ONE SIZE FITS ALL?

THE INFLUENCE OF BUILT ENVIRONMENT ON ACTIVE TRAVEL ACROSS POPULATION SEGMENTS AND GEOGRAPHICAL CONTEXTS

JIE GAO

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The influence of built environment on active travel across population segments and geographical contexts

One size fits all?

De invloed van de gebouwde omgeving op actief transport voor verschillende bevolkingsgroepen en in verschillende geografische contexten

(met een samenvatting in het Nederlands)

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Jie Gao

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Contents

Chapter 1

General Introduction

Moderate-intensity physical activity (e.g., walking, cycling) can reduce the risk of cardiovascular disease, diabetes, colon and breast cancer, depression, and other chronic diseases or disorders (WHO, 2012). Despite these known benefits of physical activity, there is a worldwide trend showing declining physical activity levels. It is estimated that globally about 23% of adults (18+) are not sufficiently physically active (WHO, 2018). In Europe, estimates indicate that more than one-third of adults are insufficiently active (Hallal et al., 2012). Among Dutch adults, approximately 25% do not meet the recommendation of being moderately active for at least half an hour on at least five days per week (Hildebrandt et al., 2015). Maintaining sufficient levels of physical activity has become increasingly difficult, as most daily environments increasingly stimulate sedentary behaviors (e.g., through escalators, elevators, desk work) (WHO, 2016, 2018). Similarly, the increased use of motorized transport has contributed to reduced physical activity levels. For instance, in the Netherlands, approximately 33% of all trips up to 7.5 kilometers (which could be considered a 'cyclable' distance) are made by car, versus 25% by bike and 19% on foot. Of all somewhat longer trips, i.e., between 7.5 and 15 kilometers, 70% are made by car (CBS, 2019; KiM, 2018).

From a public health perspective, the promotion of cycling and walking is increasingly recognized as an important way to increase overall physical activity (Bentley et al., 2018; Oja et al., 2011; Rutter et al., 2013; Xiao et al., 2019), as these behaviors are accessible to almost everybody, can be integrated even into busy daily schedules (e.g., cycling/walking for commuting, shopping or social activities) and require a minimal financial investment. From a transport and planning perspective, switching from car use to cycling or walking may help to mitigate the adverse effects caused by motorized travel (Lindsay et al., 2011), as it leads to reductions in CO_2 emissions, noise pollution, air pollution, and traffic congestion (De Hartog et al., 2010; Mueller et al., 2015). Another important advantage, especially in busy and highly dense urban areas, is that on short trips (up to 7 kilometers), cycling is potentially quicker than driving (Mertens et al., 2017).

Transportation policies need to be informed on ways to further stimulate cycling and walking. Numerous determinants of cycling and walking have already been identified (Heinen et al., 2010; Saelens and Handy, 2008). However, most studies have taken a one-size-fits-all approach by implicitly assuming that environmental determinants would have similar effects on cycling and walking across different population segments and variations in geographical context. However, indications exist that the impacts of environmental determinants differ among groups and contexts (Adams et al., 2013; Heesch et al., 2012; Misra and Watkins, 2018; Van Cauwenberg et al., 2012). For example, Cerin et al. (2017) found that walking distance from home decreases with age, suggesting that the residential environment is a more important determinant of walking behavior among older adults than among younger groups. In a similar vein, Cao et al. (2010) found that shorter distance to utilitarian destinations had a stronger impact on elderly adults than on younger residents. Regarding different geographical contexts, in the Netherlands, an urban form characteristic, such as land use diversity, was not significantly related to walking behavior (Beenackers et al., 2014), although other studies (mostly from the US) found positive associations between land use diversity and active travel (Fraser and Lock, 2011).

If the impact of the built environment differs across population segments and geographical contexts, this implies that land use and transport policies aimed at stimulating active travel need to be shaped differently in different contexts and for different population segments. Therefore, this thesis aims to examine how determinants of cycling/walking differ across geographical context, population segments and types of cycling/walking.

1.1 Determinants of cycling

1.1.1 Physical environment determinants of cycling

The relationship between the natural and built environment and cycling has been proven to be important in both transportation planning and public health (Oja et al., 2011). In recent decades, a large number of studies have linked the natural and built environment with cycling behavior (Ewing and Cervero, 2010; Heinen et al., 2010; McCormack and Shiell, 2011; Wang et al., 2016), although the causality has not been fully established.

