.55	0.45 (3.12)	0.745	0.14	0.030	0.060	0.34 (0.16; 0.83)
Romberg Test Stability Assessment									
ROA Mediolateral (ML) Stability (%)	0.31 (1.55)	0.392	0.20	0.19 (1.01)	0.898	0.19	0.480	0.736	0.09 (0.40; 0.58)
ROC Mediolateral (ML) Stability (%)	0.31 (1.00)	0.138	0.31	-0.03 (1.60)	0.664	0.02	0.180	0.864	0.26 (0.24; 0.75)
RGA Mediolateral (ML) Stability (%)	1.00 (2.46)	0.039	0.41	0.39 (2.95)	0.773	0.13	0.121	0.277	0.23 (0.27; 0.72)
RGC Mediolateral (ML) Stability (%)	2.16 (3.19)	0.001	0.68	0.00 (4.10)	0.953	0.00	0.020	0.019	0.59 (0.08; 1.09)
Romberg Test ML Stability Assessment (%)	0.81 (1.20)	0.000	0.68	0.13 (1.31)	0.808	0.10	0.009	0.031	0.54 (0.04; 1.04)
ROA Anteroposterior (AP) Stability (%)	0.09 (1.51)	0.200	0.06	0.00 (0.52)	0.689	0.00	0.527	0.450	0.08 (0.41; 0.58)
ROC Anteroposterior (AP) Stability (%)	0.03 (1.06)	0.504	0.03	-0.13 (1.18)	0.291	0.11	0.212	0.630	0.14 (0.35; 0.64)
RGA Anteroposterior (AP) Stability (%)	0.50 (2.05)	0.083	0.24	0.16 (1.24)	0.739	0.13	0.235	0.700	0.20 (0.30; 0.69)
RGC Anteroposterior (AP) Stability (%)	0.31 (2.73)	0.597	0.11	0.45 (2.39)	0.467	0.19	0.388	0.874	0.05 (0.55; 0.44)
Romberg Test AP Stability Assessment (%)	0.16 (0.92)	0.669	0.17	0.16 (0.82)	0.376	0.20	0.337	0.747	0.01 (0.50; 0.49)
Somatosensory Index (%)	0.28 (0.73)	0.050	0.39	0.58 (1.52)	0.086	0.38	0.012	0.736	0.25 (0.75; 0.24)
Visual Index (%)	0.50 (1.41)	0.035	0.35	0.32 (1.38)	0.385	0.23	0.043	0.536	0.13 (0.37; 0.62)
Vestibular Index (%)	1.19 (2.40)	0.012	0.49	0.10 (2.41)	0.952	0.04	0.104	0.054	0.45 (0.05; 0.95)
Dynamic Index (%)	1.16 (1.05)	0.000	1.10	1.13 (1.88)	0.002	0.60	<0.001	0.940	0.02 (0.48; 0.51)
Sensory-Dynamic Total Score (%)	0.81 (0.86)	0.000	0.95	0.58 (1.39)	0.035	0.42	<0.001	0.429	0.20 (0.29; 0.70)
Postural Control Assessment									
Limits of Stability (LOS) Analysis									
Forward (F) Maximum Displacement (%)	2.00 (12.21)	0.722	0.16	-3.48 (15.67)	0.086	0.22	0.299	0.182	0.39 (0.11; 0.89)
Forward (F) Directional Control (%)	-2.50 (10.76)	0.071	0.23	1.35 (9.01)	0.992	0.15	0.199	0.149	0.39 (0.88; 0.11)

