Transportation, Air Pollution And Physical ActivitieS; an integrated health risk assessment progamme of climate change and urban policies (TAPAS)

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CENTRE DE RECERCA EN EPIDEMIOLOGIA AMBIENTAL

A mis padres quienes me han regalado su apoyo y paciencia durante todos estos años.

A mi hermano que siempre ha sido un gran estimulo para avanzar y ser mejor.

Y a todos ustedes que en la cercanía o lejanía me han acompañado en este camino.

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ABSTRACT

Introduction

Interventions to reduce greenhouse gas emissions and mitigate climate change can involve co-benefits of health, with special active transportation policies (including walking, cycling and travelling by public transport) having the potential to provide both co-benefits to environmental and public health.

Methods

A health impact assessment approach has been performed using a quantitative model for estimating the health impacts of different active transportation policies in urban areas.

Result

We have quantified the impacts of two risk factors, air pollution and traffic accidents, as well as the protective effect of physical activity. In total, the benefits of physical activity exceed the risks associated with active transport policies.

Conclusions

Active transportation policies can produce substantial benefits for public health, which are mainly associated with increased levels of physical activity.

RESUMEN

Introducción

Las intervenciones para reducir las emisiones de gases de efecto invernadero y cambio climático, pueden conllevar co-beneficios para la salud. En especial las políticas de transporte activo (caminar, viajar en bicicletas o en transporte público) pueden tener la capacidad de proveer beneficios para el medioambiente y la salud.

Métodos

Mediante el abordaje de la evaluación de impactos en salud se ha utilizado una modelo cuantitativo par estimar los impactos en salud de diferentes intervenciones o políticas de transporte activo, en áreas urbanas.

Resultado

Se cuantificaron los impactos de dos factores de riesgo, la contaminación del aire y los accidentes de tráfico. Se cuantifico además el efecto protector de la actividad física. En conjunto los beneficios de la actividad física superaron a los riesgos asociados con las políticas de transporte activo.

Conclusiones

Las políticas de transporte activo pueden producir grandes beneficios para la salud de la población. Estos beneficios están asociados principalmente con el incremento en los niveles de la actividad física.

RESUM

Introducció

Les intervencions per reduir les emissions de gasos d'efecte hivernacle i canvi climàtic, poden implicar beneficis per a la salut. Especialment les polítiques de transport actiu (caminar, viatjar en bicicletes o en transport públic) poden tenir la capacitat de proveir beneficis per al medi ambient i la salut.

Mètodes

Mitjançant l'abordatge de l'avaluació d'impactes en salut s'ha utilitzat una model quantitatiu per estimar els impactes en salut de diferents intervencions o polítiques de transport actiu en àrees urbanes.

Resultat

Es van quantificar els impactes de dos factors de risc, la contaminació de l'aire i els accidents de trànsit. Es va quantificar a més l'efecte protector de l'activitat física. En conjunt els beneficis de l'activitat física superar els riscos associats amb les polítiques de transport actiu.

Conclusions

Les polítiques de transport actiu poden produir grans beneficis per a la salut de la població. Aquests beneficis estan associats principalment amb l'incremento en els nivells de l'activitat física.

PROLOGUE

This thesis project focused on a health impact assessment (HIA) of active transportation policies in urban areas. Included in this thesis is the creation of a quantitative model to estimate the health impacts (in terms of mortality, life expectancy and cases of diseases) of three exposure factors (air pollution, traffic accidents and physical activity) related to active transportation (walking, bicycling and public transport use). This quantitative model, as a health impact assessment approach, was applied to different interventions of active transportation promotion in urban areas.

The thesis is comprised of four original scientific papers and one letter to de editor: 1) HIA of bike sharing program in Barcelona; 2) HIA of active transportation policies in the metropolitan area of Barcelona, in terms of mortality and life expectancy; 3) HIA of active transportation policies in the metropolitan area of Barcelona, in terms of morbidity and burden of disease; 4) the HIA of active transportation policies in six European cities (Barcelona, Basel, Paris, Copenhagen, Prague and Warsaw); and 5) Bicycle helmet law in urban areas. Is it good for public health? (Letter to the editor).

The abovementioned scientific publications were made by the PhD candidate within the TAPAS project, under the direction of Mark Nieuwenhuijsen and Audrey de Nazelle, at the Centre for Research in Environmental Epidemiology (CREAL).

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1. INTRODUCTION

Physical inactivity is a global public health problem, and has been identified for many countries as a national public health priority [1;2]. There is clear evidence to link physical inactivity with an increased risk of many chronic diseases, including coronary heart disease (CHD), ischemic stroke, type 2 diabetes, breast cancer, and colorectal cancer [1;2]**.** The negative health effects of physical inactivity are paralleled by staggering economic consequences: the annual cost directly attributable to inactivity in the U.S. is an estimated $24 billion–$76 billion, or 2.4%–5.0% of national healthcare expenditures [3;4]. Fortunately, modest increases in physical activity have the potential to produce substantial health benefits [5]**.** Physical activity is directly related to the environment, social context, our health and the built environment.

Physical inactivity and air pollution are two of the 10 leading health risk factors worldwide[6]**.** Inactivity and insufficient activity (< 2.5 hr/week of moderate-intensity activity, or < 4,000 kJ/week) have been linked with heart disease, several cancers, diabetes, high body mass index (BMI; overweight and obesity) and other adverse health impacts [7]**.** Reducing the average energy imbalance (caloric intake minus metabolic activity) among persons in the United States by approximately 100–165 kcal/day would prevent average weight gain (~ 1 kg/year)[8;9], which suggests that moderate daily exercise—as little as two or three 10-min walking trips, such as to a bus stop or grocery store—could provide major public health benefits. But transport in urban areas is dominated in most of the cases by the automobile, over public transport, walking or cycling.

One explanation for this is that currently the cities are designed for cars. The built environment can encourage the use of one mode of transport over others. The built environment also affects the public health in different ways[10;10] . Factors such as community design, travel patterns, physical activity, road safety and air pollution are related with the built environment.

The transportation sector also represents a significant contributor to greenhouse gases emissions in Europe. The introduction of more efficient cars and reducing vehicular travel are essential components of climate change mitigation policies across the continent. Shifting the population towards active modes of transportation (e.g. cycling, walking) represents a particularly promising strategy with a high potential of public health co-benefits. Shifting to active transportation modes may result in a sustained increase in physical activity in the population – a major requirement to abate the obesity epidemic. Other potential benefits include improvements in environmental quality indicators such as ambient air pollution and noise, as well as in the social environment (social capital) and quality of urban life. However, depending on local conditions and policies, these strategies may also result in adverse health effects as increase intake of air pollutants and increase rates of traffic accidents. Currently there is no holistic framework or related tools for policy makers to help assess the inputs and expected health impacts of active transportation policies.

1.1. Active Transportation

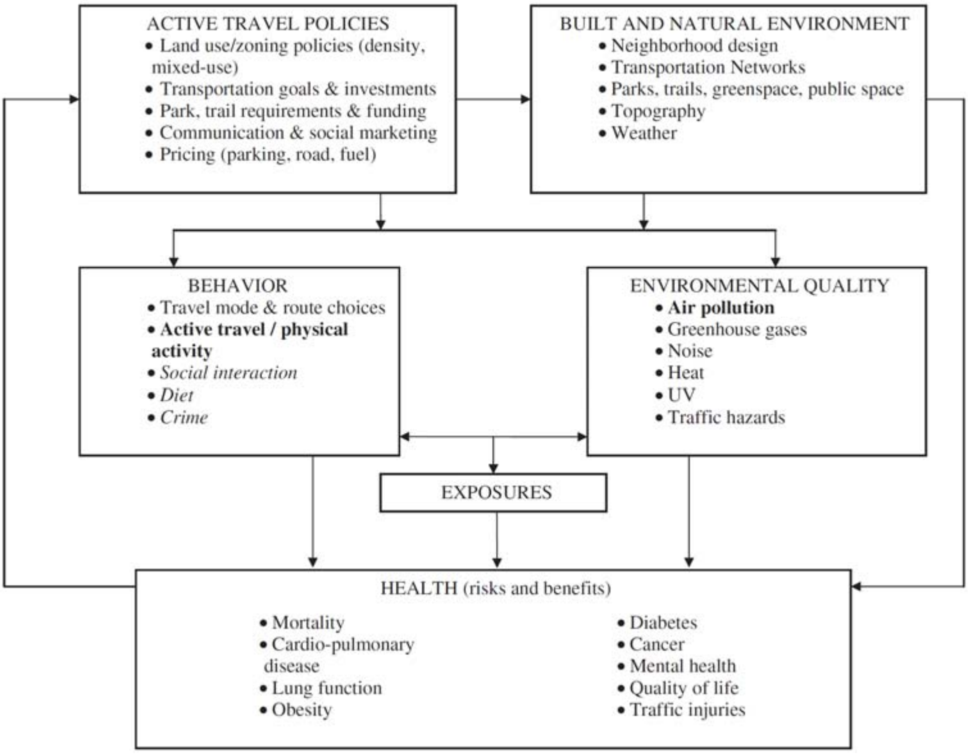
The Public Health Agency of Canada define Active transportation was any form of human-powered transportation – walking, cycling, using a wheelchair, in-line skating or skateboarding. Also known as sustainable transport, or non-motorized transport, but in the biomedical area is preferred defined as active transportation. In this thesis we have also included public transport as an element of active transportation, because includes walking segments, and is a plausible alternative to car trips.

Nazelle et al recently published a review of the relationship between active transport policies and their potential health impacts. From this review is derived Figure 1, which describes the relationship between active transportation policies, the built environment, behavior, environmental quality and health effects, which will be described in more detail in the following sections.

1.1.1 Built Environment

The past decade has seen an enthusiasm for planning cities for health, which had mostly been forgotten since the urban sanitarian movement in the mid-nineteenth century. The sanitarians saw opportunities in urban planning to prevent infectious epidemics like cholera or typhoid by airing out the city with parks and trees and wider avenues, providing sunlight and ventilation into the homes and waste disposal systems (Figure 2) [11].

Figure 1. Conceptual model of health impacts of active travel policies



Ref: de Nazelle A, et al. 2011.[12]

Today, the greatest trigger for this renewed interest in urban solutions is concerns about obesity and climate change. Obesity levels based on body mass index (BMI) have risen rapidly and now exceed 20% in many parts of Europe [13;14]. The evident failures of classic individual-based physical activity and diet control interventions has raised the interest of health professionals in community-level solutions that allow individuals to easily integrate healthy behaviors in their daily routines [15].

As for climate change, the magnitude of reductions in emissions required to slow the build up of greenhouse gases is such that multiple solutions are sought, including see changes in our travel behavior. Neighborhood design, transportation facilities, and urban policies can either support or impede certain transportation choices, like walking and bicycling, depending on how they are implemented. Evidence is accumulating about how the built environment –the catch- all phrase to describe neighborhoods, facilities, policies, and programs –is associated, and in some cases influences, travel patterns. Strong relations between built environment variables and total physical activity have been confirmed internationally. A study of 11 countries, including multiple European nations, found that when adults reported having nearby shops, public transport, sidewalks, bicycle facilities, and recreation facilities, they were 20-50% more likely to meet physical activity guidelines than if they lacked these amenities. Those with all the favorable attributes were twice as likely to be active as those with no favorable attributes[16]. Thus, built environment characteristics are strongly related to total physical activity. The potential for active transport to reduce chronic disease risk, traffic congestion, air pollution, and carbon emissions has increased attention to walking and bicycling in recent years. The strongest evidence is that land use and urban form are related to walking for transport. Walkability refers to having direct routes from homes to common destinations such as shops, work, and school. Key components are mixed land use and highly connected streets. Low-walkable or auto-dependent neighborhoods are characterized by separated land uses, disconnected streets, and low density that make walking impractical. There are highly consistent findings that adolescents, adults, and older adults walk more for transport when they live in walkable neighborhoods [17].

Figure 2. Built environment and health

Ref: Institute of Public Health in Ireland, 2006.

1.1.2. Air Pollution

Air pollution has been associated with adverse health effects. Although the health effects vary in relation to the type of contaminant, usually the air pollution exposure involves a mixture of pollutants which produce an overlapping between the health effects of each pollutant. That is why the impact assessment studies only use a single pollutant for the analysis, seeking to avoid the overestimation of the effect of multiple pollutants. The particulate matter (PM) is group of pollutants which has shown larger health effects[6]. Especially the particles less than 2.5 micrometers have been extensively studied and have been associated with health effects, such as all-cause mortality, cardiovascular and respiratory mortality, asthma, respiratory infections, low birth weight, premature birth, cerebrovascular and cardiovascular diseases, among others[18-22].

Enhanced exposures to air pollution, noise, heat and ultraviolet radiation are frequent occurrences during travel. Air pollution exposures tend to be higher than in most other non-occupational microenvironments due to proximity to other vehicles. The air pollutants that have been most commonly measured in different travel modes are CO, PM2.5, PM10, ultrafine particles (UFP), and less frequently, specific particulate metals or specific VOCs (Table 1). Due to close proximity to other vehicles exhaust, traffic emissions concentrations at roadway centers (and inside cars and buses) tend to be several times ambient levels. Pedestrians and cyclists experience somewhat lower concentrations due to their greater distance from direct vehicle emissions. Air pollution concentrations vary by location, season, meteorology, time of day, and traffic conditions. Due to these variations, fixed-site monitoring concentrations usually correlate poorly with measures of personal exposure during transport [23;24]. Walking and biking are usually the lowest exposure modes of travel, but these modes lose some of their exposure advantage when increased respiration and longer duration are taken into account. Walking and cycling concentrations can depend strongly on path taken and distance from traffic.

Table 1. Air pollution concentration in different modes of transport.

MODE	Mean concentrations by travel mode		
	PM2.5 ($\mu g/m^3$)		**CO** (ppm)
Bus	39	35	0.8
Car	36	38	1.3
Bicycle	29	34	1.1
Walking	-	35	0.9
Subway	202	-	-
Fixed site Monitor	14	10	0.3
Location	London	London	London
Reference	Adams et al., 2001	Kaur et al., 2005	Kaur et al., 2005

PM2.5 : Particulate matter les than 2.5 micrometers ; CO : carbon monoxide ; ppm : parts per million. Ref. de Nazelle A, et al. 2011.[12]

There are very few epidemiological studies that have evaluated health effects from the short high air pollution exposures during commuting. Studies have found lung function decrements and inflammation (2-hour walks in London), nonfatal myocardial infarction, physiological changes in heart function (8-hour work shifts of US troopers) and lung function decrements and airway inflammation (1-hour cycling, healthy volunteers) [25-27].

1.1.2.1 Physical Activity and Air Pollution (Inhalation)

It is well known that physical activity increases the oxygen requirement to metabolize energy. This increase in oxygen amount is reflected as an increase in respiratory rate and the amount of air we breathe. At the same time increasing the amount of air breathed can we may expose a number of pollutants in the air. The local exposure to air pollutants has been much attention in current literature. Assess the exposure to these various environmental contaminants affects people as the means of transport where travel is of vital interest to evaluate the risks to health and future recommendations in public health. There is a tendency to make comparisons between different modes, but the most studied have been the car, bus and bicycle, few studies have focused on assessing the exposure of pedestrians. When performing more physical activity the amount of air inhaled is greater, although exposure is not only here, if not that varies with the intensity of physical activity, by sex of the person, age, and chemical and physical characteristics of each pollutants, thereby influencing their distribution and absorption in the airways. The ICRP (International Commission on Radiological Protection Working Group) has described 5 regions of the respiratory tract upon which the absorption and distribution of environmental contaminants. The concentration of pollutant exposure time, breathing parameters and chemical properties of solubility and diffusion of the pollutant are variants that must be considered in assessing exposure to air contaminants [28].

In 2006 the Environmental protection agency from Untied States (EPA) conducted a study to define the population values of ventilation rate for each age group, gender and intensity of physical activity resulted in metabolic equivalent of task (METs). This study was under the tutelage of Lordo et al[29] that with the data updated national survey of health and nutrition (NHANES) 2002 and standardized values for METs, EPA defined the basal metabolic rate specified for each age group and sex, and evaluate the requirements and ventilatory equivalent of O2 [29]. The results are the benchmark EPA to conduct risk assessments for different pollutants are inhaled, where the average inhalation rate for females is 11.3 m^3/day and men of 15.2 m^3/day. More recent studies such as Zuurbier et al 2009[30], focus on comparing the differences between modes, assuming the heart rate as a representative of the ventilation rate [30]. Relevant data that shed this study are that, like previous studies such as Vrijkotte et al[31], van Wijnen et al [32] and Colucci et al [33], confirm that heart rate and ventilation rate are correlated, the rate of ventilation during physical activity such as cycling is 2 times that go by bus or 2.1 times greater than going by car, at a speed of 12 km / hr on a bicycle. And another interesting fact that the difference would be found between a passenger car and a car driver is an increase of 10% of the ventilation rate or heart rate compared to each other respectively.

1.1.3. Physical Activity Benefits

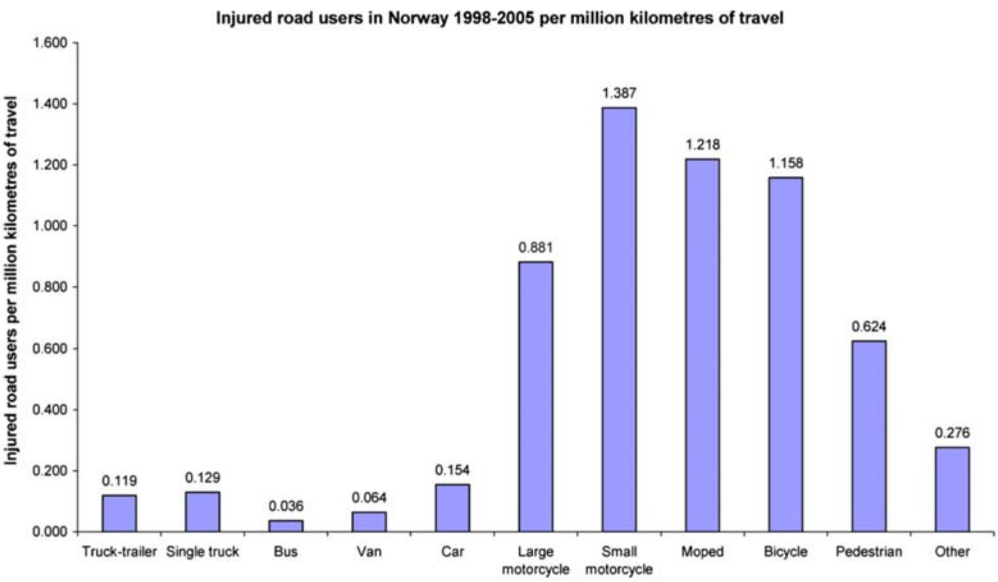
A substantial body of evidence has investigated the association between physical activity and health outcomes in adults, and has been extensively reviewed. Cross-sectional studies and exercise interventions suggest that 150 minutes of moderate-intensity aerobic activity per week or 75 minutes of vigorous-intensity aerobic activity per week are associated with favorable changes in blood pressure, lipid and lipoprotein profiles, inflammatory markers, insulin sensitivity, and other risk factors for chronic disease [34]. Prospective cohort studies suggest that physical activity can reduce the risk of all-cause mortality, cardiovascular disease (CVD) mortality and of the development of CVD, type 2 diabetes, breast cancer, depression, cognitive impairment and colon cancer.

The first large scale prospective study which analyzed the association between all-cause mortality and cycling habits was published by Andersen et al. in 2000 [35]. Information on bicycling as transportation to work was available for 783 women and 6171 men, with those who did cycle to work spending an average of 3 hours per week cycling. Among these 6954 subjects, 2291 died during follow-up. Bicycling to work was inversely related to years of education, but after adjustment for age, sex, and educational level, leisure time physical activity, body mass index, blood lipid levels, smoking, and blood pressure, the relative risk (RR) was 0.72 (95% CI, 0.57-0.91). The decrease in mortality identified in this study is not just highly statistically significant, but also substantial, indicating that commuter cycling can reduce the risk of premature mortality by approximately one third. The published data in this study was pooled from three prospective studies in Copenhagen, including the Copenhagen City Heart Study, and focused on cycling to work. All-cause mortality rates decreased with increasing amount of cycling; 0.1-3.5 MET-hours/day: RR=0.79 (95% CI: 0.61-1.01); and ≥3.5 MET-hours/day: RR= 0.66 (95% CI: 0.40-1.07). Similar estimates were found for CVD and cancer. Hu et al studied active commuting in Finnish men and women and found a lower rate of type 2 diabetes in active commuters [36]. Hamer et al [37] identified eight studies comprising a total of 173,146 participants on active commuting in adults and cardiovascular risk. The overall meta-analysis demonstrated a robust protective effect of active commuting on cardiovascular outcomes (integrated RR=0.89, 95% confidence interval 0.81–0.98, p=0.016). The protective effects of active commuting were more robust among women (0.87, 0.77–0.98, p=0.02) than in men (0.91, 0.80–1.04, p=0.17), and the authors concluded that active commuting that incorporates walking and cycling was associated with an overall 11% reduction in cardiovascular risk[37]. A few studies have looked at the association between active commuting and the levels of metabolic risk factors for cardiovascular disease in adults. Hu et al. analyzed blood lipids in 1786 males and 1922 females aged 20±49 years from China [38]. Daily walking or cycling to and from work was inversely associated with serum total cholesterol, low-density lipoprotein cholesterol and triglyceride concentrations among men, and positively associated with high-density lipoprotein cholesterol concentrations among women as compared to traveling to and from work by bus[38]. Hamer published in 2008 a meta-analysis of 18 cohort studies, as included 459.833 people, of both sexes, which measured exposure to walk and your relationship with any cardiovascular event and conclude with a RR 0.84 (CI 95% 0.79-0.90) for a walk of 3 hours per week (7.5 METs) [39]. Two meta-analysis have also identified this relationship coming to very similar results, one by Nocon[40] in 2008 which mediates the exposure to any physical activity and finally Hamer also in 2008[39] that assessed exposure to active commuting. Dementia is another disease associated with some effect by physical activity Hamer in 2009 published the most recent meta-analysis on this association including 14 cohort studies reported that performing any physical activity on incidence of dementia showed a RR of 0.72 (CI 95% 0.60-0.86) and Alzheimer's disease reported a RR of 0.55 (0.36-0.84). Two meta-analysis concluded with very similar results to those of Hamer[41]. Regarding the depression, only a systematic review of clinical trials found results apparently protective but not significant, there are also several cohort studies that try to identify this association suggests a projection of depressive symptoms. [42-48]. There is also a cohort study supports link between physical activity and reduced the anxiety symptoms.[47]. Diabetes is a metabolic disease, largely related to physical activity, where it has been reported in 2007 a meta-analysis included at 10 cohort studies of 240.605 people exposed to walk (10 METs per week) found a RR of 0.83 CI 95% 0.75 -0.91 to develop type II diabetes compared with those performing less physical activity. These results are similar to other reported studies, where the association between type II diabetes and physical activity are in the same direction.[49;50]. Finally has been related physical activity and to provide cancer protection. This has been reported specifically for breast cancer where a meta-analysis of 15 cohort studies found that for every hour of physical activity per week was 16% lower risk of breast cancer.[51] And colon cancer is also associated with physical activity where Harris reported in 2009 a meta-analysis of 10 cohort studies of risk of 20% in men and women 14% lower risk of developing colon cancer by physical activity with an intensity of 30 METs per week compared with those who did not perform physical activity. Another published meta-analysis by Wolin of 52 cohort and case-control studies reported a RR of 0.76 (CI 95% 0.72-081) of colon cancer among those doing physical activity of 21 METs per week compared with those who take exercise at an intensity of 2 METs per week[52].

