UNIVERSITAT DE BARCELONA

# The Effect of First Language Perception on the Discrimination of a Non-native Vowel Contrast: Investigating Individual Differences

Vita Kogan

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# The Effect of First Language Perception on the Discrimination of a Non-native Vowel Contrast: Investigating Individual Differences

Vita Kogan

**Doctoral Dissertation**

Doctoral Program in Cognitive Science and Language

# The Effect of First Language Perception on the Discrimination of a Non-native Vowel Contrast: Investigating Individual Differences

by

Vita Kogan

Supervised by Dr. Joan C. Mora

2020

I, Vita V. Kogan, confirm that the work presented in the dissertation is my own. Where information has been derived from other sources, I confirm that this has been indicated in the dissertation.

Vita V. Kogan

Barcelona, January 2020

# Dedication

This dissertation is dedicated to my husband, Ratko Jagodić. His guidance, encouragement, and endless love have made this dissertation come true.

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My deepest thanks go to my parents for doing their best to understand my research and being supportive of it (although secretly wishing I was a lawyer).

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# Abstract

Adult language learners often experience difficulty acquiring a new sound system. Empirical studies have shown that native phonetic categories function as a filter that removes specific acoustic cues for non-native sounds and causes “a perceptual accent”. Not being able to perceive contrastive segment categories that do not exist in learner’s native language result in production problems and accented speech. Yet, some individuals are remarkably successful at the task of non-native perception. Such instances demonstrate that perceptual ability is a subject of high variability. Whereas native language (L1) background has been the focus of much second language acquisition research to explain such variability, little attention has been paid to the role of individual differences within the same L1 perception. This dissertation seeks to fill this gap and investigate how individual differences in native perception affect the degree of perceived dissimilarity between two members of a novel contrast that does not exist in learners’ L1. We argue that not only individuals with various L1s are equipped differently for the task of non-native perception, but also individuals with the same L1 vary in how their native phonological categories are represented in the perceptual space. Such variability is observable in measures of compactness of L1 phonetic categories, and its effects on non-native perception can be assessed by relating the degree of compactness to the perceived dissimilarity between novel contrasting sounds. We hypothesized that compact L1 categories give an initial advantage in distinguishing non-native contrasts.

Sixty-eight Spanish monolinguals participated in the present study. The degree of compactness of their native category /i/ was measured through a goodness-of-fit rating task, where participants listened to synthesized variants of the Spanish /i/ vowel (differing in F1, F2 or both) and rated them as either good or bad exemplars of their internal representation of the category /i/ on an intuitive scale. These ratings provided an individual /i/ compactness index for each participant that was related to the individual perceived dissimilarity score for the novel Russian contrast /i - ɨ/. The results obtained confirmed the hypothesis. Even though L1-based individual differences in perception were small, compactness of the L1 category /i/ contributed significantly to the participants' ability to perceive the acoustic distance between the Russian /i/ and /ɨ/. These findings suggest that having more compact vowel categories might facilitate the process of category formation for unfamiliar sounds.

Keywords: individual differences, phonetic ability, speech perception, phonetic category compactness.

# Resumen

Los estudiantes adultos de idiomas a menudo experimentan dificultades para adquirir un nuevo sistema fonológico. Los estudios empíricos han demostrado que las categorías fonéticas nativas funcionan como un filtro que elimina las señales acústicas específicas de los sonidos no nativos y causan "un acento perceptivo". La impossibilidad de percibir categorías segmentales contrastivas que no existen en el idioma nativo del aprendiz correctamente ocasiona problemas en la producción de los fonemas conducentes a la presencia de acento extranjero en el habla. Sin embargo, algunos individuos son capaces de percibir fonemas no-nativos con notable éxito. Tales casos demuestran la gran variabilidad entre sujetos en cuanto a su capacidad perceptiva para los sonidos del lenguaje. Dicha variabilidad se ha investigado extensamente a través de numerosos estudios que han investigado el factor de la lengua nativa (L1) como principal causa de los problemas de percepción y producción en una segunda lengua. No obstante, se ha prestado poca atención al papel potencial de las diferencias individuales en la percepción de la L1. Esta tesis pretende abordar esta cuestión empírica investigando hasta qué punto las diferencias individuales entre sujetos en la percepción de su lengua nativa afectan el grado de disimilitud perceptiva entre los miembros de un nuevo contraste fonológico inexistente en la L1 de los aprendices. Nuestra hipótesis plantea la idea de que no sólo los individuos de primeras lenguas diferentes están preparados de diferente forma para la percepción de los sonidos de una segunda lengua, sino que también los individuos que comparten una misma L1 presentan variabilidad en cómo representan sus categorías fonológicas en su espacio perceptivo, y ello puede también tener consecuencias para la percepción de los sonidos de una lengua no nativa. Partimos de la base de que la variabilidad inter-sujetos en la percepción de las categorias fonológicas nativas es observable a partir de medidas del grado de compactación de las categorías fonéticas en la L1. Los efectos del grado de compactación sobre la percepción no nativa pueden evaluarse relacionando el grado de compactación de una categoría fonológica nativa con el grado de disimilitud perceptiva observada en la percepción de contrastes fonológicos al inicio del proceso de adquiscíón de una nueva lengua. Nuestra hipótesis es que aquellos individuos que presentan un mayor grado de compactación de las categorías fonológicas de la L1 obtienen una ventaja inicial en la distinción de contrastes fonológicos no nativos.

Sesenta y ocho monolingües de español participaron en el presente estudio. El grado de compactación de su categoría nativa /i/ se midió a través de una tarea perceptiva donde los participantes escucharon variantes sintetizadas de la vocal española /i/ que presentaban diferèncias equidistantes en F1, F2 o ambos a la vez, y que calificaron en una escala intuitiva como buenos o malos ejemplares de su representación interna de la categoría vocálica /i/. Esta tarea nos proporcionó un índice individual del grado de compactación de la vocal /i/ para cada participante que relacionamos con la medida de disimilitud perceptiva individual que cada participante obtuvo para el contraste del ruso /i - ɨ/. Los resultados obtenidos confirmaron la hipótesis. Aunque las diferencias individuales en la percepción de la vocal /i/ del español observadas fueron de pequeña magnitud, el grado de compactación de /i/ contribuyó significativamente a la capacidad de los participantes de percibir la distancia acústica entre los fonemas vocálicos del ruso /i/ y /ɨ/. Estos resultados sugieren que tener categorías de vocales más compactas podría facilitar el proceso de formación de categorías fonológicas en la adquisición inicial de una nueva lengua.

Palabras clave: diferencias individuales, adquisición de fonología, percepción del habla, grado de compactación, categorísa fonéticas.

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# Chapter 1 – Introduction

> The limits of my language means the limits of my world.
>
> –Ludwig Wittgenstein

## 1.1 Motivation for the dissertation

This dissertation reflects a scientific journey into the field of speech perception. It is widely acknowledged that adult second language (L2) learners experience difficulty when acquiring non-native sound systems. The proverbial struggle to avoid accented pronunciation, labeled by the common use of the term “Joseph Conrad Phenomenon” (Reiterer et al., 2011), granted phonetic skills a special status in second language acquisition (SLA) research. The situation, in which a learner successfully acquires all other subsystems of a target language (e.g., syntax, morphology), but still cannot manage accurate L2 pronunciation, is way too common. From the neuropsychological perspective, there is a clear division between the substrates that are responsible for the acquisition of “grammar” and “accent” (Schneiderman & Desmarais, 1988). The acquisition of the latter is more difficult since it is a lower order function and cannot be easily influenced by conscious learner’s efforts. Sociopsychological accounts of SLA also set the phonetic aspect apart from other linguistic features by introducing the concept of “language ego” (Guiora, 1980) that is more susceptible to the challenges of speech production than other linguistic tasks. In short, the separation of pronunciation from other L2 skills has a long history and has been supported by a number of experimental studies (e.g., Dogil & Reiterer, 2009; Neufeld, 1987).

As much as L2 pronunciation is important for native-like performance (unintelligible speech has sociological consequences, such as obstructing communication and decelerating integration into the community of native speakers) L2 perception has to be in place first to ensure accurate production. Even though there is no consensus in the field on such a sequence of L2 sound acquisition (L2 production following L2 perception), in our study we assume that difficulties with L2 sound production have a perceptual basis, i.e. learners have "perceptual foreign accents" (Escudero, 2005). For that reason, we prioritize the role of perception in the L2 acquisition process and focus our study on learner's ability to perceive non-native sounds, rather than to produce them.

Previous research has suggested that a native phonological system functions as a perceptual filter that impedes the accurate processing of novel sounds (Best & Tyler, 2007; Flege, 1995). We argue that not only individuals with various native languages (L1s) are equipped differently for the task of L2 perception, but also individuals with the same L1 vary in how their native phonological categories are represented in the perceptual space. Such variability is observable in measures of compactness of L1 phonetic categories (category compactness in production: Kartushina & Frauenfelder, 2014), and its effects on initial L2 perceptual learning can be assessed by relating the degree of compactness to the discrimination accuracy of novel L2 contrasts. The concept of compactness in relation to L1 phonetic categories and perception is a new source of inter-individual variability that we would like to introduce to better understand individual differences in L2 perception. Because of the ethereal nature of speech perception and methodological difficulties associated with measuring it, but also because of the notion that speakers (and listeners) of the same language vary minimally in the way they process their mother tongue, only a handful of empirical studies investigated L1-based individual differences in perception. This dissertation seeks to close this gap and to show how L1-based individual differences contribute to the task of L2 phonological acquisition.

## 1.2 Outline of the dissertation

This chapter introduces the concept of phonetic talent and discusses individual differences in L2 phonological acquisition. The following chapter discusses speech processing mechanisms and similarities and differences between L1 and L2 speech perception. Chapter 3 explores individual differences in native perception, which come from anatomical biases and cognitive differences, but also a linguistic environment. The notion of perceptual category compactness is also introduced in this chapter in greater detail. Chapter 4 presents the methodology of the study: the description of the perception and the cognitive tasks used. The results obtained can be found in Chapter 5. Chapter 6 evaluates and discusses the results in the light of previous research findings, suggests possible implications and presents the limitations of the study. Chapter 7 concludes this dissertation by outlining its contribution to the field of SLA and proposing directions for future research.

## 1.3 Phonetic talent in L2

Despite the numerous neuro- and sociopsychological reasons we briefly identified above, some individuals still manage to achieve a near-native phonological proficiency (Moyer, 2014). Certainly, external factors, such as age of onset of L2 learning, L2 exposure and L1/L2 use constitute a stable source of inter-speaker variability, i.e. a various degree of success among L2 learners in perceiving and producing non-native sounds. The general trend is the more L2 input, the better. However, even when only limited input is available, cases have been reported of learners demonstrating exceptional outcomes in phonology (Bongaerts, Planken, & Schils, 1997; Ioup, Boustagi, El Tigi, & Moselle, 1994). The term “phonetic talent” first appeared in Jilka’s research (Jilka et la., 2007; Jilka, 2009) who defined the concept broadly as an individual skill to acquire L2 phonetics and phonology and clearly separated it from other linguistic skills. Yet, the notion that the phonetic talent or phonetic ability is an independent subcomponent of language aptitude has a long history: half a century ago, Carroll (1981) coined the term “phonemic coding ability” that he defined as the innate stable ability to recognize new sounds and store them in long-term memory. Thus, from its origins the concept traditionally is connected primarily to the cognitive perspective, i.e., phonetic talent as a combination of specific cognitive skills.

### 1.3.1 Cognitive abilities and phonetic talent

Research on the role of aptitude in L2 phonological acquisition has shown that a number of cognitive abilities influence L2 phonological performance; the most researched one being phonological short-term memory (Cervino-Povedano & Mora, 2015). This type of memory has been found to be related to successful L2 phonological acquisition. Recent studies suggest that greater phonological short-term memory capacity is related to higher L2 learners’ perceptual accuracy. Other candidates that might play a role in L2 phonological processing are: acoustic memory (Safronova & Mora, 2012), attentional control (Darcy, Park, & Yang, 2015, Safronova & Mora, 2013), inhibition (Darcy, Mora, & Daidone, 2016), and musical ability (Coumel, Christiner & Reiterer, 2019).

Carroll’s (1981) phonemic coding ability resembles closely the phonological loop, the sub-component of working memory that Baddeley (1986) associated with phonological short-term memory. Phonological short-term memory, the ability to hold phonological material in the short-term store for about two seconds and to generate accurate phonological representations, seems to play a central role in first and second language acquisition (L1: Baddeley, 1986; L2: Hummel, 2009; Kormos & Sáfár, 2008a). Brooks, Kempe, and Donache (2009) suggested that the phonological short-term memory capacity could be a better predictor of L2 attainment than the working memory capacity, non-verbal intelligence or prior language learning experience. In regard to the L2 phonological development, phonological short-term memory has been shown to influence the perception of L2 consonants (MacKay, Meador & Flege, 2001) and vowels (Cerviño-Povedano & Mora, 2011) by facilitating the development of the target-like cue-weighting. A more recent study by Cerviño-Povedano and Mora (2015) investigated the role of phonological short-term memory in the weighting of spectral and duration cues in the perception of the English vowel contrast /iː - ɪ/ by Spanish L2 learners of English. Predictably, Spanish L2 learners of English over-relied on the duration (and not so much the spectral cues) in the categorization of /iː - ɪ/. Interestingly, individuals with greater phonological short-term memory capacity demonstrated higher stimuli categorization accuracy in comparison with the low phonological short-term memory group. The authors concluded that phonological short-term memory is an important factor in L2 phonological acquisition and should be taken into account in future speech perception studies.

Besides phonological short-term memory, there is another memory component that might be responsible for phonetic talent – acoustic memory. Acoustic memory is a memory system identified in a variety of ways in the literature: echoic memory (Neisser, 1967), a sensory buffer store (Atkinson & Shiffrin, 1968), or a pre-categorical acoustic storage (Crowder & Morton, 1969). Acoustic memory is operationalized as an individual's memory capacity to temporarily store non-verbal speech-like acoustic information at a pre-categorical level, i.e. prior to phonological encoding. Previous research has shown that acoustic memory plays a significant role in within-category vowel discrimination (Cowan & Morse, 1986; Darwin & Baddeley, 1974; Safronova, 2016). Safronova (2016) argues that greater acoustic memory capacity provides the potential for processing a larger amount of L2 speech input, which facilitates the detection of fine acoustic-phonetic differences between sounds. In her recent study (Safronova, 2016), she found that acoustic memory contributes significantly to the perception of cross-language phonetic distance. Earlier, Safronova and Mora (2012) tested a group of Spanish/Catalan L2 learners on their ability to perceive the English tense-lax vowel contrast /iː - ɪ/ and did not find the relationship between acoustic memory and the discrimination ability. Yet, they observed that the acoustic memory scores did not correlate with the phonological short-term memory measures suggesting that different cognitive substrates underlay these skills. Ghaffarvand Mokari and Werner (2019) confirmed this observation: in their study there was no significant relationship between phonological short-term memory and acoustic memory. Contradictory results coming from acoustic memory studies can be explained by the fact that acoustic memory and its connection to L2 perception remains largely an under-researched area; more empirical data is necessary to understand its precious functioning and architecture.

Recently, attention control has been investigated as a potential predictor of enhanced L2 phonological processing (Darcy, Park, & Yang, 2015; Mora & Mora-Plaza, 2019; Safronova & Mora, 2013). Selective attention assists learners in choosing relevant cues in the linguistic input and making phonemic distinctions, whereas attentional flexibility is necessary to rapidly shift perceptual focus from one linguistic or phonetic dimension to another. Individuals with more efficient attentional control might be better at detecting relevant phonological information, thereby accelerating their perceptual learning. Safronova & Mora (2013) examined Spanish/Catalan L2 learners' individual differences in attention control and learners' ability to attend to native-like cue-weighting in the perception of the L2 English lax-tense contrast. They reported a significant difference between the high-attention control and the low- attention control groups' performance. The high-attention control participants were better at keeping the non-relevant acoustic information (either vowel duration or voice quality) in the perceptual background in an attention control task. The same participants demonstrated a superior ability to focus on the spectral differences underlying the /i: - ɪ/ contrast in the discrimination tasks.

Darcy, Park, and Yang (2015) also investigated attention control, among other cognitive skills, in relation to the phonological acquisition (Korean L2 learners of English). The authors used an attention control task targeting voice identity for indexical information (male or female voice), and a lexical dimension (word or non-word). At each trial, with respect to the item heard, participants answered "yes" or "no" to either of two questions: Male voice? Word? There was no significant effect of attention control on the variable of interest — the individual L2 phonological acquisition score. The authors concluded that this cognitive skill might contribute to L2 phonological development as a part of a cognitive complex that also includes a working memory ability and proceeding speed: when taken together, they are especially conducive to efficient learning. Since phonological processing is a multifarious task requiring the recruitment of various cognitive abilities, it would only make sense that no one single cognitive variable is responsible for phonological processing. That being said, in the following study, Darcy, Mora, and Daidone (2016) found a connection between attention and phonological development. In this study, greater attention control was associated with more accurate performance in an ABX task, meaning that L2 learners with greater attention control skills were able to perceive the contrastive vocalic and consonantal features better. In the same study, the authors investigated the role of inhibition in L2 speech perception. They found a positive correlation between the inhibition scores and ABX accuracy. Inhibitory skills are important for deactivating (or inhibiting) the language-not-in-use, which leads to more accurate L2 perception and production. A stronger separation between L1 and L2 ensures that the cognitive pathways established for L1 are avoided and direct interaction with the L2's properties takes place, which would make L2 acquisition more similar to that of L1 and potentially more successful.

Lev-Ari and Peperkamp (2013, 2014) also investigated individual differences in inhibition. Their participants were late English-French bilinguals residing in France who performed a retrieval-induced-inhibition task together with the tests that measured participants' voice onset time (VOT) in perception and production. The hypothesis was that lower inhibitory skill results in the greater influence of the second language on the first. In other words, poorer inhibition leads to greater co-activation of the competing linguist units, which leads to more L2-like representation. The hypothesis was confirmed. In a production task, speakers with the lower inhibitory skill demonstrated more French-like pronunciation of the English word-initial voiceless stops. In a perception task, speakers with lower inhibitory skill demonstrated a shift between /d/ and /t/ in English tokens to the lower, more French-like, VOT values. The authors concluded that inhibitory skill plays a significant role in controlling the co-activation of competing phones in bilinguals' two languages.

Phonological short-term memory, acoustic memory, attention control, and inhibition have been prominent candidates to explain the cognitive bases of phonetic talent. Yet, only phonological short-term memory has been consistently linked to exceptional gains in L2 phonetics and phonology. We included the measures of phonological short-term memory in the present study together with acoustic memory to understand how the two are connected.

Another line of research (Christiner & Reiterer, 2013, Christiner, Rüdegger & Reiterer, 2018; Fonseca-Mora, Jara-Jiménez, & Gómez-Domínguez, 2015; Milovanov, 2009) advocates for musical ability as a core component of phonetic talent. A number of studies indicate an overlap of the neural resources between language and music (Seither-Preisler, Parncutt, & Schneider, 2014), which explains why musical expertise leads to higher memorization and imitation ability of foreign language material (Christiner & Reiterer, 2015). Marques, Moreno, Castro, and Besson (2007) investigated the effects of musical expertise on pitch perception in an unfamiliar L2 and demonstrated that adult musicians perceived pitch variation better than non-musicians. In another study, Moreno and colleagues (2009) confirmed that musical training improves the perception and production of the linguistic pitch. A series of studies conducted by Milovanov and colleagues (Milovanov, Pietilä, Tervaniemi, & Esquef 2010; Milovanov, Huotilainen, Välimäki, Esquef & Tervaniemi, 2008; Milovanov, Tervaniemi, Takio, & Hämäläinen, 2007) showed a robust connection between greater musical aptitude and L2 pronunciation and perceptual discrimination.

Even though there seems to be an agreement on musical training being beneficial for the acquisition of L2 phonology, not all musical training contributes the same way or to the same linguistic skills. In their study, Christiner and Reiterer (2013) showed that singers outperform instrumentalists in their ability to imitate unintelligible speech and foreign accents. Since speech imitation relies on vocal-motor processes as well as audition, the vocal flexibility of singers facilitates this task for them. Schneider, Sluming, Roberts, Bleeck, and Rupp (2005) went even further and linked differences in auditory perception to the type of musical instrument their subjects play or the type of voice (soprano vs. alto) they have. Depending on the neuroanatomical structure of the auditory cortex, individuals can be assigned to various perceptual profiles with each listening type perceiving pitch and timbre of a sound differently. A fine-grained measure for musical expertise that accounts for various aspects of musicality might help establish further connections with specific linguistic skills. Christiner, Rüdegger, and Reiterer (2018) tested how singing and a sense of rhythm benefit the imitation of an unfamiliar language, Chinese and Tagalog in their study. Results revealed that children with a high ability for singing discriminated tonal differences of the Chinese language better, whereas children who excelled at the rhyme-related tasks did better with the syllable-based Tagalog.

That being said, musicality might be in fact a byproduct of the functioning of phonological short-term memory, the cognitive skill that we discussed above. For example, Williamson, Baddeley, and Hitch (2010) suggest that there is a correspondence in the way verbal and musical sounds are processed in phonological short-term memory.

### 1.3.2 Affective factors and phonetic talent

So far we have been discussing cognitive skills that previous research has associated with phonetic talent. However, there is a number of non-cognitive factors that are also connected to the acquisition of phonetic skills. For example, there is a body of research that investigates how empathy, an emotional resonance that takes place in an individual when she engages in affective communication, influences L2 perception and production. In the 1970s, Guiora and colleagues suggested that individual differences in L2 pronunciation reflect the degree of empathic capacities that people possess (Guiora, Paluszny, Beit-Hallahmi, Catford, Cooley, & Dull, 1975; Guiora, Brannon, & Dull, 1972a; Guiora, Beit-Hallahmi, Brannon, Dull, & Scovel, 1972a). A more recent study conducted by Rota and Reiterer (2009) examined empathy using the questionnaire that explores sensitivity and concern (E-Skala: Leibetseder, Laireiter, Riepler, & Köller, 2001) in relation to phonetic abilities in L2 pronunciation and perception. The significant correlations obtained demonstrated that the theory of empathy in acquiring a foreign accent has convincing grounds and must be investigated further. Another interesting development in the direction of personality traits is the study done by Hu and Reiterer (2009), in which the authors administered an exhaustive assessment of personality integrating the dispositional perspective of personality — the perspective that is based on the idea that each individual's personality consists of a consistent pattern of dispositional qualities. The measures of personality included a self-report questionnaire based on the Five-Factor Model (Costa & McCrae 1992), a behavioral inhibition and behavioral activation scale test (BIS/BAS: Carver & White, 1994), and several more specific measures: empathy with E-Scale (Leibetseder et al. 2001), tendencies to experience positive and negative affects with Positive and Negative Affect Schedule (PANAS: Watson, Clark & Tellegen,1988) and state aspects of anxiety with State-Trait Anxiety Inventory (Spielberger, 1983). The results showed that the participants who experience more positive affects, tend to be more agreeable and empathetic and less conscientious, also possess a greater degree of phonetic talent. Certainly, more specific investigations are needed to clarify the nature of the relationships between the personality measures and the phonetic-articulatory aspect of L2 aptitude. Yet, this study demonstrates that some personality traits might indeed influence learning outcomes in the acquisition of L2 sound systems.

Even though it is not relevant to the present study (our participant were naive listeners of a novel language that they never learned before and not L2 learners), a few words must be said about motivation, since it consistently correlates with all aspects of SLA (Lewandowski, 2012) and the picture would not be complete without this important concept. A common concern is how to define or capture motivation. The most influential framework comes from Gardner and Lambert (1972) who differentiate between instrumental and integrative motivation with the former defined as a more pragmatic, goal-oriented type and the later — the motivation to connect with people or culture. Gardner and Lambert (1972) have argued that integrative motivation has a stronger influence on L2 proficiency, especially the phonetic component since learners seek to become undisguisable from native speakers. Flege (1995) confirmed this finding reporting integrative motivation as a significant variable for predicting accented pronunciation. Moyer (1999) showed a strong correlation between the degree of L2 accent and the factor of professional motivation as well. A word of caution comes from Dörnyei (2010) who observed that motivation is a continuously changing construct that never remains stable or context-independent, thus, it might be premature to make conclusions based on the measures of motivation extracted at a specific moment of a learning trajectory.

From a process-oriented perspective, several scientists have proposed that, rather than being interpreted as an innate, genetically determined predisposition, phonetic talent should be seen as a competence dynamically emerging from the interaction between speaker-specific linguistic, cognitive and psychological determinants and individual experiences (Delvaux, Huet, Piccaluga, & Harmegnies, 2014). Attempts to separate phonetic talent as a neurobiologically grounded individual skill from other interacting variables, such as L2 proficiency or motivation that contribute to language development have been rather challenging (Jilka, 2009). Instead, Delvaux and colleagues (2014) propose to focus on a more direct and pragmatic concept of phonetic compliance that encompasses the "here and now" speaker-specific phonetic ability to produce unfamiliar speech sounds as it is revealed by the speaker's actual behavior in specific tasks. Even though it is hard to separate between innate phonetic talent and L2-learning competence or skill, there are many studies that strive to at least approximate the notion of phonetic talent through a "combination of many different tests" (Jilka, 2009, p. 41). Whether phonetic talent is influenced by nurture or reflects an inherent predisposition remains a matter of unresolved debate. In either case, innate or not, phonetic talent should not be seen as a “monolithic” construct. The studies mentioned above imply that many constituent components contribute to phonetic talent.

### 1.3.3 L1 influence and phonetic talent

In the present study, we support the componential view and define phonetic talent as a complex interplay between cognitive (especially memory-related), psychological (especially personality-related) and linguistic (especially L1) factors. We consider the latter particularly important since every language learner is already an expert in at least one language – her mother tongue. According to various speech models (discussed in greater detail in the following chapter), the phonetic distance between L1 and L2 predicts an L2 learning trajectory. Some accounts argue that difficulties arise when the L2 sound system is very dissimilar to the L1 phonemic inventory (e.g., Lado, 1957); other accounts support the opposite view and argue that it is the similarity between L1 and L2 sounds that create a perceptual challenge (e.g., Flege, 1995, 2002, 2003). In any case, it seems that native phonetic categories function as a filter that removes specific acoustic properties of non-native sounds. Yet, the exact mechanisms underlying this process remain largely unclear. Even though a large body of research has been dedicated to investigating L1-L2 interaction, the empirical results do not always match the models’ predictions or even show the opposite (e.g., Zobl, 1980). Instead, we propose to focus on individual differences in the same native language that might explain why some individuals perceive and produce novel sounds effortlessly regardless of the language they speak as L1.

In sum, second language acquisition studies single out phonetic talent or phonetic ability as an independent aptitude phenomenon and define it as a multicomponent entity. This chapter attempted to briefly describe the complex nature of phonetic talent to provide a better understanding of the concept and how it is defined by various accounts. In the present study, we focused on one specific realization of phonetic ability – the perception of an acoustic distance between a pair of contrasting non-native sounds. We focused on a few factors, which, as we believe, contribute to this ability and which previous research has identified most saliently as contributing to phonetic talent: phonological short-term memory and acoustic short-term memory, personality traits, and individual differences in L1 speech perception.

# Chapter 2 – Speech perception

## 2.1 Introduction

The process of listening is highly complex: there are several processing stages and mechanisms involved from perceiving an acoustic wave to building a mental representation of what has been said. Before looking at L2 speech perception, this chapter will briefly explain how speech processing takes place generally, i.e., the basic components and the processing mechanisms involved, and will then evoke some similarities and differences between L1 and L2 speech perception. We will also take a look at the vocalic inventory of Russian, in particular, the contrast /i- ɨ/ that we used in the rated dissimilarity task to assess L0 perception. The chapter will be organized in three parts. First, we will describe the general architecture with the basic components required for speech processing in a language. Second, we will present the most prominent L2 speech acquisition models juxtaposing the feature-based and exemplar-based frameworks. Finally, the third part is dedicated to the perception of the Russian contrast /i - ɨ/ and the difficulties that it causes for naïve listeners and L2 learners, whose native language lacks this contrast.

## 2.2 Native speech perception

Speech perception, i.e. mapping the speech signal to meaningful linguistic units, entails a complex decoding task. In real time, listeners have to cope with the acoustic effects of coarticulation, prosodic structures, background noise and talkers' idiolects that alter speech sounds (the problem known as the lack of invariance in perception) should make word recognition very challenging, yet, it is not the case in L1. In fact, listeners are remarkably attuned to the lack of invariance and an average 2-year-old is capable of parsing acoustic speech signals without much effort. To explain how listeners achieve reliable comprehension given the lack of one-to-one mapping between the acoustic signal and individual speech sounds, most of the existing speech perception models assume an intermediate level of processing, often referred to in the literature as prelexical or sublexical coding (Figure 1). This intermediate level in the speech perception system normalizes the signal and abstracts the phonetic code that can then be used for lexical access. It is yet to be determined what is the nature of this code; among the most prominent candidates are phonemes (Norris, 1994), syllables (Massaro & Simpson, 2014), acoustic-phonetic features (Stevens, 2002), articulatory gestures (Liberman & Mattingly, 1985), and context-sensitive allophones (Luce, Goldinger, Auer, & Vitevitch, 2000). There is also no agreement on whether speech perception depends on a general auditory ability (Brown, 1998; Hume & Johnson, 2001) and, thus, the perceptual mapping is an automatic result of the human auditory system,  or it triggers different mechanisms than those of other auditory stimuli and calls on special processes (Escudero, 2005).

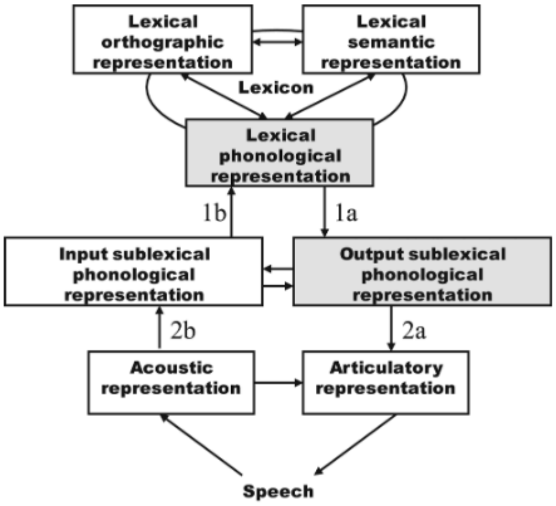


Figure 1. An information processing model of speech perception and production. The boxes in grey represent the standard model of phonological theory (Ramus et al., 2010, p. 313).

What we do know is that speech perception machinery becomes quickly attuned to best handle the acoustic-phonetic properties of a specific linguistic environment. Kuhl (2000) claims that “no speaker of any language perceives acoustic reality” (p. 11852), i.e., perception is always transformed by the language-specific knowledge that guides listener’s discrimination between tokens. The process of language attuning takes place early on, with some accounts stating that interactions between neural biases and environmental shaping may be at work as early as in utero (Jardri et al., 2012; Morokuma et al., 2004). The data from near-infrared spectroscopy studies show an early neural sensitivity to configurations of auditory stimuli that are often heard in speech (Gervain, Macagno, Cogoi, Peña, & Mehler, 2008). This neural sensitivity further contributes to a complex developmental phenomenon called perceptual tuning, that is the narrowing of perception of speech sounds over the first year of life (see Figure 2, but also: Eimas, Siqueland, Jusczyk, & Vigorito, 1971; Kuhl et al., 2008).