The built environment refers to urban form characteristics that are mostly operationalized at the level of the residential neighborhood. Typically, the characteristics of the built environment can be classified into three dimensions: density, diversity, and design (Cervero and Kockelman, 1997). Several aspects of density are commonly used, including population density, address density, and employment density. The association of population density with cycling behavior may be indirect. Higher population density is thought to represent pronounced diversity in local destinations while reducing distances between origins and destinations. A review by Heinen et al. (2010) concluded that higher population density is related to a higher level of bicycle use. Based on longitudinal data, Beenackers et al. (2012b) found that higher residential density was positively associated with an increase in transport-related cycling after residential relocation. In contrast, another study reported that residential density is uncorrelated with bicycle use (Rodríguez and Joo, 2004). Land use diversity refers to the mix of commercial, institutional, office, and residential areas available in the neighborhood. Higher land use diversity has been consistently associated with more bicycle use. Mixed-use neighborhoods make bike trips more convenient (Ewing and Cervero, 2010). Regarding urban design, a cycling-friendly street network and infrastructure design may increase the accessibility of destinations. Studies found that street connectivity was positively associated with cycling usage (Cervero et al., 2009; Wong et al., 2011). In addition to these three dimensions, studies also consider the effects of other built environmental characteristics, such as destination accessibility and distance to public transport (e.g., train station and bus stops) (Heesch et al., 2014; Mertens et al., 2017). Additionally, green space has been found to be positively related to cycling (Lee and Moudon, 2008; Wang et al., 2016). For example, Jansen et al. (2017) found that different domains of physical activities (including cycling) were related to different types of natural environments (i.e., parks, recreation area, agricultural green, forest & moorland, and blue space). Fraser and Lock (2011) concluded, based on a review study, that the proximity of green space was positively associated with cycling. Others found no (Christiansen et al., 2016) or even reverse associations (Fishman et al., 2015). Bicycle-friendly infrastructure (e.g., dedicated cycling routes and the presence of bicycle signage) and street network density have been found positively related with transport-related cycling (Ma et al., 2014; Winters et al., 2010).

1.1.2 Individual-level determinants of cycling

With regard to cycling levels among population subgroups (Heesch et al., 2014; Scheepers et al., 2013), it has been found that in the Netherlands women cycle longer and more than men (Scheepers et al., 2013). Additionally, higher educated people have been found to cycle more than less educated groups (Scheepers et al., 2013). However, different results were found in the UK and the USA (Edwards and Mason, 2014; Woodcock et al., 2014). Woodcock et al. (2014) found that men had higher cycling levels than women in the UK. No gender differences seem to be present in the USA (Edwards and Mason, 2014). In addition to sociodemographic characteristics, attitudes also influence cycling behavior. Heinen et al. (2011) found that having a positive attitude toward the benefits of cycling would have a positive impact on commute cycling. Two American studies also confirmed that positive attitudes toward walking and cycling were positively associated with walking and cycling behavior (Cao et al., 2009; Handy et al., 2006). Joh et al. (2012) found that the built environment had a stronger impact on those with positive attitudes toward walking than on those with negative walking attitudes. However, these studies did not consider interactions between cycling attitudes and attitudes toward other travel modes. Studies found that enjoying cycling had a positive effect on transport-related cycling, whereas not enjoying driving (Dill and Voros, 2007) and limiting driving (Xing et al., 2010) are correlated with transport-related cycling.

1.2 Determinants of walking

1.2.1 Physical environment determinants of walking

An improved understanding of walking patterns is important because walking is one of the most common physical activities among adults and an environmentally friendly travel mode (Bentley et al., 2018; Winters et al., 2017). Unlike cycling, which may include longer distance trips beyond the residential areas, walking is more often undertaken within the local neighborhood (Van Dyck et al., 2009a). Therefore, walking is likely more influenced by environmental attributes of the residential neighborhood than cycling. To design a place that facilitates and encourages walking, it is necessary to understand the specific characteristics of the natural and built environment that correlate with walking for transport and walking for recreation.