Forward (F) Reaction Time (s)	-0.18 (0.46)	0.059	0.38	0.03 (0.66)	0.332	0.04	0.542	0.041	0.36 (0.85; 0.14)
Forward (F) Assessment Score (%)	-0.34 (2.99)	0.208	0.11	0.16 (3.87)	0.515	0.04	0.715	0.226	0.15 (0.64; 0.35)
Right-Forward (RF) Maximum Displacement (%)	-0.47 (8.56)	0.948	0.05	2.06 (9.45)	0.312	0.22	0.535	0.375	0.28 (0.78; 0.22)
Right-Forward (RF) Directional Control (%)	6.75 (15.18)	0.041	0.44	-1.42 (14.17)	0.754	0.10	0.102	0.165	0.56 (0.05; 1.06)
Right-Forward (RF) Reaction Time (s)	-0.06 (0.56)	0.355	0.10	-0.07 (0.66)	0.456	0.11	0.239	0.805	0.02 (0.47; 0.52)
Right-Forward (RF) Assessment Score (%)	2.81 (3.85)	0.000	0.73	0.81 (6.12)	0.415	0.13	0.003	0.125	0.39 (0.11; 0.89)
Right (R) Maximum Displacement (%)	1.81 (10.55)	0.303	0.17	-0.13 (13.03)	0.992	0.01	0.470	0.492	0.16 (0.33; 0.66)
Right (R) Directional Control (%)	0.47 (12.19)	0.822	0.04	1.00 (9.78)	0.659	0.10	0.584	0.945	0.05 (0.54; 0.45)
Right (R) Reaction Time (s)	-0.05 (0.58)	0.701	0.09	-0.08 (0.71)	0.158	0.12	0.211	0.509	0.05 (0.45; 0.54)
Right (R) Assessment Score (%)	1.41 (3.62)	0.047	0.39	0.97 (7.27)	0.421	0.13	0.054	0.606	0.08 (0.42; 0.57)
Right-Backward (RB) Maximum Displacement (%)	-0.84 (12.01)	0.594	0.07	-0.26 (6.38)	0.867	0.04	0.691	0.645	0.06 (0.55; 0.43)
Right-Backward (RB) Directional Control (%)	3.88 (10.25)	0.149	0.38	0.77 (10.67)	0.868	0.07	0.358	0.248	0.30 (0.20; 0.79)
Right-Backward (RB) Reaction Time (s)	0.06 (0.39)	0.345	0.16	-0.05 (0.65)	0.791	0.08	0.386	0.700	0.22 (0.28; 0.71)
Right-Backward (RB) Assessment Score (%)	0.72 (3.08)	0.208	0.23	0.42 (4.19)	0.679	0.10	0.244	0.592	0.08 (0.41; 0.58)
Backward (B) Maximum Displacement (%)	7.03 (20.18)	0.083	0.35	3.97 (12.49)	0.084	0.32	0.015	0.747	0.18 (0.31; 0.68)
Backward (B) Directional Control (%)	0.03 (8.58)	0.963	0.00	-1.45 (10.27)	0.336	0.14	0.478	0.409	0.16 (0.34; 0.65)
Backward (B) Reaction Time (s)	0.05 (0.41)	0.660	0.13	-0.06 (0.46)	0.666	0.12	0.981	0.582	0.25 (0.24; 0.75)
Backward (B) Assessment Score (%)	0.13 (2.12)	0.724	0.06	-0.10 (2.86)	0.534	0.03	0.739	0.364	0.09 (0.41; 0.58)
Left-Backward (LB) Maximum Displacement (%)	2.09 (11.34)	0.454	0.18	1.06 (10.66)	0.717	0.10	0.419	0.690	0.09 (0.40; 0.59)
Left-Backward (LB) Directional Control (%)	1.66 (14.58)	0.933	0.11	-1.55 (13.73)	0.953	0.11	0.816	0.923	0.23 (0.27; 0.72)
Left-Backward (LB) Reaction Time (s)	0.01 (0.46)	0.985	0.02	0.04 (0.57)	0.474	0.06	0.624	0.864	0.05 (0.55; 0.44)
Left-Backward (LB) Assessment Score (%)	1.34 (6.20)	0.821	0.22	-0.32 (3.59)	0.581	0.09	0.915	0.280	0.33 (0.17; 0.82)
Left (L) Maximum Displacement (%)	-1.00 (10.14)	0.866	0.10	-1.06 (7.87)	0.480	0.14	0.540	0.660	0.01 (0.49; 0.50)
Left (L) Directional Control (%)	0.16 (10.23)	0.729	0.02	0.45 (11.85)	0.739	0.04	0.962	0.716	0.03 (0.52; 0.47)
Left (L) Reaction Time (s)	-0.15 (0.45)	0.059	0.34	-0.00 (0.48)	0.930	0.01	0.256	0.201	0.32 (0.82; 0.18)
Left (L) Assessment Score (%)	0.34 (3.57)	0.592	0.10	1.39 (5.41)	0.239	0.26	0.219	0.559	0.23 (0.72; 0.27)
Left-Forward (LF) Maximum Displacement (%)	-0.75 (8.06)	0.918	0.09	1.03 (8.32)	0.383	0.12	0.528	0.390	0.22 (0.71; 0.28)
Left-Forward (LF) Directional Control (%)	5.50 (13.46)	0.022	0.41	-2.39 (10.39)	0.263	0.23	0.312	0.014	0.65 (0.14; 1.16)
Left-Forward (LF) Reaction Time (s)	0.09 (0.50)	0.449	0.18	-0.04 (0.46)	0.518	0.09	0.894	0.429	0.27 (0.23; 0.77)
Left-Forward (LF) Assessment Score (%)	1.06 (3.93)	0.195	0.27	1.19 (5.00)	0.231	0.24	0.081	0.762	0.03 (0.52; 0.46)
Average Score of Maximum Displacement (%)	1.22 (3.75)	0.073	0.33	0.77 (3.78)	0.315	0.20	0.053	0.582	0.12 (0.38; 0.61)
Average Score of Directional Control (%)	2.00 (4.33)	0.016	0.46	-0.29 (3.28)	0.256	0.09	0.212	0.014	0.60 (0.09; 1.10)
Average Score of Reaction Time (s)	-0.02 (0.19)	0.432	0.11	-0.03 (0.19)	0.450	0.16	0.333	0.837	0.04 (0.45; 0.54)
Limits of Stability (LOS) Analysis Score (%)	0.81 (1.60)	0.011	0.51	0.45 (1.36)	0.073	0.33	0.002	0.626	0.24 (0.25; 0.74)

Rhythmic and Directional Control Assessment									
Mediolateral (ML) Ability (%)	0.22 (1.62)	0.375	0.13	0.45 (3.15)	0.400	0.14	0.240	0.655	0.09 (0.59; 0.40)
Mediolateral (ML) Control and Efficacy (%)	0.69 (2.62)	0.400	0.26	0.58 (6.40)	0.662	0.09	0.875	0.445	0.02 (0.47; 0.52)
ML Rhythmic and Directional Control Assessment (%)	0.38 (1.18)	0.130	0.32	0.58 (2.62)	0.647	0.22	0.245	0.559	0.10 (0.60; 0.39)
Anteroposterior (AP) Ability (%)	0.09 (0.93)	0.589	0.10	0.16 (1.00)	0.622	0.16	0.948	0.710	0.07 (0.56; 0.42)
Anteroposterior (AP) Control and Efficacy (%)	-0.13 (4.58)	0.699	0.03	0.29 (5.34)	1,000	0.05	0.786	0.902	0.08 (0.58; 0.41)
AP Rhythmic and Directional Control Assessment (%)	0.00 (1.59)	0.840	0.00	0.13 (1.98)	0.797	0.07	0.953	0.934	0.07 (0.57; 0.42)
Postural Control Assessment (Total Score) (%)	0.44 (1.13)	0.052	0.39	0.00 (1.21)	0.885	0.00	0.236	0.199	0.37 (0.13; 0.87)
Functional Balance Assessment - Global Score (%)	0.66 (0.87)	0.000	0.76	0.26 (1.00)	0.194	0.26	0.001	0.182	0.43 (0.07; 0.92)

11.18 Results of changes in instrumental functional gait analysis from post-intervention to 3-month follow-up

Appendix R: Results of changes in instrumental functional gait analysis from post-intervention to 3-month follow-up in the two groups.