1.1.4. Traffic Hazards

One way of promoting environmentally sustainable transport would therefore be to encourage walking and cycling, in particular if more walking or cycling is associated with a corresponding reduction in the use of motorized transport. However, concerns about road safety would seem to represent an important argument against encouraging walking or cycling. These modes of transport are associated with a considerably higher risk of injury accidents than travel by car or bus [53] (Figure 3). Elvik in 2009, publish the risk of injury when walking is about 4 times higher than when driving a car. The risk of injury when cycling is about 7.5 times higher than for car occupants. Although cycling brings many personal and societal benefits, exist important barriers to cycling part of traffic hazards as include: fear of crime/vandalism, bad weather, social pressure, hills and slopes and long commuting distances [54;55]. Yet the most important barrier to cycling is concerns over traffic safety and lack of adequate infrastructure [54]. Concerns over exposure to air pollution seem to be relatively unimportant [56].

Figure 3. Risk of injury accidents for transport mode.



Ref: Elvik R, 2009 [53]

Determining accident risks involves the collection of two types of data: the number of accidents (or fatalities, injuries, etc) and the "exposure" that can be expressed by the proportion of cycling trips, the number of kilometers or minutes cycled. Pedestrian injury risks are similar to those of cyclists in several European countries[57] but pedestrian fatality rates are up to 3 times higher per kilometer in the US[53]. Accident risks for public transport seem to be considerably lower than those for private cars[57]. Among the bicycle users, males are strongly overrepresented, which explains the findings of Stutts et al. in 1990 [58] and Karkhaneh et al. in 2008 who report that 70% - 95% of cyclists treated in emergency rooms are male [59]. However when taking account of the exposure, e.g. kilometers cycled, de Lapparent et al [60], found no great gender differences in the accident risk in Europe.

In general terms cycling accident risks are most strongly correlated with the number of cyclists or the amount of cycling [61]. Possible explanations for the "safety in numbers" effect are motorists seeing cyclists [62] or being more likely to be a cyclist themselves. If more people walk or cycle, one would therefore, all else equal, expect there to be more injuries[53]. An increasing number of studies show that the risks of injury to pedestrians or cyclists are highly non-linear. The non-linearity of risk implies that, all else equal: 1) the more pedestrians or cyclists there are, the lower becomes the risk to each pedestrian or cyclist, and 2) the more motor vehicles there are, the higher becomes the risk to each pedestrian or cyclist. Hence, pedestrians or cyclists face a high risk if they are few in number and mix with a high number of motor vehicles. On the other hand, if pedestrians or cyclists are more numerous, and there are fewer motor vehicles, the risks faced by pedestrians or cyclists are comparatively low. This suggests that by getting car drivers to walk or cycle, walking or cycling would become safer and there would not necessarily be an increase in the number of road traffic injuries proportional to current levels of risk. In fact, depending on the shape of the non-linearity of risk, it is even conceivable that a large transfer of trips from motor vehicles to walking or cycling would be associated with a reduction of the number of accidents[53].

1.1.5. Other exposures.

There are other exposures associated with the active transportation as shown in Figure 1. Factors such as ultraviolet radiation, noise, diet, social interaction, etc., are factors associated with active transport and health effects. Unfortunately it was not possible to integrate these factors into the quantitative model discussed in this thesis. But in this section are briefly describes.

1.1.5.1. Noise

In the European Union about 40% of the population is exposed to road traffic noise with an equivalent sound pressure level exceeding 55 dB a daytime; and 20% is exposed to levels exceeding 65 dB. When all transportation noise is considered, about half of all European Union citizens live in zones that do not ensure acoustical comfort to residents. At night, it is estimated that more than 30% is exposed to equivalent sound pressure levels exceeding 55 dBA, which are disturbing to sleep. According to the International Programme on Chemical Safety (WHO 1994), an adverse effect of noise is defined as a change in the morphology and physiology of an organism that results in impairment of functional capacity, or an impairment of capacity to compensate for additional stress, or increases the susceptibility of an organism to the harmful effects of other environmental influences. This definition includes any temporary or long-term lowering of the physical, psychological or social functioning of humans or human organs [63]. Noise pollution can cause annoyance and aggression, hypertension, high stress levels, tinnitus, hearing loss, sleep disturbances, and other harmful effects [64]. Furthermore, stress and hypertension are the leading causes to health problems, whereas tinnitus can lead to forgetfulness, severe depression and at times panic attacks [65]. Chronic exposure to noise may cause noise-induced hearing loss.

1.1.5.2. Ultraviolet radiation

Optimal sun exposure has yet to be determined, but it can be achieved in a matter of minutes in direct summer sun. Globally, excessive solar UV exposure has caused the loss of approximately 1.5 million disability-adjusted life years (DALYs) (0.1% of the total global burden of disease) and 60,000 premature deaths in the year 2000. The greatest burdens result from UV-induced cortical cataracts, cutaneous malignant melanoma, and sunburn (although the latter estimates are highly uncertain due to the paucity of data). For most people, sunlight (UVB) is an important source of vitamin D, so sun exposure may have a health benefit for walking and biking, depending on time of day and shading factors such as buildings or tree canopy. For car and bus travel, glass panes filter out most UVB, but not necessarily UVA (which does not produce vitamin D). [66] Commutes by car and bus, if windows are closed, will not provide the benefits of vitamin D protection but still allow some cumulative sun damage by UVA over long periods. Active commuting may increase UV exposure depending on modifying factors such as clothing and time of day.

1.1.5.3. Heat

Climate change may directly affect human health through increases in average temperature. Such increases may lead to more extreme heat waves during the summer while producing less extreme cold spells during the winter. Rising average temperatures are predicted to increase the incidence of heat waves and hot extremes. In the United States, Chicago is projected to experience 25 percent more frequent heat waves and Los Angeles a four-to-eight-fold increase in heat wave days by the end of the century [67]. Particular segments of the population such as those with heart problems, asthma, the elderly, the very young and the homeless can be especially vulnerable to extreme heat. Respiratory disorders may be exacerbated by warming-induced increases in the frequency of smog (ground-level ozone) events and particulate air pollution. Studies published in Europe between 1993 and 2003 from several European cities attributed a change of between 0.7% and 3.6% in all-cause mortality to a 1 °C increase of temperature above a certain threshold. There is no reported study to estimate the risk of heat when a person travels by bicycle or walking, but existing knowledge may suggest that people who engage in these activities may have more risk of suffering a health problem during a heat wave.

1.1.5.4. Diet

The gap between dietary energy intakes (EI) and energy expenditure via physical activity (PA) is a major underlying cause of this epidemic because of its role in maintaining energy balance [13].

In addition to shifting activity patterns, temporal changes in diet have played an important role in the rise in obesity[14]. Promoting active transport can contribute to important reductions in this energy gap [68]. However, efforts to reduce energy imbalance are likely to be more effective if accompanied by other lifestyle changes to reduce EI and sedentarism. By other hand small but growing body of literature suggests that obesity and related disorders such as diabetes influence susceptibility to adverse effects of exposure to air pollutants. Studies have reported significantly increased risk of acute effects of air pollution exposure such as inflammation, and consequences of longer-term exposures such as cardiovascular events, only in these susceptible subgroups. The possibility that dietary factors such as intakes of antioxidants may influence susceptibility to adverse effects of air pollution has also been investigated, but evidence is limited and uncertain [69;70]. Promoting dietary changes such as higher consumption of fruits and vegetables and lower intakes of meats may have added effects on air pollution as a result of reduced emissions associated with production of these foods [71].

1.1.5.5. Social capital

The relationship between social isolation and mortality risk was independent of health behaviours such as smoking, alcohol consumption, physical activity, preventive health care, and a range of baseline comorbid conditions [72]. Putnam[73] identified and examined a much more inclusive concept labelled social capital, defined as the social and community interactions and networks that inspire trust and reciprocity among citizens. Putnam demonstrates that "the car and the commute…are demonstrably bad for community life. In round numbers the evidence suggests that each additional ten minutes in daily commuting time cuts involvement in community affairs by 10 percent – fewer public meetings attended, fewer committees chaired, fewer petitions signed, fewer church services attended, less volunteering, and so on" [73]. Every 1% increase in the proportion of individuals driving to work, is associated with a 73% decrease in the odds of an individual having a neighborhood social tie [74]. Mixed-use, pedestrian-oriented urban designs, for example, those typically found in older cities or older rural villages tend to enable residents to perform daily activities (e.g., grocery shopping, going to the park, taking children to school) on foot (or cycle) and without the use of a car. Many of these neighborhoods have places of worship, a local tavern, a coffee shop, or restaurants within walking distance and built on a human scale that appeals to pedestrians. Such designs or models encourage and enable walking; pedestrians are not forced to compete with cars along busy motorways or to walk across expansive parking lots. Theoretically, pedestrian-oriented, mixed-use neighborhoods are expected to enhance social capital because they enable residents to interact. This interaction can be intentional or accidental. Spontaneous "bumping into" neighbors, brief (seemingly trivial) conversations, or just waving hello can help to encourage a sense of trust and a sense of connection between people and the places they live. These also are related with physical activity and health.

1.2. Policies and Active Transportation

There are a variety of policies related with active transportation, directly or indirectly, and in different levels as local and national government. Each has a different magnitude of impact to encourage active transport, but few have been evaluated individually. What more becomes known is the fact that several policies are together. Some are policies for building infrastructures and other are to promote active transport. Few studies have evaluated these policies and their impact on health and in fewer cases by different transport modes. A review by Pucher which concentrates the main policies and initiatives to increase cycling is an extensive review but it collects a lot of information of gray literature[75]. This is one of the main difficulties of transport policies that many have not been evaluated or has done, was not published this information. Pucher describes that not all measures that seek to increase the use of bicycles have the same effect, and not all infrastructure policies or promotional / education campaigns have the same impact. The most significant policies and initiatives in their study were: the integration of bicycles on public transport, create bicycle parking, bicycle lanes and create areas of slow traffic. In contrast, the promotional and educational measures had not much impact to increase cycling. Still Pucher concludes that there is no specific policy to encourage cycling, if not a combination of several policies, which according to the needs of each city should be implemented. Ogilvie in turn issued a further revision but focused mainly on promoting interventions for walking [76]. In their review concluded that interventions most successful are promotional programs that focus on changing the travel behavior of people through motivation campaigns or information on modes of active transport. Other very effective initiatives to promote active transport were the economic incentives and in some cases promote intermodal transport modes.

2. RATIONALE

Globally, there is a gradual increase in the implementation of active transportation policies (walking, cycling and traveling by public transport), which are designed to reduce problems such as traffic congestion, greenhouse gas emissions, energy dependence and physical inactivity. However, there is an existing debate about the risks which can accompany active transport policies. Evidence indicates that active transport policies can produce health benefits, such as increasing physical activity, promoting healthy habits or facilitating social interaction. On the other hand, there are risk factors such as increased inhalation of air pollutants or the exposure to traffic accidents that may offset these benefits. Therefore, it is necessary to quantify the risks and health benefits of active transport policies to help facilitate decision making for policy makers.

3. OBJECTIVES

General Objective

Assessing the health impact of the active transportation policies in urban areas.

Specifics

- Develop a quantitative model to estimate the impact on mortality of active transport policies.

- Develop a quantitative model to estimate the impacts on morbidity and burden of disease of active transport policies.

- Perform a health impact assessment of active transportation policies in the city of Barcelona.

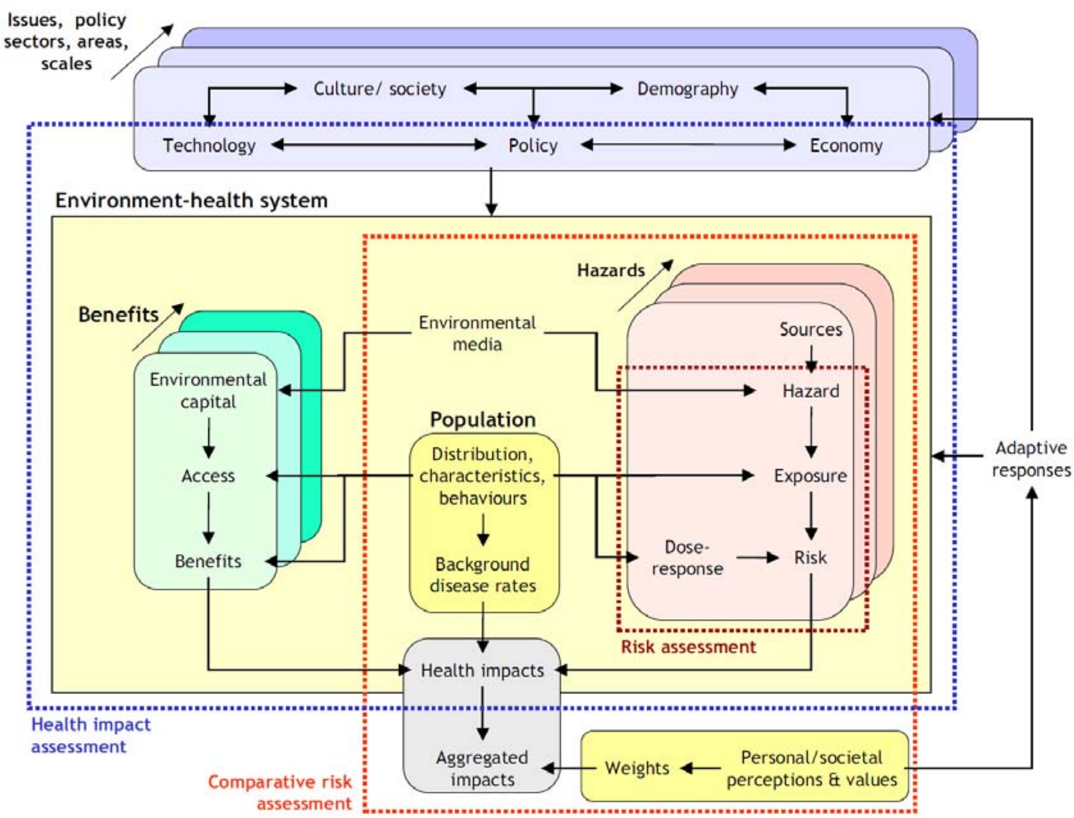
- Conduct a health impact assessment of active transportation policies in the six cities that make up the TAPAS project.

4. METHODS

4.1. Health Impact Assessment (HIA)

A combination of procedures, methods and tools by which a policy, programme or project may be judged as to its potential effects on the health of a population, and the distribution of those effects within the population[77]. In the figure 4 there is shown the description of the HIA in an environmental context.

Figure 4. Integrated environmental health impact assessment in relation to other forms of risk and impact assessment.

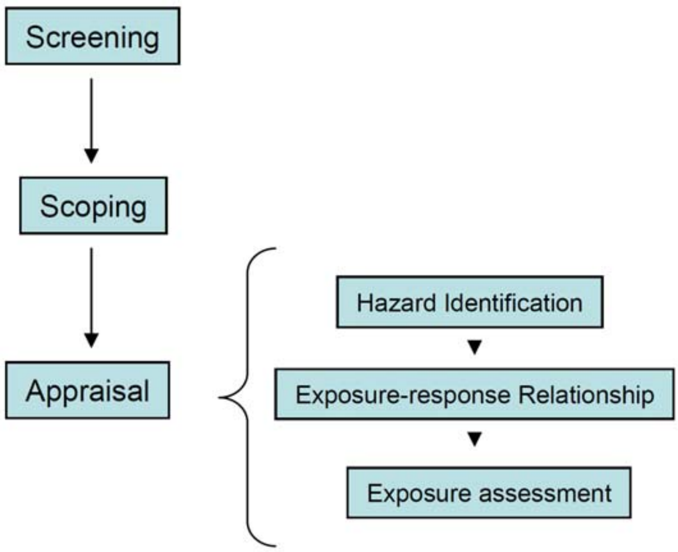


Ref: Briggs D, 2008 [78]

4.2. HIA Steps

The HIA includes different steps; Figure 5 shows the steps which compose a HIA. In the subsequent points is described each step for the specific case of this thesis.

Figure 5. Health impact assessment steps.



4.2.1. Screening

For the screening we made systematical review of active transportation policies, identifying the potential impacts on health. We used a screening tool for decide which policy will be including in health impact assessment. The screening tool includes different sections: 1) Description of the policy (the context outlined for the policy); 2) This policy have potential impact on health?, what are the potential positive / negative health impacts, intended consequences, possible unintended consequences; 3) this policy affect the population as a whole or some population groups? (We identified different groups who affected for de the policy such as young people, work population, urban population, etc.).

4.2.2. Scoping

Purpose: Assess the health impacts of active transportation policies in urban areas.

Space: The 6 cities of TAPAS project (Barcelona, Basel, Copenhagen, Paris, Prague and Warsaw).

Exposition: Physical activity, air pollution and traffic injuries related with active transportation policies.

Policies: 1) Barcelona public bike sharing system; 2) mobility plan in Barcelona metropolitan area which promotes the substitution of car trips by bike and public transport trips; 3) Active transport policies in European cities which promotes the increase of pedestrians trips to the level of Paris, or the increase of bike trips to the levels of Copenhagen, or 20% / 50% of car trips reduction.

Health impacts: For particulate mater les than 2.5 micrometers (PM2.5) all-cause mortality, cerebro-vascular disease, lower respiratory tract infections, preterm birth, low birth weight and cardiovascular diseases. For physical activity, all-cause mortality, cardiovascular diseases, dementia, diabetes type 2, breast cancer and colon cancer. For traffic accidents we choose fatal accidents, minor and major injuries.

Selection criteria: We performed a systematic review for choose the dose response functions (DRF).

Scenarios: Scenarios depend of the policies assessed, scenarios proposed by other cities and proposals for local governments. We choose different set of policies depends of the time of implementation, characteristics of the policies, and health impacts.

Stakeholders: We consider the stakeholders like a local government, local departments of public health, transport and environment, NGOs and researchers.

Data sourcing: Policies and implementation plans were obtained from municipal, regional or national reports and ordinances. Travel behavior, sociodemographic characteristics, health information and infrastructures information are derived from studies, reports, surveys and statistics made by the government, NGOs and scientific institutions.

4.2.3. Appraisal

Hazard identification: There performed a literature review of experimental studies, observational studies and meta-analysis, trying to identify risks and health benefits associated with active transport in urban areas. Also we take account the expert advice, resulted form different workshops performed each year between 2009 and 2011.

Exposure-response relationships: We performed a systematic review for select the most robust DRF related with air pollution PM2.5) and physical activity.

Exposure assessment: For air pollution in travelers, we measure the inhaled dose in each microenvironment, based on measurements performed in Barcelona for PM2.5. For estimate the exposure of PM2.5 in the general population, we estimate the inhaled dose according the concentrations derived from air dispersion model of Barcelona[79]. For physical activity we estimate the exposure according to the duration of the trip and the metabolic equivalent of task (METs) reported by Ainsworth [80] for each activity.

For traffic accidents we estimate the risk of injuries o death per kilometer traveled in each mode of transport an each city.

Risk characterization: We combined the results of the exposure assessment, dose-response functions, for estimate the relative risk (RR) for each exposure en each scenario, and we calculated the attributable fraction among the exposed population (AFexp). Here we conducted a quantitative analysis to provide a numerical estimate of risk or benefit based on a mathematical model.

5. RESULTS

Paper #	Title
1	The health risks and benefits of cycling in urban environments compared with car use: health impact assessment study. *BMJ, 2011.*
2	Replacing car trips by increasing bike and public transport in the greater Barcelona metropolitan area: A Health Impact Assessment Study. *Environment International, 2012.*
3	Health impact assessment of increasing public transport and cycling use in Barcelona: A morbidity and burden of disease approach *Preventive Medicine, (Submitted)*
4	Substitution of car trips by active transport in 6 European cities: A health impact assessment study. *(Manuscript)*
5	Ley para el uso obligatorio de casco por ciclistas en zonas urbanas. ¿Es bueno para la salud pública? Gaceta Sanitaria, 2012

Rojas-Rueda D, de Nazelle A, Tainio M, Nieuwenhuijsen MJ. The health risks and benefits of cycling in urban environments compared with car use: health impact assessment study. Supplementary information. ***BMJ.*** *2011;343:d4521*

5.2. PAPER 2

Rojas-Rueda D, de Nazelle A, Teixedó O, Nieuwenhuijsen MJ. Replacing car trips by increasing bike and public transport in the greater Barcelona metropolitan area: a health impact assessment study. ***Environment International.*** *2012; 49: 100 –109*.

Rojas-Rueda D, de Nazelle A, Teixedó O, Nieuwenhuijsen MJ. Replacing car trips by increasing bike and public transport in the greater Barcelona metropolitan area: a health impact assessment study. Supplemetary information. ***Environment international.*** *2012; 49: 100 -109.*

5.3. PAPER 3

Health impact assessment of increasing public transport and cycling use in Barcelona: A morbidity and burden of disease approach.

Rojas-Rueda D, de Nazelle A, Teixedó O, Nieuwenhuijsen MJ.