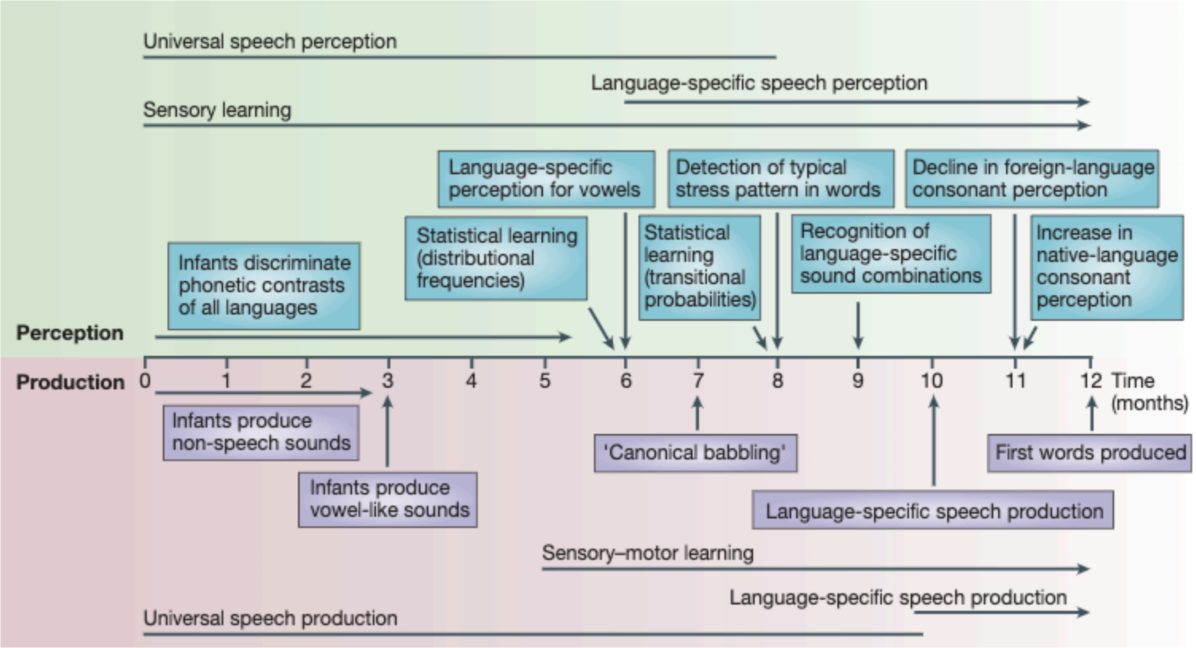


Figure 2. The universal language timeline of speech-perception and speech-production development (Kuhl, 2004, p. 832).

There are studies that demonstrate that due to prenatal experience, neonates already have a preference for the prosodic pattern of their native tongue (Byers-Heinlein, Burns, & Werker, 2010). Initially capable to discriminate many minimally contrastive phonemes, infants rapidly learn regularities of linguistic input they are engaged with (statistical learning: Saffran, 2003) and become more adept at discriminating only those phonemes that are relevant to their native language (Werker & Tees, 1984). For example, at the age of eight months, monolingual Japanese infants are able to distinguish between English /r/ and /l/; however, they lose this ability by 10-12 months of age. Thus, early in development, learners commit the brain's neural networks to patterns that reflect specific linguistic input. Later in life, this initial coding of native-language patterns interferes with the learning of new patterns, i.e., new languages. Basically, the native phonological system functions as a mental filter that impedes accurate perception of foreign sounds making the acquisition of L2 phonology a challenging task for an adult learner (Best, 1995; Escudero, 2005; Flege, 1995).

## 2.3 L2 speech perception

Initial L1 exposure early in life results in physical changes in neural anatomy; these changes are necessary to support the statistical and perceptual properties of the linguistic input in one's immediate environment (Kuhl, 2004). The concept of neural commitment that supports L1 learning and constrains future learning could explain the issue of a "critical" or "sensitive" period for second language acquisition (Lenneberg, 1967). However, in contrast to older accounts, recent studies emphasize the primary role of experience and not simply time in driving phonetic learning and L2 perception. As native language speech perception improves as a result of L1 experience, non-native speech perception declines as it is represented by uncommitted neural circuitry (Kuhl et al., 2008). L1 experience shapes attentional networks that interfere with phonetic learning of a new language later in life (Flege, 1995; Kuhl, 2004; Kuhl et al., 2008). For example, as mentioned above, Japanese adults notoriously struggle with the English /r - l/ categorization, assumedly, because they are most sensitive to the acoustic cue, F2, that is irrelevant for this contrast (Iverson et al., 2003). This does not mean though that adults permanently lose the perceptual sensitivity necessary to distinguish non-native speech sounds. Early experiments by Pisoni, Lively and Logan (1994) on voicing perception demonstrate that native English listeners can reliably perceive a difference in the prevoicing region of the VOT continuum after a very short training and can transfer their knowledge to new stimuli with a different place of articulation. These findings indicate that the underlying sensory-perceptual mechanisms have not been permanently modified or lost due to prior linguistic experience. More likely, the difficulty in distinguishing non-native phonemes depends on the degree to which the native and non-native sound inventories differ (Best, 1995; Flege, 1995). Based on this assumption, the L2 acquisition models predict various scenarios: some argue that it is the relative dissimilarity of specific L1-L2 constellations that produce L2 learning difficulties and some support the opposite view. Here we discuss L2 models that focus on L2 speech perception at a segmental level, without addressing the overall accent or the higher-level prosodic structures.

### 2.3.1 L2 speech perception models

Before taking a closer look at the existing L2 speech perception models, it is important to clarify the difference between feature-based and exemplar-based theories of phonological acquisition. Feature theories describe and categorize speech sound categories through a set of distinctive features (Chomsky & Halle, 1968; Jakobson, Fant, & Halle, 1969). Relevant articulatory or acoustic features are extracted from an acoustic signal and then translated into an abstract category that is defined by these features. For example, the vowel /i/ is defined by the features [+high], [-

back], [-round] and [+tense]. When a listener hears /i/, these features are abstracted from the acoustic cues (the formant values and the fundamental frequencies) by the perceptual system. An alternative approach, exemplar-based theories define each sound as a sum total of all tokens of the sound, or exemplars, that the person has heard with all its acoustic, lexical, social and contextual information retained (Goldinger, 1996; Morgan et al., 2001). Thus, speech perception consists of comparing each sound to a collection of stored exemplars for each category and assigning the sound in question to the category with the greatest collection of tokens most similar to it (Johnson, 1997). Both frameworks can theoretically coexist (Goldinger, 2000) leaving open the question of which memory representation is primary in speech perception. For example, Ettinger and Johnson (2009) suggest that exemplar-based representations are used for "lower-level tasks", i.e., sound discrimination and speaker normalization, and featural contrasts best account for the higher-order patterning of language.

Feature theory is represented by three perception models that constitute the most influential research body up till now and aim to explain both L1 and L2 speech perception and the connection between them. These models will be reviewed below in chronological order with the Native Language Magnet Theory (NLM: Kuhl, 1993; Kuhl et al., 2008) discussed first, followed by the Perceptual Assimilation Model-L2 (PAM: Best, 1993, 1994, 1995; also PAM-L2: Best & Tylor, 2007) and the Speech Learning Model (SLM: Flege, 1995, 2002). The models based on feature theory assume that in the course of L1 development articulatory or acoustic features are extracted from the acoustic signal to identify relevant phonetic categories. In terms of L2 perception, the models presuppose that previous linguistic experience has a direct effect on the initial state of L2 sound perception. Thus, the discrimination between non-native sounds is facilitated if the same feature is present in one's native language. Depending on the model, this feature can be articulatory or acoustic in nature (see individual models' description below). That being said, adult L2 learners have life-long access to development and are in theory capable of approximating near-native performance.

**The Native Language Magnet Theory** (NLM and NLM-e: Kuhl, 1993; Kuhl et al., 2008) is perhaps the most complete proposal for speech perception as it explicitly refers to the mechanisms underlying the learning of language-specific perception and puts forward a body of evidence showing that infants acquire sophisticated information from the signal through the detection of the distributional and probabilistic properties of the ambient language (Kuhl, 1993; Kuhl et al., 2008). NLM argues that sound perception is the result of a complex neural mapping that forms abstract phonetic categories stored in memory. Perceptual mapping is driven by earlier linguistic experience and is, thus, language-specific, i.e. no speaker of any language perceives acoustic reality as it is (Iverson & Kuhl, 1995; Iverson & Kuhl, 1996). Within the first year of life, stimulated by social interaction, infants employ categorization, statistical processing, and perceptual warping of acoustic dimensions, all of which results in the emergence of perceptual representations.

L1-specific sound mapping is supported by committed neural structures. This commitment interferes with the creation of new mappings and leads to deficient L2 perception. The perceptual magnet effect, when L1 sound categories (or rather their prototypes) act as attractors for newly perceived tokens, prevents learners from perceiving incoming speech objectively. The closer a speech token is to an L1 category prototype or a magnet, the harder it is to perceive — the phenomenon is called "a gravitational pull". In order to improve nonnative perception, L2 learners have to create new mappings, which could be more challenging with age due to the loss of neural plasticity. Once a new perceptual system has been formed, the L1 and L2 systems can coexist with minimal interference, as two distinct regions of the brain are responsible for processing native and non-native languages.

Unlike the NLM that claims that perceptual representations are stored in memory, **the Perceptual Assimilation Model** (PAM and PAM-L2: Best, 1993, 1994, 1995; Best & Tylor, 2007) is based on the ecological approach to speech perception (direct realism: Best, 1984) and proposes that listeners extract the invariants of articulatory gestures directly. A child detects and learns to hear high-level articulatory gestures that discriminate sound contrasts in her native language — this process gradually facilitates L1 perception. Next, L1-specific high-level features and categories are used in new language environments. Since non-native environments often lack familiar gestural features, beginner listeners assimilate L2 sounds to those native sounds that they perceive as most similar. If an L2 contrast is perceptually assimilated to different native categories (*two-category assimilation*), discrimination is predicted to be excellent. Whereas if contrasting L2 sounds are assimilated to the same L1 category (*single category assimilation*), the discrimination will be likely poor. The situation, in which one member of the L2 contrast is assimilated as a good version and the other as a poor version of a native category, is called *category-goodness assimilation*. In this case, the perceptual difficulty depends on the degree of difference in category goodness between the two L2 phones. It could be also that one L2 phone is categorized while the other is not – the assimilation pattern that is called *uncategorized-categorized* and discriminated quite well. Lastly, both L2 phones might be uncategorized (*uncategorized-uncategorized assimilation*), which might be difficult or easy to discriminate, depending on the phonetic and auditory similarities between the L2 phones. Over time, exposure to L2 input might lead to splitting of native categories and reorganization of assimilation patterns making them more native-like.

**The Speech Learning Model** (SLM: Flege, 1995, 2002) shares much in common with the

NLM in terms of the development of auditory perception by the means of categorization and accounts for both L2 perception and L2 production. According to the SLM, abstract phonetic categories are identified based on the phonetic features discriminated in the speech signal. This mechanism — detecting and classifying featural patterns in the input — guides the process of category formation and, consequently, the learning of L1 perception. The SLM claims that the difficulty in acquiring L2 sounds comes from the learner's tendency to relate new sounds to the existing positional allophones — a process called "equivalence classification". Because of equivalence classification,  L2 sound features and properties get filtered out by L1 phonology. Since the model presupposes that "the mechanisms and processes used in learning L1 sound system remain intact over the life span" (Flege, 1995, p. 239), in theory, adults retain the capacity to learn an accurate perception of new L2 properties. As long as a learner is capable of perceiving the phonetic differences between L2 sounds (or between L2 and L1 sounds), she can create new categories. It is predicted that it will be more difficult to perceive L2 sounds in a native-like manner if they are similar to L1 sounds. In this case, a novel sound will be merged with a preexisting native sound ("perceptual equivalence"), and this single category will be used for L2 perception. However, in contrast to the NLM that assumes different neural circuitries for L1 and L2, the SLM suggests a common phonological space for both systems, which means that newly formed phonetic categories will trigger boundary adjustments for the preexisting L1 categories.

All three models predict that it is the similarity between L1 and L2 sounds (and not differences as some models postulate: e.g., Lado, 1957) that interferes with the accurate perception of non-native contrasts: in this sense, NLM's gravitational pull, PAM's assimilation, and SLM's equivalence classification are essentially the same phenomenon. It must be noted that the above-mentioned models do not explain individual variability in non-native perception. It is assumed that all listeners with a shared L1 map non-native categories into native ones in a similar manner. For example, according to PAM’s predictions, it would be universally challenging for all listeners to perceive a non-native contrast if it is represented as a single category in their L1. However, often individuals demonstrate different perceptual assimilation patterns. Mayr and Escudero (2010) investigated whether native English learners of German vary systematically from each other in the way they map L2 sounds to native categories. They demonstrated that even at the initial stage of L2 acquisition there is substantial variability among learners: some individuals perceived the vowel German contrast in terms of a single native category, whereas other individuals perceived the same contrast as two or more native categories. The authors suggested that, among other factors, L1 accentual properties might influence non-native perception. Flege (2016) also observed that individuals might vary in their L1 phonetic categories, which leads to differences in L1-L2 mappings. He suggested that individual subjects and not groups should be considered as primary units of research analysis. Yet, the models we described above treat listeners’ L1 as a homogeneous entity, assuming that the same native language triggers the same assimilation patterns. These models need to be extended to account for individual variability found within populations with similar profiles. Exemplar-based theories might offer a suitable framework for such an extension.

In contrast to feature-based theories, **exemplar-based theories** interpret L1 speech perception in a fundamentally different manner. Phonetic categories are defined as clusters of experienced instances of speech sounds or exemplars. Because individuals process and store speech sounds together with the acoustic, lexical, and social contexts, in which the sounds occur, phonetic categories are not abstract invariant entities, but rather clusters of specific tokens (Coleman, 2002; Ettlinger & Johnson, 2009). Since phonetic categories are a result of the interplay between an individual's cognitive, affective and social experiences, speakers of the same L end up having slightly dissimilar L1 phonetic inventories that lead to slightly dissimilar perceptual profiles. Thus, the subsequent L0/L2 speech perception would depend on: 1) the perceptual similarity of a new exemplar to the existing cluster of exemplars; 2) the presence of neighboring, competing clusters of exemplars; and 3) the density of the clusters, with more exemplars in a cluster attracting new tokens more strongly (Anderson, Morgan, & White, 2003). In this regard, exemplar-based theories support feature-based theories demonstrating that non-native languages are perceived through the lens of L1. However, exemplar-based theories do not treat L1 as a homogeneous entity and attempt to explain how individual differences in L1 influence L2 perception.

It must be noted that the studies that test the assumptions of exemplar-based modeling are relatively new, and there are no L2 speech perception models that support the exemplar-based approach. Therefore, in this dissertation, we consider exemplar-based theories only as an extension for existing L2 speech models since it is the only account that explains individual differences in native perception.

### 2.3.2 Individual differences and specific languages

As discussed in Chapter 1, some adult learners exhibit learning patterns that do not go along with the developmental trajectory predicted by the existing L2 speech models. Despite the powerful influence of a native sound inventory, some individuals manage to achieve a near-native phonetic and phonological proficiency even when they acquire a language later in life (Ioup et al., 1994; Bongaerts, Planken, & Schils, 1995). On the other hand, some individuals persist listening and speaking with a heavy foreign accent, even when other aspects of the language are mastered – the so-called “Joseph Conrad Phenomenon” (Reiterer et al., 2011).

Taken together, psycholinguistic studies on phonetic talent and L1/L2 speech perception resemble a two-sided street. On the one hand, there is a research paradigm that focuses on individual differences without taking into consideration L1-L2 phonetic distance (the acoustic and articulatory similarities between L1 and L2 sounds) under the assumption that gifted listeners will succeed with any language. On the other hand, some studies investigate cross-language perception with specific language pairs, while analyzing group results and not individual assimilation patterns. Whereas each of the approaches sheds light on L2 acquisition, both approaches should be taken into consideration when investigating how non-native sound inventories interact with individual differences.

Concerning general language learning, MacWhinney (1995) suggested that language aptitude or ability might vary across languages: an individual might succeed in learning one foreign language, but not another. He distinguished between several learning patterns, according to which the learning outcome depended on learner's ability and a specific language, but most importantly – on the interaction between the two. Depending on the nature of the learning ability ("learner's strengths and weaknesses across a wide array of tasks", p. 2) and the linguistic properties that a given language has (e.g., opaque orthography, a complex inflectional system, conceptual complexity), a learner can succeed in language A and fail in language B.

The phonetic ability might also depend on a specific L2 that a listener has been exposed to. It is most likely that existing L1 categories vary across individuals as a result of different linguistic backgrounds and processing mechanisms (as exemplar-based theories describe). This means that for the same novel sound at least two scenarios exist: with the novel sound falling within an L1 category or not. Below a Spanish listener A successfully discriminates between her native /i/ and the novel Russian /ɨ/, whereas a Spanish listener B does not succeed in this task since the novel sound falls within her native category /i/ (Figure 3). The situation is reversed when the same listeners are exposed to a novel English /æ/.

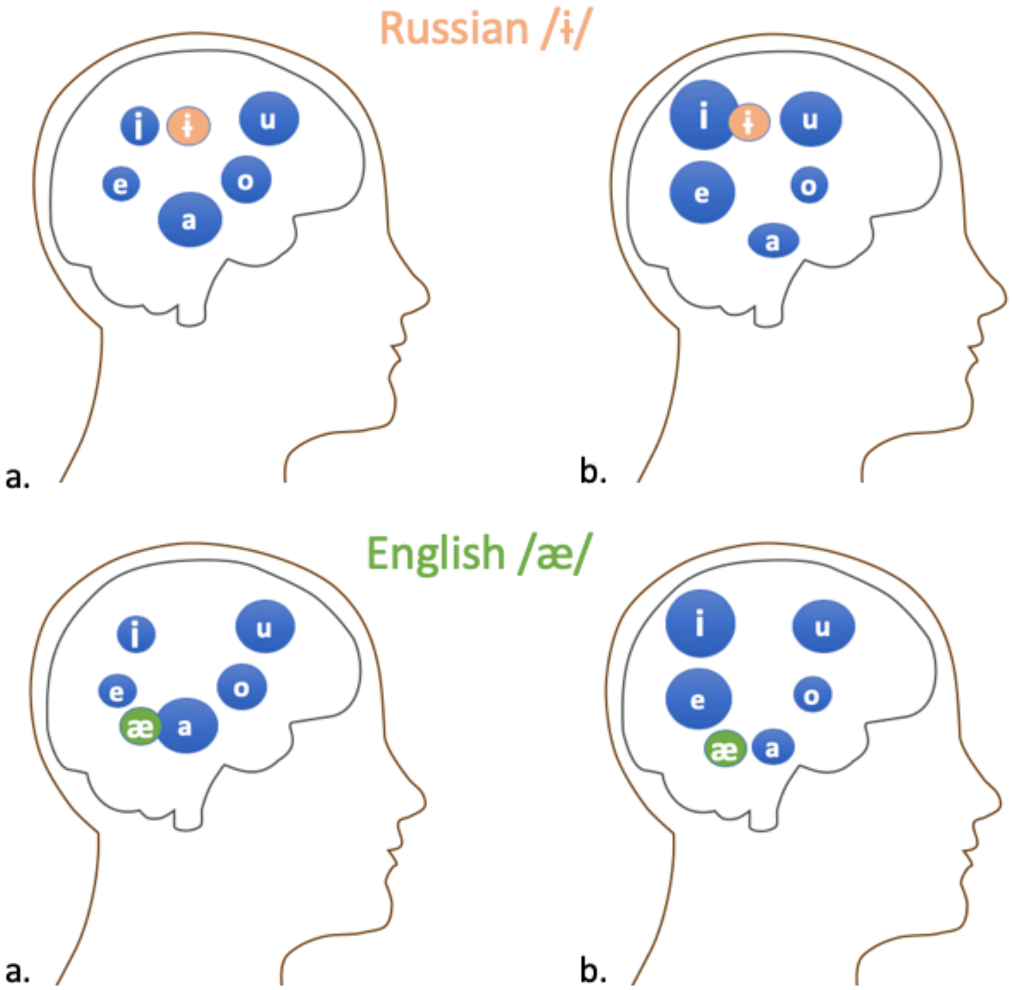


Figure 3. Spanish listeners A and B’s perception of a novel Russian vowel /ɨ/ and English /æ/.

The existing L2 perception models would predict that both Russian /ɨ/ and English /æ/ might posit a challenge for native speakers of Spanish since these sounds are acoustically and/or articulatory similar to Spanish /i/ and /a/ respectively. The studies that investigate phonetic talent would make a different prediction: according to these studies, a more talented listener should succeed to the same extent with discriminating both /ɨ/ and /æ/, whereas a less talented listener will struggle with both sounds. We propose an alternative perspective, according to which some listeners will struggle with some non-native sounds while succeeding with other non-native sounds. The idiosyncratic pattern, in which an individual assimilates a non-native sound to her native category would depend on an L1 perceptual profile, i.e., the properties of a native category and how it is positioned in the psychoacoustic space. Because of the complex nature of such interaction and the lack of previous research that would suggest appropriate methodology and theoretical guidance, in this dissertation, we limited ourselves to exploring only one category property that we believe contributes the most to non-native perception, that is L1 category size or compactness. We looked at the effects of compactness of the Spanish category /i/ on distinguishing a novel Russian contrast /i - **ɨ** /. The following section discusses the proposed contrast in greater detail.

## 2.4 Russian contrast /i - ɨ/ and Spanish /i/

In the present study, we investigated how well native Spanish listeners perceive the distance between two members of the novel Russian contrast /i - ɨ/, which does not exist in Spanish. The Spanish and Russian vowel inventories share the following five vowels: /i/, /u/, /e/, /o/, /a/, but not /ɨ/ that only exists in Russian (Figure 4). It must be noted that some accounts treat Russian /i/ and /ɨ/ as two allophones of the same phoneme /i/ since these vowels occur in near-complementing distribution: /i/ is used after palatalized consonants and /ɨ/ is used after non-palatalized consonants (Farina, 1991; Cubberley, 2002). In the present study, we followed the latest description of the Russian vowel inventory that distinguishes between /i/ and /ɨ/ (Yanushevskaya & Bunčić, 2015).

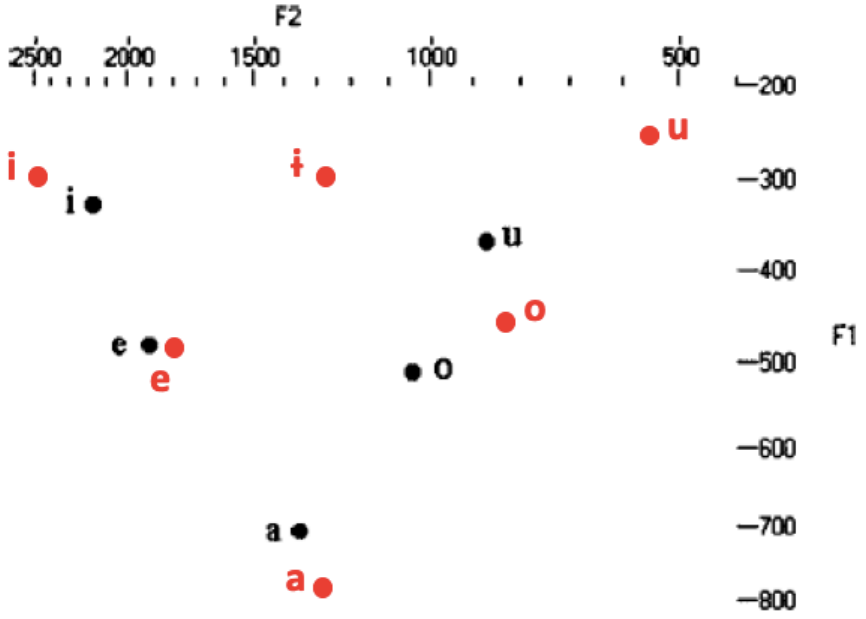


Figure 4. The vowel inventory of Spanish (in black: Martínez-Celdrán, Fernández-Planas, & Carrera-Sabaté, 2003) and Russian (in red: Jones, 1953; Yanushevskaya, & Bunčić, 2015).

This study focuses on the perception of vowels and not consonants because vowels are produced with higher intensity, longer duration, and more acoustic dimensions than consonants. These characteristics allow for the detection of the subtle perceptual differences and ensure that these differences are robust. Best, Halle, Bohn, and Faber (2003) also observe that vowels are much fewer in number, which makes them more variable than consonants among languages and dialects. Since we investigate individual differences, we assumed it would be also easier to observe individual variability in vowel perception, than consonant perception. We also assumed it would be easier to observe individual variability in vowel perception in a language with a small vowel inventory. Previous research in production has shown that vowel system size could affect vowel variability, with fewer vowels (a less crowded vowel space) imposing more vowel variability (Recasens & Espinosa, 2006). For that reason, Spanish was selected as L1 in this study.

There are several reasons why the Russian contrast /i - ɨ/ was selected to test participants' non-native perception. First of all, L2 learners of Russian whose native language does not have the above-mentioned contrast almost universally struggle with it in both perception and production (Andreyushina, 2014; Shutova & Orehova, 2018). Spanish learners are not an exception: even at the higher levels of language proficiency, both Russian /i/ and /ɨ/ are often assimilated to single Spanish /i/ (Klimova, Yurchenko, Cherkashina & Kulik, 2017). This observation goes along with the theoretical explanations offered by the L2 perception models that predict difficulty with non-native sounds that are similar to L1. Russian /ɨ/ is acoustically very similar to Spanish /i/ (Figure 4), yet it is a distinct phoneme in Russian that is used contrastively with /i/. According to the Native Language Magnet Theory (NLM and NLM-e: Kuhl, 1993; Kuhl et al., 2008), the closer a novel sound is to an L1 category acoustically, the harder it is to perceive it. When listening to Russian /ɨ/ Spanish listeners experience “a gravitational pull”, i.e., their native category /i/ acts as a magnet for a novel sound /ɨ/ preventing its accurate perception.

According to the Perceptual Assimilation Model (PAM and PAM-L2: Best, 1993, 1994, 1995; Best & Tylor, 2007), the problem lays in the proximity between the articulatory gestures required for the production (and therefore, for the perception) of /i/ and /ɨ/. Russian /i/ is a high front unrounded vowel that is very similar to Spanish /i/, and, thus, virtually indistinguishable from it, i.e. “a good exemplar” of Spanish /i/. In this case, PAM predicts no further perceptual learning for Russian /i/. However, Russian /ɨ/ is a high central unrounded vowel – the category that Spanish lacks. Most likely, Russian /ɨ/ would be perceived as deviant with respect to Spanish /i/, the closest corresponding L1 phonetic category. When one member of the L2 contrast is perceived as a good exemplar of a given L1 and the other member – as a deviant exemplar of L1, the type of assimilation is called category-goodness assimilation. The discrimination is predicted to be hard or difficult depending on the phonetic and auditory similarity between the L2 sounds, but usually, a listener is able to perceive a considerable difference between the two. The other PAM scenario, single category assimilation, describes the situation when both L2 categories are perceived as equally good or poor exemplars of the same L1 category. In this case, the discrimination is predicted to be poor as both L2 sounds are merged with the given L1 category. Klimova, Yurchenko, Cherkashina, and Kulik (2017) report the singular category assimilation pattern for Russian /i - ɨ/ by Spanish learners. There is only a handful of studies that investigated the acquisition of Russian phonetics and phonology by Spanish learners, with no studies reporting the details of the assimilation patterns for the Russian /i - ɨ/ contrast by Spanish listeners. Several patterns might be possible as Russian vowels vary greatly as a function of the lexical stress and consonantal context. In some situations, the perceived distance between Russian /i/ and /ɨ/ could be greater allowing for category-goodness assimilation; in other situations, the perceived distance could be minimal calling for single category assimilation.

The Speech Learning Model claims that the difficulty in acquiring L2 sounds comes from the learner's tendency to relate new sounds to the existing positional allophones — a process called "equivalence classification". In our case, equivalence classification ensures that the key feature that distinguishes Spanish /i/ from Russian /ɨ/, [-+back], gets filtered out, resulting in perceptual equivalence between /i/ and /ɨ/.

The acoustic and articulatory proximity of /ɨ/ to /i/ could be the reason why /ɨ/ is not commonly present across languages: only 16% of 2186 languages reported in PHOIBLE repository of the phonological inventory data have /ɨ/ as an independent phoneme. In comparison, 92% of 2779 languages reported in PHOIBLE have /i/ as an independent phoneme (Moran, & McCloy, 2019).

The second reason for choosing the Russian contrast /i - ɨ/ to test L0 perception had to do with the fact that the Russian language is not frequently spoken or taught in Spain, and we were, therefore, able to ensure that our participants did not have any previous experience with the target vowels. At the same time, both Russian and Spanish are similar in the way they use vowel duration across various contexts: e.g., in both languages vowels are longer before voiced than before voiceless consonants (Kondaurova & Francis, 2008), which would ensure that the participants would not get distracted by irrelevant acoustic cues, i.e., focus on the qualitative (spectral) and not quantitative (duration) differences between the sounds. Lastly, we are not aware of other studies that investigated the perception of Russian sounds by Spanish listeners. Moving away from the celebrated tense-lax English contrast /i - ɪ/ and introducing a less-researched vocalic pair has been viewed as a contribution to the studies on the acquisition of the Russian phonology.

The Spanish /i/ was chosen for use in this study because it is one of the three-point vowels (/i/, /a/, and /u/) that are at the articulatory and acoustic extremes of the vowel space (Jakobson, Fant, & Halle, 969), which makes it more stable and less susceptible to changes within an individual psychoacoustic space. It is important to take such intra-individual variability into consideration since previous research has shown that speech perception is affected by a number of intra-individual factors: e.g., the levels of various hormones in the body (Sao, & Jain, 2016) or time of the day (Veneman, Gordon-Salant, Matthews, & Dubno, 2013). These and other factors trigger fluctuations in the central auditory processing and psychoacoustic capabilities of an individual. For that reason, the "point" vowels (/i/, /a/, and /u/) are more reliable for perceptual experiments.

## 2.5 Summary

This chapter has discussed the nature of speech perception and the theoretical models that explain how L1 perception affects the processing of non-native sounds. These models suggest that listeners become attuned to specific acoustic-phonetic properties of their native language early on. Once the native sound system is in place, it is difficult to modify it (although not impossible). Listeners' L1 functions as a filter and impedes accurate perception of novel sounds, which tend to be mapped to the existing native categories; this process is labeled by different models as gravitation pull, category assimilation, or equivalence classification. The described models treat L1 as a homogeneous entity and do not differentiate between individual differences within the same language. Exemplar-based theories also emphasize listeners' reliance on the L1 established phonetic representations that shape L2 speech perception, but they challenge the idea of L1 convergent on the same L1 phonetic representations. According to exemplar-based theories, phonetic category development is guided by the distributional nature of the input, which is processed and stored in memory with intricate phonetic details. As a result, idiosyncratically-shaped native sound categories vary across individuals, even within the same L1 community. L1-based variability is manifested in various degrees of perceptual sensitivity towards novel sounds affecting non-native speech perception. This previously unaccounted-for systematic source of individual variability might be responsible for some individuals' success in discriminating non-native contrasts, perceptually "invisible" for others, and for the bases of phonetic talent.

# Chapter 3 – Individual differences in L1 speech perception

## 3.1 Introduction

In recent years, linguistics has been undergoing a theoretical shift: once influential, mentalist theories that emphasize invariable structures, are rapidly getting replaced by usage-based approaches to language acquisition. Cognitive science gave birth to the idea that linguistic knowledge is shaped by language use and that speakers learn the language by subconsciously analyzing and storing a vast amount of information about co-occurrent frequencies of words and structures (Ellis, 2006; Langacker, 1987). Theories of categorization such as prototype and exemplar-based theories describe linguistic categories as having probabilistic structures and ambiguous boundaries (Johnson, 1996; Pierrehumbert, 2001). From the social perspective, linguistic categories emerge as a result of the alignment between a speaker and a listener (Goldinger, 2007; Lev-Ari, 2017, 2018).

This recent theoretical shift introduces a new approach to speech processing and categorical perception of speech in particular (a phenomenon of perception, in which continuous stimuli are sorted into discrete categories: Liberman, Harris, Hoffman, & Griffith, 1957). Traditional accounts hold that listeners strip the acoustic signal of all extraneous noise and pay attention only to higher-level categorical phonetic information. In other words, the mental representations are simple and the mapping is complex – this approach assumes minimal inter-listener variability. However, the normalization required for processing at this level is still not specified by previous research: we do not know how and what kind of variability has to be removed in order to normalize the input at the prelexical level. Contrary to this approach, another line of research argues that listeners do attend to lower-level phonetic detail, such as speaker identity or speaker rate when processing speech (e.g., Goldinger, Pisoni, & Logan, 1991; Dellwo, Pellegrino, He, & Kathiresan, 2019). According to this view, the mental representations are complex — they constitute a myriad of acoustic forms stored in perceptual space, and the mapping is simple. This approach assumes substantial inter-listener variability in speech perception.