Functional Gait Analysis Parameters	MRP Group (n = 32)			CPT Group (n = 31)			Paired *p*-Value	Between-Group *p*-Value	Effect Size *d* (95% CI)
	Mean Change (SD)	*p* Value	Effect Size *d*	Mean Change (SD)	*p* Value	Effect Size *d*			
Gait speed (m/s)	0.02 (0.03)	0.000	0.80	0.01 (0.03)	0.021	0.47	<0.001	0.240	0.38 (0.12; 0.88)
Average gait speed (%)	0.38 (1.07)	0.081	0.35	1.16 (3.31)	0.112	0.35	0.027	0.559	0.32 (0.82; 0.18)
Lt. foot support time (s)	-0.02 (0.03)	0.001	0.65	-0.01 (0.04)	0.066	0.19	<0.001	0.201	0.30 (0.79; 0.20)
Rt. foot support time (s)	-0.02 (0.03)	0.003	0.50	-0.01 (0.04)	0.039	0.20	<0.001	0.413	0.18 (0.68; 0.31)
Difference in support time (%)	2.41 (2.67)	0.000	0.90	1.90 (3.67)	0.013	0.52	<0.001	0.815	0.16 (0.34; 0.65)
Anteroposterior braking force									
Lt. AP braking force (N)	1.98 (9.54)	0.299	0.21	0.62 (9.62)	0.624	0.06	0.264	0.582	0.14 (0.35; 0.64)
Lt. AP braking force (Normalized)	0.00 (0.01)	0.309	0.22	0.00 (0.01)	0.286	0.25	0.129	0.789	0.03 (0.52; 0.46)
Lt. AP braking force assessment (%)	-0.63 (6.37)	0.899	0.10	-0.03 (21.27)	0.801	0.00	0.803	0.983	0.04 (0.53; 0.46)
Rt. AP braking force (N)	1.22 (9.90)	0.620	0.12	2.83 (9.32)	0.083	0.30	0.105	0.350	0.17 (0.66; 0.33)
Rt. AP braking force (Normalized)	0.00 (0.01)	0.236	0.22	0.00 (0.01)	0.239	0.24	0.093	0.874	0.08 (0.57; 0.41)
Rt. AP braking force assessment (%)	3.31 (8.18)	0.003	0.40	0.23 (24.49)	0.484	0.01	0.020	0.390	0.17 (0.33; 0.66)
AP braking force global score (%)	0.69 (1.77)	0.096	0.39	1.10 (5.48)	0.322	0.20	0.069	0.940	0.10 (0.60; 0.39)
Anteroposterior propulsion force									
Lt. AP propulsion force (N)	3.38 (12.14)	0.150	0.28	3.40 (9.14)	0.020	0.37	0.010	0.685	0.00 (0.50; 0.49)
Lt. AP propulsion force (Normalized)	0.00 (0.02)	0.209	0.29	0.00 (0.01)	0.029	0.31	0.018	0.831	0.01 (0.48; 0.50)
Lt. AP propulsion force assessment (%)	0.25 (3.90)	0.193	0.06	5.16 (11.30)	0.036	0.46	0.016	0.290	0.58 (1.09; 0.08)
Rt. AP propulsion force (N)	1.24 (10.32)	0.852	0.12	1.75 (8.77)	0.610	0.20	0.632	0.645	0.05 (0.55; 0.44)
Rt. AP propulsion force (Normalized)	0.00 (0.01)	0.627	0.13	0.00 (0.02)	0.849	0.14	0.625	0.929	0.05 (0.54; 0.44)
Rt. AP propulsion force assessment (%)	0.06 (5.18)	0.975	0.01	1.84 (14.32)	0.759	0.13	0.751	0.710	0.17 (0.66; 0.33)
AP propulsion force global score (%)	0.84 (2.27)	0.037	0.37	1.52 (5.30)	0.319	0.29	0.051	0.731	0.17 (0.66; 0.33)
Vertical take-off force									
Lt. vertical take-off force (N)	-5.14 (24.05)	0.161	0.21	-11.21 (54.14)	0.570	0.21	0.127	0.559	0.15 (0.35; 0.64)
Lt. vertical take-off force (Normalized)	-0.00 (0.02)	0.697	0.02	-0.00 (0.02)	0.281	0.13	0.289	0.810	0.11 (0.38; 0.61)
Lt. vertical take-off force assessment (%)	-2.81 (9.43)	0.154	0.30	-1.03 (8.55)	0.270	0.12	0.078	0.721	0.20 (0.69; 0.30)
Rt. vertical take-off force (N)	-6.98 (25.82)	0.116	0.27	-0.32 (20.14)	0.906	0.02	0.212	0.224	0.29 (0.78; 0.21)
Rt. vertical take-off force (Normalized)	-0.00 (0.02)	0.396	0.16	-0.00 (0.02)	0.395	0.19	0.187	0.885	0.06 (0.43; 0.55)
Rt. vertical take-off force assessment (%)	-1.13 (4.29)	0.090	0.26	-1.39 (4.72)	0.092	0.29	0.017	0.896	0.06 (0.44; 0.55)
Vertical take-off force global score (%)	-0.19 (1.23)	0.658	0.15	-0.23 (1.78)	0.071	0.13	0.114	0.462	0.03 (0.47; 0.52)

Oscillation force									
Lt. oscillation force (N)	-5.58 (33.95)	0.400	0.16	0.03 (18.56)	0.852	0.00	0.554	0.564	0.20 (0.70; 0.29)
Lt. oscillation force (Normalized)	0.00 (0.03)	0.865	0.10	-0.01 (0.02)	0.077	0.29	0.302	0.203	0.32 (0.18; 0.81)
Lt. oscillation force assessment (%)	-0.22 (3.87)	0.967	0.06	0.97 (14.55)	0.245	0.07	0.329	0.398	0.11 (0.61; 0.38)
Rt. oscillation force (N)	-5.34 (24.53)	0.562	0.22	7.82 (20.96)	0.050	0.37	0.363	0.105	0.58 (1.08; 0.07)
Rt. oscillation force (Normalized)	0.00 (0.03)	0.880	0.02	0.01 (0.03)	0.553	0.25	0.730	0.762	0.25 (0.74; 0.25)
Rt. oscillation force assessment (%)	-0.38 (13.64)	0.555	0.03	-2.77 (20.28)	0.800	0.14	0.560	0.831	0.14 (0.36; 0.63)
Oscillation force global score (%)	0.63 (3.02)	0.171	0.21	0.06 (1.00)	0.973	0.06	0.302	0.559	0.25 (0.25; 0.74)
AP force morphology (Fx Morphology)									
Lt. AP force morphology (%)	3.09 (4.23)	0.001	0.73	0.97 (4.53)	0.382	0.21	0.002	0.053	0.49 (0.02; 0.98)
Rt. AP force morphology (%)	2.00 (3.80)	0.012	0.53	3.74 (8.49)	0.033	0.44	0.001	0.705	0.27 (0.76; 0.23)
AP force morphology global score (%)	2.38 (2.98)	0.000	0.80	3.65 (6.26)	0.003	0.58	<0.001	0.747	0.26 (0.76; 0.24)
ML force morphology (Fy Morphology)									
Lt. ML force morphology (%)	3.25 (4.83)	0.001	0.67	0.10 (5.92)	0.528	0.02	0.028	0.003	0.58 (0.08; 1.09)
Rt. ML force morphology (%)	2.66 (4.48)	0.001	0.59	1.87 (8.04)	0.730	0.23	0.009	0.034	0.12 (0.37; 0.62)
ML force morphology global score (%)	3.03 (3.95)	0.000	0.77	0.48 (5.77)	0.314	0.08	0.017	<0.001	0.52 (0.01; 1.02)
Vertical force morphology (Fz Morphology)									
Lt. vertical force morphology (%)	1.38 (3.69)	0.038	0.37	0.74 (3.31)	0.332	0.22	0.029	0.386	0.18 (0.32; 0.67)
Rt. vertical force morphology (%)	1.03 (4.04)	0.351	0.26	1.81 (4.92)	0.087	0.37	0.053	0.479	0.17 (0.67; 0.32)
Vertical force morphology global score (%)	1.28 (3.53)	0.087	0.36	1.03 (3.49)	0.135	0.30	0.022	0.973	0.07 (0.42; 0.56)
Lt. foot global assessment (%)	1.06 (1.08)	0.000	0.99	0.39 (2.09)	0.696	0.18	0.001	0.009	0.41 (0.09; 0.91)
Rt. foot global assessment (%)	1.16 (1.11)	0.000	1.04	1.10 (1.96)	0.004	0.56	<0.001	0.665	0.04 (0.46; 0.53)
Functional gait analysis global score (%)	1.16 (0.95)	0.000	1.21	0.94 (1.73)	0.006	0.54	<0.001	0.336	0.16 (0.34; 0.65)