Submitted to: Preventive Medicine

Health impact assessment of increasing public transport and cycling use in Barcelona: A morbidity and burden of disease approach

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Key words: Air Pollution, Physical activity, Traffic injuries, Public transport, Bicycling, Health impact assessment.

Words counts: Abstract: 200**;** Main text: 3473

Abstract

Objective: Quantify the health impacts on morbidity of reduced car trips and increased public transport and cycling trips.

Methods: A health impact assessment study of morbidity outcomes related to replacing car trips in Barcelona metropolitan area. Through 8 different transport scenarios, the number of cases of disease or injuries related to particulate matter air pollution < 2.5 μm ($PM_{2.5}$), physical activity and traffic incidents in travelers was estimated. An air dispersion model was used for estimating $PM_{2.5}$ exposure and cases of disease in the general population.

Results: A 40% reduction in long-duration car trips substituted by public transport and cycling trips resulted in annual reductions of 127 cases of diabetes, 44 of cardiovascular diseases, 30 of dementia, 16 minor injuries, 11 of breast cancer and 3 of colon-cancer, amounting to a total reduction of 302 DALYs per year in travelers. The reduction in $PM_{2.5}$ exposure in the general population resulted in annual reductions of 7 cases of low birth weight, 6 of preterm birth, 1 of cardiovascular disease and 1 of lower respiratory tract infection.

Conclusions: Transport policies to reduce car trips could produce important health benefits in terms of reduced morbidity, particularly for those who take up active transportation.

1.Introduction

Each day million of quotidian trips are made worldwide to go to work or school. Transportation is a key sector for the economy and social development. But transportation is also a major source of air pollutant emissions; globally represents 23% of greenhouse gas emissions (OCDE, 2010a). Furthermore car use promotes physical inactivity and sedentary lifestyle which are associated with obesity, cardiovascular disease, diabetes, cancer, and other diseases. Both physical inactivity and air pollution have been classified as two of the 10 leading risk factors of burden of disease worldwide in 2010 (Lim et al. 2013).

Various studies estimating impacts of transport interventions or policies on health have been published recently. Some quantified the impact of implementing transport interventions on all cause mortality, such as public bicycle system in Barcelona (Rojas-Rueda et al. 2011). Others quantified the possible impacts on morbidity and mortality of future transport interventions, such as increasing the number of walking or cycling trips in different urban areas around the world (De Hartog et al. 2010;Grabow et al. 2011;Lindsay et al. 2011;Woodcock et al. 2009;Holm et al. 2012;Olabarria et al. 2012;Rabl A and de Nazelle A 2012;Woodcock et al. 2013). These studies assessed impacts of transport on health through three major exposures: physical activity, air pollution and traffic incidents. Although there are other factors relating transport to health (e.g. noise, ultraviolet radiation, diet, crime and social interaction), these are more difficult to quantify and have not been integrated in quantitative health impacts studies yet (de Nazelle et al. 2011a).

The present study aims to quantify the morbidity impacts of transport policies through a health impact assessment (HIA) approach, selecting the best available evidence based on a review of the literature. It takes into account different types of trips (short and long duration), different modes of transport (bicycle, bus, tram, metro and train), different exposure populations (travelers and the general population) and different types of exposures (air pollution, physical activity and traffic incidents).

2.Methods

2.1.Scenarios

The HIA (Joffe and Mindell 2002) was based on eight different scenarios of car trip replacement by public transport and bicycle trips used in a previous study conducted in the metropolitan area of Barcelona (Rojas-Rueda et al. 2012). We modeled impacts of a 20% reduction in car traffic as suggested by the Basque country mobility plan (Gobierno Vasco 2011) and a report of the Catalan Agency of Energy (ICE 2010) and of a 40% reduction in car traffic. From these premises, eight scenarios were designed with consideration of short and long car trips in Barcelona city and its metropolitan area, assuming that these trips can be replaced by public transport (bus, tram, metro and train) and/or bicycle (Table 1).

Two populations were included in the analysis: 1) "Travelers", defined as those who performed a modal shift due to the intervention, i.e. the people who according to the scenario changed their mode of transport from car to public transport or bicycle (new cyclist or new public transport user). And 2) the "General population”, defined as those who live in Barcelona city. In our assessment the general population was exposed to changes in air pollution concentrations related to traffic reduction associated with the transport policy intervention (the 8 scenarios) in comparison with the concentrations of air pollution in the business as usual (BAU) scenario.

2.2.Transport data

The information needed on travel mode share and trip distances by mode of transport were obtained from surveys and records conducted by the city and Metropolitan area of Barcelona (DSM 2010). We estimated the average car trip length of “inside” (3.1km) and “outside” (6.4km) Barcelona and developed different scenarios of mode shifts to alternative modes (Table 1). Car trips were assumed to be replaced with either bike or public transportation trips of the same length. We assumed the shift to public transport reflected the current public transport (train, tram, metro or bus) mode share.

2.3.Morbidity outcomes

To select the health outcomes we identified the dose response functions (DRF) published in the scientific literature that associate health determinants (air pollution and physical activity) with morbidity outcomes. The selection of DRF was based on proposals derived from a series of expert meetings held in Barcelona between 2010 and 2012, a systematic review of the scientific literature, and expert judgment. For traffic incidents, another approach was used, focusing on the data available for traffic incidents in Barcelona city. In this case we used the injury records for 2002-2009 for each mode of transport, which reported minor and major injuries within the city (ASPB 2011).

For the systematic review, we searched in MEDLINE using free text and Medical Subject Headings (MeSH) terms for two exposures air pollution and physical activity. As our outcome was morbidity, we chose the 20 leading causes of death and the 20 leading causes of burden of diseases reported by World Health Organization (WHO) (WHO 2008) (see Appendix). We obtained five morbidity outcomes for physical activity and five outcomes for air pollution (Table 2).

2.4.Health determinants

As shown in our conceptual model (Figure 1), we considered three health determinants (air pollution, physical activity and traffic incidents) in the relationships between transport policy and its impact on morbidity. For these factors we created a quantitative model to estimate attributable cases of illness linked to transport policies that would affect the travelers and the general population.

2.4.1.Physical activity

To assess the physical activity in travelers it was assumed that for each public transport trip the traveler walked for 10 minutes and for cycling trips, trip duration depended on the distance traveled in each scenario. The relative risks (RR) obtained for physical activity and each morbidity outcome were used to estimate the number of cases of disease expected in each scenario. We performed various sensitivity analyses regarding morbidity outcomes of changes in physical activity. First, we estimated the impacts of increased physical activity as a function of various basal levels of physical activity adjusted for sex and age, among travelers in Barcelona (Appendix), which we obtained from an active transport survey conducted in the city (Donaire-Gonzalez *et al*. 2013). Also, we assumed a non-linear dose response relationship between physical activity and disease. Since there is no evidence for curvilinear dose response functions for the diseases considered, curvilinear functions were created based on the linear DRF used in the main analysis, using a logarithmic transformation of the exposure (see Appendix). Finally, we analyzed the impact of our scenarios on different age groups, comparing the age distribution reported in Barcelona (average age 39 years) to distributions assuming 1) a younger age group (average age 33 years) and 2) an older age group (average age 48 years) (see Appendix).

2.4.2.Air pollution

Particulate matter less than 2.5μm ($PM_{2.5}$) was selected as the main air pollutant in this model because it has shown strong associations with health outcomes (Lim et al. 2013;HEI 2010). For travelers, we estimated and compared the exposure concentration and inhaled dose for travel by car, bicycle, walking, bus/tram and metro/train. Concentration levels for car, bike, walk and bus were obtained from a measurement study conducted in Barcelona (de Nazelle A et al. 2011b). The model also assumed the same concentrations for tram and bus modes and a thrice-fold concentration level for metro and train modes compared to background concentrations, similar to data reported by different studies in other cities (Adams et al. 2001;Johansson C and Johansson P 2003;Ripanucci et al. 2006). For the public transport trips, we assumed a 10 minute walking duration in the street with a corresponding air pollution exposure. Yearly inhaled dose of $PM_{2.5}$

was estimated accounting for mode-specific inhalation rates, exposures, and trip duration (de Nazelle et al. 2009).

For air pollution exposure in the general population we used the Barcelona Air-Dispersion Model (Lao J and Teixido O 2011) to estimate the reduction in the concentrations in $PM_{2.5}$ in Barcelona city for each scenario. This dispersion model estimated PM concentrations for the BAU scenario and for the (20% and 40%) car trips reduction scenarios (see Appendix).

2.4.3.Traffic incidents

Traffic injuries in Barcelona were estimated based on the injury records from 2002 to 2009 reported by Barcelona Public Health Agency (ASPB 2011). For each mode of transport, the risk of suffering a minor or major injury per billion of kilometers traveled was estimated using the average number of injuries (minor or major) per year and the kilometers traveled per year in each mode of transport. The kilometers traveled per year were calculated based on the number of trips per mode of transport and the average trip duration reported by Barcelona transport department (DSM 2010;RMB 2006). For every public transport trip it was assumed that the trip involves 10 minutes of walking. Therefore, the risk of suffering a road traffic injury by a pedestrian was integrated into the risk of public transport. From this, the RR of minor or major injury for each mode of transport was calculated. For the metro, tram and train modes it was assumed that the risk of injury was the same as for the bus, because the specific data of injuries for these modes of transport was not published. We also performed sensitivity analyses to estimate the possible under-reporting of injuries, especially minor injuries, since the use of city records in our analysis may underestimate the number of injuries in each scenario (see Appendix) (de Geus *et al.* 2012).

2.5.Morbidity rates

The Morbidity rates used for the different diseases related with the physical activity and air pollution were obtained from different epidemiological studies and public records published for the local population (Martinez-Salio et al. 2010;Chacon et al. 2010;Medrano et al. 2006;Mata-Cases et al. 2006;Pollan et al. 2010;Lopez-Abente et al. 2010;Bermejo-Pareja et al. 2008;INE 2006;INE 2010;OECD 2010b) (Table 3). The DRF and morbidity rates was used to obtain the population-attributable number of cases for each scenario (Perez and Kunzli 2009).

2.6.Burden of disease

A disability adjusted life years (DALYs) approach was used to synthesize and compare the health impacts of different morbidity outcomes of the three main exposures and the two populations (travelers and general population) in each scenario. The DALY is a summary measure which expresses the combined effect of morbidity and mortality (Lopez A et al. 2006). For estimating the DALYs, we estimated the years of life lost (YLL) and the years lived with disability (YLD) following the WHO approach (WHO 2004).

3.Results

3.1.Physical activity impacts in travelers

For inside Barcelona scenarios where the impacts of substitution of short trips was estimated, in all scenarios there was a reduction in the number of cases with disease per year related to physical activity exposure in travelers (Table 4). For cardiovascular disease the maximum change of cases per year was -30.33, for diabetes mellitus type 2 -89.19, for breast cancer in women -7.91, for colon cancer -2.63 and for dementia -21.84, all in scenario 2. The DALYs per year estimated change for the impact of physical activity in travelers for scenarios 1 to 4 ranged from -103.33 to -283.74 (Table 5). For outside Barcelona scenarios associated with long trips substitutions, in all scenarios there was also a reduction of estimated number of cases of disease per year related with physical activity exposure in travelers (Table 4).

3.2.Air pollution impacts in travelers

For inside Barcelona scenarios we estimated that in all scenarios there was an increase in the number of cases of disease per year related to $PM_{2.5}$ exposure in travelers (Table 4). For cerebrovascular disease the maximum increment of cases per year was 0.08, for lower respiratory tract infections 0.31, for preterm birth 1.90, for low birth weight 0.43 and for cardiovascular disease 0.26, all in scenario 2. The DALYs estimates for scenarios 1 to 4 ranged from an increase of 0.90 DALYs per year to 3.17 DALYs per year (Table 5). For outside Barcelona scenarios we also estimated that in all scenarios there was an increase of number in cases of disease per year related to $PM_{2.5}$ exposure in travelers (Table 4).

3.3.Traffic injuries impacts in travelers

In the traffic injuries for inside Barcelona scenarios, a reduction of cases of minor injuries and increase in the number of cases of major injuries, was estimated. For minor injuries the maximum reduction of cases per year was -3.35, and for major injuries the maximum increase in cases was 0.014 (Table 4). For DALYs estimated change, an increase in DALYs per year for scenarios 1 (2.53) and 2 (5.37) was estimated, and a reduction in DALYs per year for scenarios 3 (-0.32) and 4 (-0.63) (Table 5). For outside Barcelona scenarios, we estimated for minor and major injuries in all scenarios a reduction in the number of injuries per year.

3.4.Air pollution impacts in the general population

For all scenarios in general population was found a reduction in the number of cases of diseases. And the maximum estimated change of the number of cases per year was for low birth weight (-7.40) and preterm birth (-6.62) for scenarios 6 and 8.

4.Discussion

Our results show that in the Barcelona metropolitan area, with a region of 1.6 million of inhabitants, a 40% reduction of short and long car trips could prevent a large number of cases of disease each year in travelers and general population. The estimated reduction in disease was much larger in those changing modes compared to the general population. The greatest benefit came from the increase in physical activity, and the largest reduction in number of cases was estimated for cardiovascular disease and type 2 diabetes.

These results follow the same tendency showed by other studies, which suggests that the increase of active transport and reduction of car trips can bring health benefits in terms of morbidity (Grabow et al. 2011;Holm et al. 2012;Woodcock et al. 2013). However, our study adds new health outcomes (e.g. preterm birth, low birth weight), based on a systematic review of the literature. Furthermore this study accounted for different trip distances (short and long trips), different populations (travelers and general population), different modes of transport (bike, metro, train, tram and bus), different exposures (air pollution, physical activity and traffic injuries) and different health outcomes for each exposure.

In contrast to two previously published morbidity models (Grabow et al. 2011; Woodcock et al. 2013) we quantified the impact of air pollution on travelers who might perform modal shifts and not only in the general population, and in contrast with the third published morbidity model (Holm et al. 2012) we included in our model the impacts of air pollution in the general population. In terms of traffic injuries, one previous study (Grabow et al. 2011) did not include in their model the impact of traffic incidents, while another study (Woodcock et al. 2013) included only serious injuries and a third study (Holm et al. 2012) did not perform an analysis by severity of injury as we did. Compared to the latest published model (Woodcock et al. 2013) in which authors applied a simplified approach to estimate the DALYs, we applied each step of the WHO approach, quantifying the cases of disease, the YLL, YLD and DALYs associated with each exposure, in travelers and the general population. Also unlike these previously published models we included in our analysis the public transport alternative, in addition to the bike.

As reported in previous studies (Grabow et al. 2011;Holm et al. 2012;Woodcock et al. 2013), we found that physical activity is the main determinant for morbidity (Table 4). When comparing the DALYs between different exposures and both populations, it is obvious that physical activity is the main predictor variable of the model (Figure 2). When comparing DALYs in different scenarios, the scenarios with more health benefits were the scenarios with a higher number of bike trips, which were also the scenarios with higher levels of physical activity. For traffic incidents, when comparing different scenarios, the scenarios with a higher reduction of DALYs associated with traffic incidents are the scenarios with a higher rate of substitution of car trips by public transport. When comparing the DALYs associated with air pollution in travelers and in the general population, the increase of DALYs in travelers is higher than the reduction of DALYs estimated in the general population, resulting in an increase of a global DALYs estimate for air pollution in all scenarios; however, this increase of DALYs by air pollution is always smaller than the DALYs reductions resulting for physical activity in all scenarios.

Comparing the mortality impacts from our previous study (Rojas-Rueda et al. 2012) with morbidity impacts in this current study, we see the same trends across the scenarios between all-cause mortality and each analyzed disease. Figures 3 to 6 show the different scenarios sorted in ascending order according to the number of deaths avoided. They show trends for all-cause mortality (Rojas-Rueda et al. 2012) and morbidity outcomes, which are consistent for all scenarios, the three health determinants and in the two populations. This suggests that the estimation of all-cause mortality in HIA models for transportation could be a reasonable indicator for the total burden of disease related to transport policies or interventions.

This study has limitations similar to all risk assessment studies due to the lack of availability of data requiring assumptions to be made to model the different scenarios. For this reason, sensitivity analyses were performed to assess the robustness of our results and to test effects of deviations from the main assumptions and data choices, and in all the sensitivity analyses we consistently found net health benefits for all of our car replacement scenarios (see Appendix).

Another limitation could be the absence of the effect of safety in numbers in our model (Jacobsen 2003). We did not include this because we did not have information that details the relationship between the increase in the number of cyclists and the reduction of traffic injuries for Barcelona. Some authors suggest that this effect may not be due simply to the number of cyclists but also to the change in traffic management when increasing the number of cyclists (Bhatia and Wier 2011).

Some studies also suggested a correlation between active transport and reduction of body weight in adults (Pucher et al. 2010;Gordon-Larsen et al. 2005), but a recently published systematic review, has been unable to define a quantitative summary measure, given the large heterogeneity between studies (Wanner et al. 2012), therefore the impact on body weight was not included in our model.

One strength of this study was the selection of different health outcomes for air pollution and physical activity (Figure 1), based on a systematic review, prioritizing dose response functions published in a high quality studies and with higher methodologically robustness. Another strength of the study was the use of local measurements of $PM_{2.5}$ concentration in the different microenvironments in the city of Barcelona (de Nazelle A et al. 2011b). In addition, for estimating the impacts of air pollution in the general population, we ran an Air-Dispersion model (Lao J and Teixido O 2011) which took into account different parameters to estimate the concentration levels of particulate mater in the city of Barcelona (see Appendix). Our results showed that the health benefit in the general population was very small, as a result of the small reduction in $PM_{2.5}$ concentration associated with our scenarios. This can be explained partially by the fact that the trip reductions only concerned car trips and not trips from the entire vehicle fleet in Barcelona (40% reduction in car trips represents only 11% of all motorized trips). In our model we performed the analysis for a single pollutant ($PM_{2.5}$), which has robust scientific evidence to be used in a HIA model.

We also found a lack of information about robust dose-response functions for air pollution and physical activity and health outcomes. We also found a lack of information related to traffic incidents, especially the under-reporting of rates in our population and the description of accidents diagnosis. Furthermore there is need for future studies comparing cities, showing the possible variability in potential health impacts for similar interventions or transport policies in different populations.

In terms of public policy implications, our study shows that there is a need to redirect transport policies and public investment, to encourage public transport, pedestrians and cyclists over cars. It also emphasizes the need for joint work between health practitioners, transport specialists and urban planners.

5. Conclusions

This study shows that transport policies directed to reduce car use and increase public transport and cycling trips have health benefits in terms of diseases. These health benefits result principally from the effect of the increase in physical activity in travelers, secondly from the reduction of traffic injuries (especially when car trips were substituted by public transport) and finally from the reduction of the exposure to air pollution in the general population. These findings also show that an estimation of all-cause mortality can be a reasonable indicator for the disease impacts in health impact assessment models of transportation.

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Contributors: AdeN and MJN conceived and designed the study. DR-R and AdeN collected the data. DR-R, AdeN and MJN analyzed and interpreted the data and wrote the manuscript. DR-R, AdeN, and MJN edited and approved the final version for submission. AdeN and MJN are guarantors.

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Ethical approval: Not required.

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Table 1. Scenarios description, number of car trips replaced and percentages.

	Inside Barcelona Scenarios [a]				Outside Barcelona Scenarios [b]			
	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7	Scenario 8
Car trips reduction	20%	40%	20%[c]	40%[c]	20%[d]	40%[d]	20%[e]	40%[e]
Trips/day replaced by Bike (%)	94,460 (100)	188,920 (100)	47,230 (50)	94,460 (50)	0	0	34,065 (20)	68,130 (20)
Trips/day replaced by Public Transport (%)[f]	0	0	47,230 (50)	94,460 (50)	170,324 (100)	340,648 (100)	136 259 (80)	272,518 (80)

[a] Inside Barcelona Scenarios refers to the trips that start and ends in Barcelona city;
[b] Outside Barcelona Scenarios refers to the trips that starts or ends in Barcelona city and start or ends in Barcelona metropolitan area;
[c] Here we assumed the 50% of the trips was replaced by bike, the 22% by bus/tram and 28% are by metro/train;
[d] Here we assumed the 26% of the trips are replaced by bus/tram and 74% are by metro/train;
[e] Here we assumed the 20% of the trips are replaced by bike, the 21% by bus/tram and 59% are by metro/train;
[f] Public transport includes: Bus, Tram, Train and Metro.

Table 2. Dose response functions (DRF), derived for the systematic review.

Health determinant	Outcome	DRF	LCI	UCI	Unit	Reference
Physical activity						
	Cardiovascular diseases	0.84	0.79	0.9	3 hours per week at 3 km/h: 7.5 METs	Hamer M, Chida Y, Br J Sports Med, 2008
	Dementia	0.72	0.6	0.86	33 METs per week (>1657 kcal per week)	Hamer M, Chida Y, Psychological Medicine, 2009
	Type 2 diabetes incidence	0.83	0.75	0.91	Per 10 METs per week	Jeon C, et al, Diabetes Care, 2007
	Breast cancer Women	0.94	0.92	0.97	for each additional hour per week	Monninkhof E, et al, Epidemiology, 2007
	Colon cancer Men	0.8	0.67	0.96	per 30,1 METs per week	Harriss D, et al, Colorectal disease, 2009
	Colon cancer Women	0.86	0.76	0.98	per 30,9 METs per week	Harriss D, et al, Colorectal disease, 2009
Air pollution (PM2.5)						
	Cerebrovascular disease	1.0081	1.0030	1.0132	10 $\mu g/m^3$	Dominici F, et al, JAMA 2006
	Lower Respiratory Tract Infections	1.0092	1.0041	1.0143	10 $\mu g/m^3$	Dominici F, et al, JAMA 2006
	Preterm Birth	1.15	1.14	1.16	10 $\mu g/m^3$	Sapkota A, et al, AirQualAtmosHealth 2010
	Low Birth Weight	1.10	1.03	1.18	10 $\mu g/m^3$	Dadvand P, et al, EHP, 2013
	Cardiovascular diseases	1.025	1.015	1.036	10 $\mu g/m^3$	Mustafic H, JAMA 2012

* DRF: Dose response function; LCI: Lower confidence interval; UCI: Upper confidence interval; METs: Metabolic Equivalent of Task; PM2.5: Particulate matter les than 2.5 micrometers

Table 3. Morbidity rates.