Because of the early emphasis in the field on the abstract nature of phonetic categories, individual differences in speech perception have been largely ignored. Only recently, the field of psycholinguistics, and psychophonetics, in particular, turned its attention to systematic sources of inter-listener variability in L1 perception (Yu & Zellou, 2018; Zellou, 2017). In this chapter, we review recent research and identify the possible causes of such variability. Thus, the chapter is structured as follow: first, it introduces the concept of individual differences in native perception; next, it provides an overview of the internal and external factors that might be responsible for such differences; and finally, the concept of category compactness in L1 perception is introduced. Below we will discuss variability in both perception and production, assuming a direct connection between the two.

## 3.2 Individual differences in native perception

Each individual acquires the phonetic patterns of their speech community using their idiosyncratic physiological and cognitive characteristics that, in turn, influence perceptual representations and shape how each listener experiences incoming speech. Listeners within a single speech community might, in fact, have different perceptual representations for the same phonological units. The differences among native speakers have not been considered seriously, mostly due to the SLA research focus on the idealized speaker/listener and abstract invariants. However, recent studies have examined the way native speakers and listeners use and comprehend their native language. For example, Zellou (2017) demonstrated that native speakers of American English use different patterns of perceptual compensation for nasal coarticulation. Assuming the gestural nature of speech representations, Zellou suggests that the sound representations of each individual differ from those of the community due to idiosyncratic articulatory anatomy (e.g., vocal tract architecture). Listeners use their individual phonetic knowledge of coarticulation and its acoustic consequences to determine how much acoustic variation in speech should be parsed, which results in dissimilar listener-specific expectations. This approach implies that there is a connection between production and perception, although Zellou observes that this connection is not as straightforward as we would expect ("I produce what I hear"). The production-perception loop is rather complex and multifaceted, i.e. might involve a range of cognitive processes, not necessarily language-specific, but also domain-general (e.g., Sonderegger & Yu, 2010).

Inter-speaker variability in nasal phonation in production has been widely used in forensic phonetics for speaker identification purposes. For example, Su, Li, and Fu (1974) demonstrated how the coarticulation between [m] and the following vowel context can be used as a reliable acoustic cue for identifying speakers. In forensic phonetics, nasal consonants and nasal-plus-vowel sequences are viewed as one of the most consistent speaker-specific characteristics or idiolectic staples because their production relies on the shape, size, and rigidity of the nasal cavity, which cannot be easily altered (Nolan, 1983; Rose, 2002). Such variability in the speaker's anatomy is an example of the "organic" source of inter-speaker differences, as opposed to the "learned" differences that constitute dialectal traits and sociolects. Numerous studies in forensic phonetics and sociophonetics have demonstrated that even though two individuals may be similar in terms of nature and nurture, they still exhibit differences in the native phonetic patterns they use. For example, Nolan and Oh (1996) reported differences in the realization of the sounds [r] and [l] in identical twins. A more recent study by Loakes (2006) investigated the variability in the degree of frication of [k] and [p] in identical twins with a similar conclusion.

Although forensic phonetics has accumulated a large number of studies that demonstrate variability within the same speech community, these studies have shed little light on differences in L1 perception. In the present study, we assume that production and perception utilize the same representational structures, and thus individual differences in production are reflected in individual differences in perception, and vice versa. Here we use the term individual differences and individual variability to refer to differences in how phonetic categories are represented in both perception and production across speakers of the same language: it includes category size (compactness), category boundaries and the internal structure of categories (distribution of sound invariants in their relation to a prototype).

Below we discuss how native perception and production are shaped by anatomical and cognitive individual differences and linguistic experiences. We differentiate between internal and external factors that affect L1 variability (as seen above, they are often labeled as “organic” and “learned” factors): internal factors refer to the anatomical architecture and cognitive processes that support the way individuals process, acquire and use language, whereas external factors have to do with sociocultural and environmental factors that affect language.

## 3.3 Internal factors that result in L1 variability

In the following paragraphs, we discuss how anatomical and cognitive architecture affect individual differences in sound perception and production. We will first review previous research on language-related functional anatomy and how it affects the production-perception loop, followed by the review of the cognitive factors.

### 3.3.1 The anatomy of speech sounds

Individuals vary in systematic ways in their physiological and biomechanical parameters: larynx morphology, vocal tract geometry, palatal shape, and tongue muscles are among the properties that might be responsible for inter-speaker variability. Such variability, in addition to other factors that drive language change, might be responsible for the diversity observed in sound systems around the globe (Brosnahan, 1961). Even though the normal variability of a human articulatory apparatus does not prevent an individual from speaking intelligibly, it does not mean that the speech produced is identical to that of all other speakers. Tiede, Gracco, Shiller, Espy-Wilson, and Boyce (2005) investigated speaker preferences for different tongue shapes in the production of American English /r/ in relation to palatal morphology and demonstrated that such preferences have acoustic consequences in some contexts. Winkler, Fuchs, and Perrier (2006) showed relationships between speaker-specific vocal tract geometries and their articulatory vowel space. Their results indicate that speakers with longer pharynxes have larger degrees of freedom in the vertical direction and produce larger displacements between low back and high front vowels than speakers with shorter pharynxes.

The differences in production influenced by vocal tract morphology might affect speech perception as well. The Motor Theory of speech perception (Liberman & Mattingly, 1989; Liberman & Mattingly, 1985; Liberman, Cooper, Shankweiler, & Studdert-Kennedy, 1967) proposes that humans perceive speech sounds as the intended vocal tract gestures of the speaker and assumes that the production and the perception of speech share the same neural processes and representations. The discovery of a class of mirror neurons in monkeys and humans (Gallese, Fadiga, Fogassi, & Rizzolatti, 1996; Rizzolatti, Fadiga, Gallese, & Fogassi, 1996) — the neurons that respond both when an action is performed and when it is seen — confirms the link between the sender and the receiver that Liberman postulated (Meister, Wilson, Deblieck, Wu, & Iacoboni, 2007; Pulvermuller et al., 2006). In their study, Meister and colleagues (2007) proposed that the listener perceives speech by simulating the articulatory gestures of the speaker. They applied repetitive transcranial magnetic stimulation to the premotor cortex to disrupt participants' ability to perform a phonetic discrimination task and showed that such a disruption impairs speech perception as well. Another study by Wilson, Saygin, Sereno, and Iacoboni, (2004) examined whether passive listening of meaningless monosyllables activates the motor areas involved in speech production. The researchers concluded that speech perception employs the motor system in a process of auditory-to-articulatory mapping. Lastly, a recent study by Lüttke, Pérez-Bellido, and de Lange (2018) on the rapid recalibration of speech perception after experiencing the McGurk effect provides one more piece of evidence to support a strong connection between articulatory gestures and auditory processing. The McGurk effect is a perceptual illusion that occurs when conflicting auditory (/aba/) and visual (/aga/) inputs are presented together, which leads to a different percept (/ada/). In Lüttke, Pérez-Bellido, and de Lange's study (2018), the ambiguous visual input resulted in a subsequent recalibration of the phonetic boundaries and affected how the syllable /aba/ was later categorized. Based on these and other recent findings, variability in L1 production due to individual articulatory constraints might lead to variability in L1 perception as well. This connection is important for the present study that investigates the effects of individual differences in L1 perception and how they influence non-native speech perception.

### 3.3.2 Individual differences in cognition

Previous studies have identified that the process of transforming the auditory signal into accurate phonological representations is modulated by higher-level cognitive processes, such as attention and phonological short-term memory. For example, when attentional resources are reduced, as, during a dual task when cognitive load is present, a detailed phonetic analysis is compromised (Mattys & Wiget, 2011). On the other hand, engaging the attentional focus by intensifying the signal improves perceptual sensitivity (Francis & Nusbaum, 2002). Conboy, Sommerville, and Kuhl (2008) argue that attentional abilities support fine-tuning perceptual representations during the first year of life. Contrarily, a pathological lack of attention can lead to developmental disorders such as dyslexia, characterized by unstable and variant phonemic representations (Ruffino et al., 2010). Thus, individual differences in attention control might lead to individual differences in L1 perception and affect the properties of phonological representations.

Not only paying attention but also inhibiting it (the cognitive ability called inhibitory control) is an important ability for phonological acquisition. Lev-Ari and Peperkamp (2014) examined whether there is a relationship between French speakers' inhibitory control and their perception of voiced stops in words that have a voicing neighbor. Inhibitory control might be responsible for disengaging from a previous stimulus to process the rapidly successive one. This alternation between engaging and disengaging attentional resources enables a listener to capture every single stimulus of the acoustic signal. Deficiencies in this mechanism may result in impoverished sensory analysis and lead to degraded phonological representations. Lev-Ari and Peperkamp (2014) found that inhibitory control is responsible for enhanced perception. They also concluded that the type of inhibition that the listeners in their study used relied on the domain-general and not language-specific mechanisms, as demonstrated by the performance on the Simon task (the Simon task measures inhibitory control with visual stimuli). A growing number of neuroimaging studies also confirmed the domain-general nature of the inhibitory control network that operates in speech processing: it seems there are similarities between the cortical circuitries engaged in auditory and visual attention switching. Ou and Law (2017) came to the same conclusion by investigating the neural responses (event-related potentials or ERPs) to two Cantonese rising tones among typically developed native speakers. They argued that it is the individual differences in domain-general attention control that affect the quality of perceptual representations by regulating how listeners encode and represent acoustic cues in the signal. Individuals with better attention control were proposed to have more distinctive tonal representations, and vice versa: less optimal attention skills led to less distinctive representations. These results are compatible with other studies that claim that perceptual sensitivity to speech sounds is modulated by domain-general attention that is not specific to language processing only (Diza, Baus, Escera, Costa, & Sebastián-Gallés, 2008; Jesse & Janse, 2012).

Previous studies have demonstrated that phonological short-term memory also plays a role in speech processing affecting the quality of phonological representations (Burgess & Hitch, 2005; Gupta, 2003; Jacquemot & Scott, 2006: Majerus & Lorent, 2009). As we explained in Chapter 1, phonological short-term memory consists of transient storage and an active subvocal rehearsal component (Baddeley, 1986; Gathercole, 1999). The transient storage stores the most recent auditory speech item in its sensory form, i.e., preserving its physical features. An active subvocal rehearsal component refreshes and maintains the information derived from the signal for further perceptual analysis and segmentation. Individual differences in phonological short-term memory lead to variable ability to keep relevant information active in memory, and therefore, to decode it accurately. Individuals with the greater phonological short-term memory capacity might be more successful in processing relevant cues in an acoustic signal, resulting in more precise representations in comparison to individuals with the poorer phonological short-term memory ability (Aliaga-Garcia, Mora, & Cerviño-Povedano, 2011). The relationship between phonological short-term memory and speech processing is especially pronounced in situations where damage or innate deficits in phonological short-term memory (as in Down syndrome or dyslexia) impair the performance in the phonological analysis (Jacquemot, Dupoux, Odile, & Bachoud-Levi, 2006; Jarrold, Thorn, & Stephens, 2009).

There are other less researched cognitive skills, such as information integration, cue weighting, and cognitive processing styles, that might play a role in L1 perceptual variability (Kong & Edwards, 2016; Yu, 2013). The studies that investigate these skills represent the growing interest in a systematic heterogeneity among individuals in L1 perception. However, more research is needed to make conclusive inferences based on these studies. Many open questions remain unanswered. In their recent review of the studies on individual differences in L1 phonological processing, Yu and Zellou (2018) concluded that “individual variability [in cognition] highlights the fact that the shared linguistic system is more complex and adaptive than group-level means can reveal” (p. 6.14). The study of the cognitive sources of individual variability not only allows us to understand the fundamental mechanisms involved in native speech processing but also how these mechanisms shape the perception of novel sounds. The present study aims at catalyzing more research to address this question.

## 3.4 External factors that result in L1 variability

Inter-speaker variability in speech production and perception not only correlates with cognitive and anatomical (internal) factors, but also with environmental and sociocultural (external) factors such as speaker gender (as a sociocultural construct), geographical origin, social class, and group affiliation. Often, there is no clear division between a socially-constructed behavior (e.g., learned patterns of phonetic realization that is characteristic of a particular gender: Lee, Hewlett, & Nairn, 1995) and biological differences (e.g., physical variability between speakers of different sexes: Laver, 1980). At other times, variability is determined by social factors alone: e.g., rhotic accents in the English indexing class (Wells, 1982).

From the exemplar-based perspective, sociophonetic variability in speech perception is the result of continued exposure to a community of speakers with specific characteristics, which are retained in the exemplars. Since no two individuals can possibly interact with identical populations of speakers at all times, there is variability in the distribution of the remembered exemplars within the cognitive space (Johnson, 1997). For example, depending on what kind of linguistic experience an individual has undergone, there will be categories with a large or limited representation of tokens. The time frame also matters since exemplars of newly stored experiences have a higher activation level than exemplars of temporally remote experiences. The idiosyncratic inner organization of categories plays a crucial role in the classification process of new tokens: the labeling process not only depends on the similarity between a new token and a stored exemplar but also on the activation strength of this exemplar. As perception and production rely on the same pool of exemplars (Pierrehumbert, 2001), the most frequent and recent exemplar is then recovered for production. This goes along with the research on adaptation processes in dialogue: for example, Pickering and Garrod (2004, 2006) showed that patterns that are heard frequently and recently guide the consequent production. Thus, speakers adapt and update their speech patterns as a function of the social roles and contexts that they experience. In other words, individual language experiences that are influenced by socio-environmental factors explain the inter-speaker variability in production and perception.

### 3.4.1 Regional dialects

Because of the challenges associated with experimental design and the indirect ethereal nature of perception, sociophonetic variability in perception has been studied far less than in speech production. Yet, a number of studies have investigated how individuals differ in this regard (e.g., Clopper & Pisoni, 2004; Evans & Iverson, 2004). Most commonly such studies are dialectal variation experiments focusing on the description of dialects, attitudes towards dialects and the perception of vowel mergers across dialects. In Clopper and Pisoni's (2004) study listeners had to categorize American English talkers by region. The results showed that perceptual similarity between a speaker's dialect and a listener's dialect played a role in this task. A number of studies on merged vowels also demonstrated perceptual biases in listeners of different dialects. Generally, speakers of merged dialects (e.g., the pin-pen merger in the U.S.) struggle to discriminate between the vowels of the target contrast (Bowie, 2001; Evans & Iverson, 2004). In Lengeris' study (2016), speakers of the standard variety of Greek and two regional dialects also showed dialect-induced differences in the positioning of vowels in the perceptual space. In yet another study, Escudero, Simon, and Mitterer (2012) examined the perception of native speakers of Dutch spoken in North Holland (the Netherlands) and in East- and West-Flanders (Belgium) and found that the two listener groups differed in how they classified non-native English /æ/ and /ɛ/. The North Holland listeners classified the English /ɛ/ more accurately than /æ/, while the Flemish listeners had a 61% correct classification for both vowels. Escudero, Simon, and Mitterer (2012) explained it by dialectal variation in the acoustic properties of the Dutch /ɛ/ that leads to differences in perception of non-native vowels. They argued that the exact acoustic vowel properties in L1 can predict how vowels of a non-native variety will be perceived. The latter finding is highly relevant to our study:

if native dialects influence second-language vowel perception then idiolects (individual dialects) might lead to variable non-native perception as well.

### 3.4.2 Social network size

Even though phonetic learning early in life results in a relatively stable specialized sound inventory, this does not mean that native categories cannot change once they are learned. Systematic shifts in production — for the language community as a whole (Labov, 1994) and for individual speakers (Pardo, Gibbons, Suppes, & Krauss, 2012) require adult listeners to adjust the category boundaries and the internal structure of a phonetic category. In the perceptual learning experiments done by Miller and colleagues, the listeners were able to shift the voicing boundary (voice onset time or VOT) and relabeled the particular category exemplars as the "best" ones (longer or shorter VOT) to accommodate speaker-specific phonetic detail, i.e. speaker differences in VOT (Volaitis & Miller, 1992; Theodore & Miller, 2010). In Chang's (2013) study novice L2 learners demonstrated systematic phonetic changes in their L1 production – the "phonetic shift" – after just a short exposure to a novel sound system. From the literature on perceptual learning in speech we also know that listeners can use lexical information to adjust the category boundaries between individual speech sounds to include a new member into an established phonetic category (e.g., Norris, McQueen, & Cutler, 2003; Sumner, 2011). Such learning is long-lasting (Eisner & McQueen, 2006) and generalizes to novel utterances (Kraljic & Samuel, 2006; Hay, Drager & Warren, 2010).

There is a sizable body of evidence that demonstrates that listeners constantly update their priors to match environment-specific statistics: when the statistics of the environment change, so do the representations (Jaeger & Snider, 2013; Chang, Dell, & Bock, 2006). In a series of studies, Lev-Ari (2016, 2017, 2018) showed that listeners are not only sensitive to the raw frequency of a certain behavior, but also to the number of sources that exhibit it. She argues that the weight ascribed to each source decreases with the increasing number of sources, i.e., the more sources we have the less informative each of them is. People who have fewer interlocutors assign greater weight to each person they encounter, and therefore, have more malleable phonological representations. For example, individuals with small social networks are more likely to change their perceptual boundary between /d/ and /t/ following exposure to a speaker with atypical productions (Lev-Ari, 2017). Thus, social network size modulates how susceptible individuals are to the influence of each interlocutor. This variable leads to fundamental differences in the boundaries of phonetic categories between the listeners that live in urban areas (a larger social network) and the listeners that reside in less populated locations (a smaller social network). According to Lev-Ari, the latter group would be more flexible in altering the location of the category boundary when confronted with a novel token. However, Theodore, Myers, and Loibao (2015) observe that not any novel token would cause boundary adjustments. They presented their participants with an unambiguous, well-defined category member and found that even though the participants robustly reorganized the internal structure of their category (i.e., established a new category prototype), they have not modified the category boundary. The authors concluded that the nature of stimuli matters and listeners adjust the boundaries only when they have to resolve ambiguity in the signal. Another explanation of why listeners might be overcautious in adjusting their phonological representations is that such adjustments do not take place overnight. It is more likely that longer exposure to a particular speaker or accent is needed for noticeable changes to occur. For example, listeners from northern England in Evans and Iverson's study (2004) consistently used their native northern vowel categories when listening to SSBE (Standard Southern British English), even though they received regular exposure to SSBE through the media.

Their compatriots from the north, who had been living in London for one year and had been exposed to SSBE for longer and more consistently, demonstrated a different pattern: they adjusted their best exemplar locations to match the southern prototypes. The authors concluded that although the adaptation to accent patterns does take place, it may require a longer experience with the speakers of that accent. But once perceptual recalibration takes place, it seems to last (Eisner & McQueen, 2006).

It is not only regional accents that influence native perception. Listeners adjust category boundaries differently in response to male and female speech. Strand and Johnson (1996) asked participants to identify tokens from a synthesized continuum between /ʃ/ and /s/. Participants were more likely to have a higher perceptual boundary between the phonemes when the stimuli were paired with a photograph of a female face. Speaker age is another factor that affects individual perception. For example, participants in Drager's (2005) study tended to shift a perceptual boundary between /e/ and /æ/, when the voice sounded younger. In another study, Hay, Warren, and Drager (2010) not only manipulated the speaker age, but her social status as well, and concluded that social characteristics of a speaker can systematically influence the perception.

To summarize, recent research suggests that not only during the first year but also later in life the listeners continue developing perceptual biases towards the acoustic properties of the speech in their environment. The characteristics of the social network continuously influence the nature of the input listeners receive, and consequently, their speech perception. The idiosyncratic combination of factors such as L1 community demographics and density, geographical location and perceiver's social status, together contributes to a relatively stable perceptual idiolect that is manifested in the preferences for specific sound prototypes (a higher density of exemplars in particular areas within a category: Johnson, 1997; Pierrehumbert, 2001). Even though individual differences in native perception might be small — ultimately all listeners of the same L1 understand each other well most of the time — they might play an important role when a new language has to be learned. From studies in language evolution we know that small individual differences or weak biases should not be dismissed, as they might have an impact on the larger timescale, i.e., they get amplified through multiple repetitions (bias amplification: Kirby, Dowman, & Griffiths 2007; Dediu, 2011). In this regard we can refer to an individual's L2 journey as one person's language evolution: small differences in native perception, not easily observable in their "static" state, get amplified by the repeated language use creating robust emergent patterning that affects non-native perception. Thus, small L1-based individual differences might be a systematic source of variability in L2 perception and partially explain outstanding gains in L2 phonetics and phonology (i.e., phonetic talent).

## 3.5 The notion of compactness and its effects on L2

As we observed earlier, native inter-speaker variability has not been a prevalent topic within language acquisition research. It has been assumed that native speakers have uniform performance in L1 acquisition, which led to further claims about a critical period and the fundamental difference between L1 and L2 acquisition (e.g., Andringa, 2014). However, a large body of evidence that has accumulated in the past decade challenges the notion of a uniform native speaker competence. We now know that native speakers vary considerably, even in the domain of phonology, which depends on lower-level functions, forms early in life and, therefore, is harder to modify than other linguistic subsystems (e.g., morphosyntax). This L1-based variability comes from the differences in the quality and quantity of the input and in the ways it is processed — that it is, although not to the same extent, triggered by the same factors as variability we observe in L2 acquisition.

One way to measure L1-based differences in perception is to look at the distribution (compactness) of tokens within a given perceptual category. A measure of category compactness has been used before in production studies with vowels; it has been referred to as category compactness (Kartushina & Frauenfelder, 2013, 2014), but also – the degree of variability of a vowel (Recasens, & Espinosa, 2006, 2009) or the size of a vowel space (Meunier, Frenck-Mestre, Lelekov-Boissard & Le Besnerais, 2003). For example, Kartushina and Frauenfelder (2013) define compactness in production as "the amount of variation observed for the production of the same sound by the same speaker" (p. 2119). They used the concept of compactness to describe the distribution of the phonetic realizations for an L1 vowel and then related individual compactness indices to the perceptual accuracy of similar L2 vowels. Their hypothesis stated that speakers with broadly distributed categories were less successful at perceiving L2 vowels than speakers with more compact categories. To obtain the category compactness index, Kartushina and Frauenfelder (2013) collected and analyzed reading data, from which the vowels of interest were extracted and the first two formants (F1 and F2) were measured for each participant. Using the formula for the area of the ellipse $A = xy\pi$ (the distribution of the produced tokens was assumed to be elliptical), where x was the F1 standard deviation and y was the F2 standard deviation, the authors were able to visualize the acoustic space that corresponded to an individual's compactness index (Figure 5). The results of this study showed that L1 compactness in production predicts L2 perception of the acoustically similar vowels. Kartushina and Frauenfelder (2013) emphasized the importance of using individual rather than group data to account for differences in L1 phonological space.

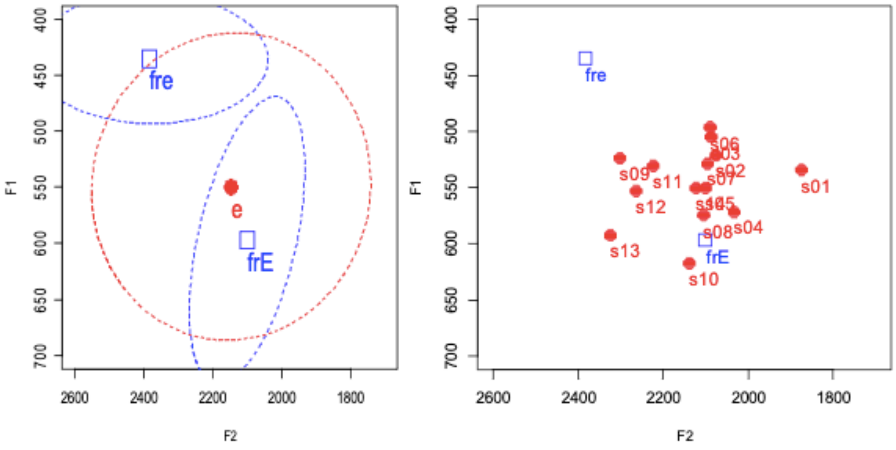


Figure 5. Group (on the left) and individual (on the right) mean formant values for Spanish /e/ in red and French /e, ɛ/ in blue in production (Kartushina & Frauenfelder, 2013, p. 2120).

In the follow-up study (Kartushina and Frauenfelder, 2014), the authors calculated the global compactness index for all native vowels to predict L2 production performance. They found significant effects of L1 compactness on L2 accuracy in production.

A similar study by Meunier, Frenck-Mestre, Lelekov-Boissard and Le Besnerais (2003) focused on differences in category compactness between languages, not individuals and compared the acoustic-articulatory spaces of French (10-12 vowels), English (13-15 vowels), and Spanish (5 vowels). They concluded that the Spanish and French spaces showed little to no overlap between categories (tighter, more compact categories overall), whereas in English, certain vowel categories were completely contained within the space of other vowels (see Figure 6). When faced with a categorization task, in which the participants had to transcribe native and foreign vowels, the English speakers struggled the most, unlike the Spanish and French speakers who did not find the task difficult. The authors argued that the density of the L1 vowel system (and the size of phonetic categories that depends on the density) may play a role in L2 perception.

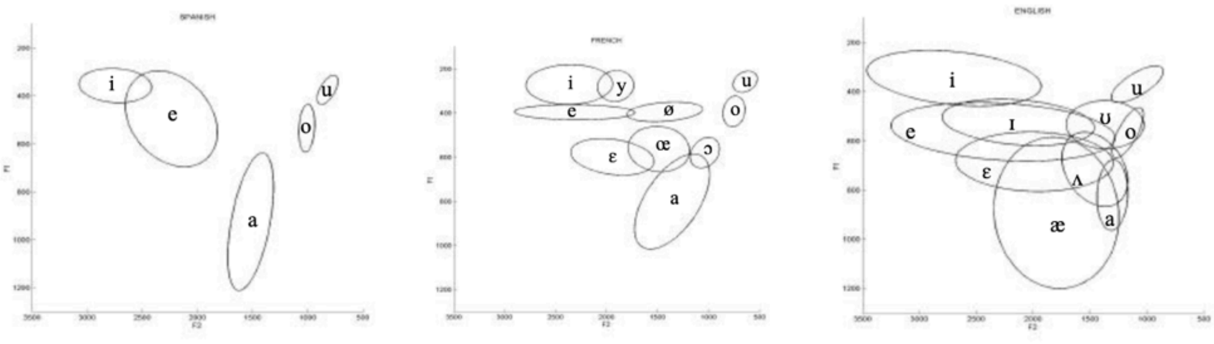


Figure 6. Vocalic spaces for Spanish, French and English languages (Meunier et al., 2003, p. 724-725).

The concept of category compactness in production can be used in perception as well. This idea has been introduced in the DIVA model (Guenther, 1995; Guenther, Hampson, & Johnson, 1998). In this model, the goals for articulatory movements to produce specific vowels are regions in multidimensional auditory-temporal space: the amount of separation among the regions for different vowels and the region size determine the degree of clarity, with which a vowel is perceived. According to DIVA, individuals whoso auditory regions for different vowels are smaller and spaced further apart perceive greater acoustic details in comparison to individuals whose auditory regions overlap. Perkell et al. (2004) used DIVA to test a link between native production and perception within individual speakers. They concluded that a distinct and compact production of similar contrastive vowels, such as [ɪ] and [i], predict accurate discrimination of these vowels. In other words, compact categories in perception would result in compact categories in production, and vice versa, since both types of categories rely on the same auditory goal regions.

Building on previous research, the present study aims to further explore the concept of category compactness in L1 perception by measuring the distribution of a vowel category in the psychoacoustic space. Using Kartushina and Frauenfelder's (2013) definition for compactness in production, we describe category compactness in perception as the amount of variation observed for the perception of the same sound by the same speaker. Because in our study we are avoiding production measures altogether, we are obtaining a more direct representation of a perceptual category that is not influenced by articulatory skills. To our knowledge, there is currently no report in the literature of a preceding attempt to study category compactness in perception in its relation to L2 phonological acquisition. We also hope to contribute to a growing body of research on L1-based individual differences in perception that might not only explain so-called phonetic talent but shed light on other puzzling perceptual phenomena such as speech perception deficits, when information transmission of phonetic features is impaired.

## 3.6 Summary

In this chapter, we discussed individual differences in the same native language production and perception (demonstrating that they are connected) and how they change during the lifespan. The notion that variability in perception is the result of the interaction between the internal or "organic" differences of an individual (such as the anatomy of articulatory apparatus and cognitive functioning) and the external or "learned" factors (found in the environment) has been the inspiration and the leitmotif of the present study. As an individual engages in communication, she dynamically con-constructs her perceptual reality that changes constantly in response to an individual's unique characteristics, but also in response to the emerging socio-cultural context. We are aware of the fact that most likely individual differences in native perception are minimal – otherwise, communicating in the same language would be no different from speaking different languages to each other – yet, we believe that even small individual differences might play an important role when a novel sound system is introduced. A number of studies already demonstrated that individual differences in L1 production measured by the degree of compactness of phonetic categories influence the initial stage of L2 perceptual learning. The goal of the present study is to test the same hypothesis for non-native perception.

## 3.7 Aims, research questions and hypotheses

This dissertation aims at investigating one aspect of non-native phonetic ability in perception, specifically the ability to perceive the acoustic distance between two non-native sounds. In the present study, we looked at how individual differences in native perception affect the degree of perceived dissimilarity of a novel (L0) vowel contrast. We hypothesized that not only individuals' various L1s contribute differently to the task of L0 perception, but also individuals with the same L1 perceive novel sounds with a high degree of variability. The source of such variability is the size of perceptual phonetic categories or category compactness that influences non-native perception and can be assessed by relating the degree of compactness to the degree of perceived dissimilarity of novel L0 contrasts. The following research questions were addressed:

1. To what extent do individuals with the same L1 vary in their perception as measured by the category compactness of their phonetic categories?
2. To what extent does L1-based variability in category compactness influence the degree of perceived dissimilarity between contrasting novel vowels?

We hypothesize that listeners with more compact phonetic categories will perceive the acoustic distance between two contrasting L0 sounds better than listeners with less compact L1 categories (Figure 7).

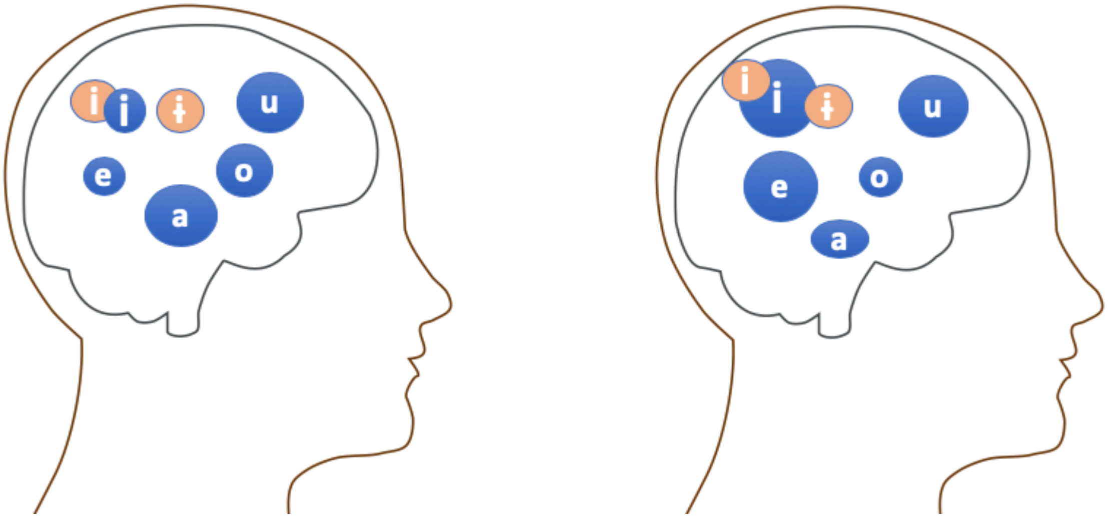


Figure 7. The compactness of L1 vowel categories (in blue) affects the perception of a novel contrast (in pink). The individual on the left is more likely to discriminate between Russian /i/ and /ɨ/ than an individual on the right.