11.19 Results of changes in instrumental functional balance assessment from baseline to 3-month follow-up

Appendix S: Results of changes in instrumental functional balance assessment from baseline to 3-month follow-up in the two groups.

Functional Balance Assessment Tests	MRP Group (n = 32)			CPT Group (n = 31)			Paired *p*-Value	Between-Group *p*-Value	Effect Size *d* (95% CI)
	Mean Change (SD)	*p* Value	Effect Size *d*	Mean Change (SD)	*p* Value	Effect Size *d*			
Static Posturography Tests									
Romberg Test with Eyes Open (ROA)									
ROA Total Displacement (mm)	-4.85 (3.84)	<0.001	1.26	-1.57 (3.20)	0.014	0.49	<0.001	0.001	0.93 (1.45; 0.40)
ROA Displacement Angle (º)	-87.08 (71.69)	<0.001	1.21	-28.79 (62.92)	0.016	0.46	<0.001	0.003	0.86 (1.38; 0.34)
ROA Mediolateral (ML) Dispersed X (mm)	-0.83 (1.13)	0.001	0.73	-0.50 (0.92)	0.004	0.55	<0.001	0.421	0.31 (0.81; 0.18)
ROA Anteroposterior (AP) Dispersed Y (mm)	-1.82 (2.41)	<0.001	0.76	-1.12 (1.96)	0.008	0.57	<0.001	0.208	0.32 (0.82; 0.18)
ROA Average Speed (m/s)	-0.00 (0.00)	<0.001	1.04	-0.00 (0.00)	0.008	0.53	<0.001	0.019	0.62 (1.13; 0.11)
ROA Mediolateral (ML) Displacement (mm)	-6.00 (8.46)	<0.001	0.71	-2.83 (5.50)	0.008	0.51	<0.001	0.151	0.44 (0.94; 0.06)
ROA Anteroposterior (AP) Displacement (mm)	-9.50 (11.70)	<0.001	0.81	-5.29 (9.01)	0.004	0.59	<0.001	0.125	0.40 (0.90; 0.10)
ROA Mediolateral (ML) Maximal Force (N)	-3.58 (5.14)	<0.001	0.70	-1.71 (3.21)	0.015	0.53	<0.001	0.206	0.43 (0.93; 0.07)
ROA Anteroposterior (AP) Maximal Force (N)	-1.73 (2.89)	0.001	0.60	-0.78 (2.09)	0.063	0.37	<0.001	0.161	0.37 (0.87; 0.13)
ROA Assessment Score (%)	3.00 (3.60)	<0.001	0.83	2.23 (2.93)	<0.001	0.76	<0.001	0.564	0.24 (0.26; 0.73)
Romberg Test with Eyes Closed (ROC)									
ROC Total Displacement (mm)	-5.86 (5.52)	<0.001	1.06	-0.90 (2.95)	0.088	0.30	<0.001	<0.001	1.12 (1.64; 0.58)
ROC Displacement Angle (º)	-108.30 (83.81)	<0.001	1.29	-32.62 (56.72)	0.005	0.58	<0.001	0.001	1.05 (1.58; 0.52)
ROC Mediolateral (ML) Dispersed X (mm)	-1.53 (2.84)	<0.001	0.54	-1.02 (1.55)	0.002	0.66	<0.001	0.171	0.22 (0.72; 0.27)
ROC Anteroposterior (AP) Dispersed Y (mm)	-2.02 (2.49)	<0.001	0.81	-0.85 (1.68)	0.012	0.51	<0.001	0.045	0.55 (1.05; 0.04)
ROC Average Speed (m/s)	-0.01 (0.01)	<0.001	0.81	-0.00 (0.01)	<0.001	0.66	<0.001	0.060	0.38 (0.88; 0.12)
ROC Mediolateral (ML) Displacement (mm)	-9.86 (9.88)	<0.001	1.00	-6.21 (7.11)	<0.001	0.87	<0.001	0.138	0.42 (0.92; 0.08)
ROC Anteroposterior (AP) Displacement (mm)	-11.89 (12.76)	<0.001	0.93	-5.44 (10.66)	0.004	0.51	<0.001	0.059	0.55 (1.05; 0.04)
ROC Mediolateral (ML) Maximal Force (N)	-4.03 (3.93)	<0.001	1.03	-1.77 (4.06)	0.014	0.44	<0.001	0.027	0.56 (1.07; 0.06)
ROC Anteroposterior (AP) Maximal Force (N)	-3.08 (4.12)	<0.001	0.75	-1.97 (3.18)	0.001	0.62	<0.001	0.361	0.30 (0.80; 0.20)
ROC Assessment Score (%)	5.41 (4.71)	<0.001	1.15	3.26 (3.45)	<0.001	0.94	<0.001	0.093	0.52 (0.01; 1.02)
Romberg Test with Eyes Open on Foam Cushion (RGA)									
RGA Total Displacement (mm)	-8.70 (6.83)	<0.001	1.27	-3.20 (5.51)	0.005	0.58	<0.001	0.001	0.89 (1.40; 0.36)
RGA Displacement Angle (º)	-94.93 (69.21)	<0.001	1.37	-30.69 (51.65)	0.002	0.59	<0.001	<0.001	1.05 (1.57; 0.52)
RGA Mediolateral (ML) Dispersed X (mm)	-1.96 (1.95)	<0.001	1.00	-0.97 (1.79)	0.002	0.54	<0.001	0.038	0.53 (1.03; 0.02)
RGA Anteroposterior (AP) Dispersed Y (mm)	-2.93 (2.26)	<0.001	1.29	-0.99 (2.17)	0.012	0.46	<0.001	0.003	0.87 (1.39; 0.35)
RGA Average Speed (m/s)	-0.01 (0.01)	<0.001	0.87	-0.00 (0.01)	0.004	0.58	<0.001	0.011	0.68 (1.19; 0.17)
RGA Mediolateral (ML) Displacement (mm)	-10.50 (7.82)	<0.001	1.34	-6.75 (10.79)	0.001	0.63	<0.001	0.076	0.40 (0.90; 0.10)