Disease	Cases/100,000	Population	Age	Year	Reference
Cerebrovascular disease (women)	370	Spain	> 65 years	2010	Martínes-Salio, et al, JNeurolScien, 2010
Cerebrovascular disease (men)	690	Spain	> 65 years	2010	Martínes-Salio, et al, JNeurolScien, 2010
Lower Respiratory Tract Infection (women)	229	Spain	20-79	2007	Chacon A, et al, AtenPrim, 2010
Lower Respiratory Tract Infection (men)	316	Spain	20-79	2007	Chacon A, et al, AtenPrim, 2010
Cardiovascular disease (women)	56	Barcelona	25-74	2005	Medrano J, et al, RevEspSalPub, 2006
Cardiovascular disease (men)	209	Barcelona	25-74	2005	Medrano J, et al, RevEspSalPub, 2006
Diabetes Mellitus 2 (women)	381	Barcelona	> 14 years	2000	Mata-Cases, et al, GasSanit, 2006
Diabetes Mellitus 2 (men)	376	Barcelona	> 14 years	2000	Mata-Cases, et al, GasSanit, 2006
Breast Cancer (women)	83	Spain	> 25 years	2004	Pollan M, et al, AnnOnc, 2010
Colon Cancer (women)	33	Spain	Age adjusted	2004	Lopes-Abente, et al, AnnOnco, 2010
Colon Cancer (men)	60	Spain	Age adjusted	2004	Lopes-Abente, et al, AnnOnco, 2010
Dementia (women)	1110	Spain	> 65 years	2008	Bermejo-Pareja, et al, JNeurolScien, 2008
Dementia (men)	960	Spain	> 65 years	2008	Bermejo-Pareja, et al, JNeurolScien, 2008
Preterm Birth	6800	Spain	15-49	2006	INE, 2006
Low Birth Weight	7600	Spain	15-49	2008	OCDE, 2010
Woman Fecundity	6800	Spain	15-49	2010	INE, 2010

* INE: National Institute of Statistics of Spain; OCDE: Organization for Economic Co-operation and Development.

Table 4. Morbidity results (cases/year) for each scenario, in travelers and general population.

	Inside Barcelona Scenarios [a]				Outside Barcelona Scenarios [b]			
	Scenario 1	Scenario 2	Scenario 3 [c]	Scenario 4 [c]	Scenario 5 [d]	Scenario 6 [d]	Scenario 7 [e]	Scenario 8 [e]
Travelers								
Air pollution (PM2.5) (cases/year)								
Cerebrovascular disease	0.04	0.08	0.02	0.04	0.01	0.02	0.01	0.03
Lower Respiratory Tract Infection	0.16	0.31	0.09	0.18	0.04	0.08	0.15	0.31
Preterm Birth	0.95	1.90	0.55	1.10	0.28	0.56	0.94	1.55
Low Birth Weight	0.22	0.43	0.13	0.27	0.02	0.05	0.19	0.36
Cardiovascular disease	0.13	0.26	0.07	0.15	0.05	0.10	0.18	0.35
Physical activity (cases/year)								
Cardiovascular disease	-15.17	-30.33	-10.92	-21.84	-12.04	-24.08	-22.17	-44.33
Diabetes Mellitus 2	-44.59	-89.19	-32.35	-64.71	-36.26	-72.53	-63.95	-127.90
Breast Cancer	-3.95	-7.91	-2.87	-5.74	-3.21	-6.43	-5.67	-11.35
Colon Cancer	-1.32	-2.63	-0.97	-1.94	-1.13	-2.26	-1.83	-3.66
Dementia	-10.92	-21.84	-8.03	-16.06	-9.27	-18.55	-15.27	-30.54
Traffic injuries (cases/year)								
Minor Injuries	-0.299	-0.598	-1.676	-3.353	-4.346	-8.691	-8.327	-16.653
Major injuries	0.007	0.014	-0.010	-0.020	-0.036	-0.071	-0.072	-0.144
General Population								
Air pollution (PM2.5) (cases/year)								
Cerebrovascular disease	-0.12	-0.25	-0.12	-0.25	-0.24	-0.50	-0.24	-0.50
Lower Respiratory Tract Infection	-0.27	-0.55	-0.27	-0.55	-0.53	-1.09	-0.53	-1.09
Preterm Birth	-1.64	-3.31	-1.64	-3.31	-3.23	-6.62	-3.23	-6.62
Low Birth Weight	-1.83	-3.70	-1.83	-3.70	-3.61	-7.40	-3.61	-7.40
Cardiovascular disease	-0.31	-0.62	-0.31	-0.62	-0.60	-1.24	-0.60	-1.24

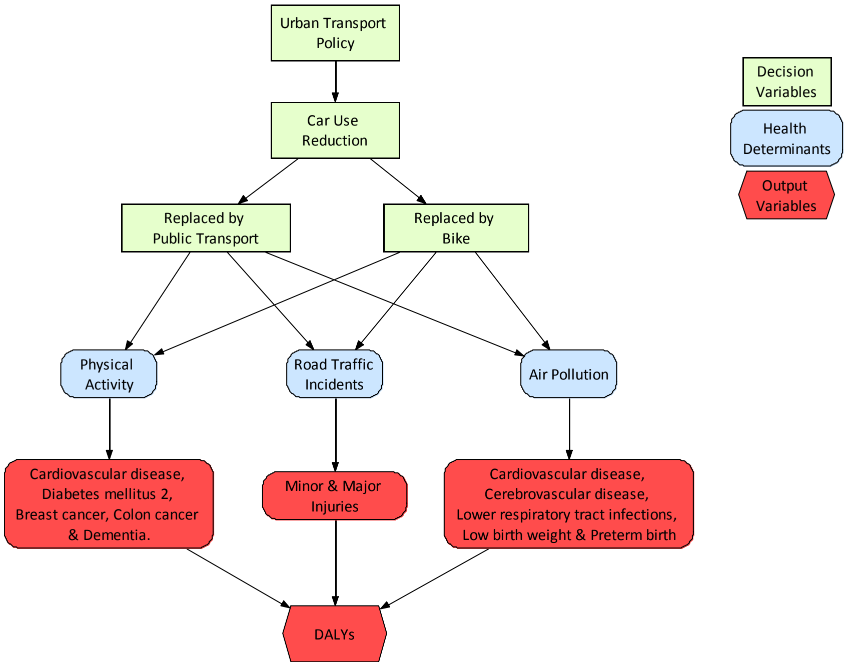
PM2.5: Particulate matter < 2.5 micrometers;
[a] Inside Barcelona Scenarios refers to the trips that start and ends in Barcelona city;
[b] Outside Barcelona Scenarios refers to the trips that starts or ends in Barcelona city and start or ends in Barcelona metropolitan area;
[c] Here we assumed the 50% of the trips was replaced by bike, the 22% by bus/tram and 28% are by metro/train;
[d] Here we assumed the 26% of the trips are replaced by bus/tram and 74% are by metro/train;
[e] Here we assumed the 20% of the trips are replaced by bike, the 21% by bus/tram and 59% are by metro/train;

Table 5. Results in Disability Adjusted Life-Years (DALY) per year, in each scenario.

	Inside Barcelona Scenarios [a]				Outside Barcelona Scenarios [b]			
	Scenario 1	Scenario 2	Scenario 3 [c]	Scenario 4 [c]	Scenario 5 [d]	Scenario 6 [d]	Scenario 7 [e]	Scenario 8 [e]
Travelers (DALY / year)								
Air pollution (PM2.5)	1.59	3.17	0.90	1.79	0.41	0.83	1.00	2.01
Physical activity	-141.87	-283.74	-103.33	-206.66	-117.18	-234.36	-161.93	-259.16
Traffic injuries	2.53	5.37	-0.32	-0.65	-30.96	-61.61	-22.46	-45.23
Travelers-Total	-137.76	-275.19	-102.76	-205.51	-147.73	-295.14	-183.39	-302.39
General Population (DALY / year)								
Air pollution (PM2.5)	-0.19	-0.38	-0.19	-0.38	-0.38	-0.75	-0.38	-0.75
Total (DALY / year)	-137.95	-275.58	-102.95	-205.90	-148.10	-295.89	-183.76	-303.14

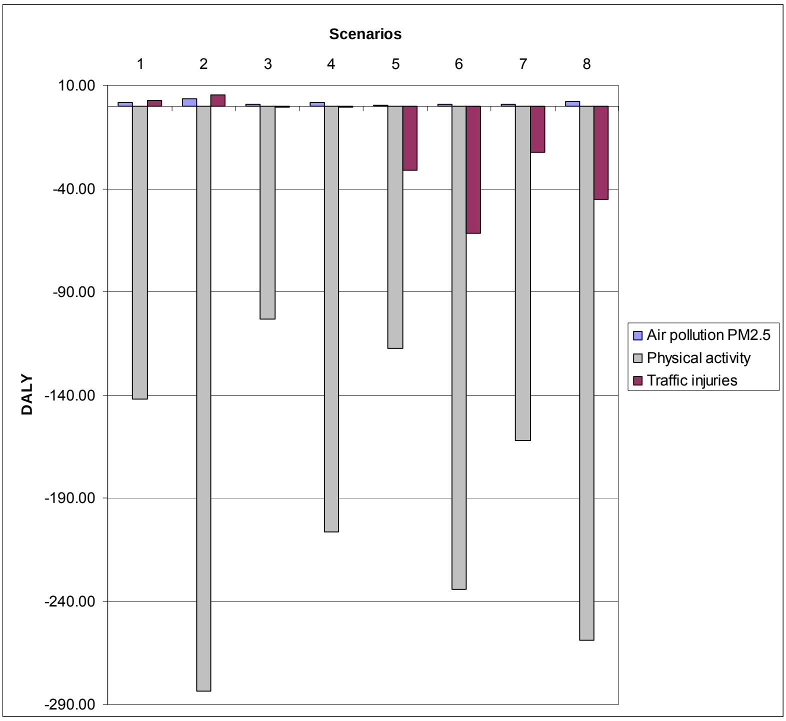
PM2.5: Particulate matter < 2.5 micrometers;
[a] Inside Barcelona Scenarios refers to the trips that start and ends in Barcelona city;
[b] Outside Barcelona Scenarios refers to the trips that starts or ends in Barcelona city and start or ends in Barcelona metropolitan area;
[c] Here we assumed the 50% of the trips was replaced by bike, the 22% by bus/tram and 28% are by metro/train;
[d] Here we assumed the 26% of the trips are replaced by bus/tram and 74% are by metro/train;
[e] Here we assumed the 20% of the trips are replaced by bike, the 21% by bus/tram and 59% are by metro/train;
[f] Public transport includes: Bus, Tram, Train and Metro;

Figure 1. Health impacts assessment model of transport policies and morbidity.



DALYs: Disability Adjusted Life Years

Figure 2. Disability Adjusted Life-Years by scenario and exposure, in travelers and general population



DALYs: Disability Adjusted Life-Years; PM2.5: Particulate matter < 2.5 micrometers

Figure 3. Number of deaths, disease cases or DALYs avoided per year related to physical activity in each scenario (in travelers).

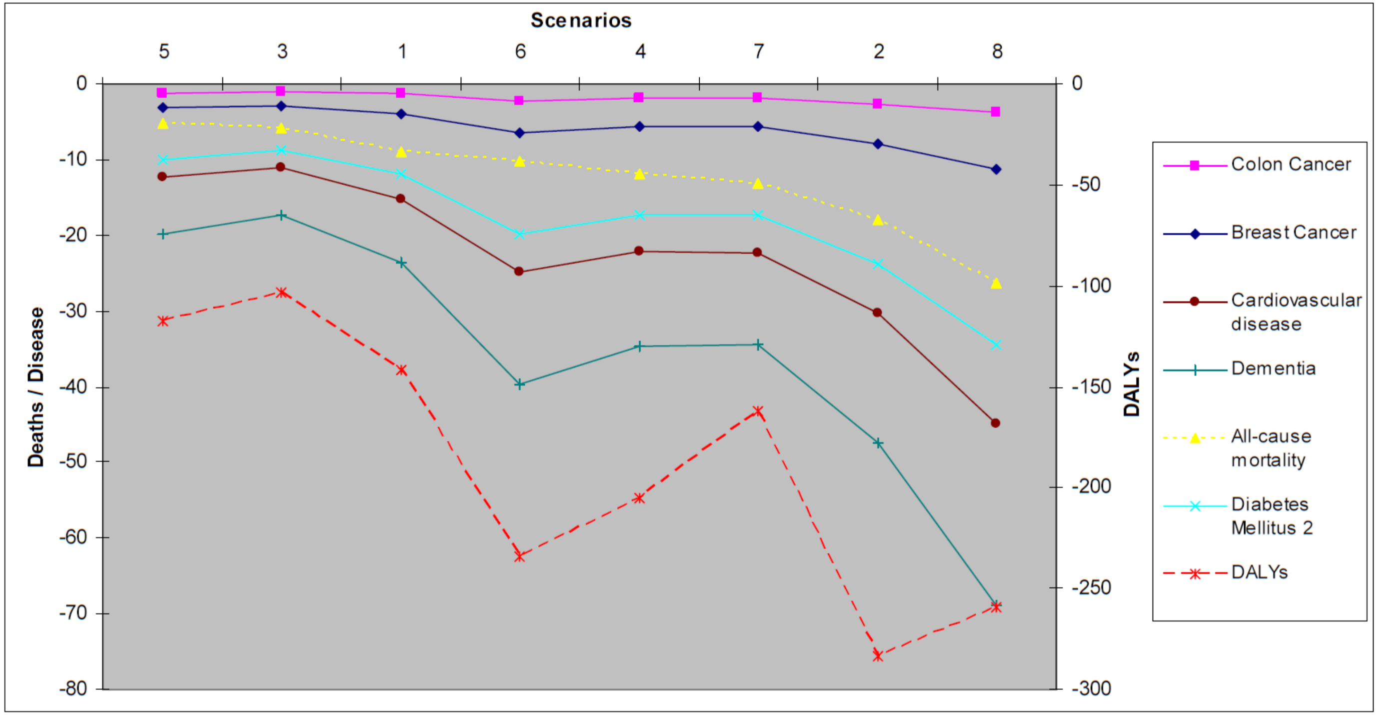


Figure 4. Number of deaths, disease cases and DALYs related to air pollution in each scenario (in travelers).

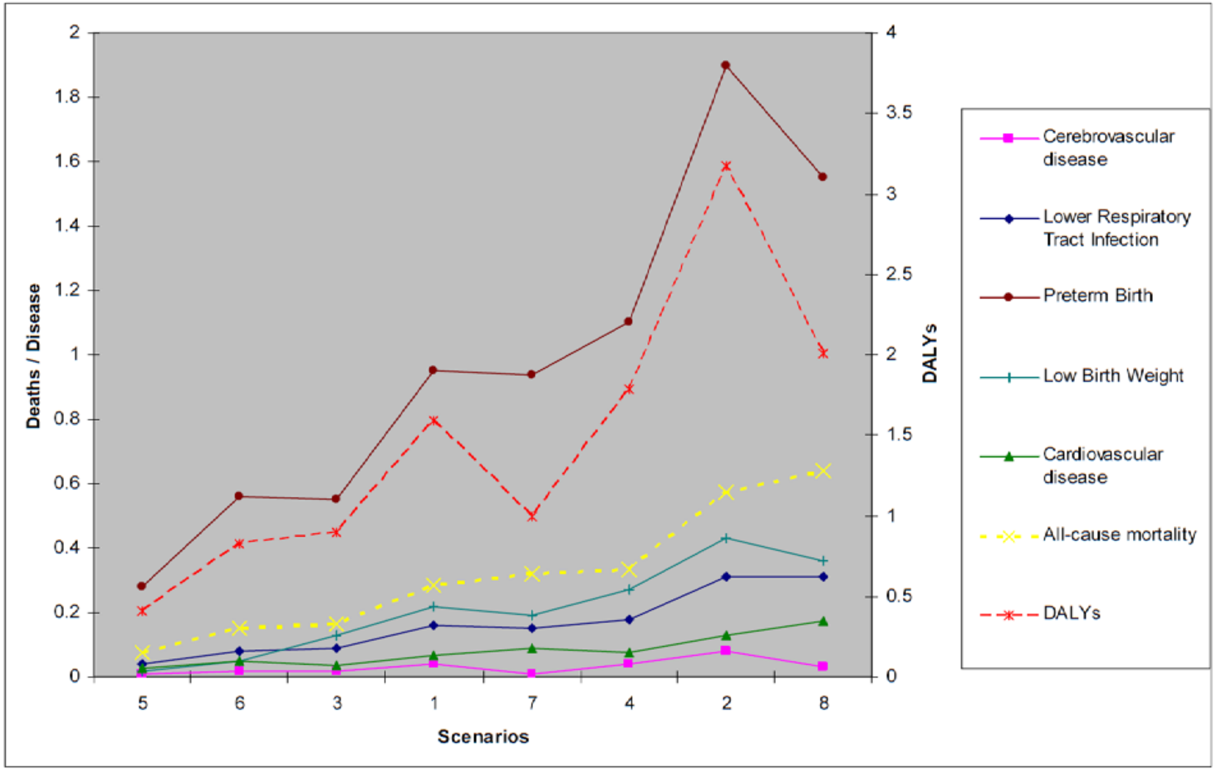


Figure 5. Number of deaths, injuries and DALYs related to traffic incidents in each scenario (in travelers).

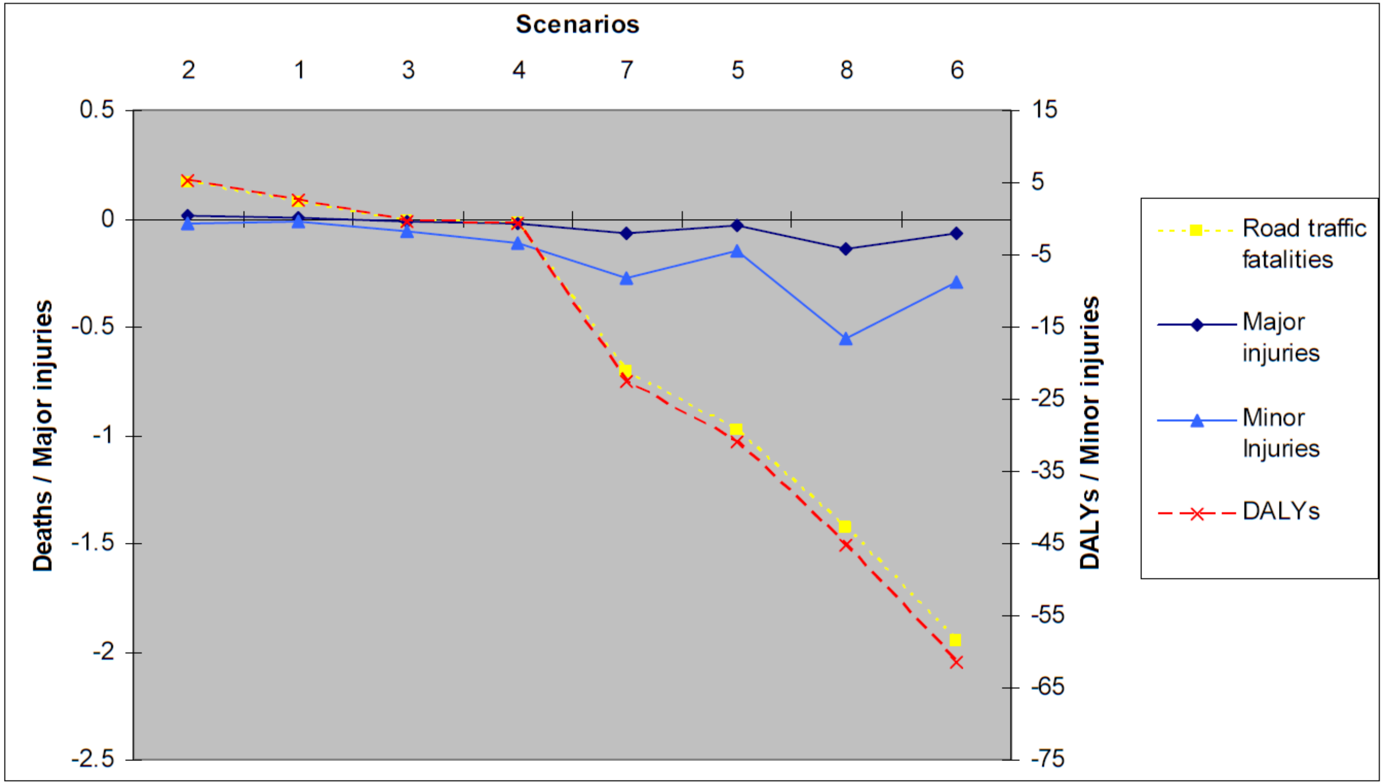
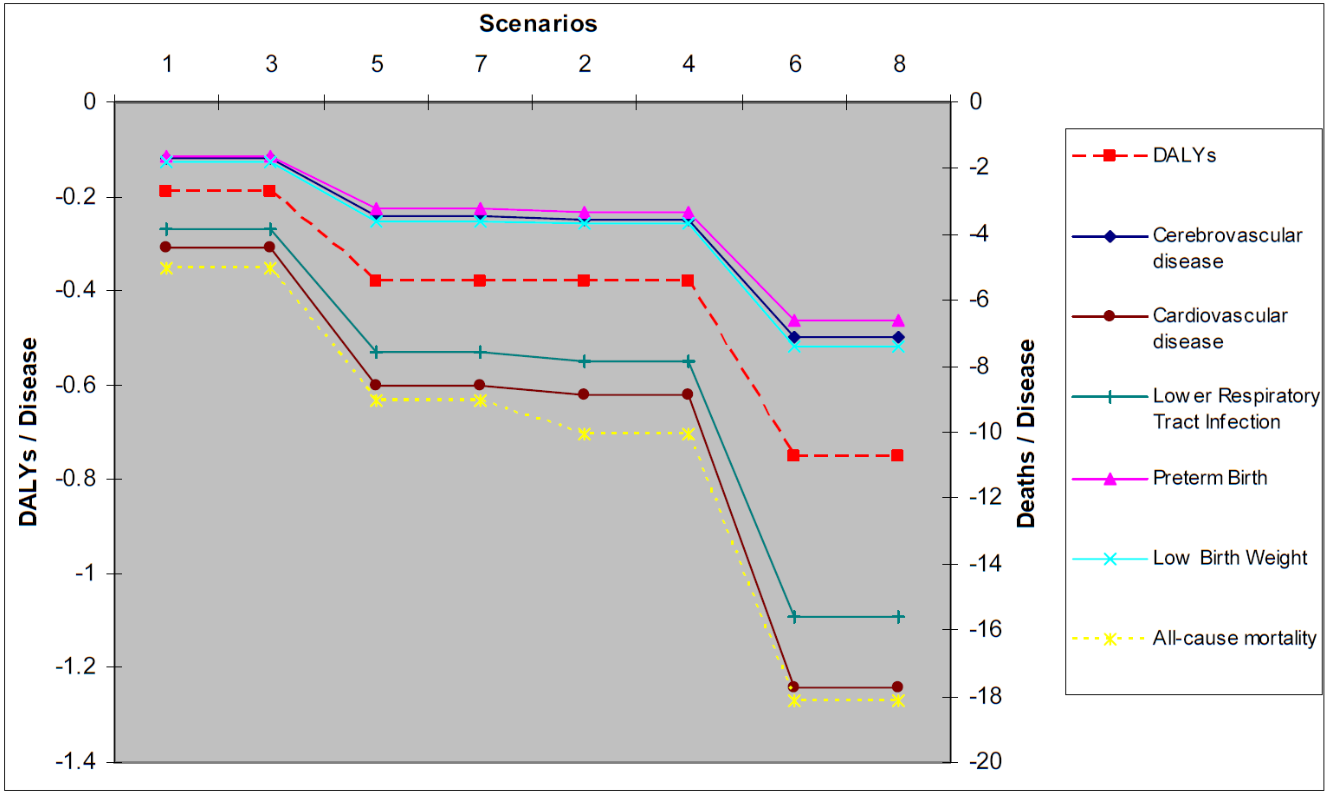


Figure 6. Number of deaths, disease cases and DALYs related to air pollution in each scenario (in general population).