In order to answer the research questions, we assessed participants' ability to perceive a distance between two L0 vowels and measured the size of their native vowel category. To take into account the effects of cognitive skills on both L1 and L0 perception, we measured the phonological short-term memory and acoustic memory capacities. Phonological short-term memory has been consistently highlighted in the phonetic ability research and acoustic memory is closely connected to it. We also collected participants' personality measures and recorded their linguistic background information. The next chapter will introduce the methodology and the tools used.

# Chapter 4 – Methodology

This chapter reports on the experiment investigating the relationship between the degree of compactness of a native phonetic category in perception and perceived dissimilarity of an unfamiliar (L0) contrast. The experiment design is summarized in Figure 8. The goal of the experiment was threefold: first, to relate the measures of category compactness to the scores of an L0 vowel perception task and to estimate the contribution of category compactness to variability in perceived dissimilarity between two novel sounds; second, to explore the effects of acoustic and phonological memory capacities, gender, age, the number of languages studied and spoken in the family, and previous exposure to L0 on the degree of perceived dissimilarity of an L0 contrast; and third, to examine whether individual differences in social network size and personality contribute to L1 category compactness. There is no study in the literature to experimentally test how native category compactness influences non-native perception, specifically, how naïve listeners perceive the acoustic distance between two non-native contrasting vowels. Rather than measuring category compactness in production, which has been done before for assessing individual differences in L1 vowel compactness (e.g., Kartushina, & Frauenfelder, 2013), a perceptual task using synthesized variants of a native category was employed – a goodness rating task. In order to obtain representative data on how individuals define the size of their native vowel category, twenty-eight variants of Spanish /i/ were used as perceptual stimuli. That way, it was possible to evaluate the degree of category compactness for every individual, which was then related to the measures of L0 perception. Before presenting the procedures, the decryption of every task used will be provided.

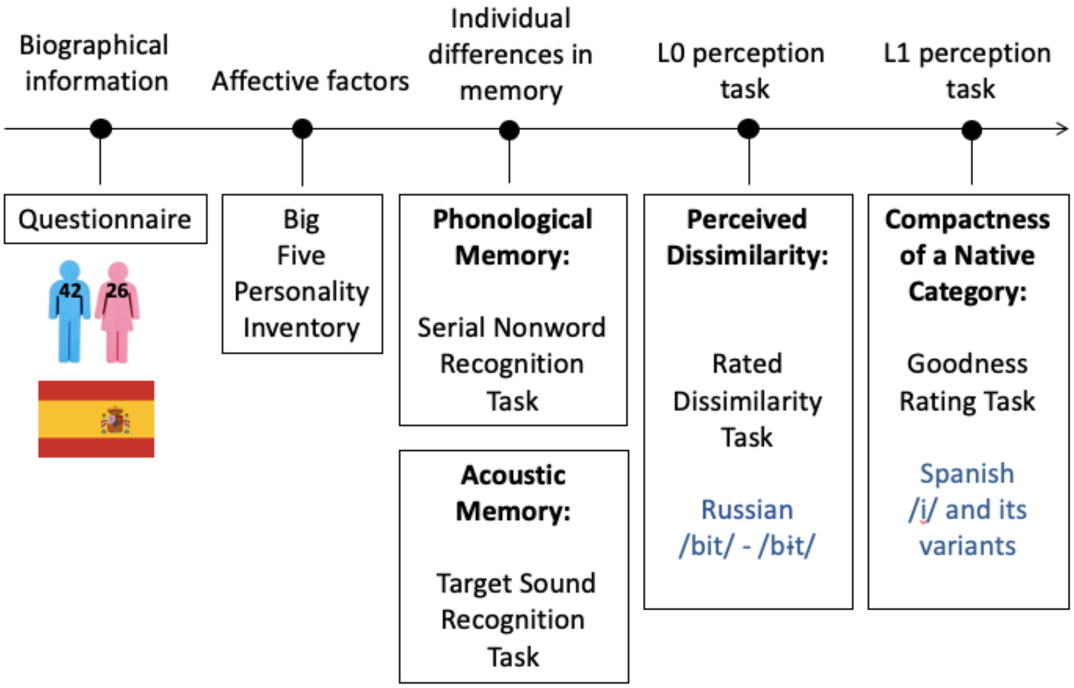


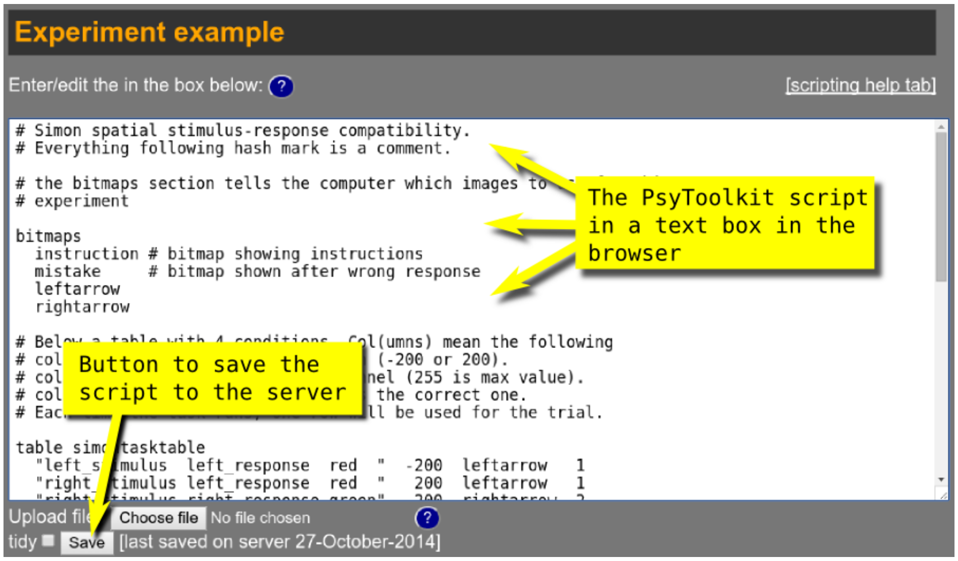
Figure 8. Overview of the study design.

## 4.1 Collecting data with PsyToolkit and TurkPrime

The data collection was administered online to obtain a bigger sample size over a short period of tim,. Online data collection also allowed us to connect to a specific population of participants, which is the Spanish monolinguals from central Spain. Nowadays, it is a challenge to find monolingual speakers in Europe, especially in bilingual Spanish-Catalan Barcelona and the surrounding area. Because of these reasons, the decision to collect data online was made. The tools that we used to accomplish this task and that are described below in detail were PsyToolkit and TurkPrime.

### 4.1.1 PsyToolkit

PsyToolkit is a free web-based service designed for programming, running and analyzing cognitive-psychological experiments and online surveys (Stoet, 2017). Based at the University of Glasgow and supported by a grant from the Economic and Social Research Council (ESRC), PsyToolkit allows online data collection, storage, analysis and retrieval (Figure 9). Once the experiment is set up, the study's URL is distributed among participants for online participation and, after collection, the data is downloaded as a spreadsheet.



```
# Simon spatial stimulus-response compatibility.
# Everything following hash mark is a comment.

# the bitmaps section tells the computer which images to
# experiment

bitmaps
  instruction # bitmap showing instructions
  mistake     # bitmap shown after wrong response
  leftarrow
  rightarrow

# Bel                                 Col(umns) mean the following
# col                                  (-200 or 200).
# col                                 nel (255 is max value).
# col                                  the correct one.
# Eac                                 ll be used for the trial.

table simc tasktable
  "left_s  imulus  left_response  red  "  -200  leftarrow   1
  "right_  timulus left_response  red  "   200  leftarrow   1
```

The PsyToolkit script in a text box in the browser

Button to save the script to the server

Figure 9. Example of the experiment's script written in PsyToolkit.

## 4.1.2 TurkPrime

Although most behavioral researchers rely on undergraduate subject pools for their primary source of research participants, this approach has a number of limitations, such as relatively small samples and lack of representativeness (Henrich, Heine, & Norenzayan, 2010). TurkPrime is an Internet-based research platform that facilitates the process of crowdsourcing data collection and is often used as a participant recruitment tool in many disciplines in the social sciences (Litman, Robinson, Abberbock, & Behav Res, 2017). TurkPrime uses proprietary algorithms to collect information across time and to check for consistency. Participants who provide inconsistent information are red-flagged and disqualified for taking part in studies. TurkPrime also uses cross-demographic comparisons to validate the feasibility of online data collection approaches. Multiple data sources are leveraged to provide a broad global network of respondents. By using digital fingerprinting technology TurkPrime prevents duplicates within the same study or between studies and across sample sources. To achieve sample representativeness, the sample demographics are matched to the proportion that is reported in the latest census in terms of the distribution of gender, age, ethnicity, region, and income.

TurkPrime participants are informed about available studies through a dashboard which lists all studies for which participants are qualified. Respondents are given cash incentives determined by supply/demand market forces. By using multiple attention-manipulation check questions, TurkPrime ensures that the participants pay attention to the study's details. Additionally, participants who consistently pass attention-quality checks are given an overall higher rating, which makes them eligible to take part in other studies. While this encourages high performance, participants cannot complete any study more than once.

In this study, we used TurkPrime to target Spanish monolinguals located in Central Spain. Before beginning, all participants were asked to provide critical information for the study, such as proficiency in various L2 and familiarity with  Russian to ensure that all participants were, in fact, functional monolinguals (see definition below). Participants who did not provide consistent responses to these questions were prevented from participating or excluded later on.

For the experiment, all participants reported using a personal laptop and a pair of headphones. Participants were instructed to find a quiet room without distractions for one hour, the approximate duration of the study. Before the experiment began, participants checked both sound channels in their headphones and adjusted the sound appropriately.

# 4.2 Participants

## 4.2.1 Spanish participants

Of the 109 normal-hearing adults who took part, 91 completed all the tasks. A further 23 participants were excluded from the data analysis either because they did not fit the study's criteria, i.e. they were highly proficient in foreign languages, were not born in Spain, or had studied Russian before, or because of abnormal data: unrealistic completion time (the experiment was finished in less than 30 minutes) or deviant scores (e.g., unrealistic reaction times, zero scores).

The remaining 68 participants were European Spanish functional monolinguals without any prior knowledge of Russian. According to Best and Tyler (2007), functional monolinguals are those who were raised in monolingual homes without learning another language prior to attending school. They have only a basic knowledge of English acquired at school (i.e., basic grammar instruction), have not resided in an English-speaking country for more than a month, and use only Spanish in their daily lives. All participants were screened for knowledge of languages other than Spanish, by being presented with the appropriate warning and the questions (Appendix C). Eleven participants reported being unable to speak any foreign language at the intermediate level of proficiency. Fifty-seven participants reported basic knowledge of English that did not surpass the intermediate level. Other languages that the participants indicated they were "familiar with" included (here in the alphabetic order): Basque, Catalan, French, Galician, Italian and Valencian. One participant mentioned studying German and Japanese briefly long ago, and another reported a "very rudimentary" knowledge of Romanian.

Table 1. Characteristics of the Spanish participants.

| **Measure** | *N* | *M* | *SD* | *Min* | *Max* |
|---|---|---|---|---|---|

| | | | | | |
|---|---|---|---|---|---|
| Age | 68 | 41 | 11 | 19 | 62* |
| Number of L2s studied | 68 | 1 | 1 | 0 | 5 |
| Number of L2s spoken in the family | 68 | 1 | 1 | 0 | 3 |

* It was assumed that all participants were normal-hearing adults as they have been qualified by TurkPrime for experiments that involve listening.

### 4.2.2 Russian participants

The study also recruited a group of 16 native speakers of Russian to provide baseline data for the L0 rated dissimilarity task that used the Russian vowels as stimuli. Recruited and screened online, with the help of several social networks, principally Facebook, participants were informed about the study's purpose, experimental procedures, risks, and benefits. The volunteers gave oral consent and were asked to fill in an anonymous linguistic background questionnaire, which was used to control for language backgrounds, such as Russian-speaking parents, place of birth, residence, and exposure to and use of other languages (see Appendix A). The participants were not paid. The data from the Russian speakers (male = 6, female = 10, $M_{\text{age}} = 24.2$, *range* = 18-33) were further analyzed and compared to the Spanish speakers' performance.

## 4.3 Instruments

### 4.3.1 Questionnaire with the Big Five Inventory

To collect demographic and language history information a questionnaire was administered. The questionnaire contained questions about demographic information, social network size, and proficiency in various languages among family members (Appendix C). In addition, the questionnaire included a brief test to evaluate five personality features: extraversion vs. introversion, agreeableness vs. antagonism, conscientiousness vs. lack of direction, neuroticism vs. emotional stability, openness vs. closedness to experience. The study used a short version of the Spanish version of the NEO Five-Factor Inventory (FFI) (Costa & McCrae, 1992), a self-reported measure of personality based on the Five-Factor Model, which was translated from the original American NEO-FFI scale (Rodriguez-Fornells, Lorenzo-Seva, & Andres-Puevo, 2001). This version contained 15 statements, each to be rated on a 5-point scale from "strongly agree" to "strongly disagree". The information was analyzed with respect to the data collected from other tasks in the study.

### 4.3.2 Serial nonword recognition task

To measure phonological short-term memory, a serial nonword recognition task was used. Phonological short-term memory is one of the domain-specific subsystems of working memory responsible for processing verbal material (Baddeley, 1998). It comprises the phonological store, which holds information for about two seconds, and the phonological loop, which refreshes decaying information over time by an articulatory rehearsal process. The phonological short-term memory capacity has a limited span, which can be measured by the serial recall: numbers or words. In this experiment, phonological short-term memory was assessed through a serial nonword recognition task following the procedure described in Cerviño-Povedano and Mora (2011). The only difference between theirs and this study is that we used Spanish nonwords instead of Catalan nonwords. Compared to nonword repetition, a serial nonword recognition task is a better measure of the phonological short-term memory capacity since the articulatory constraints are avoided (Cerviño-Povedano & Mora, 2011; Cerviño-Povedano & Mora, 2015).

Participants heard 24 pairs of nonword sequences blocked by item length. There were three blocks with five-, six- and seven-item sequences presented to the participants in this order (Appendix D). Each block consisted of eight trails presented randomly: four identical sequence pairs (e.g., NW1, NW2, NW3, NW4, NW5 – NW1, NW2, NW3, NW4, NW5) and four different sequence pairs (e.g. NW1, NW2, NW3, NW4, NW5 – NW1, **NW3**, **NW2**, NW4, NW5). The inter-stimulus interval between the nonwords within a trial was 300 ms; the inter-stimulus interval between the trials was 100 ms.

The nonwords were developed using Syllabarium, an online application for deriving complete statistics for Spanish syllables (Duñabeitia, Cholin, Corral, Perea, & Carreiras, 2010). The Syllabarium corpora are based on the Spanish B-PAL (Davis & Perea, 2005) and composed of 31491 words in their lemmatized form. Only the CVC syllables of high frequency were selected (equal to or greater than 1000 on the frequency index). The selected 160 syllables were recorded by a native female speaker of European Spanish as a part of a carrier sentence "Yo digo _ / Yo digo _ una vez". The recorded CVC nonwords were extracted from the sentences and processed in Praat[1] (Boersma & Weenink, 2013) to normalize for peak amplitude (70dB) and to remove low-frequency noise. The nonword duration values were normalized with respect to length, which was determined by taking the average length of all nonword stimuli (650 ms). The best tokens were selected on the basis of auditory judgments and acoustic measurements. Every trial contained a variety of vowels and consonantal contexts.

*Example of the same sequence:*

*bul tad som fes sil*

*bul tad som fes sil*

*Example of a different sequence (the 3rd and the 4th nonwords are switched):*

*bul tad* ***som fes*** *sil*

*bul tad* ***fes som*** *sil*

---

[1] Software that scientifically analyzes speech in phonetics.

Participants were asked to listen to the pairs of sequences and after each trial decide whether the order of the nonwords in the sequences was the same or different. In this task, a weighted score was obtained by assigning five, six and seven points to the correct responses of five-, six- and seven-item sequences with a maximum score of 144 points.

### 4.3.3 Target sound recognition task

To test acoustic short-term memory, which we defined as the ability to process and store the acoustic properties of speech stimuli at the pre-phonological level, we used a target sound recognition task (Li, Cowan, & Saults, 2013; Safranova & Mora, 2012). In this task, participants have to judge if a target speech-like sound is a member of the previously heard sequence or not.

The stimuli consisted of 101 Spanish CV syllables (Appendix E) recorded in the same manner as the nonwords in the serial nonword recognition task (see above). The CV syllables were manipulated through frequency rotation (speech rotation: Scott, Rosen, Beaman, Davis, & Wise 2009) and varied in length from 180 ms to 240 ms. This technique preserves the acoustic complexity of the stimuli while making it impossible to encode phonologically.

The stimuli were presented in three blocks of two-, three- and four-item sequences. Each sequence was followed by 3000 ms silence and a target sound afterward, which could be the same or different from the sequence items (Figure 10). Each block contained eight trials in a randomized order. The participants were asked to listen to each sequence and the following sound and judge whether or not the target sound was included in the previously presented sequence.

A weighted score was computed by assigning scores of two, three and four points to the correct responses of two-, three- and four-item sequences, respectively, with a maximum score of 72 points.

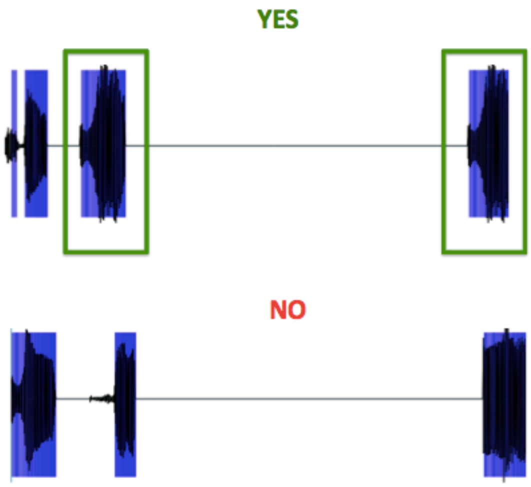


Figure 10. Sample trials of "yes" (same) and "no" (different) two-item sequences in the target sound recognition task.

### 4.3.4 Rated dissimilarity task

A rated dissimilarity task was designed to assess the degree of perceived dissimilarity between two contrasting vowels in a novel contrast. A rated dissimilarity task has been widely used in previous non-native speech research (Flege, Munro, & Fox, 1994; Cebrian, Mora, & Aliaga-Garcia, 2011). In this task, participants have to decide if two sounds are the same or different and if different – to assess the difference on a rating scale.

The vowel contrast that we used in a rated dissimilarity task was Russian /i - ɨ/. In addition, the following distractors were randomly included in the task: /a - i/, /o - a/, /i - e/, /e - o/, /a - u/, /ɨ - e/, /o - u/, /u - ɨ /. Two female and two male native speakers of the Central Russian dialect from Moscow recorded the target vowel contrasts in a /bVt/ context as part of a carrier sentence "Я сказал(а) _ / Я сказал(а) _ опять". The stimuli were digitally recorded (Praat and Edirol UA-25 USB Audio Capture device) in a soundproof booth at a sampling rate of 44.1 kHz with a 16-bit resolution on a mono channel in the Phonetics Laboratory at the University of Barcelona. The selected tokens were extracted from the sentences and processed using Praat to normalize for pitch and amplitude. The word-final /t/ release burst was removed, and the offset of the spliced portion occurred when the amplitude of the vowel waveform began to decrement with the exact cut at a zero crossing. The original duration values of the tokens were preserved to make vowels sound as natural as possible and ranged from 310-370 ms. The best tokens per speaker were selected on the basis of auditory judgments and acoustic measurements. Each sound category was represented by at least five tokens to encourage participants to respond in a general rather than in a token-specific manner.

The stimuli were organized into trials where each token A and B within a pair were spoken by the same or different individual(s) and presented with an inter-stimulus interval of 700 ms. Participants were tested on their ability to detect acoustic differences between the tokens. To avoid presentation order effects due to perceptual asymmetry such peripherality (the distance between sounds is perceived better when a less peripheral vowel goes first; Polka & Bohn, 1996) and nativeness (the distance between sounds is perceived better when a native or a native-like sound goes first; Ettlinger & Johnson, 2010), the token order within a pair was counterbalanced. The four test blocks consisted of eight change (/i - ɨ/ or /ɨ - i/) and eight no-change (/i - i/) trials in a randomized order per block; eight distractor trials were randomly included in each block, with the total number of tokens equal to ninety-six.

Participants were told that they would hear two vowels that might (or might not) sound familiar and that their task was to decide whether the vowels sounded the same or not. Participants were asked to assess the difference between two vowels by marking the degree of mismatch on an intuitive rating scale (Jilka, 2009): the representation of the difference between two sounds corresponded to the least-to-most intensity of the red color (Figure 11).

Figure 11. An intuitive rating scale (reproduced from Jilka, 2009).

Participants were instructed to respond by clicking a mouse or a touch panel alongside the scale and given 3000 ms to respond. The next trial came immediately after the response or after 3000 ms if no response was given. To familiarize participants with the procedure, the task started with a four-trial practice block with no visual feedback provided. The experiment began after the participants had completed the practice block.

For computational purposes, the intuitive scale used in this task was divided into ten segments, with 1 indicating “similar” and 10 – “different”. Thus, an average numerical response from 1-10 to the target contrast /i - ɨ/ (or /ɨ - i) was calculated for every individual. For example, a score of 1 would represent a poorly perceived distance between the contrasting sounds (/i - ɨ/ appear to sound the same) and the score of 10 would represent a perfectly perceived distance (/i - ɨ/ appear to sound different).

### 4.3.5 Goodness rating task

To map the perceptual space underlying the native Spanish vowel /i/ in each participant, we employed a goodness rating task. In this task, the perceptual stimuli varied in quantifiable steps to examine how listeners differ in the way they define the size or compactness of their native category. The task was developed to measure the number and the distance of the variants labeled by participants as good exemplars of /i/.

Using Klatt's synthesizer (Klatt, 1980), we created 28 synthesized vowels that were distributed overall a mel-scaled F1*F2 psychoacoustic space (Figure 12). The prototypical Spanish /i/ vowel was selected based on the description of production values reported by Chládková and Escudero (2012) for a European Spanish male speaker. The frequency values of the first two formants for the prototype vowel, around which the 28 variants were generated, were: F1 = 286 Hz (386 mels) and F2 = 2367 Hz (1665 mels).

Following the procedure described in Kuhl (1991), we created a set of variants that formed four vectors in a psychoacoustic space around the vowel prototype /i/. Variants were obtained by modifying F1, F2, or both at the same time. The difference in F1 values between the variants was 30 mels and the difference in F2 values 50 mels (see Appendix F for the exact values of the variants). F1-F2 pairings outside the range of a possible human vowel space were excluded. The frequencies of the third through sixth formants were set to the following values for all vowel tokens: F3 = 3010 Hz, 3300 Hz, 3850 Hz, and 4990 Hz. The bandwidths used were: B1 = 60 Hz, B2 = 90 Hz, B3 = 150 Hz, B4 = 200 Hz, B5 = 200 Hz and B6 = 1000 Hz. The stimuli were 500 ms in duration. The fundamental frequency began at 112 Hz, rose to 132 Hz over the first 100 ms, and dropped to 92 Hz over the next 400 ms to produce a natural-like rise-fall contour.

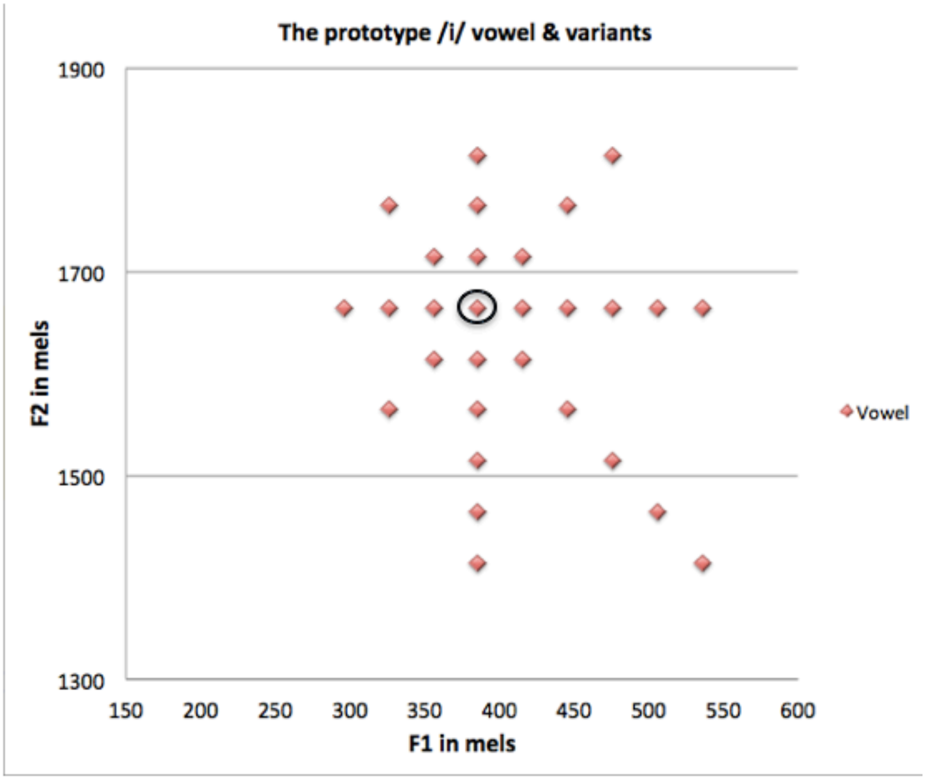


Figure 12. The 28 synthesized vowels that are distributed overall a mel-scaled F1*F2 psychoacoustic space with a prototype /i/ in the center.

The participants were presented with one variant at a time and had to decide how well it matched their native /i/ category. They were asked to rate each variant by marking the degree of mismatch between the variant and /i/ on an intuitive rating scale (Figure 11): the left edge of the scale (“Similar”) was associated with a good exemplar of their inner category /i/ and the right edge of the scale (“Diferente”) signified a poor exemplar. Participants were instructed to estimate the goodness of fit between the variant they heard and their own internal representation of /i/ as in the Spanish word “sin” (without). No reference for a good exemplar of the Spanish vowel /i/ was provided. We encouraged the participants not to limit themselves to the two extreme ends of the scale and to use the intermediate values when appropriate. To ensure task reliability each participant had to rate each variant four times for a total number of 112 trials. i.e., four blocks of

28 trials presented randomly. This optimal number of blocks was determined during the piloting stage of the study: the tedious nature of the task prevented many participants to complete it if the number of blocks exceeded four. The practice block was also presented at the beginning of the task and consisted of four trials.

To calculate the compactness index of the Spanish vowel /i/ for each individual, we followed several steps. First, we counted the number of variants consistently selected as good exemplars of a native category, with the rating goodness greater than 5 (since the intuitive scale had 10 divisions, we selected the median value). The maximum number of variants to select was 28, which included all possible variants of /i/. We only counted the variants that were selected as good exemplars consistently, i.e. out of the four times the variant was presented, it was rated higher than 5 at least three times. Otherwise, we assumed the rating was not reliable (e.g., a participant rated a variant as a good exemplar of /i/ only on one or two occasions) and did not count that variant. Such calculating procedure was necessary because of the nature of the task: perceptual judgments (particularly when collected online) tend to fluctuate. Ensuring that the variant was rated as a good exemplar of a native category consistently would make this task more reliable. Thus, at this step, the compactness index of 6 would indicate a rather compact phonetic category; i.e., fewer variants are selected as good exemplars of this category (Figure 13). On the other hand, the compactness index of 15 would signify a large/less compact phonetic category; i.e., more variants are selected as good exemplars of /i/.

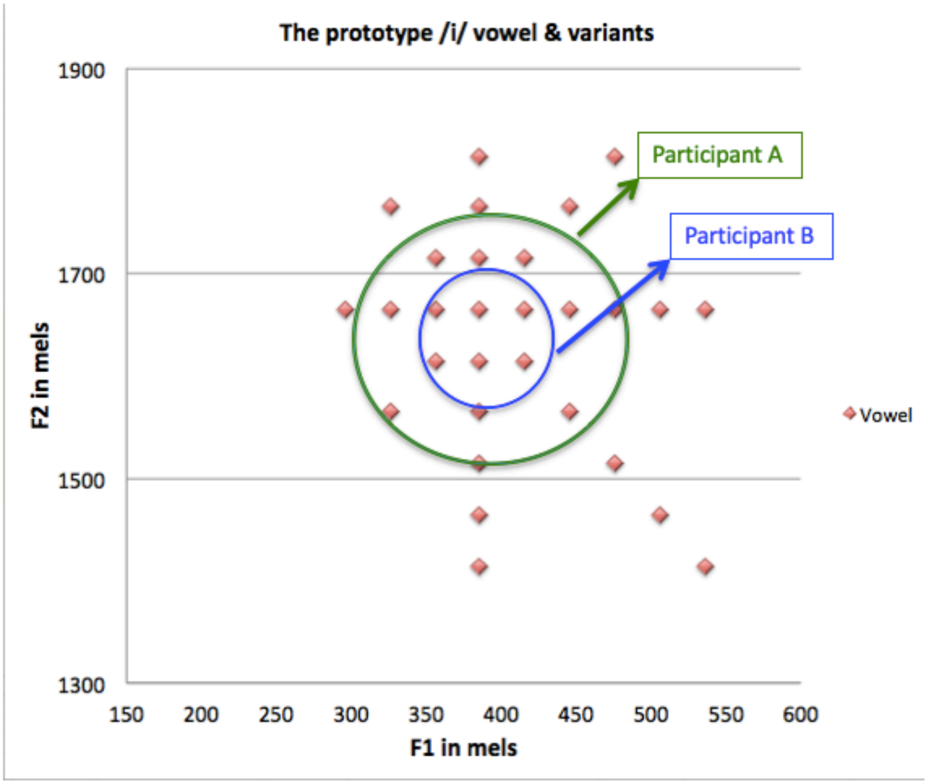


Figure 13. First step in calculating compactness: Participant A has a less compact category (15 variants) than Participant B (6 variants).

The next step in calculating the compactness index was to assign different values to the variants based on their distance from the prototypical /i/. This step was necessary to account for the situations when fewer variants selected further from the center. For example, because a participant selected only 6 variants, her phonetic category can be defined as compact. However, if these variants are far from the prototypical /i/, such category cannot be counted as compact. To take this structural layer into consideration, each variant was assigned a value from 10 to 50 based on how many steps away it was located from the prototype (Figure 14). In this way, the final weighted score that represented the compactness index was the sum of the values of the selected variants added, with the maximum score equal to 690 (calculated as follows: 8*10+8*20+6*30+3*40+3*50=690). In our previous example (Figure 13), the participant A would have the compactness index equal to 210 (calculated as follows: 8*10+5*20+1*30=210) and the participant B – 50 (calculated as follows: 5*10=50).

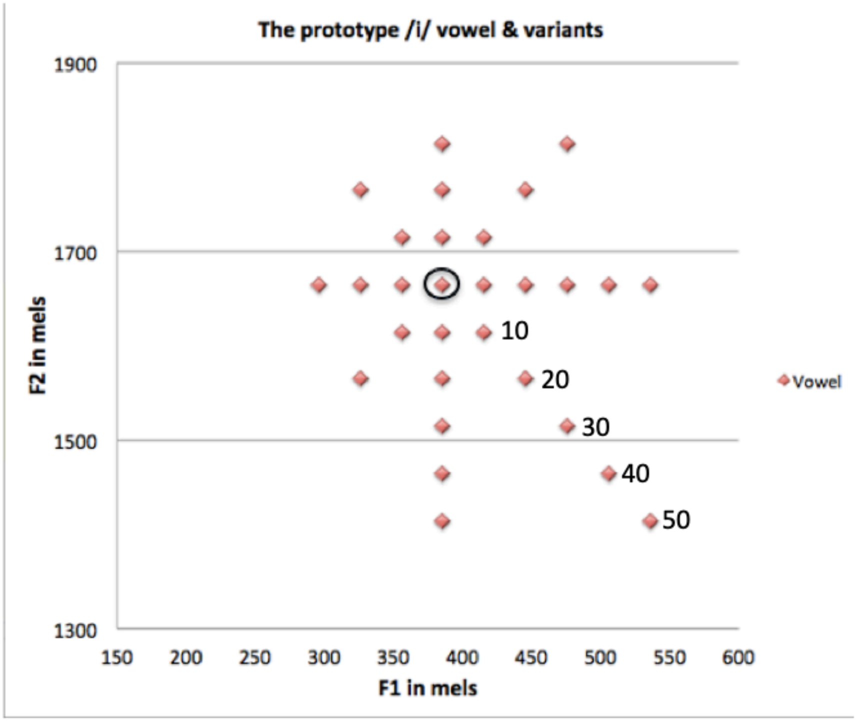


Figure 14. Each variant has a different value from 10 to 50 based on its distance from the prototypical Spanish /i/.