RGA Anteroposterior (AP) Displacement (mm)	-14.75 (10.92)	<0.001	1.35	-6.46 (9.43)	0.001	0.69	<0.001	0.003	0.81 (1.32; 0.29)
RGA Mediolateral (ML) Maximal Force (N)	-5.17 (3.87)	<0.001	1.34	-2.85 (4.39)	0.002	0.65	<0.001	0.052	0.56 (1.06; 0.06)
RGA Anteroposterior (AP) Maximal Force (N)	-3.65 (5.66)	0.001	0.65	-1.32 (3.80)	0.040	0.35	<0.001	0.201	0.48 (0.98; 0.02)
RGA Assessment Score (%)	6.25 (4.98)	<0.001	1.25	4.03 (3.36)	<0.001	1.20	<0.001	0.080	0.52 (0.02; 1.02)
Romberg Test with Eyes Closed on Foam Cushion (RGC)									
RGC Total Displacement (mm)	-13.75 (10.60)	<0.001	1.30	-2.62 (4.27)	0.004	0.61	<0.001	<0.001	1.37 (1.92; 0.82)
RGC Displacement Angle (º)	-83.62 (62.17)	<0.001	1.35	-28.49 (46.66)	0.001	0.61	<0.001	<0.001	1.00 (1.52; 0.47)
RGC Mediolateral (ML) Dispersed X (mm)	-5.72 (4.95)	<0.001	1.16	-2.31 (3.41)	0.002	0.68	<0.001	0.006	0.80 (1.31; 0.28)
RGC Anteroposterior (AP) Dispersed Y (mm)	-3.87 (4.54)	<0.001	0.85	8.69 (53.76)	0.102	0.16	<0.001	0.004	0.33 (0.83; 0.17)
RGC Average Speed (m/s)	-0.02 (0.02)	<0.001	1.39	-0.01 (0.01)	0.002	0.61	<0.001	<0.001	1.23 (1.77; 0.69)
RGC Mediolateral (ML) Displacement (mm)	-28.17 (17.56)	<0.001	1.60	-9.53 (10.30)	<0.001	0.92	<0.001	<0.001	1.29 (1.83; 0.74)
RGC Anteroposterior (AP) Displacement (mm)	-14.83 (15.25)	<0.001	0.97	-4.44 (8.79)	0.011	0.51	<0.001	0.009	0.83 (1.34; 0.31)
RGC Mediolateral (ML) Maximal Force (N)	-9.18 (9.75)	<0.001	0.94	-3.18 (8.20)	0.044	0.39	<0.001	0.003	0.66 (1.17; 0.15)
RGC Anteroposterior (AP) Maximal Force (N)	-9.34 (9.88)	<0.001	0.95	-3.68 (7.72)	0.011	0.48	<0.001	0.014	0.64 (1.14; 0.13)
RGC Assessment Score (%)	15.72 (6.49)	<0.001	2.42	5.97 (4.13)	<0.001	1.45	<0.001	<0.001	1.79 (1.19; 2.37)
Romberg Test Stability Assessment									
ROA Mediolateral (ML) Stability (%)	2.28 (3.99)	<0.001	0.57	1.10 (1.94)	<0.001	0.57	<0.001	0.545	0.38 (0.12; 0.87)
ROC Mediolateral (ML) Stability (%)	3.41 (3.52)	<0.001	0.97	1.84 (3.77)	0.003	0.49	<0.001	0.087	0.43 (0.07; 0.93)
RGA Mediolateral (ML) Stability (%)	5.03 (4.74)	<0.001	1.06	2.94 (3.11)	<0.001	0.94	<0.001	0.129	0.52 (0.02; 1.02)
RGC Mediolateral (ML) Stability (%)	13.63 (7.35)	<0.001	1.85	5.26 (7.69)	<0.001	0.68	<0.001	<0.001	1.11 (0.58; 1.64)
Romberg Test ML Stability Assessment (%)	6.22 (3.09)	<0.001	2.01	2.71 (2.52)	<0.001	1.08	<0.001	<0.001	1.24 (0.70; 1.78)
ROA Anteroposterior (AP) Stability (%)	1.13 (2.24)	0.002	0.50	0.74 (1.53)	0.002	0.49	<0.001	0.710	0.20 (0.30; 0.69)
ROC Anteroposterior (AP) Stability (%)	2.31 (3.97)	<0.001	0.58	1.26 (2.16)	0.002	0.58	<0.001	0.545	0.33 (0.17; 0.82)
RGA Anteroposterior (AP) Stability (%)	1.97 (4.37)	0.003	0.45	1.45 (2.64)	0.002	0.55	<0.001	0.757	0.14 (0.35; 0.64)
RGC Anteroposterior (AP) Stability (%)	8.50 (8.41)	<0.001	1.01	3.87 (5.05)	<0.001	0.77	<0.001	0.046	0.66 (0.15; 1.17)
Romberg Test AP Stability Assessment (%)	3.88 (3.92)	<0.001	0.99	1.97 (2.18)	<0.001	0.90	<0.001	0.083	0.60 (0.09; 1.10)
Somatosensory Index (%)	5.53 (4.34)	<0.001	1.27	3.16 (2.52)	<0.001	1.26	<0.001	0.048	0.67 (0.15; 1.17)
Visual Index (%)	3.38 (3.38)	<0.001	1.00	2.90 (2.66)	<0.001	1.09	<0.001	0.826	0.15 (0.34; 0.65)
Vestibular Index (%)	16.00 (7.12)	<0.001	2.25	5.29 (3.78)	<0.001	1.40	<0.001	<0.001	1.87 (1.27; 2.46)
Dynamic Index (%)	14.84 (7.10)	<0.001	2.09	7.10 (3.60)	<0.001	1.97	<0.001	<0.001	1.37 (0.81; 1.91)
Sensory-Dynamic Total Score (%)	9.53 (2.86)	<0.001	3.33	4.48 (1.84)	<0.001	2.43	<0.001	<0.001	2.09 (1.47; 2.70)
Postural Control Assessment									
Limits of Stability (LOS) Analysis									
Forward (F) Maximum Displacement (%)	22.09 (20.89)	<0.001	1.06	13.97 (14.72)	<0.001	0.95	<0.001	0.153	0.45 (0.05; 0.95)
Forward (F) Directional Control (%)	10.09 (16.90)	0.002	0.60	12.52 (11.79)	<0.001	1.06	<0.001	0.783	0.17 (0.66; 0.33)