Appendix (Paper 3)

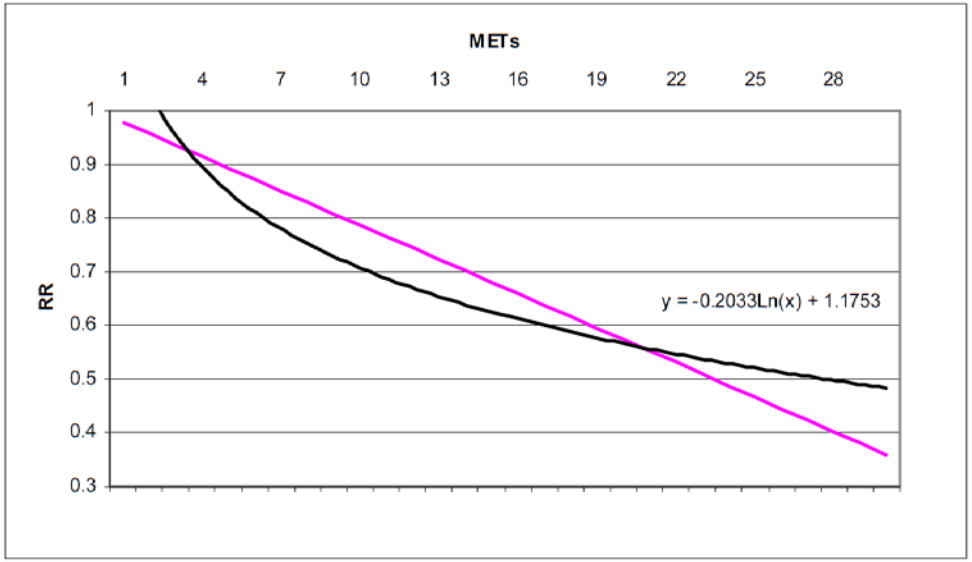
A. Sensitivity analyses.

Appendix-Table 1. Basal level of physical activity in Barcelona travelers, per age and sex.

	METs/h/w *	
Age	Men	Women
< 30 years	21.35	18.43
31-40	20.34	17.56
41-50	19.38	16.73
> 50 years	18.47	15.94

* METs/h/w : Metabolic equivalent task per hour per week.

Appendix-Figure 1. Dose response functions for physical activity and cardiovascular disease.



Blue line: linear dose response function

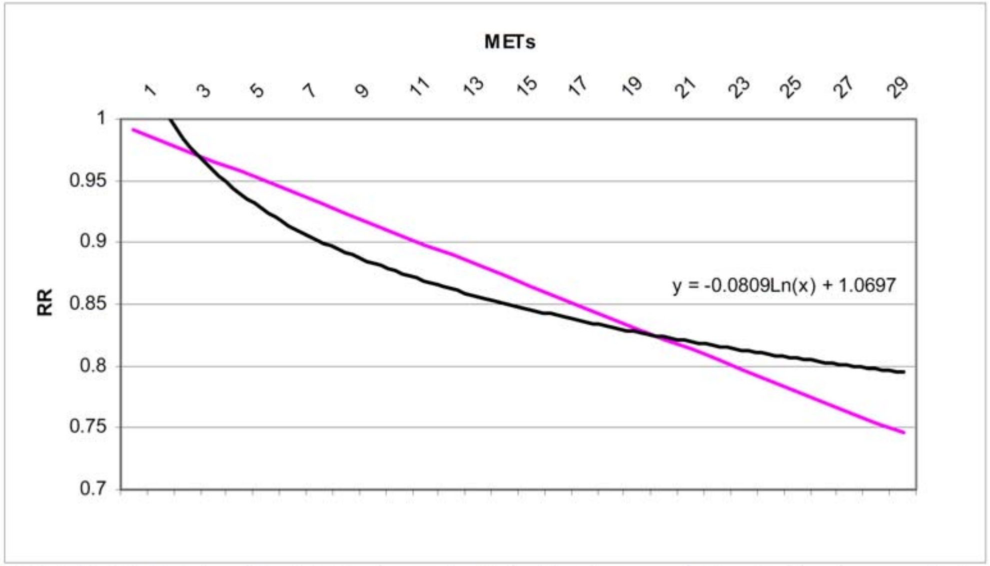
Black line: Curvilinear dose response function

RR: Relative risk; METs: Metabolic equivalent of task; Formula presented: y: RR of curvilinear dose response function; x: RR of linear dose response function.

5.1. PAPER 1

Rojas-Rueda D, de Nazelle A, Tainio M, Nieuwenhuijsen MJ. The health risks and benefits of cycling in urban environments compared with car use: health impact assessment study. ***BMJ.*** *2011;343:d4521*

Appendix-Figure 2. Dose response functions for physical activity and dementia.

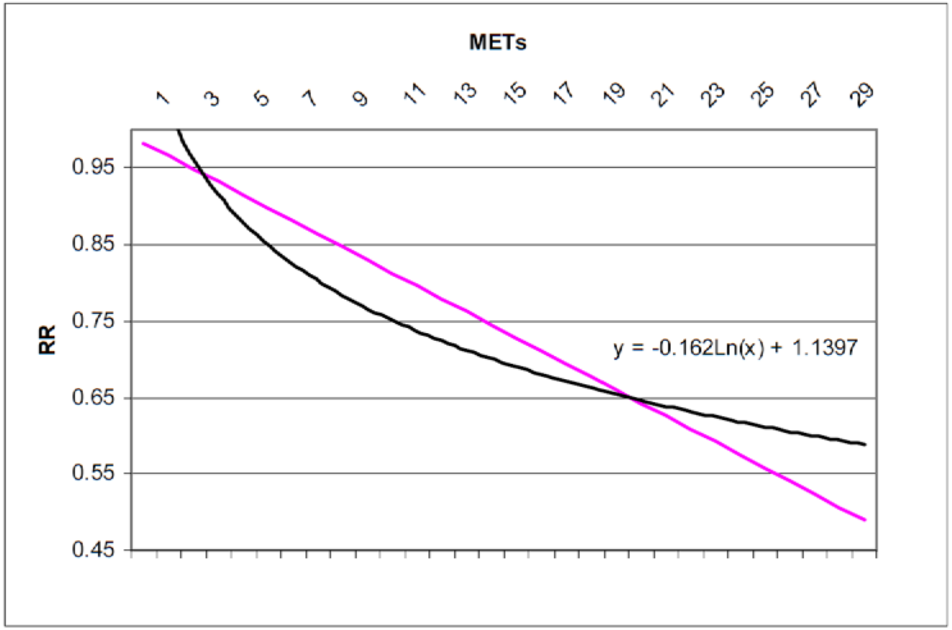


RR: Relative risk; METs: Metabolic equivalent of task; Formula presented: y: RR of curvilinear dose response function; x: RR of linear dose response function.

Blue line: linear dose response function

Black line: Curvilinear dose response function

Appendix-Figure 3. Dose response functions for physical activity and type 2 diabetes.

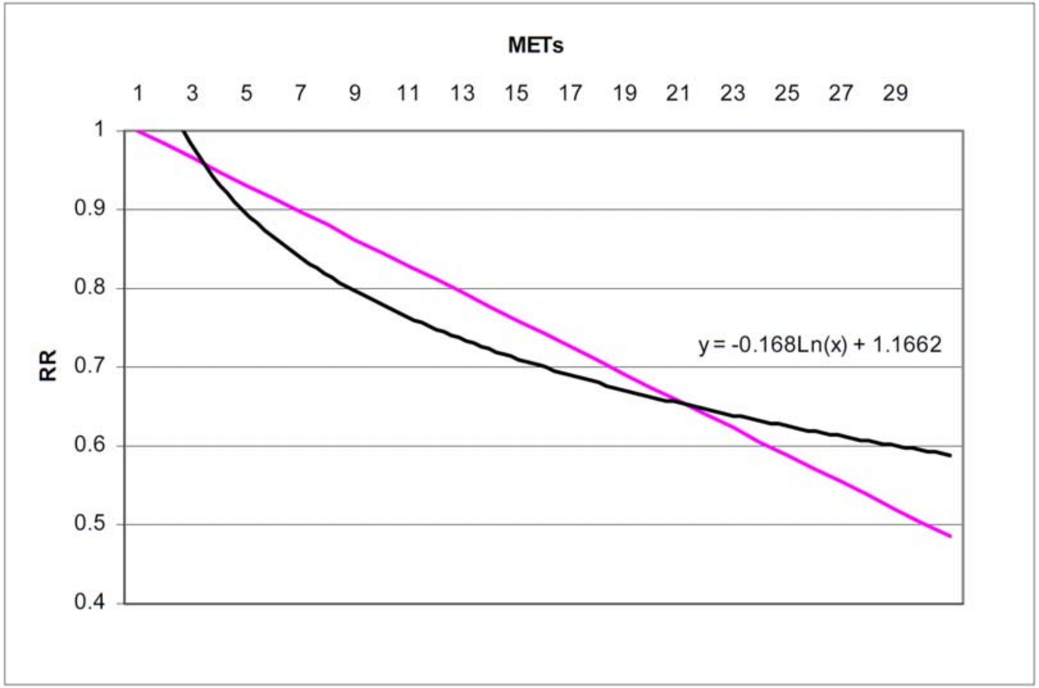


Blue line: linear dose response function

Black line: Curvilinear dose response function

RR: Relative risk; METs: Metabolic equivalent of task; Formula presented: y: RR of curvilinear dose response function; x: RR of linear dose response function.

Appendix-Figure 4. Dose response functions for physical activity and breast cancer in women.

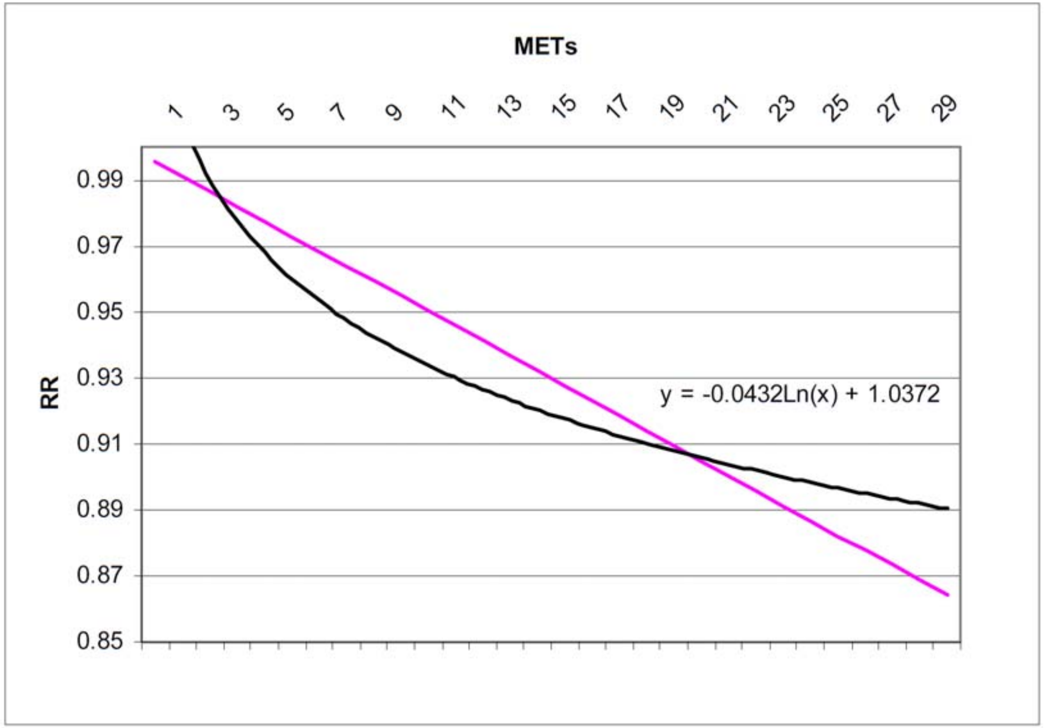


Blue line: linear dose response function

Black line: Curvilinear dose response function

RR: Relative risk; METs: Metabolic equivalent of task; Formula presented: y: RR of curvilinear dose response function; x: RR of linear dose response function.

Appendix-Figure 5. Dose response functions for physical activity and colon cancer in women.

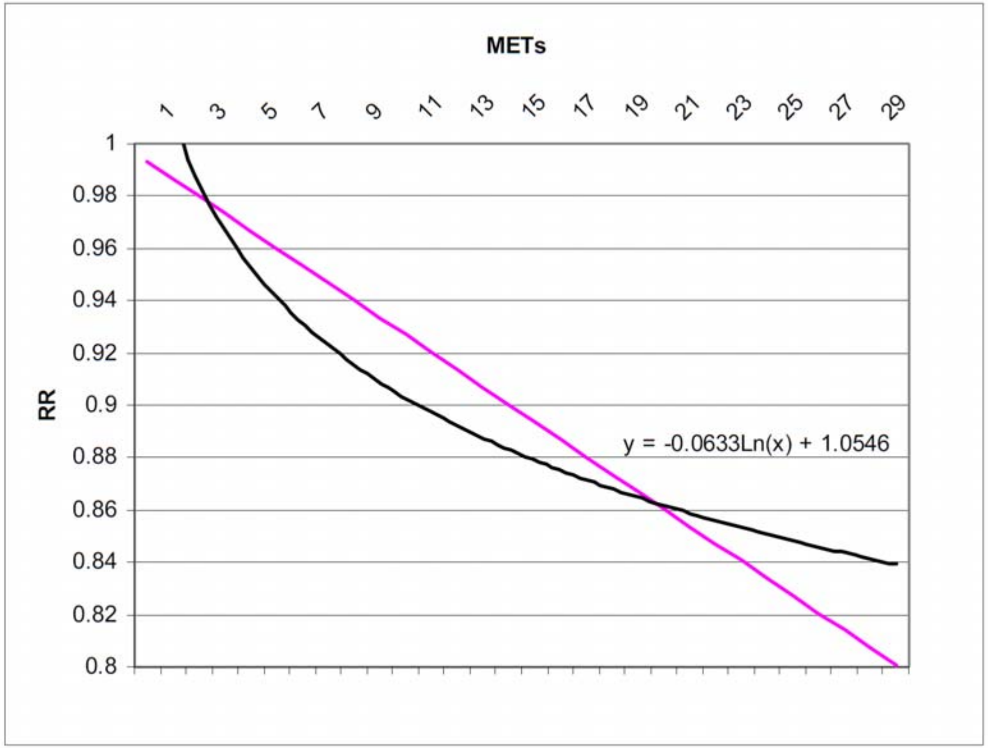


Blue line: linear dose response function

Black line: Curvilinear dose response function

RR: Relative risk; METs: Metabolic equivalent of task; Formula presented: y: RR of curvilinear dose response function; x: RR of linear dose response function.

Appendix-Figure 6. Dose response functions for physical activity and colon cancer in men.



Blue line: linear dose response function

Black line: Curvilinear dose response function

RR: Relative risk; METs: Metabolic equivalent of task; Formula presented: y: RR of curvilinear dose response function; x: RR of linear dose response function.

Appendix-Table 2. Cases of diseases related to physical activity, using a curvilinear dose response functions.

	Inside Barcelona Scenarios [a]				Outside Barcelona Scenarios [b]			
	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7	Scenario 8
Car trips reduction	20%	40%	20%[c]	40%[c]	20%[d]	40%[d]	20%[e]	40%[e]
Trips replaced by Bike (%)	100	100	50	50	0	0	20	20
Trips replaced by Public Transport (%)[f]	0	0	50	50	100	100	80	80
Physical activity (cases/year)								
Cardiovascular disease	-24.57	-49.14	-15.71	-31.43	-12.36	-24.72	-25.05	-50.10
Diabetes Mellitus 2	-80.86	-161.71	-50.73	-101.47	-37.17	-74.34	-73.86	-147.73
Breast Cancer	-6.91	-13.83	-4.34	-8.68	-3.19	-6.38	-6.32	-12.63
Colon Cancer	-2.21	-4.43	-1.43	-2.86	-1.16	-2.32	-2.04	-4.08
Dementia	-18.65	-37.30	-11.96	-23.92	-9.50	-19.00	-17.14	-34.28

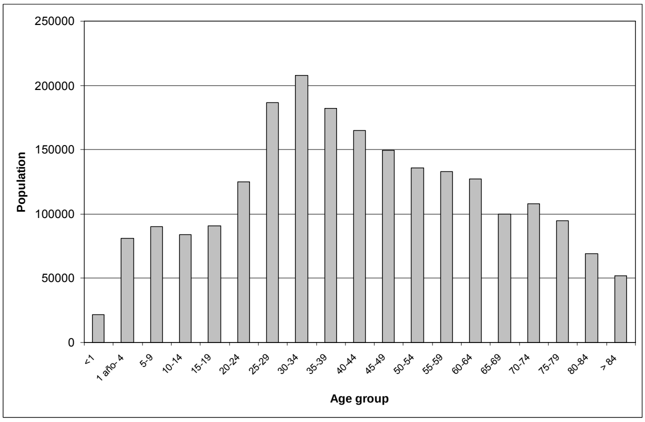
[a] Inside Barcelona Scenarios refers to the trips that start and ends in Barcelona city;
[b] Outside Barcelona Scenarios refers to the trips that starts or ends in Barcelona city and start or ends in Barcelona metropolitan area;
[c] Here we assumed the 50% of the trips was replaced by bike, the 22% by bus/tram and 28% are by metro/train;
[d] Here we assumed the 26% of the trips are replaced by bus/tram and 74% are by metro/train;
[e] Here we assumed the 20% of the trips are replaced by bike, the 21% by bus/tram and 59% are by metro/train;
[f] Public transport includes: Bus, Tram, Train and Metro.

Appendix-Table 3. Age scenarios for physical activity outcomes.

	Population distribution		
	Barcelona distribution[a]	**Younger population**	**Older population**
Average age	39	33	48
Scenario 2			
Cardiovascular disease	-30.33	-16.74	-52.23
Diabetes mellitus 2	-89.19	-50.79	-149.86
Breast cancer	-7.91	-5.40	-11.62
Colon cancer	-2.63	-1.51	-4.42
Scenario 6			
Cardiovascular disease	-24.08	-17.73	-55.33
Diabetes mellitus 2	-72.53	-42.49	-125.38
Breast cancer	-6.43	-4.39	-8.13
Colon cancer	-2.26	-1.33	-3.90

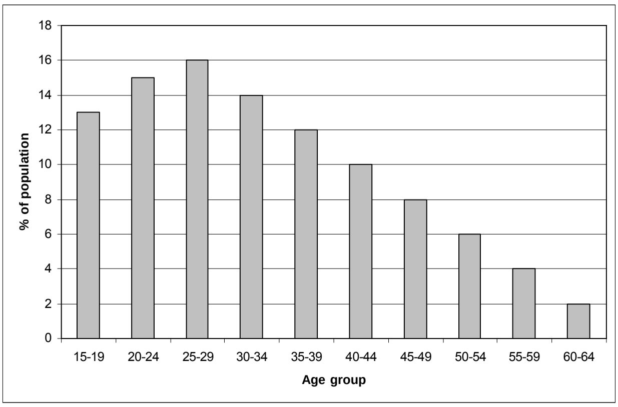
[a] Statistics and information service, Catalan government 2007.

Appendix-Figure 7. Distribution by age groups of Barcelona population*

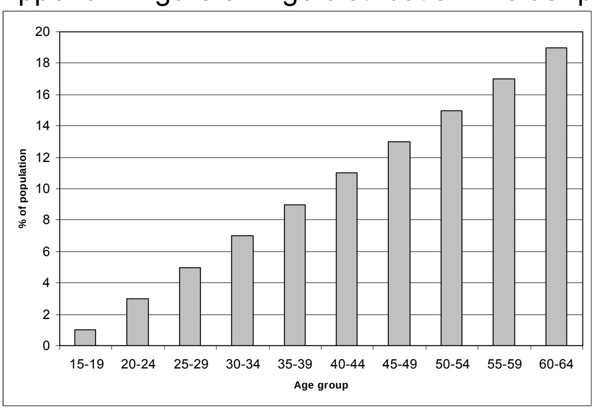


* Statistics and information service, Catalan government 2007.

Appendix-Figure 8. Age distribution in younger population scenario.



Appendix-Figure 9. Age distribution in older population scenario.



Appendix-Table 4. Particulate matter reduction Barcelona city related to each scenario.