Another concern in calculating the compactness index was the shape of a phonetic category: a category elongated along one dimension — e.g., along F1 — could affect the perception of a non-native contrast with particular acoustic characteristics. However, as we were processing the data, none of the participants demonstrated a category that would be large in diameter alongside only one dimension, as often observed in production. Participants tended to have perceptual categories shaped as a more or less balanced sphere (Figure 15).

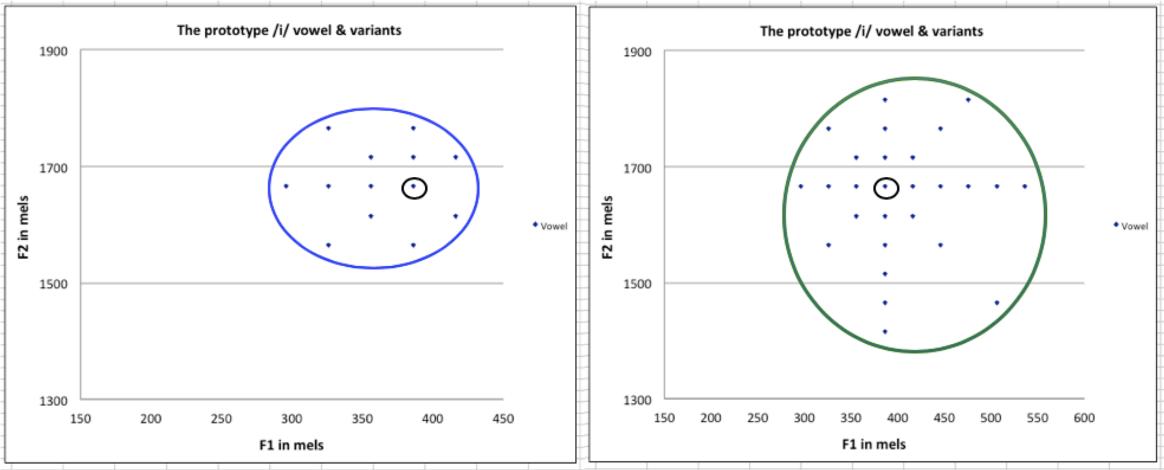


Figure 15. The shape of the native category /i/ did not vary much from individual to individual (subject 4 and 11 here) and resembled a sphere.

## 4.4 General procedure

All participants were informed about the main purpose of the research, procedures, and risks as well as its potential benefits. They voluntarily agreed to participate, signed a consent form (Appendix B) and received monetary compensation for their participation (except for the Russian participants who were not compensated for their participation, since they only took part in the rated dissimilarity task). First, all participants were asked to fill in a questionnaire about their demographics (Appendix C). This was followed by a short version of the Big Five Inventory (BFI) that measures personality according to five factors or dimensions (Goldberg, 1993). Third, the participants were asked to perform two speech perceptions tasks: a rated dissimilarity task that assessed their ability to discriminate between contrasting L0 sounds and a goodness-of-fit task, in which they judged if a synthesized variant was a close approximant of their native vowel. Finally, participants performed a battery of cognitive tasks measuring phonological short-term memory and acoustic short-term memory. All participants reported having no speech or hearing disorders;

as well as screened for normal hearing by TurkPrime. Data from 68 participants (male = 39, female = 27, $M_{\text{age}}$ = 41 years, *range* = 19-65 years, *SD* = 11) were considered valid in the statistical analyses.

The experimental design consisted of a single testing session conducted in Spanish on the same day to promote the activation of a single language. The testing session's estimated duration was one hour. After a short screening session to confirm proficiency in one language only — Spanish — the participants were briefed on the study's purpose and procedure. Following this, each participant received a URL to the experiment's website on PsyToolkit platform. On entering the website, participants were taken to an information sheet and informed-consent screens. They were also required to declare the type/model of technology/device they were using to perform the tasks with headphones and computer models. Participants were not allowed to use mobile phones to complete the experiment. Before beginning the audio portion of the experiment, participants were prompted to check the sounds in the right and the left channels of their headphones to ensure that the volume was at a comfortable level. After a short survey to collect demographics and language history, participants had to complete the Big Five Inventory. Two memory and two perception tasks with multiple opportunities to take breaks followed as depicted in Figure 8. At the end of the experiment, each participant received an automatically-generated individual code that they used to received compensation.

# Chapter 5 – Results

This chapter provides a description of the data analysis and reports the results obtained regarding the relationship between individual differences in L1 perception, specifically, the compactness index of a native phonetic category /i/, and the degree of perceived dissimilarity between two novel contrasting sounds /i/ and /ɨ/. In addition, in order to control for factors that in previous research have been identified as strong predictors of non-native perceptual sensitivity, i.e., phonological short-term memory, acoustic short-term memory, and personality, we analyzed the relationship between these variables and the perceived dissimilarity rating scores. At last, we explored the relationships between the measure of category compactness and social network size.

The first section of the chapter (5.1) is devoted to exploratory analysis: the descriptive statistics for each task and checking the distribution of the main variables. In the second section (5.2), we examine the rated dissimilarity task in greater detail: we check if the task measures the degree of perceived dissimilarity between Russian /i/ and /ɨ/, as anticipated, and we compare the resulting dissimilarity scores to the baseline data, i.e., to the scores obtained by Russian speakers on the same task. The contribution of the factors such as gender, age, exposure to Russian, the number of foreign languages studied, and previous formal phonetic training are reported in section 5.3. In the following section (5.4), we focus on the contribution of phonological short-term memory and acoustic short-term memory to the degree of perceived dissimilarity. Using a series of correlation and regression analyses we first check whether the memory tasks used in this study worked as anticipated and then explore the relationships between phonological and acoustic memory and perceived dissimilarity. Section 5.5 presents the results of the L1 perception task that we used to obtain a measure of participants' /i/ category compactness and describes how these measures relate to memory and social network size. The last section (5.6) introduces the analysis regarding the key question of the study: the effects of category compactness on the degree of perceived dissimilarity between the two Russian vowels. The research questions are answered and the predicted hypotheses are verified by reporting the results of a series of regression analyses. We used linear mixed-effects models where appropriate to better account for the distribution of the dependent variable, in particular, for the issue of non-independent observations characterized by grouping (repeated measurements within subjects and within items), which often leads to increased type I errors, i.e., erroneous significant results (Hurlbert, 1984; Baayen, Davidson, & Bates, 2008).

All statistical analyses were performed using RStudio 0.99.486. An alpha level of .05 was used as a significance criterion in the present study.

## 5.1 Overview of the data

As described in Chapter 4, all participants had to complete a survey and the Big Five Inventory, followed by two memory and two perception tasks. The descriptive statistics across all four tasks are summarized in Table 2, with the measures of central tendency (mean and median) specifying the values that tend to be the most typical and the measures of dispersion (minimum, maximum and standard deviation or *SD*) showing how variable the data are.

Table 2. Summary of performance across all tasks.

| Task | Scoring (max) | n | min | max | mean | median | SD (IQR) |
|---|---|---|---|---|---|---|---|
| Serial Nonword Recognition Task | 144 | 68 | 22.00 | 137.00 | 86.65 | 84.50 | 24.07 (30.5) |
| Target Sound Recognition Task | 72 | 68 | 16.00 | 72.00 | 54.24 | 54.00 | 10.54 (14.25) |
| Rated Dissimilarity Task | 10 | 68 | 4.69 | 9.94 | 8.39 | 8.80 | 1.26 (1.52) |
| Goodness Rating Task | 690 | 68 | 80.00 | 560.00 | 313.51 | 305.00 | 100.37 (145) |

Visual inspection of the distribution of scores for each variable (Figure 16) revealed that the phonological short-term memory scores and the category compactness scores were distributed normally. The distribution of the acoustic memory scores had a slight negative skew (-0.73), i.e., there were several extremely low scores. Further examination with the help of a box plot showed a single outlier that was preserved since the departure from normality was not severe (the Shapiro-Wilk test: $W = 0.96$, $p = .03$). Since the Shapiro-Wilk test is influenced by the sample size, i.e., if the number of observations is high there is a bigger chance to detect deviations from normality, hereinafter we relied on the quantile-quantile plot examination in determining normality (Levshina, 2015). Another variable that did not form a normal distribution was perceived dissimilarity: the deviation from normality was severe: $W = 0.90$, $p < .001$. The negative skew of -1.01 reflected the fact that most of the participants nearly excelled in discriminating between L0 sounds /i/ and /ɨ/ on the rated dissimilarity task. The two outlier scores detected with the help of a box plot equated to 4.69 and 5.19 (10 was a maximum score on this task) and were preserved since they did not represent a sampling or coding error. After a reverse logarithmic transformation (log10($K$ + 1 - $X$), where $K$ is the highest value of the variable $X$, the perceived dissimilarity scores appeared significantly normal ($W$ = 0.97, $p$ = .102). Since applying non-linear data transformation is a controversial issue in statistics (Field, Miles, & Field, 2012; Coupé, 2018), in the final section of this chapter we supplemented ordinary linear regression analysis with the use of the generalized linear regression to confirm our findings. The generalized linear regression allows a response variable to have an error distribution other than normal.

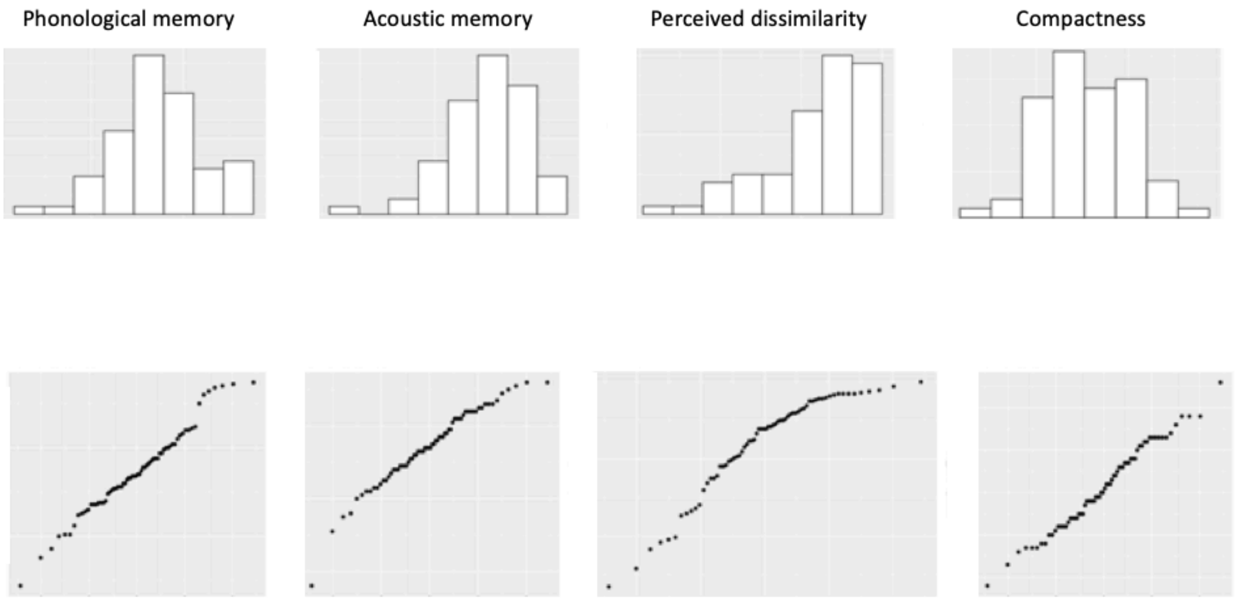


Figure 16. Histograms and quantile-quantile plots of phonological memory, acoustic memory, perceived dissimilarity and category compactness respectively.

## 5.2 Perceived dissimilarity between Russian /i/ and /ɨ/ and rated dissimilarity task

Our study investigated individual differences in naïve perception of a non-native contrast. In order to measure the degree of perceived dissimilarity between L0 Russian /i/ and /ɨ/, we used a rated dissimilarity task. As we described in Chapter 4, in this task participants had to assess the difference between Russian /i/ and /ɨ/ by marking the degree of mismatch on an intuitive rating scale. During statistical analysis, for computational purposes, the intuitive scale was divided into ten equal sectors with 1 representing poorly perceived acoustic distance and 10 representing perfectly perceived acoustic distance . For each participant, we calculated an average response value across all instances of the contrast /i - ɨ/. As was mentioned earlier, participants obtained unexpectedly high dissimilarity rating scores for the Russian /i - ɨ/ contrast with a mean of 8.39 (min = 4.69, max = 9.94, *SD* = 1.26). It must be noted that the complexity of this task was increased twice during the piloting stage of the study: at first, the inter-stimulus interval between the two vowels was raised from the 300 ms to 700 ms; second, both male and female speakers were used to voice the two vowels within a contrast. Yet, even after these manipulations, during the real study, the majority of the participants showed a high level of accuracy in the perception of the non-native contrast /i-/ɨ/. The ceiling effect could be explained by the fact that the participants did not have to handle the contextual complexity that accompanies speech processing in real life: background noise, coarticulation, speaker's variability, etc. That being said, when compared to the Russian participants, the Spanish listeners were considerably outperformed (Figure 17): the difference between the two groups was significant, as confirmed by an independent one-tailed version of the Wilcoxon test: $W = 923$, $p < .001$. Thus, even though the Spanish participants demonstrated unexpectedly high perceived dissimilarity ratings, the Russian controls obtained significantly higher dissimilarity ratings than the experimental Spanish participants (median = 9.86, *SD* = 0.57).

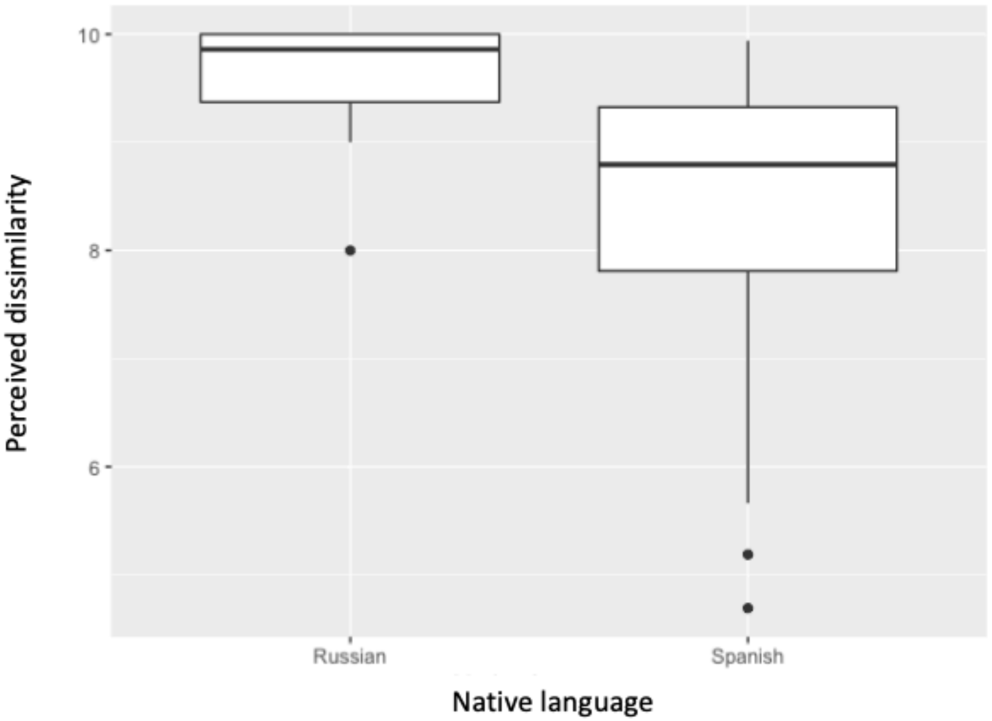


Figure 17. The Russian participants obtained significantly higher perceived dissimilarity ratings for /i - ɨ/ than the Spanish participants.

Further examination of the rated dissimilarity task scores showed that overall the task assessed the degree of perceived dissimilarity between contrasting L0 sounds as expected. Participants were consistent in measuring perceived dissimilarity between Russian /i/ and /ɨ/ across multiple instances of this contrast with the average intra-speaker variation of 1.81 points. The type of the contrast (*same* vs. *different*) functioned in an intended manner: participants responded to the *same* contrast /i - i/ in a significantly different way, when compared to their responses to a *different* contrast /i - ɨ/ as (the Wilcoxon signed-rank test: *W* = 21572, *p* < .001). The differences between the female and male start (which speaker, a man or a woman, voiced the first vowel in the contrast) did not affect participants' responses (*W* = 5248.5, *p* = .10). According to previous research, peripherality (Polka & Bohn, 1996) and nativeness (Ettlinger & Johnson, 2010) could cause certain asymmetries in vowel perception facilitating the discrimination of a vowel change presented in one direction, but not another: from the less peripheral vowel to the more peripheral vowel and from a native vowel to a non-native vowel. We did not find such presentation ordering effects in our study: the participants' responses were not affected by which vowel came first in the contrast — more peripheral native-like /i/ or less peripheral non-native /ɨ/ ($W = 5346.5$, $p = .47$). There was also a significant difference between participants' response to /i - ɨ/ contrast and the distractor contrasts /a - i/, /o - a/, /i - e/, /e - o/, /a - u/, /ɨ - e/, /o - u/, and /u - ɨ / – the distance between two members of a distractor contrast was perceived as larger than the distance between /i/ and /ɨ/ (the Wilcoxon signed-rank test: $W = 673$, $p < .01$).

## 5.3 Biographical factors and their contribution to perception of a non-native contrast

To measure the contribution of factors related to participants' biographical information to the perceived dissimilarity between Russian /i/ and /ɨ/ obtained through the dissimilarity rating task we performed a standard multiple regression analysis between the dependent variable (the logarithmically transformed *Perceived Dissimilarity* scores) and the independent variables: *Gender*, *Age*, foreign languages experience (*L2 Experience*), presence of the foreign languages spoken in the family (*Family L2s*), *Exposure to Russian* and *Phonetic Training*. Assumptions were tested by examining normal probability plots of residuals and scatter diagrams of residuals versus predicted residuals. No violation of normality, linearity, or homoscedasticity of residuals was detected. The variables were not related to each other; the variance inflation factor (*VIF*-scores) for each predictor did not exceed 5. In addition, the box plots revealed no evidence of outliers.

Regression analysis indicated that none of the factors contribute to *Perceived Dissimilarity* at the significant level, $F(6, 61) = 1.26$, $p = .29$. $R^2$ for the model was 0.11, and the adjusted $R^2$ was 0.023. Table 3 displays the unstandardized regression coefficients (*B*), standard error (*SE*), standardized regression coefficients (β) and *p*-value for each variable.

Table 3. Standard multiple regression predicting Perceived Dissimilarity from biographical data.

| Predictor | *B* | SE | β | *p* |
|---|---|---|---|---|
| Gender | 0.03 | 0.05 | 0.08 | .54 |
| Age | -0.001 | 0.003 | -0.05 | .71 |
| L2 Experience | -0.10 | 0.07 | -0.19 | .18 |
| Family L2s | -0.05 | 0.06 | -0.12 | .38 |
| Exposure to Russian | 0.07 | 0.06 | 0.13 | .30 |
| Phonetic Training | 0.004 | 0.06 | 0.01 | .94 |

Even though previous *L2 Experience* did not contribute to the *Perceived Dissimilarity* scores at a significant level ($p$ = .71), the predictor was close to significance. When true monolinguals (the participants who reported not studying any foreign languages in the past) were compared to functional monolinguals (the participants who reported studying one to five foreign languages in the past without achieving the intermediate level of proficiency), an independent two-tailed Wilcoxon test revealed significant differences between the groups ($W = 193$, $p = .04$). Figure 18 shows that the experience of studying foreign languages in the past influenced *Perceived Dissimilarity* negatively. We will come back to this seemingly counterintuitive finding in the Discussion chapter.

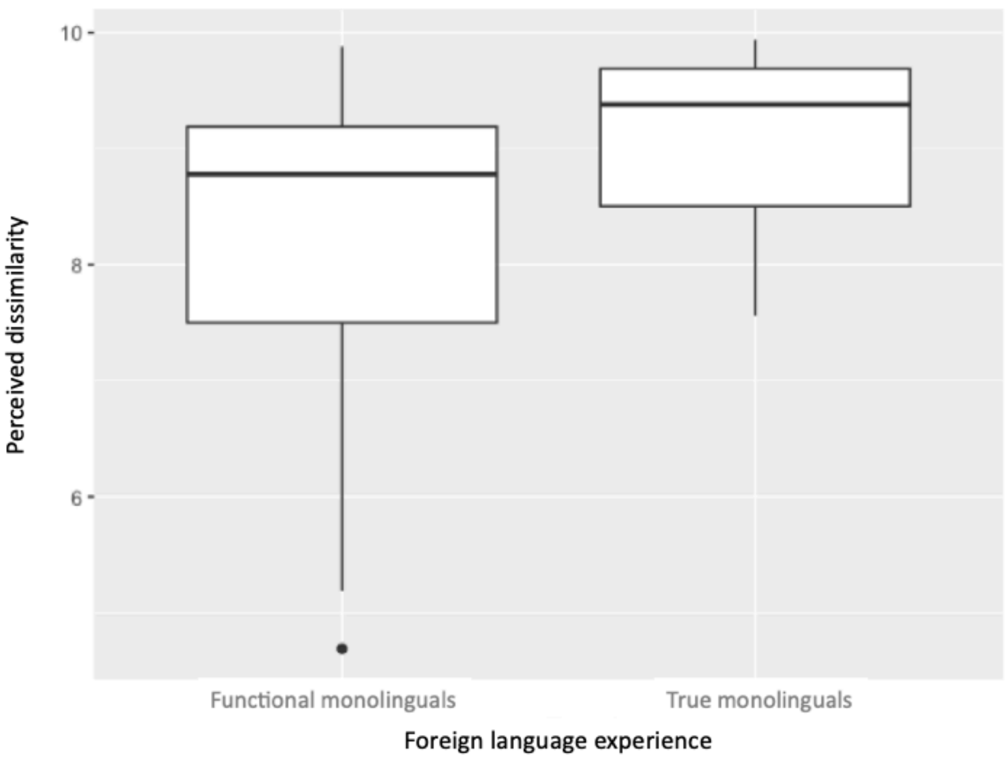


Figure 18. True monolinguals obtained higher Perceived Dissimilarity scores in comparison to functional monolinguals.

## 5.4 Phonological and acoustic memory capacities

Previous research has shown that the phonological short-term memory capacity and acoustic memory capacity play an important role in non-native speech perception. The two tasks that we developed to measure these types of memory were a serial nonword recognition task and a target sound recognition task respectively. In Chapter 4 we explained that both tasks consisted of three consequent blocks with each block using longer sequences than the previous one. The expectations were that participants will experience greater difficulty as they progress from block one to block two and to block three. To ensure that it was the case and that the tasks worked as expected, we fitted a series of mixed-effects models with *Accuracy* scores as a dependent variable and *Subject* (a random effect) and *Sequence Length* (a fixed effect) as predictors. In the phonological short-term memory task, the increasing *Sequence Length* lowered *Accuracy* by 7.6 points when the length increased from the five-word sequences to the six-word sequences and by 10.7 points when the length increased from the six-word sequences to the seven-word sequences. When compared to the null model (without the effect in question, i.e., *Sequence Length*) with the likelihood ratio test, the result revealed a significant effect of *Sequence Length* ($\chi2(5)=13.72$, $p = .001$). In the case of acoustic memory, *Sequence Length* affected *Accuracy* significantly as well (($\chi2(5)=11.62$, $p < .001$) lowering *Accuracy* by 6.4 points when *Sequence Length* increased from the two-word sequences to the three-word sequences and by 3.7 points when *Sequence Length* increased from the three-word sequences to the four-word sequences. Also, in the acoustic memory task, the length of individual sounds (rotated CV syllables) within the sequence had no effect on participants' performance, as confirmed by (a simple linear regression with sound length as a predictor ($p = .92$). These results suggest that the increased *Sequence Length* placed demands on the participants' phonological short-term memory and acoustic memory capacities and the tasks assessed these cognitive skills as expected. No violation of normality, linearity, or homoscedasticity of residuals was detected.

In order to explore the relationships between phonological short-term memory and acoustic memory and the degree of perceived dissimilarity, we fitted a series of mixed-effects models to the data. The preliminary correlational analysis suggested that there was no significant relationship between the two types of memory (Pearson's $r = 0.008$, $p = .95$).

In the first step, we fitted a mixed-effects model with logarithmically transformed *Perceived Dissimilarity* as a dependent variable and *Phonological Short-term Memory* as an independent variable (fixed effects), as well two random-effects to allow for by-*Subject* and by-*Item* adjustments to the intercept. The effect of *Phonological Short-Term Memory* did not reach significance (*p* = .16). We included *Acoustic Memory* as a second fixed effect in the consequent step and it significantly improved the fit (χ2(1) = 6.40, *p* = .01) boosting *Perceived Dissimilarity* by about 0.04 points (or -0.005 points – unlogged value). Taking *Phonological Short-term Memory* out of the model did not affect the fit significantly (χ2(1) = 2.16, *p* = .14), from which we concluded that it is *Acoustic Memory* and not *Phonological Short-Term Memory* that influenced participants' performance on the rated dissimilarity task. The model that consisted of *Acoustic Memory* alone as a fixed effect confirmed this assumption (B = -0.005, *p* = .01). For this model, the visual tests of the assumptions showed some deviation from normality, but it was not severe (Figure 19).

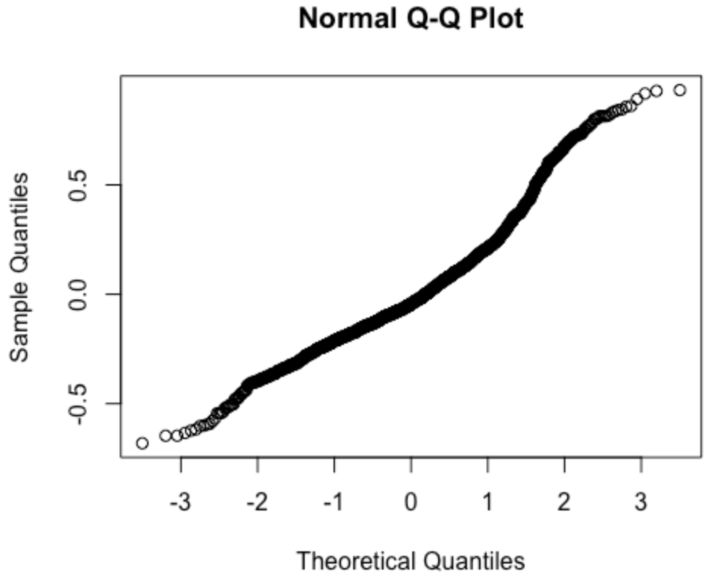


Figure 19. The distribution of residuals in the model with Acoustic Memory as a fixed effect and Subject and Item as random effects.

## 5.5 The measure of category compactness

To map the perceptual space underlying the native Spanish category /i/ in each participant, we used a goodness rating task, in which participants rated 28 synthesized variants of /i/ four times in terms of variants' distance from a prototypical Spanish /i/. The variants that were rated as good exemplars (higher than 5) at least three times formed a perceptual category /i/ for each participant: the more variants a participant rated as good exemplars, the larger her perceptual category was. Because the variants were located at an unequal distance from the prototypical /i/, they were also assigned values from 10 to 50 based on their distance from the prototype (Figure 20). Thus, the compactness index represented the weighted score of all variants selected as good exemplars, with the maximum of 690.

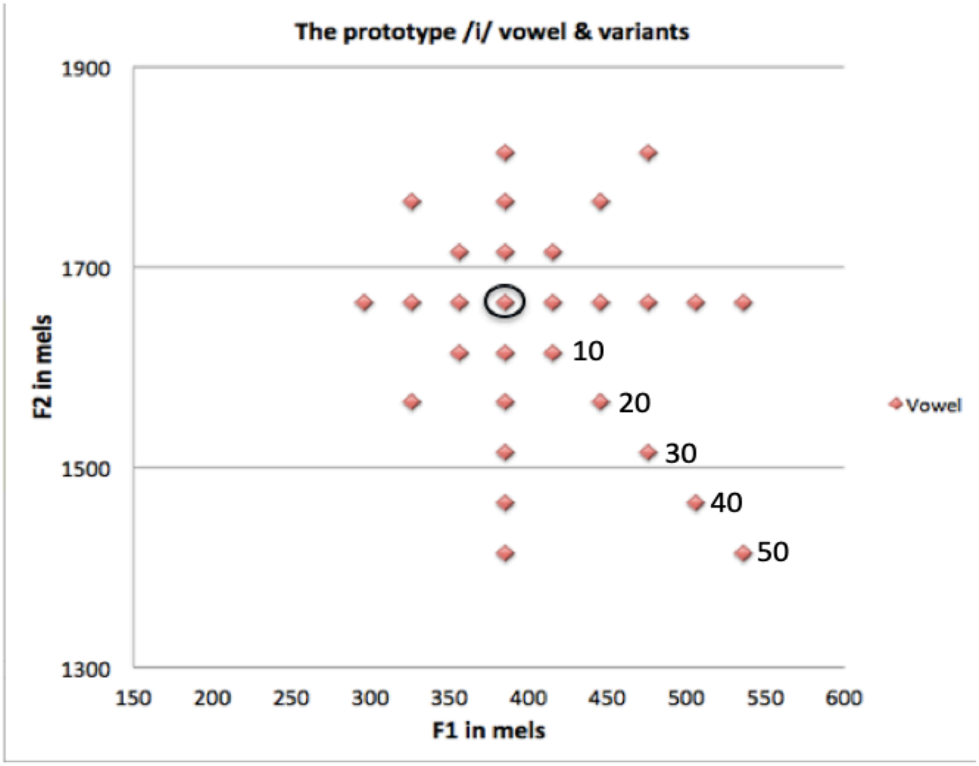


Figure 20. Each variant has a different value from 10 to 50 based on its distance from the prototype.

The resulting scores from the goodness rating task formed a normal distribution as confirmed by the Shapiro-Wilk test (*W* = 0.99, *p* = .59) with a slight positive skew (0.05) and no extreme values as detected by the box plot. Figure 6 shows that the histogram for the compactness scores resembled a bimodal distribution, yet, Hartigans' dip test confirmed unimodality (*D* = 0.04, *p* = .42). Participants on average varied in their compactness index by 100.37 points with the maximum result of 560 and the minimum of 80 (Table 2).

Since each participant responded four times to each variant, we collected four sets of responses that we used to calculate intra-rater (intra-subject reliability). We used Cohen's kappa statistics for this purpose since it is suitable for calculating both inter- and intra-rater reliability and can be used with more than two raters or datasets (sometimes also called Fleiss' kappa: Falotico, & Quatto, 2015). The average Cohen's kappa across 90 participants who completed the rated dissimilarity task was 0.37 (SD = 0.16), which is very close to Cohen's suggested interpretation that a score of 0.4 might be acceptable. Considering the nature of the test (perception) and the study design (online data collection) we concluded that in general participants were responding to the stimuli consistently. Another way to ensure that the task worked appropriately was to look at the average response rate per variant: we would expect lower scores to be assigned to the variants located closer to the prototype (similar to /i/) and higher scores — to the variants located further from the prototype (different from /i/). That was indeed the case: the variants further away from the referent vowel were perceived as less similar. Figure 21 shows that participants demonstrated remarkable perceptual sensitivity when judging each variant's distance from its prototype: when checked with a help of a simple linear regression, the effect of distance was highly significant ($R^2 = 0.58$, $p < .001$). Participants were more sensitive to the differences in F1 (the average perceptual distance between the variants was 0.67 point, *SD* = 0.56) than to the differences in F2 (the average perceptual distance between the variants was 0.51 point, *SD* = 0.46). As expected, when both formants were manipulated, the distance between the variants was perceived as the greatest (the average perceptual distance between the variants alongside the diagonal vectors was 0.74 point, *SD* = 0.58).