Forward (F) Reaction Time (s)	-0.66 (0.76)	<0.001	0.88	-0.29 (0.65)	0.007	0.45	<0.001	0.007	0.53 (1.03; 0.03)
Forward (F) Assessment Score (%)	14.22 (11.06)	<0.001	1.29	9.29 (5.75)	<0.001	1.62	<0.001	0.139	0.56 (0.05; 1.06)
Right-Forward (RF) Maximum Displacement (%)	18.63 (15.86)	<0.001	1.17	13.55 (12.80)	<0.001	1.06	<0.001	0.203	0.35 (0.15; 0.85)
Right-Forward (RF) Directional Control (%)	23.91 (21.77)	<0.001	1.10	10.55 (14.84)	<0.001	0.71	<0.001	0.004	0.71 (0.20; 1.22)
Right-Forward (RF) Reaction Time (s)	-0.39 (0.60)	0.002	0.65	-0.24 (0.57)	0.026	0.41	<0.001	0.284	0.26 (0.76; 0.24)
Right-Forward (RF) Assessment Score (%)	19.00 (9.86)	<0.001	1.93	10.74 (9.16)	<0.001	1.17	<0.001	0.002	0.87 (0.35; 1.38)
Right (R) Maximum Displacement (%)	18.50 (21.43)	<0.001	0.86	10.32 (10.71)	<0.001	0.96	<0.001	0.043	0.48 (0.02; 0.98)
Right (R) Directional Control (%)	18.34 (22.67)	<0.001	0.81	9.48 (13.83)	<0.001	0.69	<0.001	0.091	0.47 (0.03; 0.97)
Right (R) Reaction Time (s)	-0.53 (0.66)	<0.001	0.81	-0.25 (0.68)	0.029	0.37	<0.001	0.216	0.43 (0.93; 0.07)
Right (R) Assessment Score (%)	16.44 (11.72)	<0.001	1.40	7.48 (7.23)	<0.001	1.03	<0.001	0.001	0.92 (0.39; 1.43)
Right-Backward (RB) Maximum Displacement (%)	13.91 (25.90)	<0.001	0.54	9.13 (10.42)	<0.001	0.88	<0.001	0.132	0.24 (0.26; 0.74)
Right-Backward (RB) Directional Control (%)	19.28 (14.60)	<0.001	1.32	8.58 (14.47)	0.003	0.59	<0.001	0.009	0.74 (0.22; 1.24)
Right-Backward (RB) Reaction Time (s)	-0.46 (0.65)	<0.001	0.71	-0.15 (0.50)	0.186	0.30	<0.001	0.014	0.54 (1.04; 0.04)
Right-Backward (RB) Assessment Score (%)	12.03 (11.52)	<0.001	1.04	5.16 (4.97)	<0.001	1.04	<0.001	0.010	0.77 (0.25; 1.28)
Backward (B) Maximum Displacement (%)	18.06 (21.16)	<0.001	0.85	17.58 (20.14)	<0.001	0.87	<0.001	0.685	0.02 (0.47; 0.52)
Backward (B) Directional Control (%)	19.84 (18.33)	<0.001	1.08	6.71 (12.83)	0.004	0.52	<0.001	0.003	0.83 (0.31; 1.34)
Backward (B) Reaction Time (s)	-0.13 (0.65)	0.194	0.19	-0.32 (0.48)	0.001	0.67	0.002	0.280	0.34 (0.16; 0.84)
Backward (B) Assessment Score (%)	7.75 (10.22)	<0.001	0.76	3.55 (4.65)	<0.001	0.76	<0.001	0.055	0.53 (0.02; 1.03)
Left-Backward (LB) Maximum Displacement (%)	19.19 (17.91)	<0.001	1.07	9.19 (14.35)	0.001	0.64	<0.001	0.039	0.61 (0.11; 1.12)
Left-Backward (LB) Directional Control (%)	19.59 (18.85)	<0.001	1.04	9.42 (13.07)	<0.001	0.72	<0.001	0.009	0.63 (0.12; 1.13)
Left-Backward (LB) Reaction Time (s)	-0.34 (0.55)	0.003	0.62	-0.23 (0.51)	0.025	0.45	<0.001	0.454	0.20 (0.69; 0.30)
Left-Backward (LB) Assessment Score (%)	12.94 (12.69)	<0.001	1.02	5.94 (6.32)	<0.001	0.94	<0.001	0.012	0.69 (0.18; 1.20)
Left (L) Maximum Displacement (%)	17.34 (18.81)	<0.001	0.92	11.42 (12.74)	<0.001	0.90	<0.001	0.117	0.37 (0.13; 0.86)
Left (L) Directional Control (%)	17.81 (15.28)	<0.001	1.17	11.65 (11.57)	<0.001	1.01	<0.001	0.044	0.45 (0.05; 0.95)
Left (L) Reaction Time (s)	-0.65 (0.67)	<0.001	0.97	-0.15 (0.51)	0.098	0.29	<0.001	0.004	0.84 (1.36; 0.32)
Left (L) Assessment Score (%)	14.28 (13.74)	<0.001	1.04	8.97 (8.31)	<0.001	1.08	<0.001	0.064	0.47 (0.04; 0.97)
Left-Forward (LF) Maximum Displacement (%)	19.81 (14.70)	<0.001	1.35	12.45 (9.92)	<0.001	1.25	<0.001	0.031	0.59 (0.08; 1.09)
Left-Forward (LF) Directional Control (%)	24.38 (17.42)	<0.001	1.40	11.23 (13.62)	<0.001	0.82	<0.001	0.002	0.84 (0.32; 1.35)
Left-Forward (LF) Reaction Time (s)	-0.21 (0.59)	0.064	0.36	-0.39 (0.61)	0.003	0.63	<0.001	0.383	0.29 (0.21; 0.79)
Left-Forward (LF) Assessment Score (%)	18.50 (11.59)	<0.001	1.60	9.68 (7.67)	<0.001	1.26	<0.001	0.003	0.90 (0.37; 1.41)
Average Score of Maximum Displacement (%)	18.78 (10.71)	<0.001	1.75	11.90 (5.78)	<0.001	2.06	<0.001	0.001	0.80 (0.28; 1.31)
Average Score of Directional Control (%)	18.69 (7.40)	<0.001	2.52	9.61 (5.54)	<0.001	1.74	<0.001	<0.001	1.39 (0.83; 1.93)
Average Score of Reaction Time (s)	-0.42 (0.26)	<0.001	1.63	-0.24 (0.22)	<0.001	1.09	<0.001	0.005	0.75 (1.26; 0.24)
Limits of Stability (LOS) Analysis Score (%)	14.25 (7.12)	<0.001	2.00	6.90 (3.05)	<0.001	2.26	<0.001	<0.001	1.33 (0.78; 1.88)