Percentage of car trips reduction	PM 2.5 [a]	
	Reduction ($\mu g/m^3$) [b]	Percentage of reduction (%) [c]
Inside Barcelona [d]		
20%	0.07	0.32
40%	0.14	0.64
Outside Barcelona [e]		
20%	0.13	0.58
40%	0.26	1.16

[a] PM 2.5 = Particulate matter < 2.5 micrometers;
[b] Estimated by the Barcelona Air-Dispersion Model for PM 10, applying the ratio of 0.6 (PM2.5/PM10);
[c] Percentage of reduction with respect to the total concentration estimated by the Barcelona Air-Dispersion Model;
[d] Inside Barcelona refers to the trips that start and ends in Barcelona city;
[e] Outside Barcelona refers to the trips that starts or ends in Barcelona city and start or ends in Barcelona metropolitan area.

Appendix-Table 5. Injuries per billion of km traveled, by mode in Barcelona.

		Injuries / billion of km traveled
Minor injury		
	Bike	1469
	Bus	339
	Walk	783
	Car	2489
Major injury		
	Bike	51
	Bus	4
	Walk	69
	Car	26

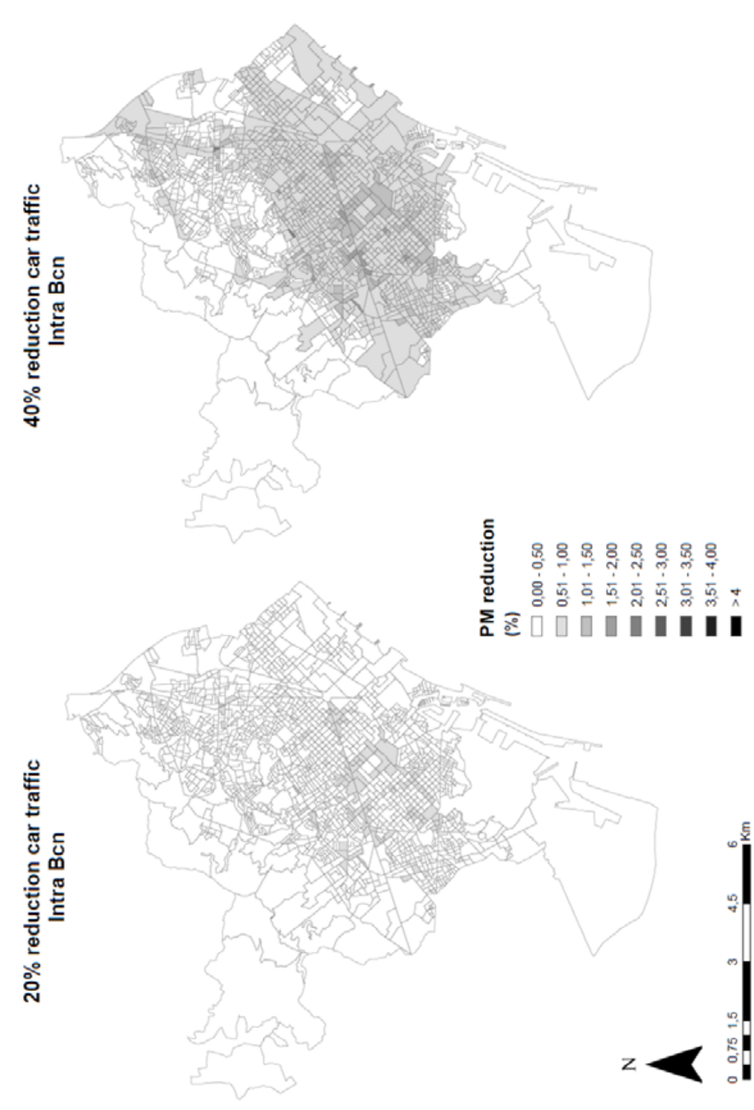
Km: kilometers.

Appendix-Table 6. Relative risk for traffic injuries, between cars and other modes of transport.

	Inside Barcelona Scenarios				Outside Barcelona Scenarios			
	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7	Scenario 8
Minor Injuries								
Car to bike	0.9993	0.9993	0.9982	0.9982	NA	NA	0.9944	0.9944
Car to PT	NA	NA	0.9979	0.9979	0.9944	0.9944	0.9948	0.9948
Major Injuries								
Car to bike	1.0005	1.0005	0.9998	0.9998	NA	NA	0.9987	0.9987
Car to PT	NA	NA	0.9996	0.9996	0.9987	0.9987	0.9988	0.9988

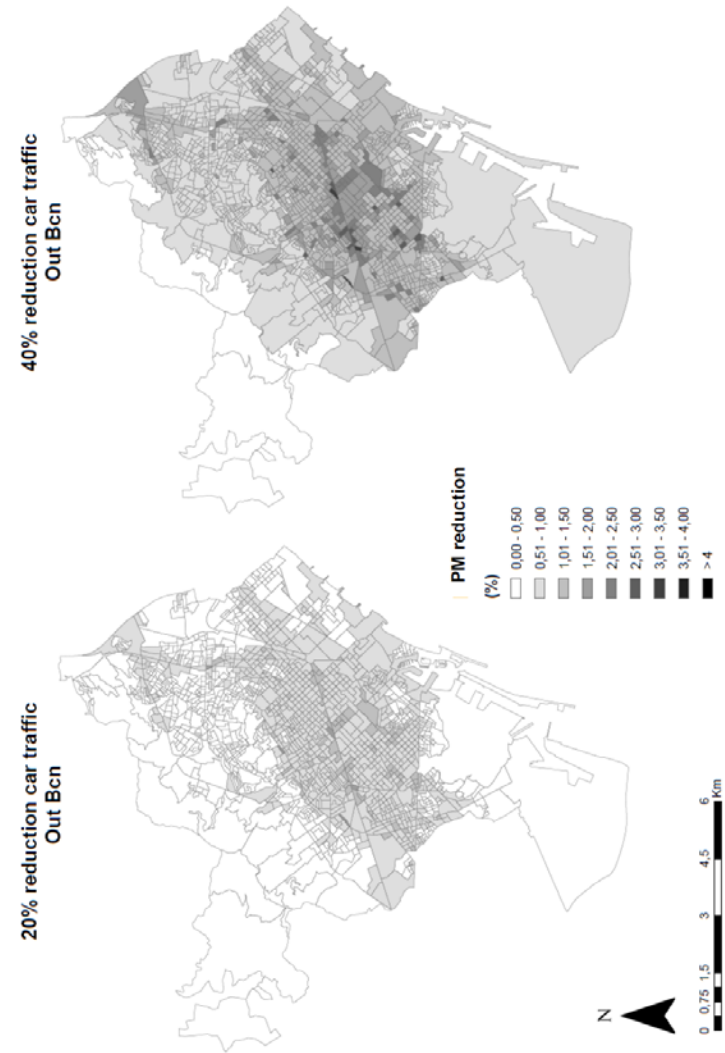
NA: not applicable.

Appendix-Figure 10. Reduction in PM for Inside Barcelona Scenarios.



* 20% reduction map corresponds to scenarios 1 or 3; 40% reduction map corresponds to scenarios 2 or 4; PM10: Particulate matter les than 10 micrometers; BCN: Barcelona

Appendix-Figure 11. Reduction in PM for scenarios outside Barcelona.



* 20% reduction map corresponds to scenarios 5 o 7; 40% reduction map corresponds to scenarios 6 or 8; PM10: Particulate matter les than 10 micrometers; BCN: Barcelona.

Appendix-Table 7. Injuries expected per scenario, adjusted by under-report correction factors.

	Inside Barcelona Scenarios [a]				Outside Barcelona Scenarios [b]			
	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7	Scenario 8
Car trips reduction	20%	40%	20%[c]	40%[c]	20%[d]	40%[d]	20%[e]	40%[e]
Trips/day replaced by Bike (%)	94,460 (100)	188,920 (100)	47,230 (50)	94,460 (50)	0	0	34,065 (20)	68,130 (20)
Trips/day replaced by Public Transport (%)[f]	0	0	47,230 (50)	94,460 (50)	170,324 (100)	340,648 (100)	136 259 (80)	272,518 (80)
Travelers								
Traffic injuries (cases/year)								
Minor Injuries [g]	-2.39	-4.78	-7.15	-14.30	-4.35	-8.69	-38.47	-76.94
Major injuries [h]	0.02	0.04	-0.02	-0.03	-0.04	-0.07	-0.14	-0.28
DALYs[i]	2.53	5.37	-0.34	-0.68	-30.96	-61.61	-22.55	-45.42

[a] Inside Barcelona Scenarios refers to the trips that start and ends in Barcelona city;
[b] Outside Barcelona Scenarios refers to the trips that starts or ends in Barcelona city and start or ends in Barcelona metropolitan area;
[c] Here we assumed the 50% of the trips was replaced by bike, the 22% by bus/tram and 28% are by metro/train;
[d] Here we assumed the 26% of the trips are replaced by bus/tram and 74% are by metro/train;
[e] Here we assumed the 20% of the trips are replaced by bike, the 21% by bus/tram and 59% are by metro/train;
[f] Public transport includes: Bus, Tram, Train and Metro.
[g] Minor Bike Injury Under-Report Correction Factor = 8 (Bickel, et al. 2006)
[h] Major Bike Injury Under-Report Correction Factor = 2.75 (Bickel, et al. 2006)
[i] DALY: Disability Adjusted Life-Years.

B. Literature Review

In the first screening, eligible articles were identified for further review by performing an initial screen of identified abstracts and titles. Articles were eliminated in this initial screen if they were not performed in humans and if they did not investigate the relation between the exposure and outcome variables mentioned previously. Studies that did not report original data or were duplicated publications were also excluded. Full-text of the remaining articles was retrieved and reviewed in a second screening. Articles were considered for inclusion in the second screening if they reported a measure of association between our exposure and outcome variables. Finally the studies that did not report dose response functions were excluded.

The seven selection criteria for the second screening were: 1) Priority is given to outcomes related to the 20 leading causes of death and the first 20 conditions that produced the highest burden of disease worldwide reported by the WHO **(WHO 2008) (see Appendix-Table 1)**; 2) Meta-analysis or, if none existed, cohort studies, case-control, time series or reports of expert panels; 3) Priority is given to studies with longer follow-up, recent publications and with greater number of subjects; 4) Priority is given to studies that have been used in other HIA, or in reference studies suggested by organizations such as WHO, Centers for Disease Control and Prevention (CDC), Health Effects Institute (HEI), etc; 5) Priority is given to studies which are within the "A" or "B" classification of causality reported by the Health Effects Institute (HEI) **(HEI 2010) (see Appendix-Table 2)**; 6) For epidemiological studies (except the meta-analysis) we applied the quality scale developed by Effective Public Health Practice Project **(Effective Public Health Practice Project 2008)** (Quality assessment tool for quantitative studies), we prioritize the studies that show a "moderate" or "strong" quality, according to this classification **(see Appendix-Table 3 and 4)**; 7) For the meta-analysis we apply the requirements of the PRISMA – statement (Preferred Reporting Items for Systematic reviews and Meta-Analyses) **(Moher et al. 2010;Moher et al. 2009)** to assess quality of meta-analyses. In addition, we manually reviewed the reference lists from relevant original articles, review articles and reports published by international institutions (reports of WHO, CDC, European Union, INTARESE project, HEIMSTA project, etc.).

We abstracted the articles that met the selection criteria. For data extraction, we developed a tool to collect the necessary information such as exposure variable, outcome, Relative risk (RR) or Odds ratio (OR), confidence intervals, unit of increase in exposure, population, type of study, date of publication, HEI classification, EPHPP rating, PRISMA rating, among others **(see Appendix-Table 5)**. Furthermore we apply an expert judgment derived for a series of expert groups meetings held in Barcelona between 2010 and 2012.

A.1. Search strategy

- Search strategy for exposure variables:

1. Search for Physical Activity: Active transportation OR transport OR walking OR walk OR cycling OR biking OR

bicycling OR bike OR physical activity OR motor activity OR Commuting OR "Walking"[Mesh] OR "Bicycling"[Mesh] OR "Motor Activity"[Mesh] OR "Transportation"[Mesh]

2. Search for Air pollution: air pollution OR particulate matter OR PM10 OR PM2.5 OR UFP OR NO2 OR nitrogen dioxide OR NOx OR nitrogen oxides OR ozone OR Black carbon OR Black smoke OR Soot OR Smoke OR "Air Pollution"[Mesh] OR "Particulate Matter"[Mesh] OR "Soot"[Mesh] OR "Smoke"[Mesh] OR "Nitrogen Dioxide"[Mesh] OR "Nitrogen Oxides"[Mesh] OR "Ozone"[Mesh]

- Search strategy for 20 leading causes of burden of disease and 20 leading causes of death, reported by WHO:

((((((((((((((((((((((((Colon cancer OR Rectum Cancer OR "Colorectal Neoplasms"[Mesh] OR "Colonic Neoplasms"[Mesh] OR "Rectal Neoplasms"[Mesh]) OR (Nephritis OR "Nephritis"[Mesh]) OR Nephrosis OR "Nephrosis"[Mesh])) OR (Cirrhosis of the liver OR "Liver Cirrhosis"[Mesh])) OR (gastric cancer OR stomach cancer OR "Stomach Neoplasms"[Mesh]]) OR (Hypertensive heart disease OR "Hypertension"[Mesh] OR high blood pressure) OR ("Lung Neoplasms"[Mesh] OR Lung cancer) OR "Carcinoma, Bronchogenic"[Mesh] OR bronchus cancer OR Tracheal cancer OR Trachea cancer) OR (Violence OR "Violence"[Mesh])) OR (Alcohol use disorders OR Alcohol abuse disorders OR "Alcohol-

Induced Disorders, Nervous System"[Mesh])) OR (Congenital anomalies OR "Congenital Abnormalities"[Mesh])) OR (Hearing loss, adult onset OR "Hearing Loss"[Mesh])) OR (refractive errors OR "Refractive Errors"[Mesh])) OR (Unipolar depressive disorders OR "Depressive Disorder"[Mesh])) OR (self inflicted injuries OR ((self inflicted injury OR "Self Mutilation"[Mesh]) OR Suicide OR "Suicide"[Mesh]) OR "Suicide, Attempted"[Mesh])) OR (Birth asphyxia OR "Asphyxia Neonatorum"[Mesh])) OR (Malaria OR "Malaria"[Mesh])) OR (Neonatal infections))) OR (Tuberculosis OR "Tuberculosis"[Mesh])) OR ((AIDS OR "Acquired Immunodeficiency Syndrome"[Mesh]) OR "HIV"[Mesh] OR "HIV Seropositivity"[Mesh])) OR (diarrhoeal diseases OR diarrheal diseases OR "Dysentery"[Mesh]) OR ((Diabetes) OR "Diabetes Mellitus"[Mesh])) AND (prematurity OR "Infant, Premature"[Mesh] OR low birth weight OR "Infant, Low Birth Weight"[Mesh] OR "Infant, Very Low Birth Weight"[Mesh] OR "Infant, Extremely Low Birth Weight"[Mesh])) OR (Emphysema OR "Emphysema"[Mesh] OR "Pulmonary Emphysema"[Mesh] OR Chronic bronchitis OR "Bronchitis, Chronic"[Mesh] OR COPD OR "Pulmonary Disease, Chronic Obstructive"[Mesh]) OR (lower respiratory infections OR "Respiratory Tract Infections"[Mesh])) OR (Cerebrovascular disease OR "Cerebrovascular Disorders"[Mesh] OR "Basal Ganglia Cerebrovascular Disease"[Mesh])) OR (Ischemic heart disease OR "Myocardial Ischemia"[Mesh] OR "Coronary Artery Disease"[Mesh])))

- Search strategy for types of studies:

(Dose-response OR exposure-response OR epidemiological studies OR cohort studies OR case-controls studies OR time series studies OR meta-analysis OR review OR systematic review OR expert panel OR report OR technical report OR Clinical trial OR Multicenter Studies OR "Epidemiologic Studies"[Mesh]) OR "Cohort Studies"[Mesh] OR "Case-Control Studies"[Mesh] OR "Meta-Analysis" [Publication Type] OR "Review" [Publication Type] OR "Research Report"[Mesh] OR "Technical Report" [Publication Type] OR "Multicenter Study" [Publication Type] OR "Clinical Trial" [Publication Type] OR "Consensus Development Conference" [Publication Type] Limits:Humans) OR Risk assessment OR Health impact assessment

A.2. Data extraction

For data extraction, we developed a tool to collect the necessary information such as, exposure variable, outcome, RR/ OR, confidence intervals, unit of increase in exposure, population, type of study, date of publication, HEI classification, EPHPP rating, PRISMA rating, among others (see Appendix-Table 6).

Appendix -Table 8. 20 leading causes of death and 20 leading causes of burden of disease, reported by World Health Organization in 2004.

	Leading causes of death, all ages, 2004			Leading causes of Burden of disease (DALYs), all ages, 2004		
	Disease or Injury	Deaths (millions)	Per cent of Total deaths	Disease or Injury	DALYs (millions)	Per cent of Total DALYs
1	Ischemic heart disease	7.2	12.2	Lower respiratory infections	94.5	6.2
2	Cerebrovascular disease	5.7	9.7	Diarrheal diseases	72.8	4.8
3	Lower respiratory infections	4.2	7.1	Unipolar depressive disorders	65.5	4.3
4	COPD	3.0	5.1	Ischemic heart disease	62.6	4.1
5	Diarrheal diseases	2.2	3.7	HIV/AIDS	58.5	3.8
6	HIV/AIDS	2.0	3.5	Cerebrovascular disease	46.6	3.1
7	Tuberculosis	1.5	2.5	Prematurity and low birth weight	44.3	2.9
8	Trachea, bronchus, lung cancers	1.3	2.3	Birth asphgyxia and birth trauma	41.7	2.7
9	Road traffic accidents	1.3	2.2	Road traffic accidents	41.2	2.7
10	Prematurity and low birth weight	1.2	2.0	Neonatal infections and other[c]	40.4	2.7
11	Neonatal infections[a]	1.1	1.9	Tuberculosis	34.2	2.2
12	Diabetes mellitus	1.1	1.9	Malaria	34.0	2.2
13	Hypertensive heart disease	1.0	1.7	COPD	30.2	2.0
14	Malaria	0.9	1.5	Refractive errors	27.7	1.8
15	Birth asphyxia and birth trauma	0.9	1.5	Hearing loss, adult onset	27.4	1.8
16	Self-inflicted injuries[b]	0.8	1.4	Congenital anomalies	25.3	1.7
17	Stomach cancer	0.8	1.4	Alcohol use disorders	23.7	1.6
18	Cirrhosis of the liver	0.8	1.3	Violence	21.7	1.4
19	Nephritis and nephrosis	0.7	1.3	Diabetes mellitus	19.7	1.3
20	Colon and rectum cancer	0.6	1.1	Self-inflicted injuries	19.6	1.3

[a] This category also includes other non-infectious causes arising in the perinatal period, apart from prematurity, low birth weight, birth trauma and asphyxia. These non-infectious causes are responsible for about 20% of deaths shown in this category. [b] Self-inflicted injuries resulting in death can also be referred to as suicides. [c] This category also includes other non-infectious causes arising in the perinatal period apart from prematurity, low birth weight, birth trauma and asphyxia. These non-infectious causes are responsible for about 20% of DALYs shown in this category. COPD: Chronic Obstructive Pulmonary Disease; DALYs: Disability Adjusted Life Years; HIV/AIDS: Human Immunodeficiency Virus / Acquired Immunodeficiency Syndrome. Reference: World Health Organization. The Global Burden of Disease: 2004 Update. 2008, Switzerland.

Appendix-Table 9. Health Effects Institute (HEI) classification of health effects of traffic-related air pollution.

HEI* Classification	
A	Sufficient evidence to infer the presence of causal association
B	Suggestive but not sufficient evidence to infer the presence of causal association
C	Inadequate and Insufficient evidence to infer the presence or absence of a causal association
D	Evidence suggestive of no causal association

* HEI: Health Effects Institute

Appendix-Table 10. EPHPP quality assessment tool, components rating.

		Rate		
	Component rating	1	2	3
A	Selection Bias	Strong	Moderate	Weak
B	Study design	Strong	Moderate	Weak
C	Confounders	Strong	Moderate	Weak
D	Blinding	Strong	Moderate	Weak
E	Data collection method	Strong	Moderate	Weak
F	Withdrawals and dropouts	Strong	Moderate	Weak

EPHPP: Effective Public Health Practice Project

Appendix-Table 11. EPHPP quality assessment tool, global rating.

EPHPP* Quality assessment	
Strong	No weak component rating
Moderate	One weak component rating
Weak	Two or more weak component ratings

* EPHPP: Effective Public Health Practice Project

Appendix-Table 12. Data extraction tool.

ID	Variable	Exposure	Specification	Outcome	RR / OR	LCI	UCI	Unit	Exposure	Population	Intra or extra city (comparison)
1	Air Pollution										
2	Air Pollution										
3	Air Pollution										
4	Physical Acrivity										
5	Physical Acrivity										
6	Physical Acrivity										

Type of study	Comment	Year of publication	Reference	Referred for other studies	HEI Classification	EPHPP Quality	PRISMA*	Causes of death 2004	Causes of Burden of disease (DALYs) 2004

RR: Relative risk; OR: Odds ratio; LCI: Lower confidence interval; UCI: Upper confidence interval; EPHPP: Effective Public Health Practice Project; PRISMA: Preferred Reporting Items for Systematic reviews and Meta-Analyses; DALYs: Disability Adjusted Life Years.

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5.4 PAPER 4

Substitution of car trips by active transport in 6 European cities: A health impact assessment study.

Rojas-Rueda D, de Nazelle A, Nieuwenhuijsen M, Andersen Z, Braun-Fahrlander C, Bruha J, Bruhova-Foltynova H, Desqueyroux H, Nassif H, Praznoczy C, Rabl A, Ragettli M, Tainio M, Toussaint J.

Manuscript

SUBSTITUTION OF CAR TRIPS BY ACTIVE TRANSPORT IN 6 EUROPEAN CITIES: A HEALTH IMPACT ASSESSMENT STUDY.

Rojas-Rueda D [a,b,c,d], de Nazelle A [e], Nieuwenhuijsen M [a,b,c,d], Andersen Z [f], Braun-Fahrlander C [g], Bruha J [h], Bruhova-Foltynova H [h], Desqueyroux H [i], Nassif H [j], Praznoczy C [k], Rabl A [l], Ragettli M [g], Tainio M [m], Toussaint J [j].