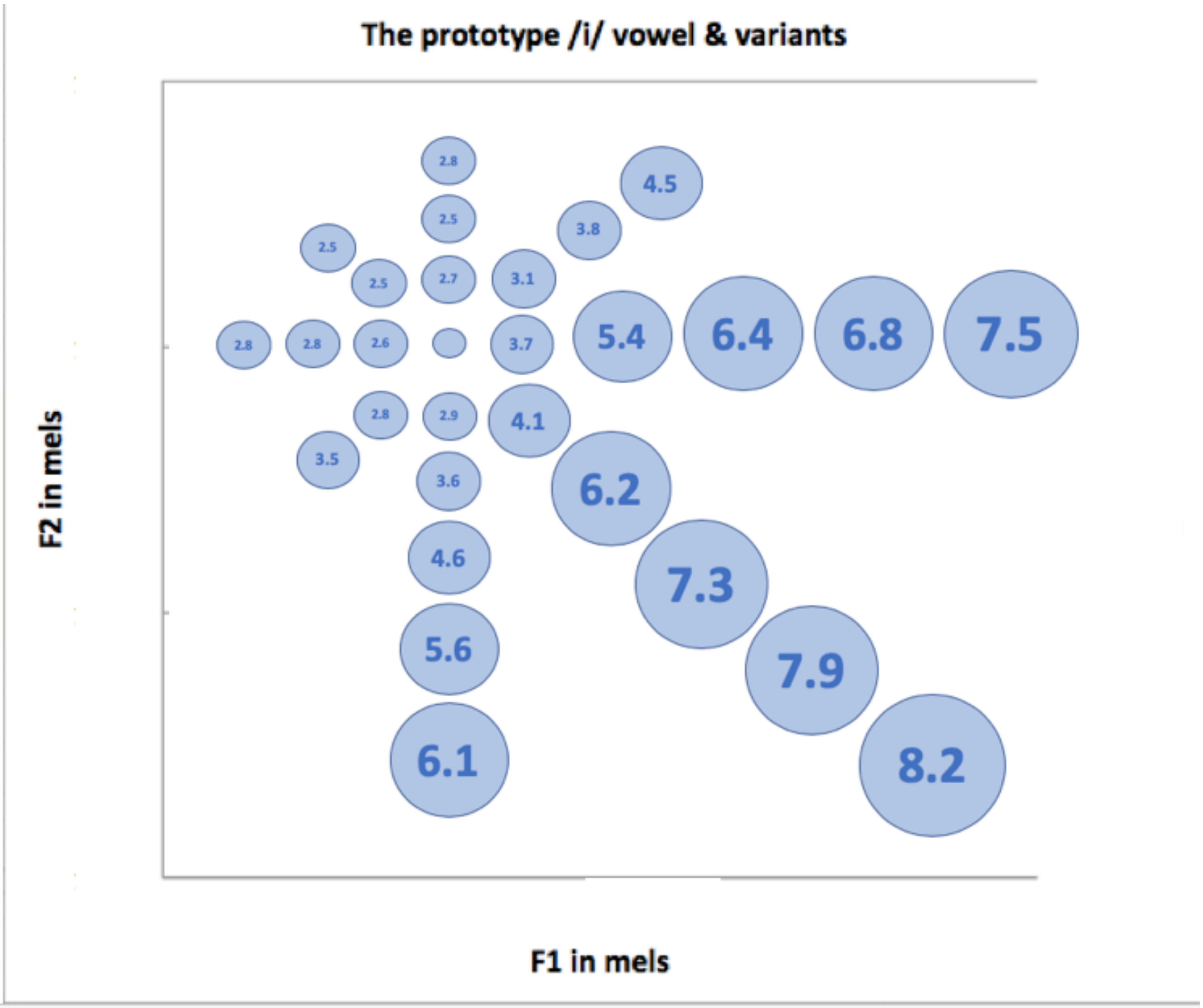


Figure 21. The size of the circles signifies the perceived psychoacoustic distance of a given variant from a prototypical /i/, with smaller circles indicating smaller distance (perceived as a good exemplar of /i/).

In Chapter 3 we identified several internal and external factors potentially responsible for individual differences in native perception, with phonological short-term memory and social network size (i.e., how many people a person communicates to on a weekly basis) leading the list. To explore the effects of these variables on category compactness, we fitted a linear model with *Compactness* as a dependent variable and *Phonological Short-Term Memory* and *Social Network Size* as predictors. Visual inspection of residual plots did not reveal any severe deviations from the assumptions of normality, linearity, and homoscedasticity. Although *Phonological Short-Term*

*Memory* did not reach the significance level, the correlation between *Phonological Short-Term Memory* and *Compactness* was negative ($r$ = - 0.06, $p$ = .61) pointing to a directional pattern we expected: participants with the greater phonological short-term memory capacity tended to have more compact categories (Figure 22). Yet, we have to acknowledge that no meaningful conclusions can be made based on such a low coefficient and insignificant p. On the other hand, *Social Network Size* affected *Compactness* significantly ($R^2$ = 0.17, $p$ = .008) lowering it by about 68 points when participants reported a medium size network (5 to 10 people) and by about 93 points when participants reported a small size network (1 to 5 people). Since *Social Network Size* is a categorical variable, a large size network served as the base level, to which the medium and small size network scores were compared.

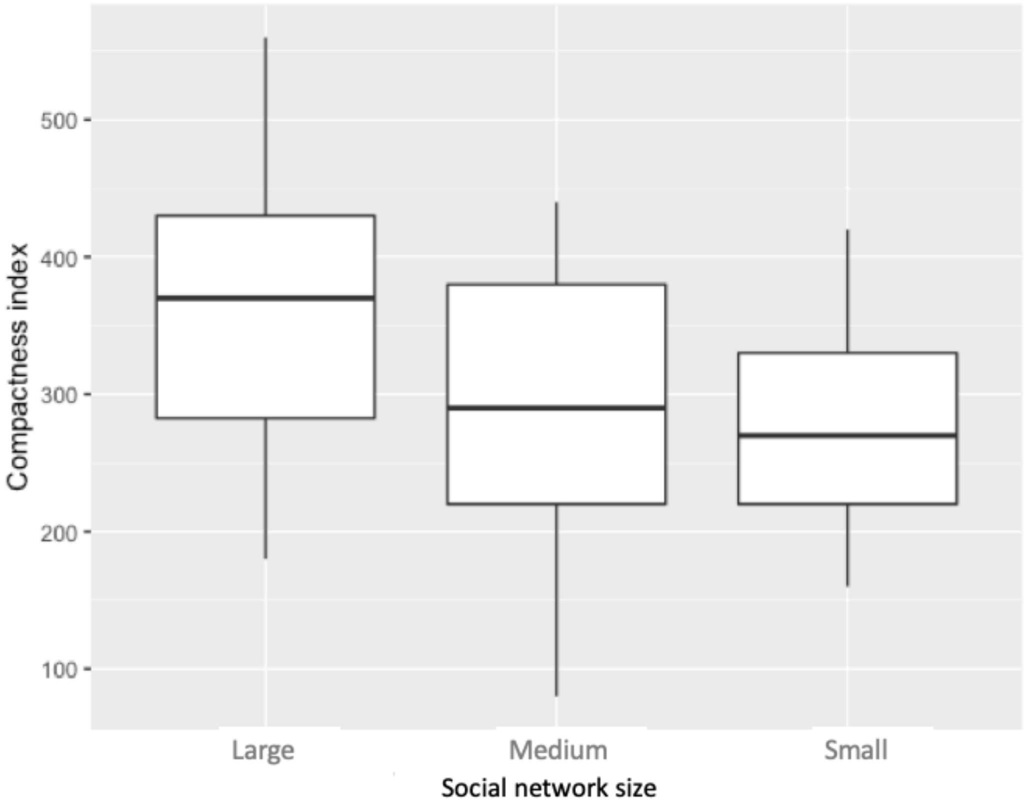


Figure 22. The smaller social network size is, the more compact the native category.

This finding seems to go along with the results of Lev-Ari's study (2017) that examined whether having increased input variability (a larger network) effects native speech perception. She found that when the input comes from a large network, learners form larger categories and vice versa. We will discuss these findings further in the following chapter.

*L2 experience* did not contribute to *Compactness* at the significant level (($R^2 = 0.031$, $p = .15$), but the direction of the trend was intriguing, with true monolinguals tended to have slightly more compact categories in comparison to functional monolinguals (Figure 23).

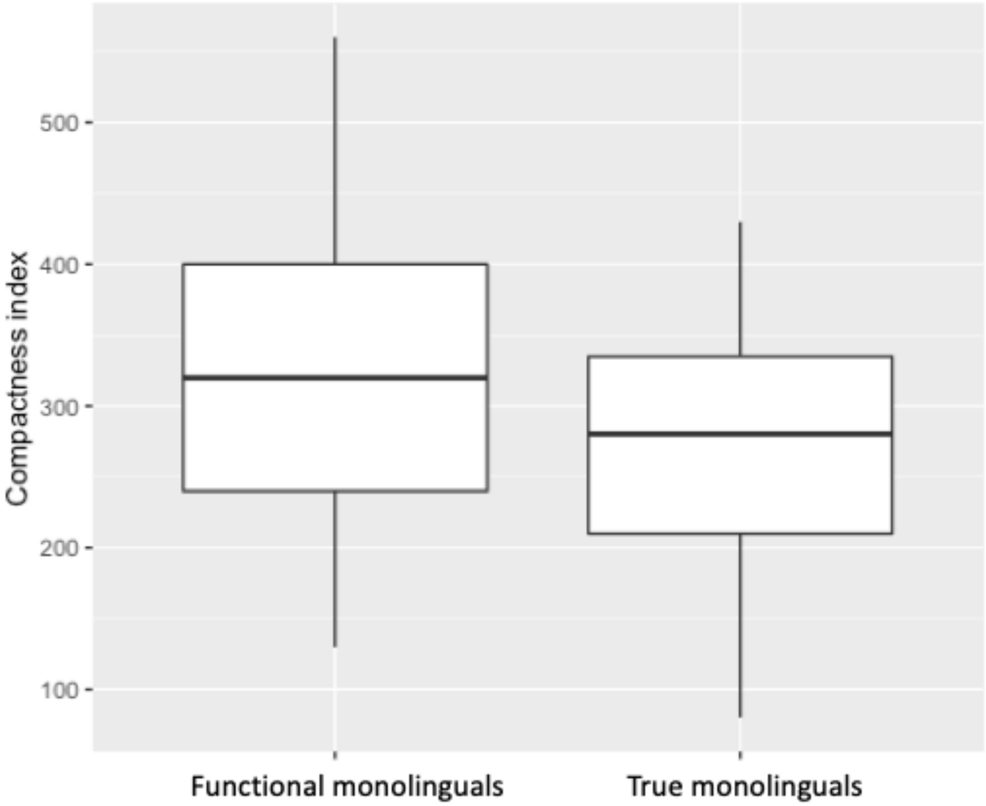


Figure 23. Functional monolinguals have on average larger categories than true monolinguals.

## 5.6 The relationships between perceived dissimilarity in L0 and compactness of a native category

From the previous section, in which the measure of category compactness was statistically analyzed, we know that the compactness index varied across individuals. To assess the effects of this variability on the degree of perceived dissimilarity between contrasting L0 sounds (Russian /i/ and /ɨ/), we fitted a series of mixed-effects models (Table 4; Appendix G). Before fitting the models to the data, we inspected quantile-quantile plots for each subject that demonstrated log-transformed perceived dissimilarity scores from the rated dissimilarity task (Figure 24). Recall that because we used the reverse score transformation to correct a negative skew, the interpretation of the variable is reversed: big scores have become small and small scores have become big (Field, Miles, & Field, 2012).

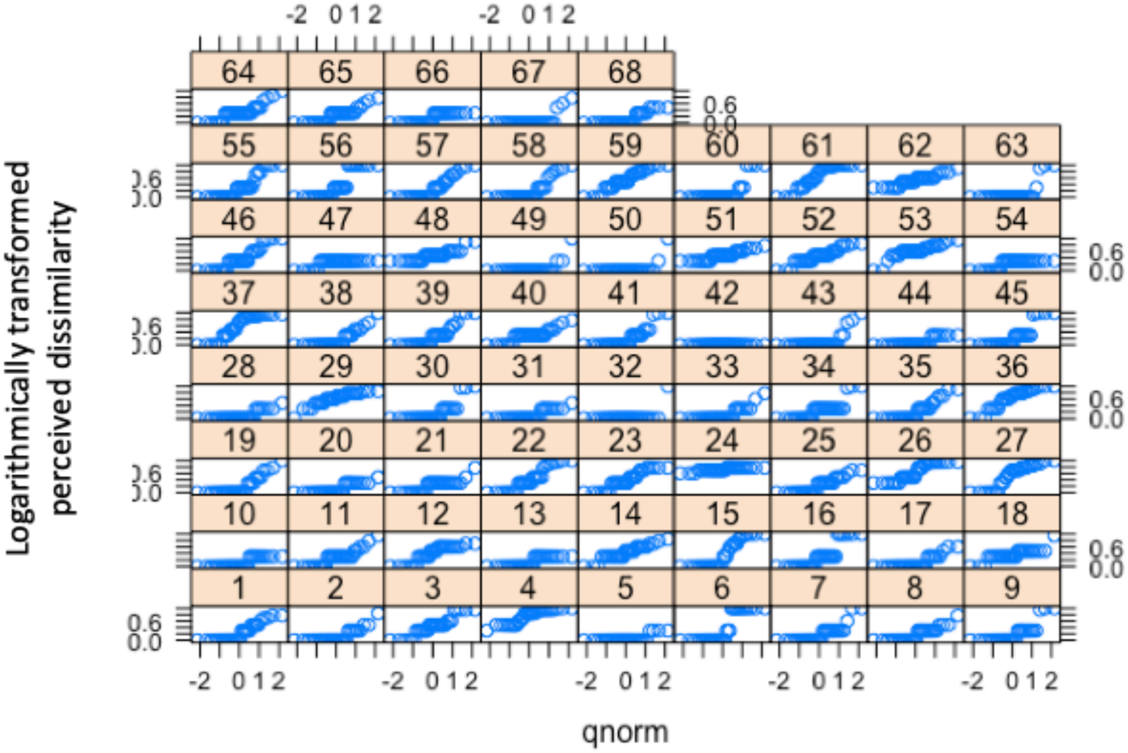


Figure 24. Quantile-quantile plots for the logarithmically transformed perceived dissimilarity scores in a rated dissimilarity task grouped by subject.

As can be seen in Figure 24, most of the score sets have thick right tails indicating outliers, which were preserved since none of them were suspect for experimental reasons. In fact, considering the online mode of data collection, we would expect a higher degree of intra-subject variability, i.e., how consistently each participant was performing on the rated dissimilarity task. The average standard deviation on the rated dissimilarity task was 1.81 points. Removing data points with more than two or three standard deviations away from the mean would imply unnecessary and unjustified data trimming (Baayen, 2008). Another way to address intra-subject variability would be to remove the participants with the greatest standard deviation values. Two of such participants, number 6 (*SD* = 4.28) and 56 (*SD* = 3.95), were identified and removed. This alteration did not improve the fit of the following regression model, thus, for the more ecological approach, the original number of data points was used.

We began our analysis by examining the effect of the main variable of interest — *Compactness*, on *Perceived Dissimilarity*. Figure 25 shows a negative linear relationship between *Compactness* and *Perceived Dissimilarity* (untransformed scores here): as the size of a category increases, the ability to perceive dissimilarity between two contrasting L0 sounds decreases.

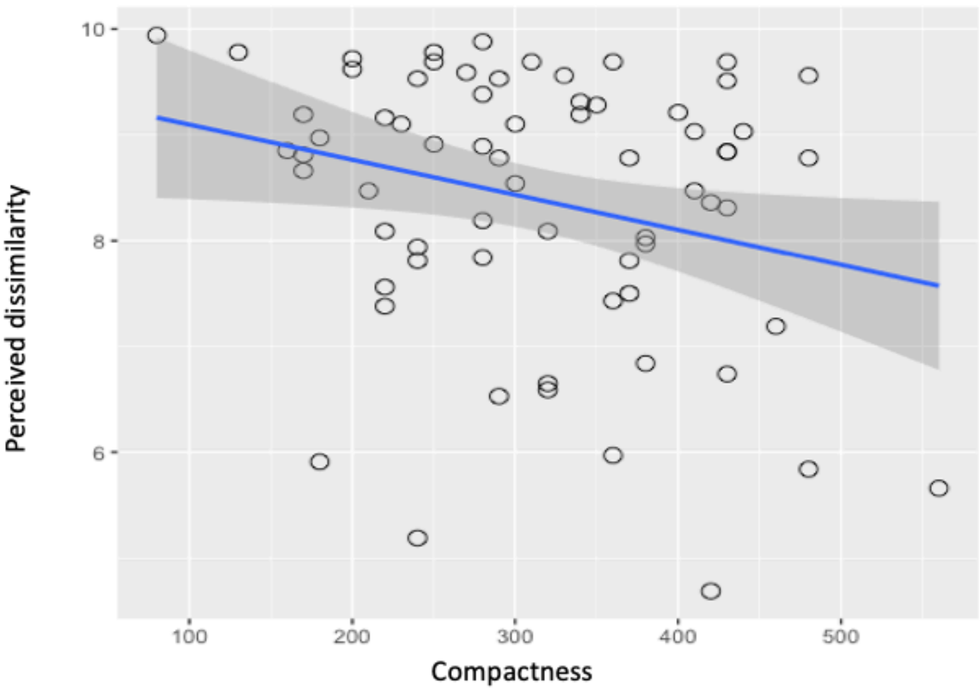


Figure 25. The relationships between Compactness and Perceived Dissimilarity (untransformed scores).

A mixed-effects model with *Compactness* as a fixed effect and *Subject* and *Item* as random effects showed that *Compactness* affected *Perceived Dissimilarity* at a border significance level (χ2(5) = 3.84, *p* = .05), decreasing it by about 0.003 points (or 0.0004446 points – unlogged value; Appendix G, Table 11). When we allowed the slope of the effect of *Compactness* to vary across subjects, the model did not improve: it seemed that all subjects were influenced by this measure in a similar way (χ2(7) = 0.83, *p* = .66).

In the previous section, we reported significant relationships between *Compactness* and *Social Network Size*: participants with a smaller network tended to have more compact categories. To test if the effect of *Compactness* might be different for participants with different network sizes we included *Social Network Size* as a predictor, together with an interaction of *Social Network Size* by *Compactness* (Appendix G, Table 12). The interaction of *Social Network Size* by *Compactness* did not come significant meaning that the effect of *Compactness* did not vary across small, medium and large network groups: all groups showed the same pattern of the relationship between *Compactness* and *Perceived Dissimilarity*. However, the effect of *Social Network Size* alone (when the interaction term was taken from the model; Appendix G, Table 13) came close to significance: participants with a small network tended to cope better with a novel vowel contrast than participants with a large network (*p* = .06) (Figure 26).

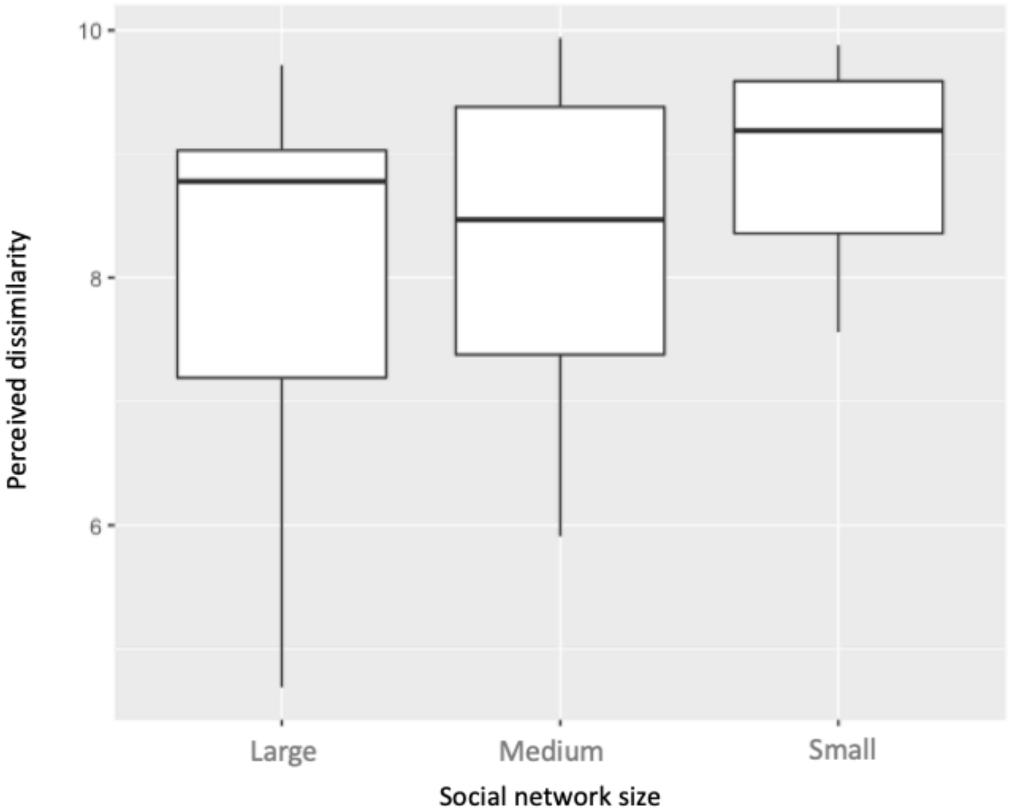


Figure 26. Participants with a small social network have higher Perceived Dissimilarity ratings in comparison to participants with a medium or a large network.

Recall that *L2 Experience* came close to significance when we used standard multiple regression analysis with *Perceived Dissimilarity* as a dependent variable. In subsequent analysis, the difference between true monolinguals and functional monolinguals was significant when measured with an independent two-tailed Wilcoxon test (*W* = 193, *p* = .04). However, in combination with *Compactness* there was no effect of *L2 Experience* as another fixed effect in our model ($\chi2(7) = 2.79$, $p = .25$; Appendix G, Table 14). Even though *L2 Experience* did not seem to show a direct significant effect on *Compactness*, *L2 Experience* might influence Compactness indirectly: *Compactness* could be the link connecting *Perceived Dissimilarity* with *L2 Experience*. We observed that true monolinguals tend to have more compact categories, which might explain their superior performance on a rated dissimilarity task that measured *Perceived Dissimilarity*. The opposite could be also true: functional monolinguals tend to have larger L1 categories, and this interferes with their ability to differentiate a novel contrast.

The interaction term between *Compactness* and *L2 Experience* did not show significance ($\chi2(9) = 3.56$, $p = .47$; Appendix G, Table 15). Another interaction term introduced in the model was between *L2 Experience* and *Social Network Size* (Appendix G, Table 16). This time, true monolinguals with a medium social network significantly outperformed functional monolinguals with the same network size: $p = .02$ (Figure 27). It seems that having no previous language-learning experience benefited the participants with a medium network size by enhancing their non-native perception significantly. There was no difference between true monolinguals and functional monolinguals with large and small social networks. One explanation is that an unsystematic and brief exposure to a highly variant input (a larger network of interlocutors and superficial familiarity with foreign languages) results in larger categories, i.e., categories that are “contaminated” with a greater number of variants. Large categories make it more difficult to identify a new token as a member of a new category. Unfortunately, in our study, we only had 11 true monolinguals and 57 functional monolinguals, which makes a fair comparison less reliable statistically.

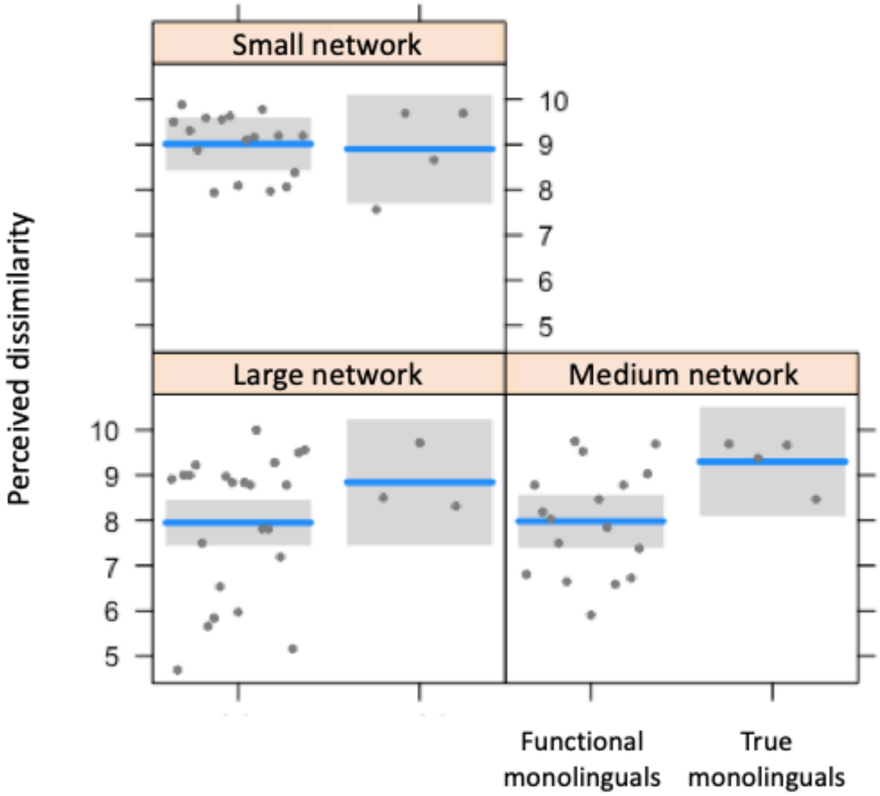


Figure 27. True monolinguals with a medium social network demonstrate higher Perceived Dissimilarity than functional monolinguals with the same social network size.

Previous research has shown that a number of personality factors can also relate to the acquisition of phonetic skills (e.g., Rota & Reiterer, 2009). In this study, the measures of personality included a self-reported questionnaire based on the Five-Factor Model (Costa & McCrae, 1992; McCrae & Costa, 1985). The obtained measures of *Openness*, *Conscientiousness*, *Extraversion*, *Agreeableness*, and *Neuroticism* were added to the model as fixed effects while *Subject* and *Item* as random effects. None of the personality factors came out significant, and, thus, were taken out from the analysis (Appendix G, Table 17).

When *Phonological Short-term Memory* and *Acoustic Memory* were added to the model that already had *Compactness* and an interactional term between *L2 Experience* and *Social*

*Network Size*, the model improved significantly ($\chi2(15) = 10.12$, $p = .006$; Appendix G, Table 18). Significant effects were obtained for *Acoustic Memory* ($\beta = 0.04$ or unlogged - 0.0057, $p = .006$), but not for *Phonological Short-term Memory* ($\beta = -0.003$ or unlogged 0.0011, $p = .26$). The interaction between *Acoustic Memory* and *Compactness* reached moderate significance ($p = .063$; Appendix G, Table 19) indicating that the effect of *Compactness* tended to vary depending on the acoustic memory capacity: participants with the lower acoustic memory capacity relied heavily on the size of their native category to differentiate between L0 sounds /i/ and /ɨ/, whereas participants with the greater acoustic memory capacity were not affected by *Compactness* (Figure 28).

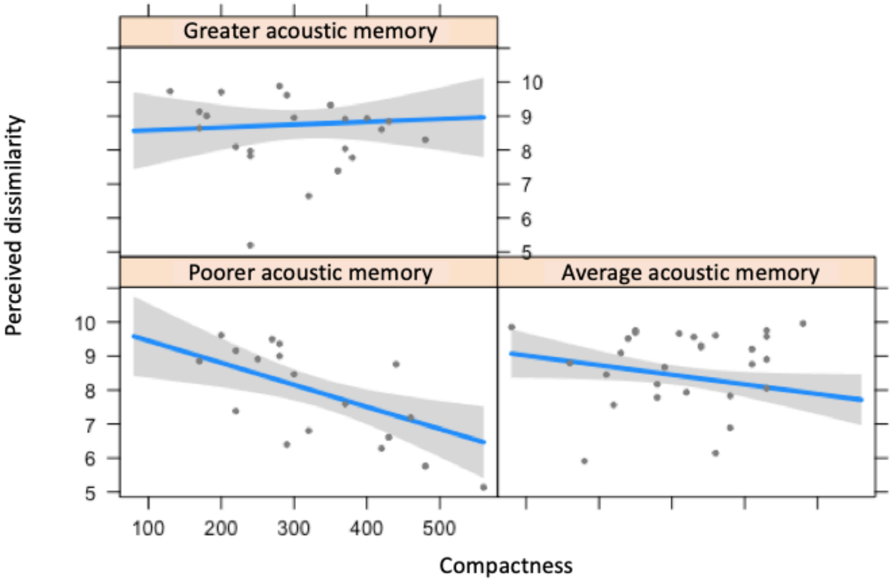


Figure 28. Participants with poorer acoustic memory relied on compactness to differentiate between /i/ and /ɨ/, whereas participants with greater acoustic memory were not affected by compactness and “used” acoustic memory instead.

Thus, our most successful model that explained the variance in *Perceived Dissimilarity* included two interaction terms: between *Compactness* and *Acoustic Memory* and between *L2 Experience* and *Social Network Size*.

Table 4. Regression models with Perceived Dissimilarity as a dependent variable.

| Regression model | Predictors: Fixed effects + (1\|Random effect) |
|---|---|
| 1 | Compactness + (1\|Subject) + (1\|Item) |
| 2 | Compactness + Social Network Size + Compactness*Social Network Size + (1\|Subject) + (1\|Item) |
| 3 | Compactness + Social Network Size + (1\|Subject) + (1\|Item) |
| 4 | Compactness + L2 Experience (1\|Subject) + (1\|Item) |
| 5 | Compactness + L2 Experience + Compactness *L2 Experience + (1\|Subject) + (1\|Item) |
| 6 | Compactness + L2 Experience* Social Network Size + (1\|Subject) + (1\|Item) |
| 7 | Openness + Conscientiousness + Extraversion + Agreeableness + Neuroticism + (1\|Subject) + (1\|Item) |
| 8 | Compactness + L2 Experience* Social Network Size + Phonological Sort-term Memory + Acoustic Memory + (1\|Subject) + (1\|Item) |
| 9 | Compactness*Acoustic Memory + L2 Experience* Social Network Size + (1\|Subject) + (1\|Item) |

*interaction

Lastly, we checked whether including random effects — *Subject* and *Item* — was justified by comparing the final model with the model without random effects. Both random effects had a significant contribution to make to the model ($p$ < .001). In fact, this linguistically uninteresting model with *Subject* and *Item* as the only predictors captured 99% of the variance in *Perceived Dissimilarity.* The fixed predictors only explained 1% of the overall variance. This is often the case when the fixed-effects structure of the models is used: most of the variance is typically accounted for by the variability among subjects and items (Baayen, 2008).

Even though the final model rendered the best characteristics in terms of AIC, BIC and p-values, the inspection of the residuals showed that there was strong heteroscedasticity of the residuals and a visually clear, although moderate, departure from normality. Even though mixed-effects models are robust to a certain degree of non-normality (Coupé, 2018), the conclusions from the final model should be reported with caution. To confirm if the same predictors would remain significant, we used a beta regression model, a type of a generalized linear regression that does not assume normality and linearity of residuals. This model also works well for a rating scale as a dependent variable, as it is in our case, and does not require a logarithmic transformation of a dependent variable, which remains a controversial issue in the field (Field, Miles, & Field, 2012; Coupé, 2018). However, in order to use beta regression, the dependent variable must vary between 0 and 1 with no observation equal to zero an/or one. Thus, first, we had to create a proportional variable of *Perceived Dissimilarity*, and, then, we used two interaction terms for the formula: 1) *Compactness* and *Acoustic memory*, and 2) *L2 Experience* and *Social Network Size*. *Compactness* alone and the *Compactness* and *Acoustic memory* interaction came significant with pseudo-$R^2$ equal to 0.32 (Table 5). Thus, we were able to confirm the main finding, i.e., the role of category compactness in perceived dissimilarity of a novel contrast. We provide interpretation and further discussion of our findings in the following chapter.