Rhythmic and Directional Control Assessment									
Mediolateral (ML) Ability (%)	16.09 (9.20)	<0.001	1.75	5.29 (4.47)	<0.001	1.18	<0.001	<0.001	1.49 (0.92; 2.04)
Mediolateral (ML) Control and Efficacy (%)	12.34 (14.78)	<0.001	0.83	2.77 (7.27)	0.014	0.38	<0.001	0.001	0.82 (0.30; 1.33)
ML Rhythmic and Directional Control Assessment (%)	14.31 (5.68)	<0.001	2.52	4.97 (3.61)	<0.001	1.38	<0.001	<0.001	1.96 (1.35; 2.55)
Anteroposterior (AP) Ability (%)	3.94 (6.34)	<0.001	0.62	1.58 (3.93)	0.005	0.40	<0.001	0.203	0.44 (0.06; 0.94)
Anteroposterior (AP) Control and Efficacy (%)	25.81 (13.06)	<0.001	1.98	10.61 (8.28)	<0.001	1.28	<0.001	<0.001	1.39 (0.83; 1.93)
AP Rhythmic and Directional Control Assessment (%)	10.75 (5.32)	<0.001	2.02	4.58 (3.12)	<0.001	1.47	<0.001	<0.001	1.41 (0.85; 1.96)
Postural Control Assessment (Total Score) (%)	13.53 (5.38)	<0.001	2.51	5.52 (2.43)	<0.001	2.27	<0.001	<0.001	1.91 (1.30; 2.50)
Functional Balance Assessment - Global Score (%)	11.84 (3.42)	<0.001	3.46	4.87 (1.54)	<0.001	3.16	<0.001	<0.001	2.62 (1.93; 3.29)

11.20 Results of changes in instrumental functional gait analysis from baseline to 3-month follow-up

Appendix T: Results of changes in instrumental functional gait analysis from baseline to 3-month follow-up in the two groups.

Functional Gait Analysis Parameters	MRP Group (n = 32)			CPT Group (n = 31)			Paired *p*-Value	Between-Group *p*-Value	Effect Size *d* (95% CI)
	Mean Change (SD)	*p* Value	Effect Size *d*	Mean Change (SD)	*p* Value	Effect Size *d*			
Gait speed (m/s)	0.22 (0.10)	<0.001	2.11	0.10 (0.05)	<0.001	2.13	<0.001	<0.001	1.48 (0.91; 2.03)
Average gait speed (%)	17.50 (18.94)	<0.001	0.92	10.45 (8.86)	<0.001	1.18	<0.001	0.441	0.47 (0.03; 0.97)
Lt. foot support time (s)	-0.19 (0.15)	<0.001	1.31	-0.11 (0.09)	<0.001	1.16	<0.001	0.002	0.70 (1.21; 0.19)
Rt. foot support time (s)	-0.18 (0.14)	<0.001	1.27	-0.10 (0.09)	<0.001	1.13	<0.001	0.008	0.65 (1.15; 0.14)
Difference in support time (%)	31.72 (20.73)	<0.001	1.53	11.74 (6.08)	<0.001	1.93	<0.001	<0.001	1.30 (0.75; 1.84)
Anteroposterior braking force									
Lt. AP braking force (N)	13.79 (15.48)	<0.001	0.89	10.85 (9.35)	<0.001	1.16	<0.001	0.243	0.23 (0.27; 0.72)
Lt. AP braking force (Normalized)	0.02 (0.02)	<0.001	0.91	0.02 (0.02)	<0.001	1.20	<0.001	0.578	0.08 (0.41; 0.58)
Lt. AP braking force assessment (%)	8.22 (20.37)	0.013	0.40	9.77 (19.83)	<0.001	0.49	<0.001	0.768	0.08 (0.57; 0.42)
Rt. AP braking force (N)	17.28 (13.28)	<0.001	1.30	7.64 (12.45)	<0.001	0.61	<0.001	0.001	0.75 (0.23; 1.26)
Rt. AP braking force (Normalized)	0.03 (0.02)	<0.001	1.29	0.01 (0.02)	<0.001	0.73	<0.001	0.004	0.79 (0.28; 1.30)
Rt. AP braking force assessment (%)	22.31 (29.91)	<0.001	0.75	8.29 (21.33)	0.004	0.39	<0.001	0.194	0.54 (0.03; 1.04)
AP braking force global score (%)	14.81 (19.91)	<0.001	0.74	6.81 (8.42)	<0.001	0.81	<0.001	0.268	0.52 (0.02; 1.02)
Anteroposterior propulsion force									
Lt. AP propulsion force (N)	23.52 (19.96)	<0.001	1.18	11.83 (11.23)	<0.001	1.05	<0.001	0.004	0.72 (0.21; 1.23)
Lt. AP propulsion force (Normalized)	0.03 (0.03)	<0.001	1.22	0.02 (0.01)	<0.001	1.08	<0.001	0.002	0.79 (0.27; 1.30)
Lt. AP propulsion force assessment (%)	19.19 (29.46)	<0.001	0.65	12.10 (18.65)	<0.001	0.65	<0.001	0.695	0.29 (0.21; 0.78)
Rt. AP propulsion force (N)	20.93 (17.87)	<0.001	1.17	7.24 (8.27)	<0.001	0.88	<0.001	0.001	0.98 (0.45; 1.50)
Rt. AP propulsion force (Normalized)	0.03 (0.02)	<0.001	1.22	0.01 (0.01)	<0.001	0.96	<0.001	0.002	0.93 (0.41; 1.45)
Rt. AP propulsion force assessment (%)	17.66 (25.65)	<0.001	0.69	5.87 (11.49)	0.003	0.51	<0.001	0.112	0.59 (0.08; 1.09)
AP propulsion force global score (%)	18.81 (20.68)	<0.001	0.91	6.71 (8.91)	<0.001	0.75	<0.001	0.019	0.76 (0.24; 1.26)
Vertical take-off force									
Lt. vertical take-off force (N)	23.96 (53.31)	0.020	0.45	7.58 (26.53)	0.117	0.29	0.007	0.248	0.39 (0.11; 0.88)
Lt. vertical take-off force (Normalized)	0.04 (0.05)	<0.001	0.77	0.02 (0.04)	0.008	0.40	<0.001	0.008	0.53 (0.02; 1.03)
Lt. vertical take-off force assessment (%)	6.91 (17.71)	<0.001	0.39	1.45 (8.48)	0.204	0.17	<0.001	0.022	0.39 (0.11; 0.89)
Rt. vertical take-off force (N)	21.45 (47.74)	0.043	0.45	-2.47 (61.36)	0.739	0.04	0.100	0.243	0.44 (0.07; 0.93)
Rt. vertical take-off force (Normalized)	0.04 (0.05)	<0.001	0.79	0.02 (0.04)	0.020	0.37	<0.001	0.011	0.52 (0.01; 1.02)
Rt. vertical take-off force assessment (%)	4.09 (20.49)	0.013	0.20	-0.03 (9.63)	0.325	0.00	0.009	0.145	0.26 (0.24; 0.75)
Vertical take-off force global score (%)	5.88 (11.70)	<0.001	0.50	1.39 (4.36)	0.049	0.32	<0.001	0.012	0.51 (0.00; 1.00)