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Key words: Walking, Bicycling, Public transport, Air Pollution, Physical activity, Road traffic fatality, Health impact assessment.

Abstract

Objective: Assess the health risks and benefits of promoting active transport modes (walking, bicycling and public transport), in six European cities.

Methods: We conducted a Health impact assessment (HIA), creating 4 different scenarios on the increase of public transport, pedestrians or bike trips and reduction of car trips. The primary outcome measure was all-cause mortality related to the exposure of travelers to physical activity, air pollution to particulate matter <2.5 μm (PM2.5), and road traffic fatality. The secondary outcome was a change in emissions of carbon dioxide.

Results: Among the different scenarios analyzed, the 50% reduction in car use is the one that produced higher profits in the six cities analyzed. The numbers of deaths avoided related with this scenario were in Prague 18.84, Paris 12.84, Basel 10.66, Warsaw 10.37, Copenhagen 8.51 and Barcelona 7.22. The scenario that consider an increase in bike trips in 35% of all trips also produced great health benefits, but only in 4 cities (50 deaths avoided in Prague, 32 Warsaw, 24 Barcelona and 5 Basel). In Paris this scenario produced an increase in the estimated annual number of deaths (18 deaths), due to the increase in projected traffic accidents in Paris by increasing the use of bicycles. The scenarios can avoid between 870 to 189,779 (ton/ year) of CO_2 emissions in our six cities.

Conclusions: Interventions to reducing car use in European cities can produce health benefits for travelers. Also these interventions help to reduce green house gas emissions

1. Introduction

Motorized transport is a major source of environmental and noise pollution in urban areas (Schwela D et al. 2008). About 70% of environmental pollution and 40% of greenhouse gases in European cities come from motorized transport (European Environment Agency 2010;European Environment Agency 2010). Multiple programs of international organizations such as United Nations Environmental Program (UNEP), European Environmental Agency (EEA) and the United States Environmental Protection Agency (US EPA) have proposed changes in transport policies to encourage non-motorized transport (walking and cycling) and public transport in the cities (European Environment Agency 2010;UNEP 2010;EPA 2011).

Active transportation policies which encourage the use of public transport, walking and cycling in cities can bring not only environmental benefits such as reducing air pollution emissions, but also important health co-benefits, in particular through an increase in physical activity or. Physical inactivity and air pollution have been classified as two of the 10 leading risk factors of burden of disease worldwide in 2010 (Lim et al. 2013).

Previous studies have quantified the health benefits of replacing the car trips by public transport and bicycle trips in urban areas (Rojas-Rueda et al. 2011;De Hartog et al. 2010a;Lindsay et al. 2011;Rabl and de Nazelle A 2012;Rojas-Rueda et al. 2012). These health benefits have been attributed mainly to increased levels of physical activity. Also the economic and health benefits of the use of public transport have been estimated in previous studies, related not only in terms of increased physical activity, but also with a reduction of road traffic fatalities and crime (Litman T 2010;Stokes et al. 2008;Edwards 2008).

To date there no published studies that has compared the impact of similar active transport policies between different cities. The aim of our study is to perform for the first time an health impacts assessment of four different scenarios (active transport policies) which increase active transportation modes and reduce car use and estimated the health impacts of theses scenarios in six different European cities (Barcelona, Basel, Copenhagen, Paris, Prague and Warsaw). We also estimated the greenhouse gas emissions avoided with these scenarios.

2. Methods

2.1. Scenarios

The active transport scenarios used in the 6 cities are presented in Table 1, and were compared to the business as usual (BAU) scenario for each city. The four scenarios developed included various hypotheses: A.1) achieve the levels of cycling of the city of Copenhagen (35% of all trips in the city are made by bicycle); A.2) achieve the levels of walking of the city of Paris (50% of all trips in the city are made walked); B.1) reduction of 20% of car trips (and its replacement by active transport modes and public transport); and B.2) reduction of 50% of car trips (and its replacement by active transport modes and public transport).

2.2. Framework

The conceptual framework for assessing health impacts in travelers is shown in Figure 1. We used a health impact assessment framework as published by Joffe and Mendell (Joffe and Mindell 2002)*,* to estimate the health effects of mode shifts in our scenarios. Exposure-response functions were derived from existing studies and calibrated for current exposure and health conditions in each of our six cities. We modeled all-cause mortality effects due to physical activity behavior, road traffic fatality, and exposure to air pollution. These three health determinants were expected to have the greatest impact and best available data, based on discussions held amongst experts during a workshop in Barcelona in 2009 (de Nazelle et al., 2011b). Recent publications of HEAT for walking and for cycling (Kahlmeier S et al. 2011), Woodcock et al. (Woodcock et al. 2009), de Hartog et al. (De Hartog et al. 2010b) and Rojas-Rueda et al. (Rojas-Rueda et al. 2011;Rojas-Rueda et al. 2012) provided further guidance to our approach.

We focused the health impacts analysis on city residents who started walking, cycling or travelling in public transport as a result of the mode shift. In other words we assessed incremental benefits from physical activity and risks due to increased air pollution inhalation and increased/reduction in exposure to road traffic fatality of new pedestrians, new public transport passengers and new cyclist, compared to previous exposures. We focused on the age group 16 to 64 because we expected them to conduct the majority of trips and travel regularly to work or study.

2.3. Data modelling

2.3.1. Transport data

Main input data used in the model are summarized in Table 2. Transportation data were obtained from a combination of data provided by travel surveys and records reported by transportation departments of each city, local governments and intergovernmental institutions. We assumed that the trips were replaced by pedestrians, cyclist or public transport trips of the same length. We include within public transport trips the metro, train, bus and tram trips, depending on the city.

2.3.2. Road traffic fatality

We calculate in each city the road traffic fatalities per billion kilometers travelled by mode of transport from estimates of the total distance traveled annually by mode of transport which we linked to traffic mortality data by mode reported by each city. We assumed that every public transport trip involves 10 minutes walking. Therefore the risk of suffering a road traffic fatality as a pedestrian (10 minutes walking) was estimated and integrated in the risk of public transport. We then calculated the relative risk (RR) of all-cause mortality of road traffic fatality for each mode compared with the corresponding mode transport substituted, assuming the same distance traveled for each mode.

2.3.3. Physical activity

To assess levels of physical activity it was assumed that for each public transport trip the traveler walked for 10 minutes. For cycling or walking trips, trip duration depended on the average distance traveled in each city. The relative risk (RR) function used to estimate the number of cases of death expected in each scenario and city associated with physical activity was a curvilinear dose response function for physical activity and all-cause mortality derived from a meta-analysis (Woodcock et al. 2010). We estimated the health impacts of increased physical activity by active transport taking into account baseline levels of physical activity adjusted for sex and age (see Appendix), which we obtained from an active transport survey conducted in Barcelona (Donaire-Gonzalez D et al. 2013) and which we used as a reference for all cities.

2.3.4. Air pollution exposure

The air pollution assessment model considered the exposure to particulate matter less than 2.5μm (PM2.5), which has shown strong associations with all-cause mortality (Krewski et al. 2009). We compared exposure concentrations and inhaled dose for travel by car, bicycle, walk and public transport. Concentration levels for car, bike, walk and bus were obtained from measurement studies conducted in Barcelona (de Nazelle A et al. 2010) and Paris (INERIS 2009). For other cities we used a ratio between the average annual concentration of PM2.5 in each city and the expected concentration in each mode of transport using as reference the cities of Paris and Barcelona. We assumed that the relative concentrations between modes collected during the study were representative of year-round average relative concentrations. We assumed that all public transport trips included a 10 minute walk in the street, for which we also estimated corresponding exposure concentrations. We estimated yearly inhaled dose of PM2.5 accounting for mode-specific inhalation rates, exposures, and trip duration, as in de Nazelle et al (de Nazelle et al. 2009). To simplify, non-travel times were assumed to be spent resting and sleeping while exposed to outdoor concentration levels of PM2.5. To estimate the RR of mortality associated with the increment of pollutant intake for travelers who walk, cycling and use public transport compared to car users, as in de Hartoge et al (2010) we applied the ratio between the estimated inhaled dose for active transportation travelers and for car users to exposure-response function reported in the literature. We used the PM2.5 RR function from the ACS study (Pope, III et al. 2002) updated by Krewski et al. (2009) .

2.3.5. Mortality rates

We estimated the population attributable number of deaths for each scenario using the classic steps of health impact assessments as reported by Perez and Kunzli (2009) and the World Health Organization (2008). We applied the RR functions from the three domains to city-specific all-cause mortality rates for the population between 16 and 64 years old (Table 2).

2.3.6. CO_2 emissions

CO_2 emissions savings estimates were calculated taking into account emission factors (kg of CO2/ litter of fuel) provided by each city and calibrated to the characteristics of vehicle fleet (number of vehicles using diesel or gasoline and engine efficiency) in each city (see appendix).

2.4. Model

The different model parts of health impacts assessment outlined above were linked together in a quantitative model built in Analytica

4.2 (Lumina Decisions Systems, CA, 2010) Monte Carlo simulation program. The main model employed average values for all inputs described previously.

We carried out a sensitivity analysis testing the impact of using alternative values for the input variables in a Monte Carlo simulation. The sensitivity analysis was meant to 1) assess the stability of our results when employing a range of possible input values, 2) provide a range of likely outcomes as a simple form of uncertainty and variability analysis, and 3) identify which inputs are most influential in determining the outcomes. The range of values included for each tested variable depended on the type of information available on the probability distribution for each variable. When the data was available, the mean and standard deviation were used to create normal distribution. If data was not available or the source of data did not include information from distribution parameters, we used triangular distributions. If it was possible to select a minimum and maximum from the data or by comparing the results of different datasets, we chose a triangular distribution with a maximum and minimum based on the data. For input variables without any other information than mean, we assumed the triangular distribution with minimum and maximum values 50% around the mean value. This uncertainty range was chosen to avoid underestimation of the uncertainty. We identified input variables of highest importance by calculating rank-order correlations between each variable and the model outcome.

3. Results

3.1. Barcelona

The scenario for which most deaths were avoided in Barcelona was scenario A.1 (35% of all trips in the city made by bicycle) with 24.85 deaths avoided per year (Table 3). Most of the benefits from scenario A.1 come from physical activity (23.57 deaths avoided) and to a lesser extent by the reduction of fatal accidents (3.55 deaths avoided per year) (see appendix). In this scenario the increase in PM2.5 inhalation causes an increase in the expected deaths of 2.28 deaths per year (see appendix).

3.2. Basel

The scenario that produced greatest health benefits for Basel is scenario B.2 (reduction of 50% of car trips) with 10.66 deaths avoided per year (Table 3). Most of the benefits from scenario B.2 come from physical activity (11.39 deaths avoided) (see appendix). In this scenario, the PM2.5 inhalation causes an increase in the expected deaths by 0.32 deaths per year and fatal accidents increase the expected deaths by 0.41 deaths per year (see appendix).

3.3. Copenhagen

The scenario that produces greatest health benefits for Copenhagen is scenario B.2 (reduction of 50% of car trips) with 8.51 deaths avoided per year (Table 3). Most of the benefits from scenario B.2 are associated with the effect of physical activity (8.18 deaths avoided) and to a lesser extent by the reduction of fatal accidents (0.47 deaths avoided per year) (see appendix). The inhalation of PM2.5 in this scenario causes an increase in the expected deaths of 0.14 deaths per year (see appendix).

3.4. Paris

The scenario that produces greatest health benefits in Paris is scenario B.2 (reduction of 50% of car trips) with 12.84 deaths avoided per year (Table 3). Most of the benefits from scenario B.2 come from physical activity (16.44 deaths avoided) (see appendix). In this scenario the PM2.5 inhalation causes an increase in the expected deaths of 1.31 deaths per year and fatal accidents increase the expected deaths by 2.30 deaths per year (see appendix).

3.5. Prague

The scenario for which most deaths were avoided in Prague was scenario A.1 (35% of all trips in the city made by bicycle) with 50.37 deaths avoided per year (Table 3). Most of the benefits from scenario A.1 come from physical activity (63.77 deaths avoided) (see appendix). In this scenario the air pollution causes an increase in the expected deaths of 2.58 deaths per year and fatal accidents increase the expected deaths by 19.17 deaths per year (see appendix).

3.6. Warsaw

The scenario for which most deaths were avoided in Warsaw was scenario A.1 (35% of all trips in the city made by bicycle) with 32.41 deaths avoided per year (Table 3). Most of the benefits from scenario A.1 come from physical activity (20.12 deaths avoided) and to a lesser extent by the reduction of fatal accidents (16.50 deaths avoided per year) (see appendix). In this scenario the air pollution inhalation causes an increase in the expected deaths of 4.22 deaths per year (see appendix).

3.7. CO_2

The maximum annual reduction in carbon dioxide emissions for the six cities was found for scenario B.2 (50% of car trips reduction) with reductions between 34,751 to 189,779 tons/year (see Table 4). The rest of the scenarios produced a reduction in CO2 emissions from 870 to 75.912 tons/year (see Table 4).

4. Discussion

Our results show that the same policy targets to promote active transport, may produce different health benefits among the six studied cities. Cities like Barcelona, Prague or Warsaw would benefit most by the implementation of active transportation policies that favor the use of bicycles (Table 3). On the other hand in Paris this same intervention would not produce net health benefits, but rather would increase the risks. This is explained by the increase of the fatal accidents in bike in Paris (see appendix). For Basel, Copenhaguen and Paris, the scenario that most health benefit provided, was the scenario addressed to the reduction of 50% of car trips (Table 3).

Within this panorama of results, it is important to emphasize that the implementation of policies of active transportation, aimed at improving the health of the population, should take into account the characteristics of the city and may not be generalisable. Cities where accident rates on bicycles far exceeds that of cars, a policy that encourages only the bicycle (without addressing cycling safety) will not produce the expected health benefits and will require choosing other strategies such as reducing car trips stimulated the use of public transportation, as is the case of Paris.

On the other hand we also have cities like Warsaw, which despite their high accident rates, the benefits of implementing policies favoring the bicycle can produce more positive health impacts than policies aimed to reduce car trips. This happens in Warsaw for two main reasons 1) the bicycle trips rates are very low, and when increasing bicycle trips to Copenhagen levels, the levels of physical activity in the population increase significantly, and this produce largers health benefits; and 2) when walking trips are substituted by bicycle, the high risk of suffering a fatal accident as a pedestrian (271.91 deaths per billion km traveled) diminished when using a safer mode of transport such as bicycles (91.79 deaths mileage per billion) in Warsaw (Table 2).

As in all risk assessments, our study was limited by the availability of data and the necessity to make assumptions to model likely scenarios. For this reason, sensitivity analyses were performed to assess the robustness of our results and to test effects of deviations from the main assumptions and data choices. A strength of our study is the use of curvilinear dose-response functions (between physical activity and all-cause mortality) and taking in consideration the basal levels of physical activity among travelers (Sattelmair et al. 2011;Woodcock et al. 2010). These are two determining factors in the magnitude of our results. When comparing our results with the results of other studies, the magnitude of our results (deaths avoided) are much lower, this is because we do not use a linear dose-response function between physical activity and all-cause mortality. Our analysis also takes into consideration the basal levels of physical activity among travelers, above which the benefits of physical activity increase in smaller magnitude (see appendix).

Our study compares identical interventions in different European cities. The results show that there is a big difference even between cities within Europe. Furthermore our scenarios include assumptions about the distribution and travel substitution, but these assumptions are applied equally to all cities. We have designed these scenarios taking into consideration that travel substitution nearest to reality will be made primarily by public transport to a lesser extent for cycling and walking (Table 1).

As noted in other studies, our results also confirm that the impact of air pollution is much lower compared to the benefits of physical activity, and is the less influential factor in our model (see appendix).

Unlike other studies, which report their results quantifying morbidity and mortality, we only focus on mortality. We chose all cause mortality as our main outcome to provide the most robust results possible, given the strongest evidence found in the epidemiological literature for that outcome. Also a previous study (Rojas-Rueda et al. 2013) show that an estimation of all-cause mortality can be a reasonable indicator for the disease impacts in health impact assessment models of transportation

We run a sensitivity analysis taking into account "safety in numbers" effect by modeling decreasing relative risks of a traffic accidents on a bicycle as cycling increases. With this analysis, our scenarios where there is increased number of bike trips, we found a greater reduction in the number of annual deaths. And this is especially important for scenario A.1 where in the example of the city of Paris in the main analysis showed increased risk of fatal accidents (fatal accidents 18.32), and with the analysis taking into account the risk reduction effect of safety in numbers, we found with 17.72 deaths avoided (see appendix).

For greenhouse gases emissions the interventions aimed to reduce car use, are those that achieved higher reductions in CO_2 emissions (Table 4).

During this study we found that there is a lack of information in terms of available data on mobility. And in some cases the statistics are not comparable with other countries, and the lack of continuity in the publication of these statistics. We also found a lack of studies on the quantitative relations between the increase in the number of cyclists and the reduction in the number of traffic accidents. We also emphasize the need for more studies to measure the concentrations of different air pollutants, in each microenvironment that comprise the modes of transport.

In terms of public policy implications, this study shows that the implementation of active transport policies should consider the accident rates and the percentage of use of active transport in the city before its implementation. It also emphasizes the need for joint work between health practitioners, transport specialists and urban planners.

5. Conclusiones

Active transport policies can produce health benefits. But these policies must be accompanied with a description of the accident rate and modal split in the city, to choose the active transport that provides greater health benefits. Interventions that promote active transportation can also produce large reductions in emissions of greenhouse gases.

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Table 1. Active transportation scenarios.

Scenario	Description	Assumptions
A.1	Achieve the levels of cycling of the city of Copenhagen (35% of all trips in the city are made by bicycle)	50% of the trips coming from PT trips [a]
		40% of the trips coming from Walk trips [a]
		10% of the trips coming from Cars trips [a]
A.2	Achieve the levels of walking of the city of Paris (50% of all trips in the city are made walked)	50% of the trips coming from PT trips [b]
		40% of the trips coming from Bike trips [b]
		10% of the trips coming from Cars trips [b]
B.1	Reduction of 20% of car trips (and its replacement by active transport modes)	70% of the trips replaced by PT trips [c]
		20% of the trips replaced by Bike trips [c]
		10% of the trips replaced by Walk trips [c]
B.2	Reduction of 50% of car trips (and its replacement by active transport modes)	70% of the trips replaced by PT trips [c]
		20% of the trips replaced by Bike trips [c]
		10% of the trips replaced by Walk trips [c]

PT: Public Transport ; [a] 50% of trips replaced by Bike sharing systems coming from PT / 10% of trips replaced by BSS coming from Cars (United Nations 2011); [b] We assumed the same proportion that for bike trips; [c] 70% of car trips are > 3km and can be replaced by PT trips / 30% of car trips are < 3 km and can be replaced by bike or walk (European Commission 1999)

Table 2. Basal data and key assumptions used in the model.

Variable		Barcelona	Basel	Copenhagen	Paris	Prague	Warsaw
Population in the city		1,619,357	188,408	539,542	2,193,030	1,260,469	1,619,087
Trips per day	PT	1,484,788	443,900	303,333	2,027,880	1,860,517	401,181
	Walk	2,302,569	608,808	520,615	2,819,239	888,383	467,987*
	Bike	109,282	265,186	492,805	162,147	9,737	13,922*
	Car	457,095	429,320	491,576	731,482	932,643	526,196
Trips per person per day	All modes	3.1	3.4	3.2	3.4	2.9	1.8
Average distance traveled per trip (km)	PT	10.0*	13.1	2.8*	7.6	15.7	13.3*
	Walk	1.4*	1.3	0.6*	1.1	1.2	1.1*
	Bike	3.3*	2.9	3.7*	3.4	5.9	5.4*
	Car	8.9*	9.5	5.1*	11.4	20.9	14.1*
Average trip duration (minutes)	PT	33.2*	44.4	9.3	35.0	33.4	44.0
	Walk	16.2*	24.0	9.9	14.0	16.1	17.0
	Bike	14.0*	14.9	14.0	20.0*	29.0	24.0
	Car	24.4*	22.8	11.3	28.0	27.9	32.0
Average speed (km/h)	PT	18.1	17.7*	18.1*	8.4	28.2	18.1*
	Walk	5.0*	3.3*	3.8*	2.6	4.5	3.8*
	Bike	14.0*	11.6*	16.0	13.4*	12.0	13.4*
	Car	21.8	25.0*	27.0	13.5	45.0	26.5*

PT: Public Transport; PM2.5: Particulate matter < 2.5 micrometers; * Assumptions or data derived from secondary analysis

Table 2. Continuation.

Variable		Barcelona	Basel	Copenhagen	Paris	Prague	Warsaw
Fatal accidents per year (Deaths/year)	PT	0.0	0.0	0.0	0.0	0.3	32.0
	Walk	14.6	2.6	5.0	21.0	35.9	50.5
	Bike	0.3	1.6	3.0	5.0	0.9	2.5
	Car	4.1	1.2	6.0	2.0	7.6	50.0
Concentration of PM2.5 ($\mu g/m^3$)	City annual average	17.0	13.6	11.0	30.0	21.0	23.6
	in the Car	34.0	27.2*	22.0*	40.0	42.0*	47.2*
	in the Bike	28.0	22.4*	18.1*	58.0	34.6*	38.9*
	in the PT	24.0	19.2*	15.5*	40.0	29.6*	33.3*
	Walking	20.0	16.0*	12.9*	40.0	24.7*	27.8*
Expected mortality (deaths/1000 inhabitants) **	16-64 years	2.05	2.64	2.22	2.73	2.90	3.70
Deaths per billion of kilometer traveled	PT	0.00*	0.00*	0.00*	0.00*	0.03*	16.46*
	Walk	12.87*	9.14*	41.56*	18.55*	91.50*	271.91*
	Bike	2.30*	5.63*	4.47*	24.85*	42.92*	91.79*
	Car	2.79*	0.79*	6.58*	0.66*	1.07*	18.45*

PT: Public Transport; PM2.5: Particulate matter < 2.5 micrometers; * Assumptions or data derived from secondary analysis; ** Expected mortality in both sexes.