Table 5. Results for the beta regression model with proportional Perceived Dissimilarity as a dependent variable.

| Predictor | B | SE | *p* |
|---|---|---|---|
| Intercept | -4.491 | 0.02301 | 0.0002 |
| Compactness | -0.0001588 | 0.00006482 | 0.0143* |
| Acoustic Memory | -0.0006156 | 0.0004079 | 0.1313 |

| | | | |
|---|---|---|---|
| Social Network Size: Medium | -0.001352 | 0.003239 | 0.6765 |
| Social Network Size: Small | 0.006435 | 0.003334 | 0.0536 |
| L2 Experience: No | 0.006495 | 0.005938 | 0.2741 |
| Compactness*Acoustic Memory | 0.000002691 | 0.000001175 | 0.0220* |
| Social Network Size: Medium* L2 Experience: No | 0.005559 | 0.007962 | 0.4851 |
| Social Network Size: Small* L2 Experience: No | -0.006637 | 0.007967 | 0.4048 |

# Chapter 6 – Discussion

## 6.1 Individual differences in non-native perception

In the past decades, exceptional L2 phonetic performance has been investigated from a number of different angles, showing significant correlations with cognitive skills, musicality, personality, motivation, and L1 background. The reason is evident: assuming comparable learning conditions, adult learners vary greatly in their ability to acquire foreign sound systems. In this dissertation, we investigated non-native perception, in particular — the ability to distinguish between novel sounds, and how individuals differ in this regard. Our results showed that some individuals are more successful than others when dealing with sound contrasts that do not occur in their native language. Even though the majority of the Spanish participants in our study demonstrated high accuracy in differentiating between Russian /i/ and /ɨ/, their performance differed significantly from Russian speakers' performance on the same task. The observed difference between the Spanish and Russian participants suggests that the Spanish participants' perception was influenced by the differences between their native phonological system and that of Russian. This goes along with previous L2 speech perception research that predicts difficulties in perception when the sound inventory in L1 and L2 are very different (Best & Tyler, 2007; Flege, 1995; van Leussen & Escudero, 2015). The Spanish participants also showed significantly lower perceived dissimilarity of the novel /i - ɨ/ contrast in comparison to the Russian distractor contrasts in the task: /a - i/, /o - a/, /i - e/, /e - o/, /a - u/, /ɨ - e/, /o - u/, /u - ɨ /. It is not simply the absence of /ɨ/ that caused Spanish listeners to struggle with /i - ɨ/ contrast on the rated dissimilarity task, it is the proximity of /ɨ/ to /i/. Both Russian vowels occupy more or less the same perceptual space where Spanish has a single category

/i/.

The rated dissimilarity task to assess participants' perception of an L0 phonological contrast was designed to tap the pre-phonological level of speech perception since our Spanish participants did not have an established phonetic category for either Russian /i/ or /ɨ/. Despite the lack of these phonemes in their L1, some participants perceived /i/ or /ɨ as distinct sounds (reflected by the greater perceived dissimilarity ratings) and some participants perceived little or no acoustic distance between /i/ and /ɨ/. To investigate such inter-individual variability, first, we looked at the information about participants' gender, age, foreign language experience, the number of foreign languages spoken in a family, exposure to Russian, and formal training in phonetics. In the present study, among the factors listed above, only foreign language experience moderately related to the measure of L0 perception, affecting it negatively: the more languages an individual learned in the past, the poorer was her ability to perceive dissimilarity between two non-native vowels. Notice, that all participants were considered to be monolinguals since none of them reported speaking a foreign language at a level higher than intermediate. Yet, the difference in L0 perception between the true monolinguals (individuals who reported speaking no foreign languages) and the functional monolinguals (individuals who had studied foreign languages before but reported not being able to hold a conversation in any of them) was significant: true monolinguals were more successful at distinguishing between Russian /i/ and /ɨ/ than functional monolinguals. This significant difference points to a seemingly counterintuitive assumption: having previous exposure to foreign languages does not result in better non-native perception. Studies that have investigated the effects of previous language experience on non-native phonological awareness, i.e., explicit and implicit knowledge about the sound structure of the language (also known as phonological sensitivity: Cunningham & Carroll, 2015; Kivistö de Souza, 2015) that might result in enhanced non-native perceptual sensitivity, have shown mixed results. Previous L2 experience does not always guarantee enhanced non-native perception (Kennedy, 2012; Kennedy & Trofimovich, 2010; Venkatagiri & Levis, 2007). The amount of language exposure necessary to develop non-native phonological awareness might be important in this regard. Shoemaker (2014) compared third-year English majors with first-year English majors — the number of years showed significant effects on L2 phonological awareness. It should be noted that the studies mentioned above investigated the effects of L2 exposure on phonological awareness in the same L2, i.e., language-specific phonological awareness (e.g., exposure to English influencing phonological awareness in English). In our case, the participants with prior L2 experience in various L2s were exposed to a novel vowel contrast in a language they have never studied before. Thus, the situation resembles that of L3 acquisition, rather than L2 acquisition. Studies on the effects of L2 experience in L3 perception report that general experience in learning a foreign language gives a global advantage in phonological perception (Chang, 2013), even though previously acquired languages create more opportunities for linguistic interference (Onishi, 2016; Wrembel, 2010). It would be reasonable to expect the learning of foreign languages have equipped our functional monolinguals with improved phonological awareness and/or perception — yet, our study did not provide supporting evidence for this. A certain level of L2 proficiency might be necessary for previous language learning to have a beneficial effect on further (L3) perceptual learning.

We would like to suggest the following interpretation of the finding discussed above. The previous L2 learning experience of functional monolinguals might have enlarged their native perceptual categories. Since the functional monolinguals on our study never continued learning their L2s and, thus, never reached a proficiency level higher than intermediate, the process of category split (the division of a single native category that handles both instances of a non-native contrast into two new categories; Mayr & Escudero, 2010) never took place leaving our functional monolinguals with slightly larger native categories. In other words, their previous L2 experience resulted in the "looser" or less compact native category /i/, which included more "deviant" variants of /i/ (more various allophones of /i/), than the same category of the true monolinguals who had no previous experience with other languages and, thus, preserved more compact categories (Figure 29). According to exemplar theory (Pierrehumbert, 2001), variability is essential for defining category boundaries and size, e.g., which tokens are not /i/. It is critical for a learner to hear a variety of exemplars in order to define the psychoacoustic space occupied by a particular phonetic category. Limited input in a foreign language might be responsible for including too many noncontrastive (or perceived as noncontrastive) variants into a native category, which might impede the processing of other novel sounds. Lev-Ari's (2017) computational simulations also offer some insights into the mechanisms underlying the effects of limited L2 proficiency on initial perceptual learning. She demonstrates that at the onset of L2 acquisition learners fail to attend to relevant acoustic dimensions,  this hinders the acquisition of novel phonetic categories. At the early stage of learning, there is a tendency towards forming large categories, each comprised of several non-native categories, and only later, with an increased amount of input, large categories may be split into two or several smaller categories. Thus, the amount and quality of input matter when novel phonetic categories are formed. In this sense, although somewhat counterintuitively, when compared to functional monolinguals, true monolinguals enjoy a perceptual advantage for distinguishing a novel contrast since their native categories have not been "contaminated" with irrelevant variants.

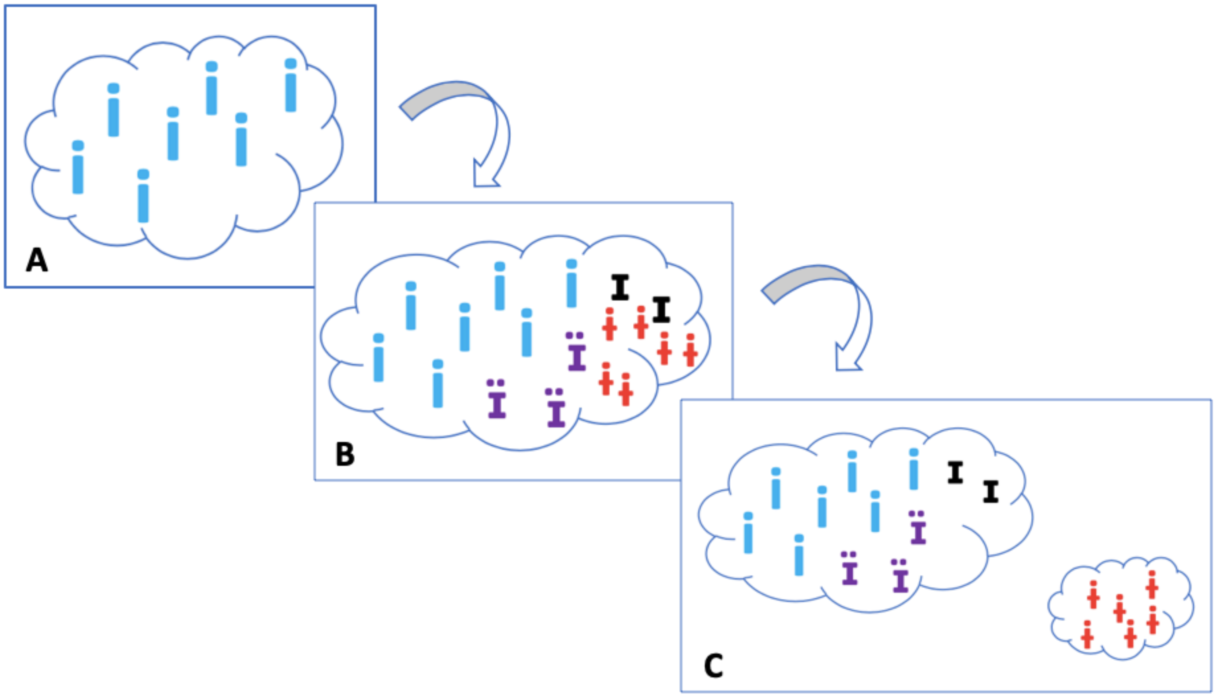


Figure 29. At the initial stage, the learning of multiple L2s “contaminates” a native phonetic category with non-native variants (B). As learning progresses further, these variants are grouped and identified as a new category (C).

Following this logic, we would expect a significant difference between true monolinguals and functional monolinguals in terms of category compactness: true monolinguals should have significantly more compact categories than functional monolinguals. Even though such a trend was detected in the present study, it has not reached significance. Since the effect of previous L2 experience on category compactness was not the focus of this study, we did not target specific populations of participants in this regard, i.e., a balanced group of functional and true monolinguals. Therefore, we only had 11 true monolinguals, which made the comparison to functional monolinguals (57 participants) a statistically challenging task. Besides, considering how much exposure to English through the Internet and media the speakers of other languages have nowadays, recruiting true monolinguals might be a hopeless task.  Yet, we are intrigued about the trend towards less compact native categories as a function of limited L2 learning. Understanding how a native sound system is affected by L2 phonetic and phonological acquisition at different stages of the process is of great theoretical and practical importance.

## 6.2 Cognitive and personality factors

Recent research has shown that phonological short-term memory and acoustic memory contribute to listeners' success in perceiving acoustic differences between novel sounds. In the present study, we did not find a connection between phonological short-term memory and acoustic memory indicating that they are autonomous concepts that contribute to non-native perception independently from each other. Our results confirmed a significant effect of acoustic memory, but not phonological short-term memory on Spanish listeners' degree of perceived distance between Russian (L0) /i/ and /ɨ/, more specifically listeners obtaining higher scores in the acoustic memory task were found to perceive a larger perceptual distance between the target vowels. This finding points to the fact that, when perceiving the distance between novel /i/ and /ɨ/, the participants relied on their ability to detect a physical (auditory) difference between a pair of stimuli, rather than judging the two sounds as instances of different categories. Acoustic memory supports a perceptual system in encoding acoustic detail at the pre-categorical level when it is necessary to recognize differences between the sounds which are not two instances of two distinctive categories. Since none of our participants were familiar with Russian, their vowel inventory lacked a phonetic category /ɨ/, which made it difficult to distinguish between /ɨ/ and /i/ based on the category-relevant dimensions. It comes as no surprise that the participants used auditory-based judgments, rather than judgments based on the comparison of the phonetic codes. If they had more experience with Russian, they might have employed phonological short-term memory to the same extent as acoustic memory, if not greater.

The facilitating effect of acoustic memory on the degree of perceived dissimilarity was not the same for all participants. The interaction between acoustic memory and compactness found in our study suggested that there were two fundamentally different perceptual patterns involved. Whereas participants with greater acoustic memory were barely influenced by the effects of compactness, participants with poorer acoustic memory relied heavily on category compactness in discriminating between two novel sounds. Since perceptual compactness is a relatively new concept, the interplay between memory and compactness has not been researched thoroughly yet. Thus, we can only hypothesize that there could be a number of specific compensatory perceptual patterns that individuals employ in order to reach optimal perception. It is quite likely that having a deficiency in one cognitive structure that supports perception, e.g., reduced acoustic memory storage, a listener has to rely on another structure, e.g., category compactness, in order to reach a better perceptual resolution. A similar idea of two compensatory strategies for linguistic processing was proposed by Skehan (1998) within his cognitive theory of L2 learning. He suggested that there are two populations of learners, memory-oriented and analysis-oriented. According to this classification, high memory learners do not use a complex analytic system to make a hypothesis about a new language, rather they store a wide range of linguistic exemplars in their memory systems to be used later on. On the other end of Skehan's scale are analytical learners that regularly engage in structuring and systematization of incoming linguistic stimuli to fit it into an abstract model. Kormos (1999) supported Skehan's theory explaining it by finite attentional resources being allocated to the task: some learners pay more attention to storing the input and some learners – to analyzing and monitoring it. That could be the case with our participants as well: listeners with greater acoustic memory benefit from storing larger chunks of acoustic input and processing it for longer, thus, achieving better non-native perception irrelevantly of the size of their native categories. In our study, there was no connection between the degree of perceived dissimilarity and compactness for the group of listeners with greater acoustic memory capacity. In other words, the performance of the greater acoustic memory group in the rated dissimilarity task was not affected by compactness of their native category /i/. On the other hand, the group of listeners with the poorer acoustic memory capacity was significantly affected by compactness when trying to discriminate between L0 sounds. In Skehan's terminology, this group of listeners would belong to the analysis-oriented (as opposed to memory-oriented) listeners that have to employ analytical skills (as oppose to memory capacity) to process novel linguistic stimuli. Since we have not measured analytical skills in our study, it is hard to draw a connection between the analytical skills and increased category compactness. We can hypothesize that listeners with poorer acoustic memory might have superior analytic skills (as Skehan describes) that help them to identify a novel variant more efficiently, which leads to more compact native categories. Guenther (1995) suggested that compact categories in perception might be the result of an increased rejection rate for poorly produced sound tokens of a phoneme. It could be that more analytical listeners are striker judges when evaluating new variants of their native phonemes and, thus, they reject more tokens as a result.

We did not observe a relationship between L0 perception and personality. One explanation for such results is that it is hard to find an appropriate level of analysis for both constructs (Furnham, 1990; Dörnyei, 2014). The multiplicity of theories in the field of personality and the complexity of selecting the appropriate measurements and instruments make interpretation of the findings a dubious undertaking (Dörnyei, 2014, 2010). In our study, due to testing time limitations, we used the short version of the Spanish NEO Five-Factor Inventory (FFI) (Costa & McCrae, 1992), a self-reported measure of personality based on the Five-Factor Model. Even though Lang, John, Lüdtke, Schupp, and Wagner (2011) suggested strong robustness of a 15-item inventory in all modalities, for future studies, we would suggest employing the full version of the FFI inventory and, if the time permits, more than one instrument to capture the personality traits accurately. Another explanation for the insignificant effects of personality on perception could be the level of linguistic analysis that we used in this study. Previous research has suggested connections between personality and pronunciation (Guiora, 1979; Hu & Reiterer, 2009), fluency (Dewaele & Furnham, 1999), communication competence (Verhoeven & Vermeer, 2002), listening, speaking (MacIntyre & Gardner, 1991), and foreign-language academic achievement (Onwuegbuzie, Bailey & Daley, 2000). However, in our study, we measured the ability to perceive an acoustic distance between two novel sounds, which is a low-level processing mechanism that might not be connected to personality in its classical depositional sense (the trait and type approach: Costa & McCrae, 1992). If we have defined the construct of personality through the biological standpoint that bases all psychological phenomena in the neural-biological systems (Canli, 2004; Gray et al., 2005; Wright, Feczko, Dickerson, & Williams, 2007) and measured it with the brain imaging methods (which provide the chance to directly map brain anatomy and functioning) the outcomes could have been different.

Since personality was not the primary focus of the present study, we did not have research questions associated with it directly and used the personality data to ensure that neither openness, conscientiousness, extroversion, agreeableness, or neuroticism influenced the judgments on the rated dissimilarity task. We concluded that the performance on the rated dissimilarity task was not affected by inter-subject personality differences.

## 6.3 Individual differences in category compactness and their connection to L0 perception

The purpose of the present study was to investigate whether individual differences in L1 perception are large enough to influence L0 perception. Even though adults seem to process native speech flawlessly despite a highly variant phonetic input, they do not cope equally well with speech perception, when non-native sounds have to be processed. We hypothesized that individual differences in L1 perception might partially explain variable outcomes in L2 phonetics and phonology. There are a number of reasons to take L1-based variability into consideration. One such reason is that people learn their first language from their environment via statistical learning (Saffran, Aslin, & Newport, 1996), which ensures that they use a language variety prevailing in their community. Thus, the number and quality of L1 phonological categories are affected by the input received. For example, in their study, Maye, Werker, and Gerken (2002) showed that infants develop two categories if they are exposed to the bi-modal distribution of phonemes (/d/ vs /t/) and one category if the distribution is uniform. Since no two listeners received the same input throughout their life, there are likely to be differences in how individuals develop L1 perceptual categories, which may vary from individual to individual within the same L1.

In the present study we observed that when the input came from a larger network, it resulted in larger categories. In her recent study, Lev-Ari (2017) investigated whether individuals who regularly interact with more people were better at L1 speech perception. She measured the robustness of participants' vowel representations and found that participants with a larger social network correctly transcribed more vowels embedded in noise than less socially active listeners. It seems that a greater level of variability in the input (in this case, multiple speakers in the network) had a faciliatory effect on L1 phonological acquisition. The infants from Rost and

McMurray's (2009) study benefited more from exposure to 18 speakers than to a single speaker when listening to a /buk-puk/ minimal pair. Sumner (2011) confirmed this line of argument demonstrating that listening to multiple tokens produced by a speaker accelerates learning as opposed to listening to a single token produced the same number of times by the same speaker. Our results reconcile these observations. It seems plausible that L1 perception is better when categories are built through exposure to more exemplars (more robust categories) since it allows a listener to cope with a greater degree of variance. The question addressed by the current study was: To what extent does L1-based variability in category compactness influence the degree of perceived dissimilarity of a novel vowel contrast? Our results indicated that when non-native perception is involved, individuals with large categories benefit the least. The reason could be simply quantitative in nature: one large native category might contain two small non-native categories inside it making L0 perception difficult. Best's Perceptual Assimilation Model (e.g., Best 1995) postulates that the difficulty associated with listening to non-native sounds, depends on phonetic-articulatory similarities between L1 and non-L1 sounds. According to this model, the situation when two foreign sounds are assimilated to one phoneme in the native language is labeled as single-category assimilation (SC). The SC contrast is predicted to be difficult since two sounds are either equally different from or similar to the native sound. Another PAM assimilation pattern, category-goodness assimilation, involves two non-native contrasting sounds representing one good and one poor exemplar of a given L1 category. In this case, the distance between the non-native sounds should be distinguished better than with single-category assimilation. It seems that in our study listeners with a large Spanish category /i/ showed a tendency towards single-category assimilation: they perceived a small or no distance between Russian /i/ and /ɨ/ as if they assimilated both L0 sounds to the same Spanish category /i/. On the other hand, listeners with a compact

Spanish category /i/ showed category-goodness assimilation: they perceived a larger distance between Russian /i/ and /ɨ/, as if they judged one member of this contrast as a good exemplar of their native /i/ and the other member (most likely Russian /ɨ/) as a poor or deviant exemplar of Spanish /i/. Thus, we argue, individuals might have different perceptual assimilation patterns in L1/L0, based on the size of their native phonetic categories.

Another explanation for larger categories causing difficulty in non-native perception is mediated by the concept of social network size mentioned earlier. Lev-Ari (2018) shows that people with smaller social networks tend to assign greater weight to each person they encounter, and therefore, they are more susceptible to each person's influence. It could be that in our study listeners with compact categories (who also had smaller social networks) weighted input differently from listeners with large categories (and large social networks). Could it be that listeners with smaller social networks were less likely to generalize and would rather create a new category for an atypical sound? Previous research on linguistic diffusion (the process of passing new linguistic forms among adults) has suggested that people with smaller social networks are indeed better in spotting and propagating the innovation, thus, driving linguistic change (Bakshy, Rosenn, Marlow, & Adamic, 2012). Listeners with a smaller social network and a smaller collection of tokens might perceive every incoming token with greater attention, which would result in deeper processing, as opposed to listeners who are "desensitized" by a large collection of tokens in their category. On the one hand, such a desensitizing effect helps listeners to cope with variability in the speech input (the so-called lack of invariance phenomenon). On the other hand, it prevents a listener from identifying a new token as an instance of a novel category.

It must be noted that several previous studies that have investigated the effects of individual differences in L1 perception on non-native perception failed to find the connection. One such study by Langeris and Hazan (2010) looked at how individuals from the same L1 background (Greek) vary in their ability to learn to perceive an L2 contrast (English). They found no evidence of the relationship between individual L1 profiles on non-native perception and how flexible individuals were in learning new categories as a function of L1-based differences. It could be that L1-based differences only play a role at the initial stage of perceptual learning and later, as the learning progresses, other factors take over (e.g., phonological short-term memory, motivation). In Lengeris and Hazan's study, all participants had 10 to 12 years of English instruction with the language proficiency level described as "moderately high". It could be also that L1-based individual differences in perception, specifically, category compactness, affect individuals differently. As we observed before, individuals with greater acoustic memory were not affected by compactness when distinguishing between two novel sounds. On the other hand, individuals with poorer acoustic memory relied heavily on category compactness in the rated dissimilarity task.

In our study, the effect of compactness on non-native perception was small yet significant. Nevertheless, from the studies on the cultural evolution of language, we know that given enough time, a weak bias acting on learning can have strong cumulative effects called "bias amplification" (Dediu, 2011; Kirby et al., 2007; Thompson, Kirby, & Smith, 2016). On a larger timescale (e.g., years of learning a second language), category compactness might have a substantial impact on the acquisition of L2 phonetics and phonology. A longitudinal study that observes learners with various degrees of category compactness acquiring a novel language would offer an interesting insight into the role of perceptual compactness in shaping L2 perceptual learning.

## 6.4 Implications and future directions

The ability to discern subtle phonetic differences, either due to category compactness or other factors, provides an advantage in the acquisition of L2 phonetics and phonology. The next question to ask is whether the improved L2 perception benefits other aspects of second language acquisition. We hypothesize that exceptional phonetic abilities lead to more efficient use of the mechanisms responsible for speech perception and production in general. Evidence from fMRI/MRI studies shows that having phonetic talent reshapes brain anatomy improving performances in the "language network" (Rota, 2009). In a series of studies, Kachlicka, Saito, and Tierney (2019) propose that individual differences in neurocognitive functioning related to auditory processing can explain variability in the rate and ultimate attainment of L2 acquisition overall. They argue that precise audition can predict advanced L2 phonological, but also L2 lexical and grammatical skills. Thus, enhanced auditory processing might be a gate into language-learning.

In our study, we focused on one particular aspect of L0 speech perception, which is the degree of perceived dissimilarity of a novel vowel contrast. We hypothesized that, aside from other factors that contribute to non-native perception, category compactness plays an important role in distinguishing between two contrasting L0 sounds. Our results raised a number of new questions. For example, do all phonetic categories within one individual's vowel space have the same compactness index? In our study, due to time and resource constraints, we only measured one native category. However, if we follow the assumption of exemplar theory about the structure of a cognitive map for perception, we would see that the size of any particular category depends on frequency effects, i.e., how often particular exemplars are encountered. More frequent categories will have more tokens and less frequent categories fewer tokens (Pierrehumbert, 2001). For example, the Spanish categories /e/ and /a/ occur 13% and 11% of the time respectively (these numbers could be slightly different depending on the size and genre of the text: Version 18.2.17; WordCreator, 2019), which could mean that these categories on average are larger than the Spanish category /i/ (5%). High-frequency categories that are represented by more numerous exemplars would also have a higher activation level and, thus, a greater labeling power, i.e. recruiting more newly encountered tokens.

Another question is what would be the benefit of describing individual vowel profiles (the size and shape of each L1 category). Could we use it for more accurate predictions of the learning outcomes for specific languages? In our study, we measured the size of the Spanish category /i/ under the assumption that individuals with larger categories would struggle to discriminate between various allophones of /i/. Based on this assumption, we can predict that learning languages where several (more than one) allophones of /i/ are labeled as distinct phonetic categories will be a challenge. In this regard, Russian that has a /i - ɨ/ contrast or English that has a /i - ɪ/ contrast would be difficult, but not Japanese, as there are no contrasts in the high front area of the vowel space. Acquiring similar measures for other vowels (and possibly consonants, e.g., based on individual VOT, etc.) would allow for building individual psychoacoustic profiles and determining a so-called language match for every individual, i.e., the easiest language to learn in terms of phonetics. In the situation, when a learner has a choice of a foreign language to acquire (e.g., academic or military settings), measuring a phonetic distance between an individual's psychoacoustic profile and a specific language might serve as a useful guide for optimal L2 selection. Existing language aptitude tests (Hi-LAB: Doughty et al., 2010, etc.; CANAL-F: Grigorenko, Sternberg, & Ehrman, 2000; DLAB: Peterson & Al-Haik, 1976) do not make predictions for specific languages. Aptitude research has been concerned with the effects of individual differences in learning a foreign language, where a foreign language is a uniform phenomenon, i.e. any language, regardless of its phonetic and other linguistic properties. Accounting for idiosyncratic learner-language interactions might bring aptitude testing to a new level.

Other questions we would like to see answered in the future include: How does category compactness affect L1 phonetic aptitude, i.e., aptitude for learning phonetics and phonology of a native language (Trecca, Bleses, Højen, Madsen, & Christiansen, 2020)? What is the connection between less compact categories and phonetic disabilities (e.g., dyslexia)? How is the bilingual vowel space different from the monolingual vowel space in terms of category compactness? What does the polyglots' and gifted learners' vowel space look like? In other words, the present study offers fruitful opportunities for investigating a wide range of phenomena through the lenses of category compactness.

## 6.5 Limitations of the present study

The present study has some limitations that should be taken into account when interpreting the findings. The first and most important limitation concerns the design of the goodness rating task and the rated dissimilarity task. As we mentioned above, an ideal scenario for the goodness rating task would include measuring all native vowel categories in an individual's perceptual space. We have not been able to do so due to limited time and funding resources: measuring all five vowels with a goodness rating task would include several sessions with the same participants. It is not recommended to administer a goodness rating task for all vowels in one sitting because of the monotonous nature of the task requiring considerable attentional resources and a willingness to maintain the performance. The alternative solution would be to design this task in a way that is less demanding for participants, such as including gamified elements. Measuring all five vowels is not only important for understanding how phonetics categories vary within a single perceptual space but also for relating the categories and their size to the size of the perceptual space itself.

The second limitation is the subjective nature of the intuitive rating scale used in the goodness rating task. As any self-reported measure, such a scale might not be able to capture the small perceptual differences that we hoped to observe. Instead, future research may employ electrophysiological measurements of perception. By measuring mismatch negativity (MMN) brain responses to deviant sounds (in our case, the synthesized variants of /i/), it is possible to determine with a higher degree of accuracy if neural discrimination of these sounds is better or worse in comparison to the prototypical native sound. Generally speaking, when processing unfamiliar sounds, the brain’s response exhibits a lower MMN amplitude as compared to prototypical sounds (Näätänen et al., 1997). By calculating a difference between the MMN amplitude peaks of a deviant token and a prototype, we can measure the degree of perceptual recognition for each deviant with greater accuracy. Such a pre-attentive measure of perception would allow calculating the category compactness index more precisely since it would give direct access to an individual's low-level processing mechanisms.

To measure L0 perception, we employed a rated dissimilarity task. Since the task does not measure the perception of everyday speech, in which listeners have to recognize words and larger units embedded in noise and produced by many speakers, certain interpretive challenges might arise. To ensure higher ecological validity, it would be better to supplement phoneme discrimination tests with other measures.

Last but not least in relation to measuring perception: as individual perceptual measures fluctuate depending on many factors, such as time of the day or the hormone level, it would be beneficial to repeat the same tests several times.

A word of caution needs to be said about collecting data with crowdsourcing online platforms. Even though multiple measures were taken to ensure the validity and reliability of the data collected, online platforms remain a novel recruiting tool in behavioral research.

Finally, in the present study we have not explored the possibilities that a longitudinal design might offer. Following the participants as they acquire Russian over time would allow us to observe how category compactness evolves with growing proficiency and what factors influence this process.

# Chapter 7 – Conclusion

In this dissertation, we aimed to shed light on individual differences in native perception and how they influence non-native speech perception. L1-based individual differences is a relatively new topic that has been explored previously in other linguistics domains (e.g., morphosyntax), but not so much in phonetics and phonology and in relation to to L2 acquisition. In order to understand how individuals differ in the way their native phonetic categories are represented in perceptual space, we measured compactness of one such category. Then, we related this measure to the degree of perceived dissimilarity of a novel L0 contrast. Sixty-eight Spanish monolinguals participated in the present study. The compactness index of their vowel category /i/ was measured. Our participants were also assessed on their ability to perceive a distance between the members of a novel Russian contrast /i - ɨ/, as well as on several cognitive skills and personality traits.

Overall, the results obtained indicate an important role of category compactness in relation to L0 perception. We observed small but significant L1-based individual differences in perception, and these differences were shown to result in better perceptual discrimination of an acoustic distance between two novel sounds suggesting that L1-based category compactness contributes to non-native perception. This dissertation makes several important contributions to the current knowledge about L2 speech perception and L2 phonological acquisition. This chapter concludes the present dissertation by outlining the key findings and their potential contribution to the field of SLA.

## 7.1 Contribution of the dissertation

It is widely assumed that all native speakers of a shared language have more or less the same phonetic and phonological knowledge of their mother tongue. However, this is very much an assumption and not an empirical fact. Considering the theoretical and practical significance of individual differences in L1 competence, there is surprisingly little research concerning this issue. Very few studies have been conducted to support the claim that there are considerable individual differences in L1, especially with regard to L1 phonetics and phonology (Mayr & Escudero, 2010; Zellou, 2017). In this dissertation, we investigated individual differences in the size of native phonetic categories or category compactness. To our knowledge it is one of the first attempts to measure category compactness in perception, not only because it is widely assumed that perception is less variable than production, but also because of the ethereal nature of perception, measuring which posits a substantial methodological challenge. Our second aim was to determine whether individual differences in L1 category compactness lead to variability in L2 perception. Again, we are only aware of a handful of studies that related these measures. In particular, we wanted to contribute to the research line that investigates L2 phonetic ability or phonetic talent appending L1-based individual differences to the list of potential contributors.

This dissertation confirms our hypothesis that some individuals have a considerable advantage processing novel sounds due to L1 category compactness. Furthermore, our experiment revealed that acoustic memory supports L2 perception, when native categories are not compact. This finding revitalizes a long-forgotten discussion about cognitive learning styles. We also came to a seemingly counterintuitive conclusion that exceling in native perception (that is signified by larger categories formed as a result of variable linguistic environment: e.g., larger social network size and/or brief exposure to other languages) might impede L0 perception. Although a surprising finding, it confirms NLM and NLM-e models' predictions that L1 experience sharpens L1 perception but interferes with L1 learning (Kuhl et al., 2006; Kuhl et al., 2008).

## 7.2 Concluding remarks

At the beginning of this dissertation, we introduced Ludwig Wittgenstein's saying that the limits of one's language signify the limits of one's world. Even though a limitation of any kind is generally perceived as a negative concept, in this dissertation we discuss how limits can lead to a better understanding of otherness and building a new world around it. Trying to assimilate objects and experiences to our inner conceptual map often leads to labeling these objects and experiences as deviant or poorer versions of the concepts we already have. However, recognizing an object as an essentially different and new category helps to preserve its identity without further expectations for it to resemble something else. Our findings show that compact phonetic categories might facilitate the discrimination of novel categories. In this sense, the limits of our language define our world, at the same time helping us to recognize and build new worlds around us.