Oscillation force									
Lt. oscillation force (N)	-5.24 (71.99)	0.304	0.07	15.48 (71.77)	0.739	0.00	0.511	0.182	0.29 (0.78; 0.21)
Lt. oscillation force (Normalized)	0.00 (0.08)	0.088	0.00	0.02 (0.10)	0.653	0.29	0.225	0.073	0.24 (0.73; 0.26)
Lt. oscillation force assessment (%)	-2.97 (28.58)	0.419	0.10	-8.19 (33.16)	0.095	0.07	0.435	0.099	0.17 (0.33; 0.66)
Rt. oscillation force (N)	-3.81 (69.08)	0.286	0.06	17.83 (57.60)	0.244	0.37	0.997	0.071	0.34 (0.84; 0.16)
Rt. oscillation force (Normalized)	0.00 (0.08)	0.186	0.03	0.03 (0.08)	0.364	0.25	0.660	0.031	0.31 (0.80; 0.19)
Rt. oscillation force assessment (%)	-5.97 (33.41)	0.959	0.18	-10.97 (37.39)	0.199	0.14	0.410	0.372	0.14 (0.35; 0.64)
Oscillation force global score (%)	4.09 (9.00)	0.009	0.46	0.71 (2.73)	0.590	0.06	0.014	0.138	0.51 (0.00; 1.01)
AP force morphology (Fx Morphology)									
Lt. AP force morphology (%)	20.81 (11.24)	<0.001	1.85	13.52 (11.78)	<0.001	1.15	<0.001	0.006	0.63 (0.12; 1.14)
Rt. AP force morphology (%)	18.47 (12.57)	<0.001	1.47	10.68 (10.35)	<0.001	1.03	<0.001	0.005	0.68 (0.16; 1.18)
AP force morphology global score (%)	19.59 (10.43)	<0.001	1.88	13.81 (9.72)	<0.001	1.42	<0.001	0.003	0.57 (0.07; 1.08)
ML force morphology (Fy Morphology)									
Lt. ML force morphology (%)	19.44 (16.38)	<0.001	1.19	5.29 (6.21)	<0.001	0.85	<0.001	<0.001	1.14 (0.60; 1.66)
Rt. ML force morphology (%)	19.59 (16.25)	<0.001	1.21	7.03 (8.27)	<0.001	0.85	<0.001	<0.001	0.97 (0.44; 1.49)
ML force morphology global score (%)	19.53 (15.95)	<0.001	1.22	5.68 (6.51)	<0.001	0.87	<0.001	<0.001	1.13 (0.59; 1.66)
Vertical force morphology (Fz Morphology)									
Lt. vertical force morphology (%)	13.59 (13.15)	<0.001	1.03	8.19 (10.89)	<0.001	0.75	<0.001	0.032	0.45 (0.06; 0.94)
Rt. vertical force morphology (%)	12.66 (11.11)	<0.001	1.14	9.74 (9.30)	<0.001	1.05	<0.001	0.219	0.28 (0.21; 0.78)
Vertical force morphology global score (%)	13.22 (11.24)	<0.001	1.18	8.94 (9.69)	<0.001	0.92	<0.001	0.049	0.41 (0.09; 0.91)
Lt. foot global assessment (%)	13.19 (8.15)	<0.001	1.62	6.35 (4.98)	<0.001	1.28	<0.001	<0.001	1.01 (0.48; 1.53)
Rt. foot global assessment (%)	14.16 (6.87)	<0.001	2.06	6.48 (3.32)	<0.001	1.96	<0.001	<0.001	1.42 (0.86; 1.96)
Functional gait analysis global score (%)	15.84 (7.03)	<0.001	2.26	7.29 (3.29)	<0.001	2.22	<0.001	<0.001	1.55 (0.98; 2.11)