Table 3. Number of deaths estimated for each scenario and city

Scenario	Barcelona	Basel	Copenhagen	Paris	Prague	Warsaw
A.1	-24.85	-5.31	-	18.32	-50.37	-32.41
A.2	0.09	-2.45	1.47	-	13.64	10.28
B.1	-2.89	-4.26	-3.40	-5.14	-7.53	-4.15
B.2	-7.22	-10.66	-8.51	-12.84	-18.84	-10.37

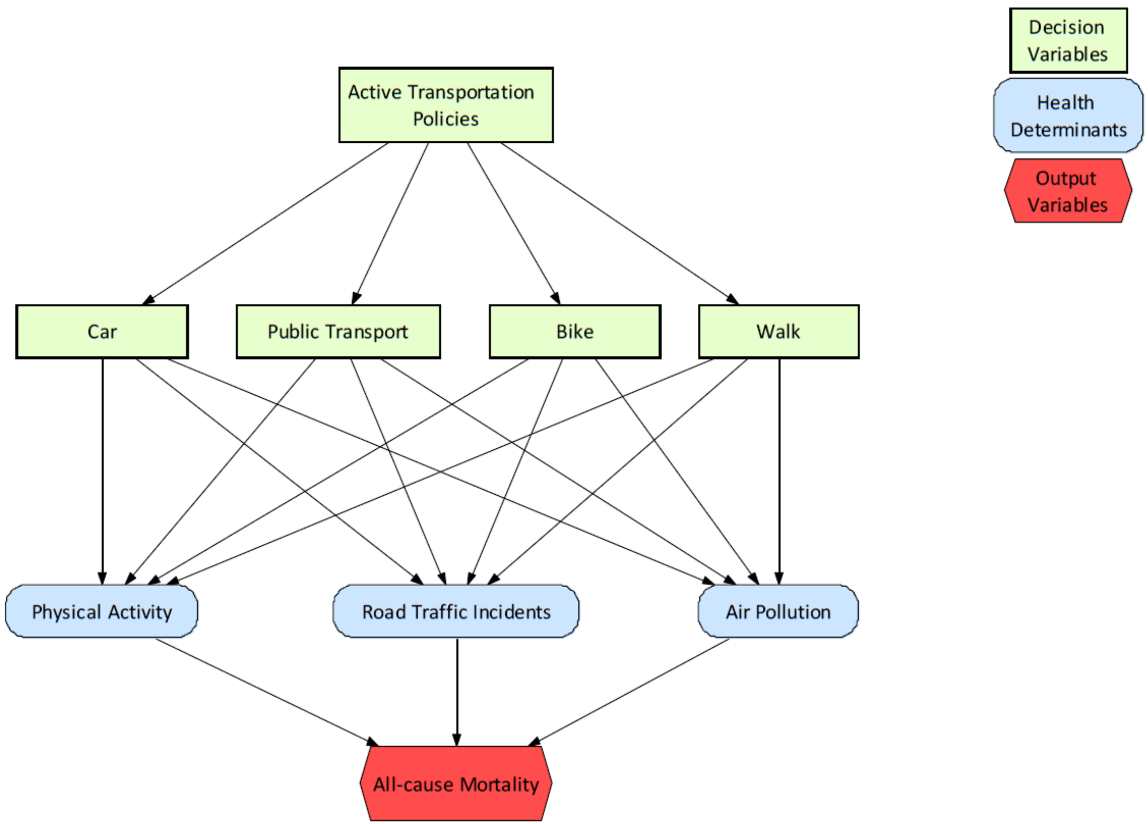
A.1: 35% of all trips made by bicycle; A.2: 50% of all trips made walked; B.1: Reduction of 20% of car trips; B.2: Reduction of 50% of car trips

Table 4. CO2 emissions (metric tons) avoided for each scenario and city

Scenario	Barcelona	Basel	Copenhagen	Paris	Prague	Warsaw
A.1	22,957	2,503	-	21,017	22,819	8,129
A.2	1,139	870	1,207	-	3,467	900
B.1	19,953	13,900	15,466	22,094	75,912	29,732
B.2	49,882	34,751	38,666	55,234	189,779	74,329

A.1: 35% of all trips made by bicycle; A.2: 50% of all trips made walked; B.1: Reduction of 20% of car trips; B.2: Reduction of 50% of car trips

Figure 1. Conceptual framework of active transportation and health.



Appendix – Paper 4

Table 1. Number of deaths estimated with each scenario in Barcelona

Barcelona			
Scenario	Traffic fatalities	Physical activity	Air pollution
A.1	-3.55	-23.57	2.28
A.2	0.65	-0.66	0.09
B.1	-0.11	-2.84	0.07
B.2	-0.28	-7.11	0.18

A.1: 35% of all trips made by bicycle; A.2: 50% of all trips made walked;
B.1: Reduction of 20% of car trips; B.2: Reduction of 50% of car trips.

Table 2. Number of deaths estimated with each scenario in Basel

Basel			
Scenario	Traffic fatalities	Physical activity	Air pollution
A.1	0.44	-6.21	0.45
A.2	0.56	-3.23	0.23
B.1	0.16	-4.55	0.13
B.2	0.41	-11.39	0.32

A.1: 35% of all trips made by bicycle; A.2: 50% of all trips made walked;
B.1: Reduction of 20% of car trips; B.2: Reduction of 50% of car trips.

Table 3. Number of deaths estimated with each scenario in Copenhagen

Copenhagen			
Scenario	Traffic fatalities	Physical activity	Air pollution
A.1	-	-	-
A.2	3.24	-1.92	0.15
B.1	-0.19	-3.27	0.06
B.2	-0.47	-8.18	0.14

A.1: 35% of all trips made by bicycle; A.2: 50% of all trips made walked;
B.1: Reduction of 20% of car trips; B.2: Reduction of 50% of car trips.

Table 4. Number of deaths estimated with each scenario in Paris

Paris			
Scenario	Traffic fatalities	Physical activity	Air pollution
A.1	24.89	-10.30	3.73
A.2	-	-	-
B.1	0.92	-6.58	0.52
B.2	2.30	-16.44	1.31

A.1: 35% of all trips made by bicycle; A.2: 50% of all trips made walked;
B.1: Reduction of 20% of car trips; B.2: Reduction of 50% of car trips.

Table 5. Number of deaths estimated with each scenario in Prague

Prague			
Scenario	**Traffic fatalities**	**Physical activity**	**Air pollution**
A.1	5.89	-63.77	7.51
A.2	18.36	-5.57	0.85
B.1	7.67	-16.23	1.03
B.2	19.17	-40.58	2.58

A.1: 35% of all trips made by bicycle; A.2: 50% of all trips made walked;
B.1: Reduction of 20% of car trips; B.2: Reduction of 50% of car trips.

Table 6. Number of deaths estimated with each scenario in Warsaw

Warsaw			
Scenario	**Traffic fatalities**	**Physical activity**	**Air pollution**
A.1	-16.50	-20.12	4.22
A.2	14.21	-4.62	0.69
B.1	4.35	-9.30	0.80
B.2	10.88	-23.24	1.99

A.1: 35% of all trips made by bicycle; A.2: 50% of all trips made walked;
B.1: Reduction of 20% of car trips; B.2: Reduction of 50% of car trips.

Table 7.. Basal level of physical activity reported in Barcelona travelers, per age and sex.

	METs/h/w *	
Age	Men	Women
< 30 years	21.35	18.43
31-40	20.34	17.56
41-50	19.38	16.73
> 50 years	18.47	15.94

* METs/h/w : Metabolic equivalent task per hour per week.

Figure 1. Curvilinear dose responses function for physical activity and all-cause mortality.

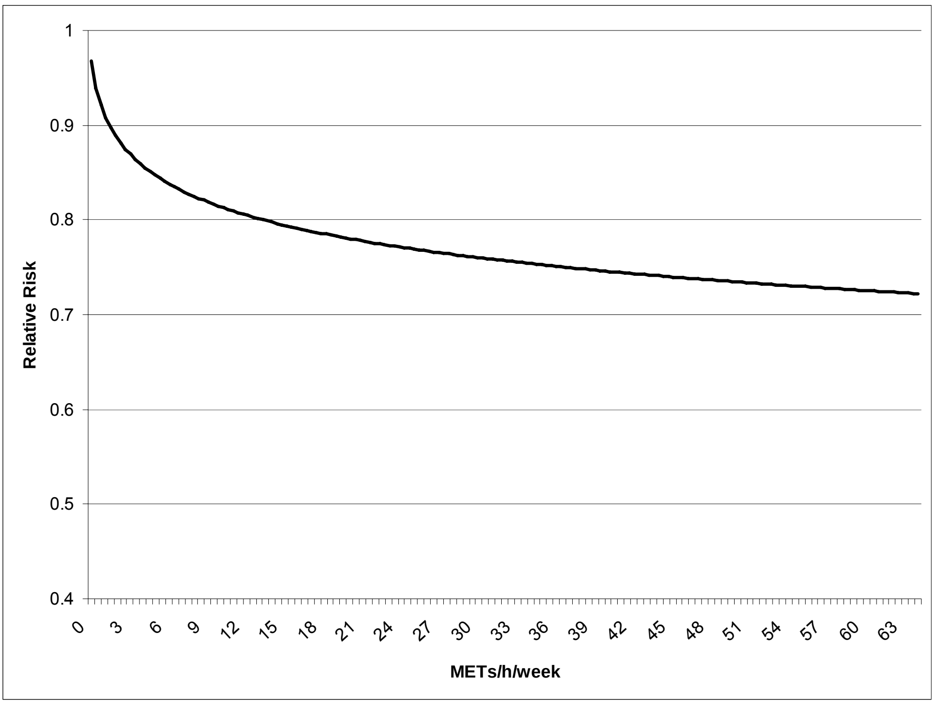
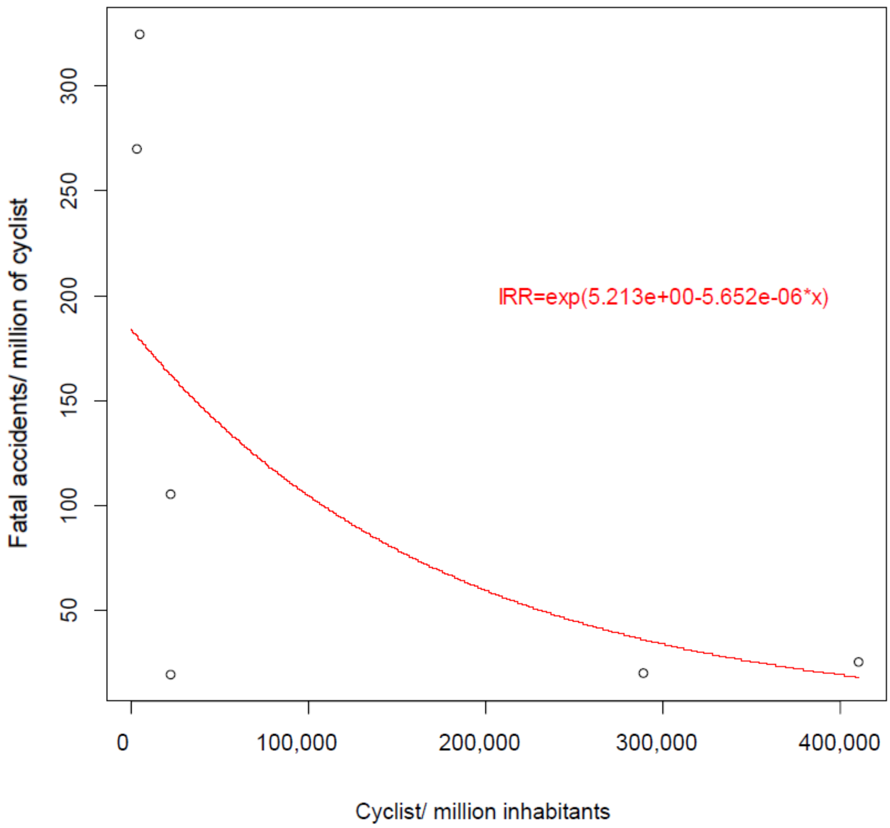


Figure 2. Incidence Rate Ratio, of fatal traffic accidents and number of cyclist



* Each white dot represents one city

Table 8. Number of deaths estimated for each scenario and city, using a quantitative approach of "safety in numbers"

Scenario	Barcelona	Basel	Copenhagen	Paris	Prague	Warsaw
A.1	-27.55	-6.63		-17.72	-125.62	-89.17
A.2	0.09	-2.45	1.47		13.64	10.28
B.1	-2.93	-4.37	-3.47	-5.84	-11.68	-7.70
B.2	-7.33	-10.98	-8.72	-14.67	-29.40	-19.35

A.1: 35% of all trips made by bicycle; A.2: 50% of all trips made walked; B.1: Reduction of 20% of car trips; B.2: Reduction of 50% of car trips

Table 9. Traffic fatalities estimated for each scenario and city, using a quantitative approach of "safety in numbers"

			Traffic fatalities			
Scenario	Barcelona	Basel	Copenhagen	Paris	Prague	Warsaw
A.1	-6.25	-0.87	0.00	-11.15	-69.36	-73.27
A.2	0.65	0.56	3.24	0.00	18.36	14.21
B.1	-0.16	0.14	-0.25	0.21	3.52	0.80
B.2	-0.40	0.41	-0.68	0.47	8.60	1.90

A.1: 35% of all trips made by bicycle; A.2: 50% of all trips made walked; B.1: Reduction of 20% of car trips; B.2: Reduction of 50% of car trips

Table 10. Carbon dioxide emission factors and vehicle fleet description by city.

		Barcelona	Basel	Copenhagen	Paris	Prague	Warsaw
Percentage of cars in the city per type of fuel (%)	Gasoline	66.0	67.6	63.4	63.4	56.7	63.4
	Diesel	44.0	30.5	39.3	39.3	43.3	39.3
Efficiency of cars fleet in the city (L/100km)	Gasoline	9.0	5.2	7.1	7.1	7.1	7.1
	Diesel	7.0	3.9	5.5	5.5	5.7	5.5
CO_2 released (kg/L)	Gasoline	2.4	2.4	2.4	2.4	2.5	2.4
	Diesel	2.6	2.6	2.6	2.6	2.6	2.6

CO_2: Carbon dioxide.

5.5 Letter

Rojas-Rueda D, Cole-Hunter T, Nieuwenhuijsen M. [Bicycle helmet law in urban areas. Is it good for public health?] Gac Sanit. 2013; 27(3): 282.

6. DISCUSION

6.1. General discussion

This project shows an approach of health impact assessment (HIA) for transport policies. It provides an integrative view of multiple risks and benefits of active transportation policies. It also provides a tool (quantitative model) that could be used to help in decision-making in transport public policies.

This project highlights the potential co-benefits for health of policies focused on reducing greenhouse gases emissions and climate change; and how the low-carbon economy could prevent non-communicable diseases. This type of study also reinforces the idea of implementing this approach (HIA) for analyze policies outside the healthcare system, which can promote the health of the population.

Our results suggest that active transport policies can produce public health benefits. In the example of the assessment of Barcelona public bicycle system (Bicing) the benefits were estimated 70 times greater than the risks. We also identified that benefits will not only focused on travelers, if not also in the general population who benefited from the reduction of the air pollution emissions in the city.

One point to note is that the major benefits associated with the implementation and promotion of active transportation policies are related to the benefits of physical activity. And the benefits that provide physical activity outweigh the risks associated with air pollution and traffic accidents. This also reinforces the idea that transport policies, which favor physical activity (e.g., walking, bicycling), may produce greater health benefits that policies aimed solely at reducing emissions of air pollutants (e.g. electric vehicles). And the implementation of transport policies must have an intersectoral approach, considering not only environmental issues but also health.

As mentioned above, physical activity is the exposure which determines in higher degree the health impacts. That is why the choice of the dose-response function between physical activity and health outcomes, is crucial to define the magnitude of the overall impacts. With the increasing scientific evidence suggesting a nonlinear relationship between physical activity and health outcomes should be considered important the use a curvilinear dose response relationships, taking also into account the baseline levels of physical activity (not transport related), in order to estimate the impacts nearest to the reality.

Regarding air pollution, it is also important to emphasize the choice of the pollutant with higher correlation with health impacts. In this aspect we chose particulate matter (PM2.5) as principal estimator of the health effects of air pollution. In the sensitivity analyzes we also included the effects of other pollutants such as black smoke and possible hypothesis of increased toxicity (five times) of pollutants emitted by motorized transport.

Finally the impacts of traffic accidents are mostly dependent on the quality of the records where these data are derived. Also the definition in the severity of injuries can determine the burden of disease related to traffic injuries. Our results also suggest that the implementation of active transport policies should consider, prior to their implementation, the distributions in accident rates between different modes of transport. This is of particular interest in cities with large differences in accident rates between transport modes (e.g. Paris and Warsaw). That is why a preliminary analysis of the accident rate in the city, must accompany the selection of active transport policies, in order to select the policy that provide greater health benefits to the population.

6.2. Strengths and limitations

As in all risk assessments, our studies were limited by the availability of data and the necessity to make assumptions to model likely scenarios. We carried out sensitivity analyses to assess the robustness of our results and tested effects of deviations from our main assumptions and data choices. Included in the sensitivity analysis were, for example, relative risk functions from the literature, choice of pollutants, age distribution, and environmental and travel conditions.

During development of the studies included in this thesis, we have integrated in each study, new features in the sensitivity analyzes. Starting for example, studies that used dose-response functions for mortality and physical activity linear, in the fourth study we have made an analysis including a curvilinear dose response function which also takes into account baseline levels of physical activity in travelers (physical activity, not transport related). Other example would be the analysis including aspects such as safety in numbers for traffic accidents.

One strength of this study was the selection of different health outcomes for air pollution and physical activity, based on a systematic review and expert advice, prioritizing dose response functions published in a high quality studies and with higher methodologically robustness. Another strength of the study was the use of local measurements of $PM_{2.5}$ concentration in the different microenvironments in the city of Barcelona and Paris. In addition, for estimating the impacts of air pollution in the general population in papers two and three, we ran an Air-Dispersion model which took into account different parameters to estimate the concentration levels of particulate mater in the city of Barcelona (e.g. weather, different emissions sources, type of motor vehicle and street canyon effect). Our results showed that the health benefit in the general population was very small, as a result of the small reduction in $PM_{2.5}$ concentration associated with our scenarios. This was be explained partially by the fact that the trip reductions only concerned car trips and not trips from the entire vehicle fleet in Barcelona (40% reduction in car trips represents only 11% of all motorized trips). In our model we performed the analysis for a single pollutant ($PM_{2.5}$), which has robust scientific evidence to be used in a HIA model.

Moreover the quantitative model has not been able to assess all the exposure factors that have been associated with active transportation policies. This is due to the lack of studies that provide dose-response functions between certain exposures such as diet, or social interaction and their health effects.

6.3. Policy implications

This thesis is aimed to create a tool to aid in decision-making in the field of transport, mobility and urbanism. From this thesis are derived the following points and recommendations to be considered during the decision making process:

- Transport policies that favor the substitution of car trips by active transportation such as walking, bicycling and public transport produce health benefits.
- The health benefits are both travelers who decide to modal shift as in the general population of the urban area.
- Public bicycle systems are a good example of active transport policies related to health benefits.
- The implementation of active transport policies should consider the accident rates between the different modes of transport and the modal split between transport modes in the city; this will help to choose the most appropriate policy to achieve greater health benefits.
- It is necessary to strengthen the partnership between health practitioners, urban planners and policy makers, to encourage transport policies that provide greater co-benefits for health.
- Although cyclist's helmet can reduce craniofacial injuries, establish a law obliging adult's cyclist to wear helmets in urban areas, is likely to decrease the use of bicycles as a mode of transport, resulting in a reduction in health benefits for the population.

6.4. Future research

In the realization of this thesis have been found areas where there is a lack of information and require further research and analysis. Among the aspects that require further research there are the following:

- Create detailed and comparable indicators on transport and mobility between different European cities (e.g. travel time by mode and purpose, speed, number of trips per day, etc).
- Studies are needed to describe the replacement rate of each mode of transport by car, bicycle, pedestrian, and public transportation.
- Homogenize and improve the description of traffic accidents between cities. Descriptive studies are needed on the type of injury (with diagnosis and classification of the injury), by mode of transport and possibly describing the risk per distance traveled (e.g. injury / death per kilometer).
- Need of studies detailing the distribution of different diagnosis of injuries by mode of transport, sex and age. This is necessary for quantify the (Disability adjusted life years) DALYs.
- Studies are needed to describe the magnitude of underreporting of traffic accidents (by injury severity) in different modes.
- Further studies are required that report the concentrations of pollutants in different modes of transport.
- Epidemiological studies or meta-analysis which report, dose-response functions for air pollution or physical activity and its health impacts. For physical activity there is a need to describe

the possible non-linear relationships being physical activity and its health effects.

- Description of basal levels of physical activity (physical activity not related to transport) in the populations.
- Epidemiological studies which quantify dose-response relationships between ultraviolet radiation and health effects.
- Epidemiological studies on noise and its impact on health, describing a dose-response function, adjusting for the effects of air pollution.
- Epidemiological studies on social interaction, standardizing definitions and quantifying health effects.
- Epidemiological studies which define and quantify the association between diet and active transport.
- Perform HIA from other public bicycle systems. This is especially important because it will help to compare the impacts of public bicycle programs in different populations, with different environmental and transport characteristics.

7. CONCLUSION

Active transportation policies can produce benefits for public health. These health benefits affect both travelers who decide to make a modal shift, as in the general population of the urban area. The benefits in travelers are mainly related to the protective effect of physical activity. The benefits in the general population are associated with the reduction in air pollution emissions.

Public transport should also be considered as a healthy alternative over the car. The benefits associated with this mode of transport are associated with low risk of traffic accidents and also by the benefits associated with physical activity (since it includes short walking trips).

The health benefits quantified in this thesis involve the disease cases, all-cause mortality and life expectancy. And our results showed that in the health impact assessments of transport policies, the estimation of all-cause mortality can be a reasonable indicator for the disease impacts.

Public bicycle systems, such as Bicing in Barcelona, are a good example of active transport policies that produces health benefits.

The implementation of active transportation policies must be accompanied by a previous analysis on the characteristics of the modal split in the city (especially for active transportation modes), and the accident rate levels (by mode of transport). This will help to choose policies that could produce the biggest benefits for the population.

Active transportation policies are also accompanied by large reductions in greenhouse gases emissions (e.g. CO_2) and these policies can also be used as a tool for climate change mitigation.

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