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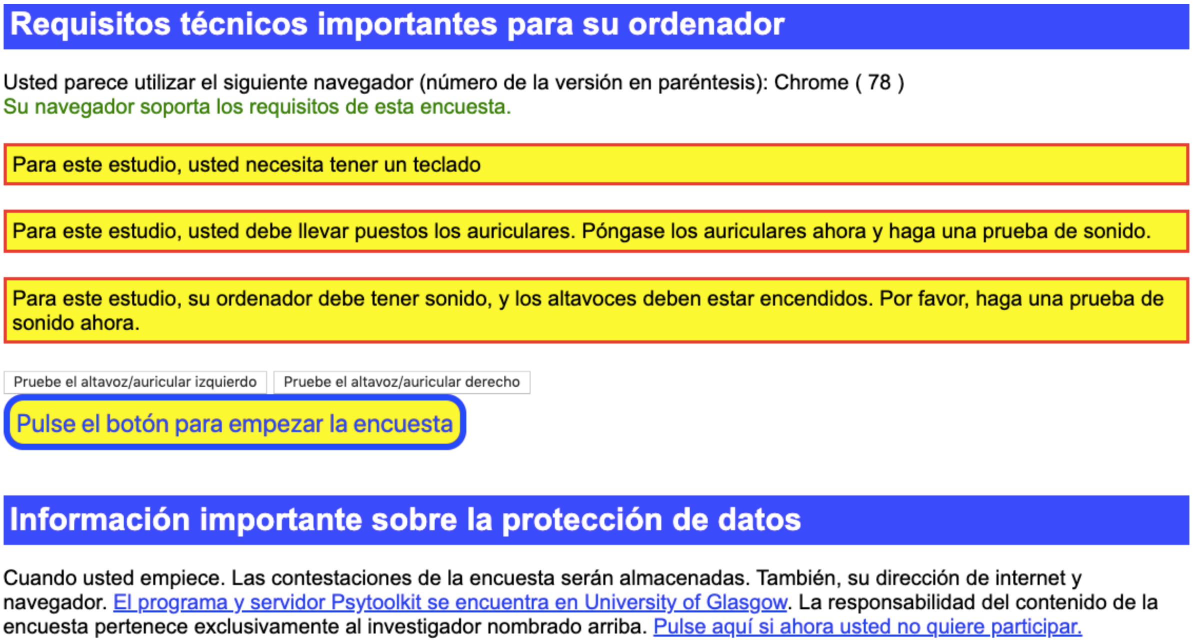
# Appendices

## Appendix A. Information about the Russian participants

Table 6. Information about the 16 Russian participants who served as a baseline in the rated dissimilarity task.

| Participant | Russian-speaking parents | Place of birth | Current residency | Other languages spoken |
|---|---|---|---|---|
| 1 | Yes | Moscow | Moscow | English |
| 2 | Yes | Yekaterinburg | Yekaterinburg | English |
| 3 | Yes | Yekaterinburg | Yekaterinburg | English |
| 4 | Yes | Yekaterinburg | Yekaterinburg | English |
| 5 | Yes | Yekaterinburg | Yekaterinburg | None |
| 6 | Yes | Moscow | Moscow | English |
| 7 | Yes | Gelendzhik | Krasnodar | English |
| 8 | Yes | Novosibirsk | Yakutsk | English |
| 9 | Yes | Moscow | Moscow | English |
| 10 | Yes | Moscow | Moscow | English |
| 11 | Yes | St. Petersburg | Moscow | English |
| 12 | Yes | Yekaterinburg | Moscow | English |
| 13 | Yes | Khabarovsk | Khabarovsk | English |
| 14 | Yes | Yekaterinburg | Yekaterinburg | English |
| 15 | Yes | Moscow | Moscow | English, French |
| 16 | Yes | Moscow | Moscow | English, French, Italian |

# Appendix B. The online consent form on PsyToolkit.org



## Requisitos técnicos importantes para su ordenador

Usted parece utilizar el siguiente navegador (número de la versión en paréntesis): Chrome ( 78 )
Su navegador soporta los requisitos de esta encuesta.

Para este estudio, usted necesita tener un teclado

Para este estudio, usted debe llevar puestos los auriculares. Póngase los auriculares ahora y haga una prueba de sonido.

Para este estudio, su ordenador debe tener sonido, y los altavoces deben estar encendidos. Por favor, haga una prueba de sonido ahora.

## Información importante sobre la protección de datos

Cuando usted empiece. Las contestaciones de la encuesta serán almacenadas. También, su dirección de internet y navegador. El programa y servidor Psytoolkit se encuentra en University of Glasgow. La responsabilidad del contenido de la encuesta pertenece exclusivamente al investigador nombrado arriba. Pulse aquí si ahora usted no quiere participar.

Figure 30. The setup screen for the experiment with the acknowledgement of personal data being collected and an option not to participate in the study.

# Appendix C. Questionnaire with the Big Five Inventory (BFI)

## ENCUESTA

**1. ¿Cuál es tu género?**

- ○ Masculino
- ○ Femenino
- ○ Otro

**2. ¿Eres hablante nativo de español europeo?**

- ○ Sí
- ○ No
- ○ Soy bilingüe

**3. ¿De qué parte de España eres?**

**4. ¿Qué edad tienes?**

**5. ¿Qué otros idiomas hablas a un nivel intermedio o superior?**

**6. ¿Qué idiomas hablan con fluidez tus padres / abuelos / otros parientes cercanos?**

**7. ¿Has estudiado ruso alguna vez?**

**8. ¿Escuchas hablar en ruso con frecuencia (en televisión, amigos o vecinos, etc.)?**

**9. ¿Alguna vez has estudiado lingüística y/o fonética/fonología?**

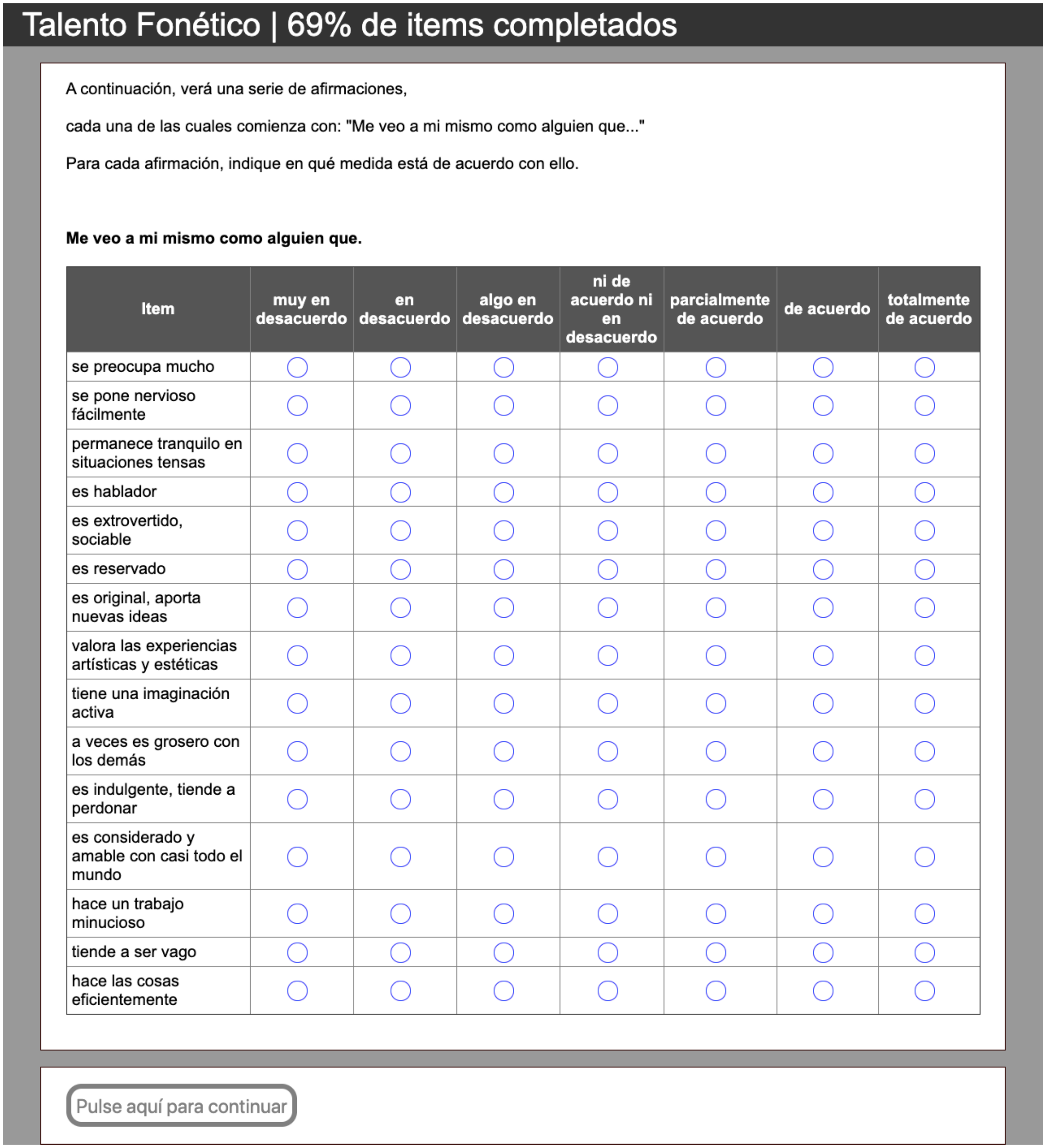
- ○ Sí
- ○ No

**10. ¿Con cuántas personas en promedio hablas a diario?**

- ○ 1-5
- ○ 5-10
- ○ Mas de 10

**11. ¿Qué tipo de computadora y auriculares estás usando en este momento?**

## TEST DE PERSONALIDAD



Talento Fonético | 69% de items completados

A continuación, verá una serie de afirmaciones,

cada una de las cuales comienza con: "Me veo a mi mismo como alguien que..."

Para cada afirmación, indique en qué medida está de acuerdo con ello.

**Me veo a mi mismo como alguien que.**

| Item | muy en desacuerdo | en desacuerdo | algo en desacuerdo | ni de acuerdo ni en desacuerdo | parcialmente de acuerdo | de acuerdo | totalmente de acuerdo |
|---|---|---|---|---|---|---|---|
| se preocupa mucho | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| se pone nervioso fácilmente | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| permanece tranquilo en situaciones tensas | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| es hablador | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| es extrovertido, sociable | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| es reservado | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| es original, aporta nuevas ideas | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| valora las experiencias artísticas y estéticas | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| tiene una imaginación activa | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| a veces es grosero con los demás | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| es indulgente, tiende a perdonar | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| es considerado y amable con casi todo el mundo | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| hace un trabajo minucioso | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| tiende a ser vago | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| hace las cosas eficientemente | ○ | ○ | ○ | ○ | ○ | ○ | ○ |

Figure 31. The short version of the Big Five Inventory as it appeared during the experiment.

# Appendix D. Nonwords in the serial nonword recognition task

Table 7. Stimuli for the serial nonword recognition task (the Spanish CVC nonwords developed using Syllabarium).

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Practice block | | | | | | | |
| 1 | ner | tas | bol | til | | | |
| 2 | rrac | **cen** | **mun** | bil | | | |
| 3 | rus | **bir** | **nom** | len | | | |
| 5-item length sequences | | | | | | | |
| 1 | far | gos | tud | nen | sig | | |
| 2 | rer | jar | ton | fir | pun | | |
| 3 | sos | mir | gus | dal | tem | | |
| 4 | din | ted | sun | gal | jos | | |
| 5 | nal | **fen** | **pol** | rin | nun | | |
| 6 | bul | tad | **som** | **fes** | sil | | |
| 7 | ler | **tus** | **tin** | ran | bos | | |
| 8 | pec | jun | **lon** | **lis** | cas | | |
| 6-item length sequences | | | | | | | |
| 9 | cel | mon | cur | sas | tir | fon | |
| 10 | nin | tes | bor | lir | pal | jus | |
| 11 | cum | ges | lan | sol | fer | tis | |
| 12 | ris | mag | col | fun | ces | tur | |
| 13 | sar | **mer** | **fil** | pul | cal | ron | |
| 14 | pen | rir | **gun** | **lam** | rer | for | |
| 15 | ros | dul | nis | **des** | **rac** | sul | |
| 16 | ral | **chis** | **lec** | tun | bom | lar | |
| 7-item length sequences | | | | | | | |
| 17 | dor | ban | cin | fut | nir | jer | cor |
| 18 | fec | duc | pos | cir | pel | can | jor |
| 19 | sis | cul | dum | bal | dic | cos | ren |
| 20 | lor | cam | jem | das | gis | mul | sec |
| 21 | dac | bun | lim | **nes** | **sor** | lud | gan |
| 22 | jes | tar | bas | tel | **lum** | **mor** | gir |
| 23 | tum | **pes** | **lin** | mos | bur | nar | gon |
| 24 | pis | gor | **Tam** | **bel** | nor | dus | fis |

*Note:* Items in bold are transposed items.

# Appendix E. Nonwords in the target sound recognition task

Table 8. Stimuli for the target sound recognition task (the Spanish CV nonwords developed using Syllabarium).

| | | | | | | |
|---|---|---|---|---|---|---|
| Practice block | | | | | | |
| 1 | fe | **ro** | | **ro** | | |
| 2 | pa | ni | | su | | |
| 2-item sequences | | | | | | |
| 1 | **ya** | lu | | **ya** | | |
| 2 | je | **do** | | **do** | | |
| 3 | **si** | ta | | **si** | | |
| 4 | gu | **fe** | | **fe** | | |
| 5 | so | be | | chi | | |
| 6 | na | cu | | θi | | |
| 7 | po | cha | | le | | |
| 8 | di | fu | | no | | |
| 3-item sequences | | | | | | |
| 9 | **bu** | ja | ñu | | **bu** | |
| 10 | to | **de** | rra | | **de** | |
| 11 | fi | ga | **ru** | | **ru** | |
| 12 | **fo** | rri | tu | | **fo** | |
| 13 | ye | mi | da | | go | |
| 14 | ro | pe | ni | | ju | |
| 15 | mu | rro | bi | | ra | |
| 16 | la | se | lo | | ti | |
| 4-item sequences | | | | | | |
| 17 | **cho** | pi | θe | pa | | **cho** |
| 18 | jo | **me** | chu | fa | | **me** |
| 19 | te | bo | **nu** | θa | | **nu** |
| 20 | ke | ma | li | **rru** | | **rru** |
| 21 | mo | che | ca | yu | | θa |
| 22 | ne | ña | yo | ji | | su |
| 23 | ño | ki | sa | du | | rre |
| 24 | θo | re | ba | ri | | θu |

*Note:* Items in bold are the same items.

# rotation script for Praat

# low-pass filtered rotated version

```
#
================================================================
====
# rotation script for Praat
# low–pass filtered rotated version
```

```
#
================================================================
====
form Rotate Sound
real Rotation_frequency 2000
word Name_of_new_sound rotated
endform

Copy... temp
d = Get total duration
sf = Get sampling frequency
Create Sound from formula... sine Mono 0 d sf
1/2*sin(2*pi*rotation_frequency*x)
select Sound temp
Formula... self * Sound_sine[col]
select Sound temp
Filter (pass Hann band)... 0 3800 20
Rename: name_of_new_sound$

select Sound temp
plus Sound sine
Remove
```

# Appendix F. Acoustic values of the variants of /i/

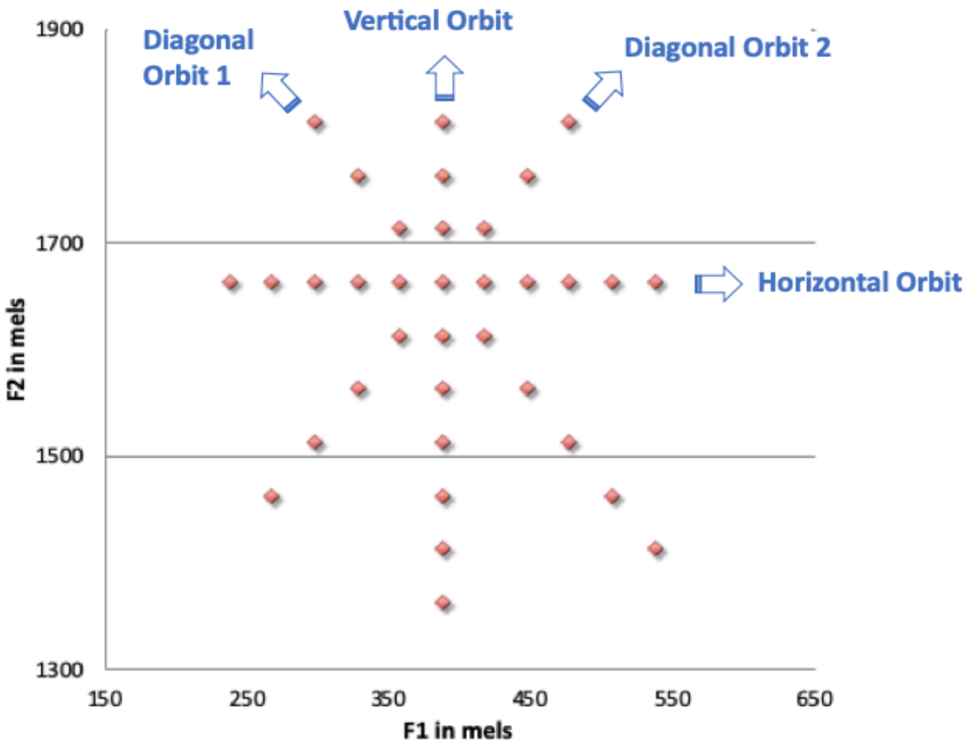
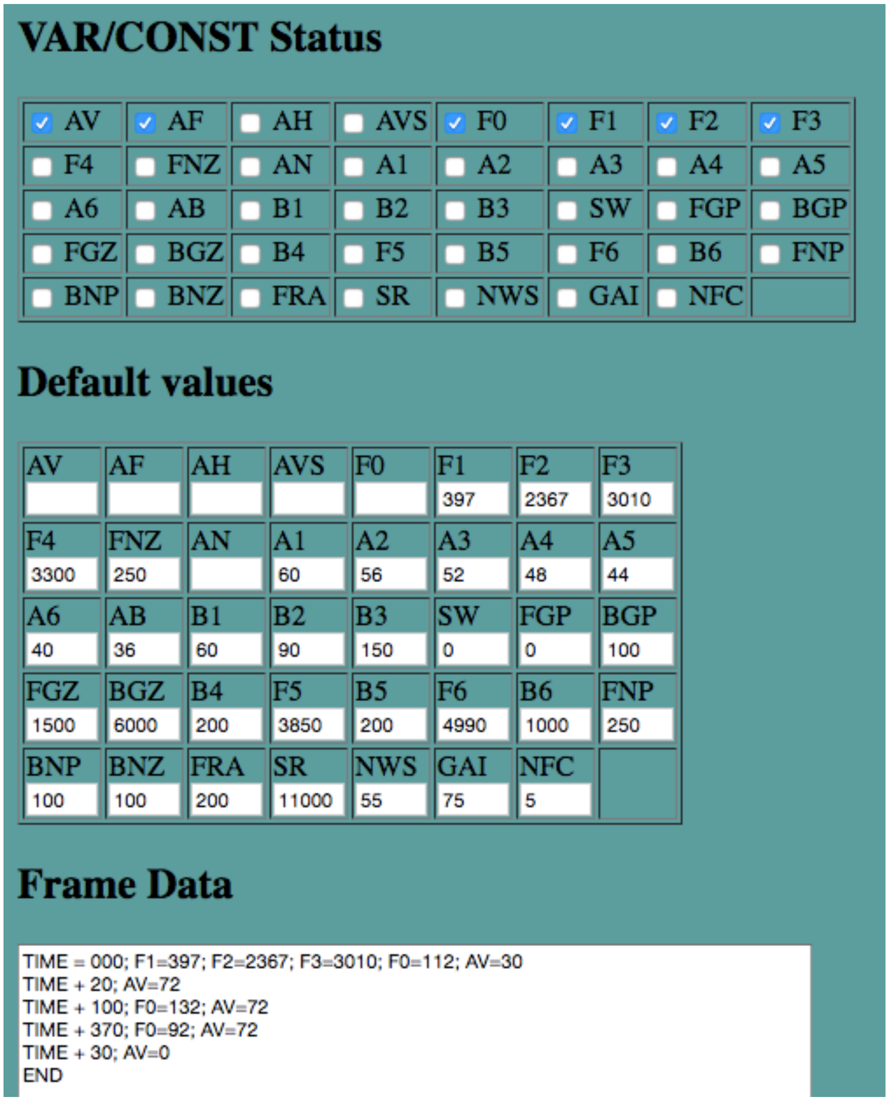


Figure 32. The names of the orbits, alongside which variants are distributed.

Table 9. F1 and F2 in mels and Hz of the 28 synthesized variants of /i/ and a prototypical /i/.

| | F1 (mels) | F2 (mels) | F1 (Hz) | F2 (Hz) |
|---|---|---|---|---|
| Prototype /i/ | 386 | 1665 | 285.9 | 2367 |
| Vertical orbit | 386 | 1715 | 285.9 | 2506.1 |
| | 386 | 1765 | 285.9 | 2651.6 |
| | 386 | 1815 | 285.9 | 2803.6 |
| | 386 | 1615 | 285.9 | 2233.9 |
| | 386 | 1565 | 285.9 | 2106.6 |
| | 386 | 1515 | 285.9 | 1984.8 |
| | 386 | 1465 | 285.9 | 1868.3 |
| | 386 | 1415 | 285.9 | 1756.8 |
| Horizontal orbit | 416 | 1665 | 313 | 2367 |
| | 446 | 1665 | 340 | 2367 |
| | 476 | 1665 | 367 | 2367 |
| | 506 | 1665 | 397 | 2367 |

| | | | | |
|---|---|---|---|---|
| | 536 | 1665 | 426 | 2367 |
| | 356 | 1665 | 260 | 2367 |
| | 326 | 1665 | 235 | 2367 |
| | 296 | 1665 | 210 | 2367 |
| Diagonal orbit 1 | 356 | 1715 | 260 | 2506.1 |
| | 326 | 1765 | 234.8 | 2651.6 |
| | 416 | 1615 | 312.5 | 2233.9 |
| | 446 | 1565 | 339.8 | 2106.6 |
| | 476 | 1515 | 367.9 | 1984.8 |
| | 506 | 1465 | 396.7 | 1868.3 |
| | 536 | 1415 | 426.3 | 1756.8 |
| Diagonal orbit 2 | 416 | 1715 | 312.5 | 2506.1 |
| | 446 | 1765 | 339.8 | 2651.6 |
| | 476 | 1815 | 367.9 | 2803.6 |
| | 356 | 1615 | 260 | 2233.9 |
| | 326 | 1565 | 234.8 | 2106.6 |



## VAR/CONST Status

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| ☑ AV | ☑ AF | ☐ AH | ☐ AVS | ☑ F0 | ☑ F1 | ☑ F2 | ☑ F3 |
| ☐ F4 | ☐ FNZ | ☐ AN | ☐ A1 | ☐ A2 | ☐ A3 | ☐ A4 | ☐ A5 |
| ☐ A6 | ☐ AB | ☐ B1 | ☐ B2 | ☐ B3 | ☐ SW | ☐ FGP | ☐ BGP |
| ☐ FGZ | ☐ BGZ | ☐ B4 | ☐ F5 | ☐ B5 | ☐ F6 | ☐ B6 | ☐ FNP |
| ☐ BNP | ☐ BNZ | ☐ FRA | ☐ SR | ☐ NWS | ☐ GAI | ☐ NFC | |

## Default values

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| AV | AF | AH | AVS | F0 | F1 | F2 | F3 |
| | | | | | 397 | 2367 | 3010 |
| F4 | FNZ | AN | A1 | A2 | A3 | A4 | A5 |
| 3300 | 250 | | 60 | 56 | 52 | 48 | 44 |
| A6 | AB | B1 | B2 | B3 | SW | FGP | BGP |
| 40 | 36 | 60 | 90 | 150 | 0 | 0 | 100 |
| FGZ | BGZ | B4 | F5 | B5 | F6 | B6 | FNP |
| 1500 | 6000 | 200 | 3850 | 200 | 4990 | 1000 | 250 |
| BNP | BNZ | FRA | SR | NWS | GAI | NFC | |
| 100 | 100 | 200 | 11000 | 55 | 75 | 5 | |

## Frame Data

```
TIME = 000; F1=397; F2=2367; F3=3010; F0=112; AV=30
TIME + 20; AV=72
TIME + 100; F0=132; AV=72
TIME + 370; F0=92; AV=72
TIME + 30; AV=0
END
```

Figure 33. Klatt’s parameters.

# Appendix G. Mixed-effects models' parameters

The results for the analysis of the role of various factors on *Perceived Dissimilarity*. Recall that we used the reverse score transformation for *Perceived Dissimilarity* scores, thus, the interpretation of the variable is reversed: positive values have become negative, and vice versa.

Table 10. Regression models with Perceived Dissimilarity as a dependent variable.

| Regression model | Predictors: Fixed effects + (1\|Random effect) |
|---|---|
| 1 | Compactness + (1\|Subject) + (1\|Item) |
| 2 | Compactness + Social Network Size + Compactness*Social Network Size + (1\|Subject) + (1\|Item) |
| 3 | Compactness + Social Network Size + (1\|Subject) + (1\|Item) |
| 4 | Compactness + L2 Experience (1\|Subject) + (1\|Item) |
| 5 | Compactness + L2 Experience + Compactness *L2 Experience + (1\|Subject) + (1\|Item) |
| 6 | Compactness + L2 Experience* Social Network Size + (1\|Subject) + (1\|Item) |
| 7 | Openness + Conscientiousness + Extraversion + Agreeableness + Neuroticism + (1\|Subject) + (1\|Item) |
| 8 | Compactness + L2 Experience* Social Network Size + Phonological Sort-term Memory + Acoustic Memory + (1\|Subject) + (1\|Item) |
| 9 | Compactness*Acoustic Memory + L2 Experience* Social Network Size + (1\|Subject) + (1\|Item) |

Table 11. Model 1: Perceived Dissimilarity ~ Compactness + (1|Subject) + (1|Item)

| Predictor | $\beta$ | SE | t-Value |
|---|---|---|---|
| Intercept | 0.1447101 | 0.0759921 | 1.904 |
| Compactness | 0.0004446 | 0.0002266 | 1.962 |

Table 12. Model 2: Perceived Dissimilarity ~ Compactness + Social Network Size + Compactness*Social Network Size + (1|Subject) + (1|Item)

| Predictor | $\beta$ | SE | t-Value |
|---|---|---|---|
| Intercept | 0.1872 | 0.1388 | 1.348 |
| Compactness | 0.0003979 | 0.0003669 | 1.085 |
| Social Network Size: Medium | 0.006886 | 0.1856 | 0.037 |
| Social Network Size: Small | 0.03449 | 0.2107 | 0.164 |
| Compactness* Social Network Size: Medium | 0.00001469 | 0.0005441 | 0.027 |
| Compactness* Social Network Size: Small | -0.0004974 | 0.0006736 | -0.738 |

Table 13. Model 3: Perceived Dissimilarity ~ Compactness + Social Network Size + (1|Subject) + (1|Item)

| Predictor | $\beta$ | SE | t-Value |
|---|---|---|---|
| Intercept | 0.2189665 | 0.0958907 | 2.284 |
| Compactness | 0.0003103 | 0.0002417 | 1.284 |
| Social Network Size: Medium | 0.0049896 | 0.0560605 | 0.089 |
| Social Network Size: Small | -0.1091217 | 0.0576741 | -1.892 |

Table 14. Model 4: Perceived Dissimilarity ~ Compactness + L2 Experience + (1|Subject) + (1|Item)

| Predictor | $\beta$ | SE | t-Value |
|---|---|---|---|
| Intercept | 0.1817932 | 0.0783236 | 2.321 |
| Compactness | 0.0003788 | 0.0002272 | 1.667 |
| L2 Experience: No | -0.1016615 | 0.0614717 | -1.654 |

Table 15. Model 5: Perceived Dissimilarity ~ Compactness + L2 Experience + Compactness *L2 Experience + (1|Subject) + (1|Item)

| Predictor | $\beta$ | SE | t-Value |
|---|---|---|---|

| | | | |
|---|---|---|---|
| Intercept | 0.1821 | 0.08553 | 2.129 |
| Compactness | 0.0003778 | 0.0002510 | 1.506 |
| L2 Experience: No | -0.1032 | 0.1834 | -0.563 |
| Compactness* L2 Experience: No | 0.000005635 | 0.0006130 | 0.009 |

Table 16. Model 6: Perceived Dissimilarity ~ Compactness + L2 Experience* Social Network Size + (1|Subject) + (1|Item)

| Predictor | *β* | SE | t-Value |
|---|---|---|---|
| Intercept | 0.1758850 | 0.1042815 | 1.687 |
| Compactness | 0.0002193 | 0.0002381 | 0.921 |
| Social Network Size: Medium | 0.2048419 | 0.0953843 | 2.148 |
| Social Network Size: Small | -0.0438336 | 0.1024117 | -0.428 |
| L2 Experience: No | -0.0307305 | 0.1185209 | -0.259 |
| Social Network Size: Medium* L2 Experience: No | -0.2692435 | 0.1633702 | -1.648 |
| Social Network Size: Small* L2 Experience: No | 0.0494521 | 0.1666693 | 0.297 |

Table 17. Model 7: Perceived Dissimilarity ~ Openness + Conscientiousness + Extraversion + Agreeableness + Neuroticism + (1|Subject) + (1|Item)

| Predictor | *β* | SE | t-Value |
|---|---|---|---|
| Intercept | 0.37105 | 0.19935 | 1.861 |
| Openness | -0.03401 | 0.02855 | -1.191 |
| Conscientiousness | -0.02432 | 0.03489 | -0.697 |
| Extraversion | -0.00562 | 0.03734 | -0.151 |
| Agreeableness | 0.00538 | 0.03422 | 0.157 |
| Neuroticism | 0.04608 | 0.03323 | 1.387 |

Table 18. Model 8: Perceived Dissimilarity ~ Compactness + L2 Experience* Social Network Size + Phonological Sort-term Memory + Acoustic Memory + (1|Subject) + (1|Item)

| Predictor | *β* | SE | t-Value |
|---|---|---|---|
| Intercept | 0.3548637 | 0.1788617 | 1.984 |

| | | | |
|---|---|---|---|
| Compactness | 0.0002125 | 0.0002273 | 0.935 |
| Social Network Size: Medium | 0.2435400 | 0.0909702 | 2.677 |
| Social Network Size: Small | 0.0209130 | 0.1004226 | 0.208 |
| L2 Experience: No | 0.0386289 | 0.1186641 | 0.326 |
| Phonological Sort-term Memory | 0.0010699 | 0.0009308 | 1.149 |
| Acoustic Memory | -0.0056986 | 0.0020104 | -2.835 |
| Social Network Size: Medium* L2 Experience: No | -0.3356865 | 0.1561287 | -2.150 |
| Social Network Size: Small* L2 Experience: No | -0.0241417 | 0.1609027 | -0.150 |

Table 19. Model 9: Perceived Dissimilarity ~ Compactness*Acoustic Memory + L2 Experience* Social Network Size + (1|Subject) + (1|Item)

| Predictor | $\beta$ | SE | t-Value |
|---|---|---|---|
| Intercept | -0.2702 | 0.418 | -0.646 |
| Compactness | 0.002308 | 0.001146 | 2.014 |
| Acoustic Memory | 0.007762 | 0.00731 | 1.062 |
| Social Network Size: Medium | 0.2461 | 0.08919 | 2.760 |
| Social Network Size: Small | 0.003302 | 0.09589 | 0.034 |
| L2 Experience: No | 0.01592 | 0.1107 | 0.144 |
| Compactness*Acoustic Memory | -0.00003982 | 0.00002101 | -1.895 |
| Social Network Size: Medium* L2 Experience: No | -0.3302 | 0.1532 | -2.156 |
| Social Network Size: Small* L2 Experience: No | -0.002672 | 0.1551 | -0.017 |