Extensive research on the built environment correlates of walking has taken place (Boulange et al., 2017; McCormack and Shiell, 2011; Saelens and Handy, 2008; Smith et al., 2017). Both public health and transportation planning fields have contributed to this body of work. Key factors encouraging walking include high address density, high street connectivity or intersection density, and high level of land use diversity, all reducing the distance between an origin and a destination (Boulange et al., 2017; Cervero and Kockelman, 1997; Christiansen et al., 2016). However, others found different associations between them (Boarnet et al., 2011; Oakes et al., 2007). In particular, Oakes et al. (2007) found that the odds of transport-related walking increased in higher-density areas, while the odds of recreational walking increased in low-connectivity areas. In addition, Giles-Corti et al. (2005) found that neither density nor street connectivity was significantly associated with overall walking distance. This finding suggests that the effects of density, diversity and connectivity are context dependent.

Many scholars have argued that the influence of the built environment depends on the purpose of walking, with transportation and recreation walking being affected differently. Prior empirical studies (Cervero et al., 2009; Hirsch et al., 2014; Kang et al., 2017; Millward et al., 2013) and reviews (Barnett et al., 2017; Saelens and Handy, 2008) have consistently found associations between transport-related walking and density, land use diversity, and shorter travel distances to utilitarian destinations (e.g., supermarkets, restaurants, and shops). In denser residential areas, destinations such as shops, services and workplaces are more likely to be closer to people's homes, supporting transport-related walking behavior. In contrast, these findings also suggest that these factors are not necessarily associated with recreational walking. Recreational walking is more likely to be positively related to open public space, and aesthetic quality (e.g., sidewalk and street lamp availability) (Saelens and Handy, 2008). Public transport services are also decisive determinants of walking. Although walking is not suitable for all travel needs on its own, in combination with public transport, it can serve almost all travel needs. However, most studies have not considered walking to/from public transport or have wrongly categorized it as transport walking.

1.2.2 Individual-level determinants of walking

Walking levels have been found to be influenced by social status (Adams, 2010; Ghani et al., 2018; Shigematsu et al., 2009). For example, in the Netherlands, adults aged 55-75 years with a lower income and education level engage less in recreational walking than do more highly educated elderly adults with a higher income (Kamphuis et al., 2009). In the US, children from lower socioeconomic status, including those with unemployed parents, had higher levels of walking to school (Davison et al., 2008). Similar trends were also found in Canada and Switzerland (Larsen et al., 2009; Robertson-Wilson et al., 2008). With respect to age, a review conducted by Cerin et al. (2017) suggested that compared to younger adults, older adults engage less frequently in walking and walk shorter distances.

Daily mobility is also significantly influenced by gender (Pollard and Wagnild, 2017). For instance, in Germany, women walked shorter distances than men partly due to short work distance to home (Scheiner et al., 2011). Regarding walking access to transit, some studies have shown that men were more likely to walk to transit (Wibowo and Olszewski, 2005). In the US, people from lower-income households were more likely to walk to transit (Freeland et al., 2013). Walking is also influenced by psychological factors (e.g., attitude, self-efficacy) (Beenackers et al., 2013; Carlson et al., 2012; Van Dyck et al., 2009b). A Dutch study found that positive built environment characteristics only contributed to leisure walking among those with a less positive attitude toward physical activity (Beenackers et al., 2014). In contrast, a US study found that a positive attitude toward walking had a stronger association with more physical activity among those living in a walking-friendly environment (Carlson et al., 2012). A three-country study suggested that people having a less positive attitude toward walking showed a stronger association between environmental perceptions and leisure-time activity (Van Dyck et al., 2014).

1.2.3 Changes in active travel behavior in relation to life events

Although many cross-sectional studies provide insight into the associations between the built environment and active travel, it is still unclear to what extent changes in the built environment lead to increases in walking. Limited evidence suggests that changes in infrastructure may lead to changes in the active travel of residents, although findings are mixed (Frank et al., 2019a; Stappers et al., 2018). The effects of changes in other aspects of the built environment are more difficult to investigate, as metrics such as density and land use mix change only very slowly, if at all. However, changes in travel behavior of people relocating to another built environment have been studied in the wider context of the Mobility Biography approach. The Mobility Biography Framework proposes that life events (such as residential relocation) are related to travel behavior (Oakil et al., 2010). However, life events may co-occur (e.g., marriage and relocation), making it important to study their effects in coherence. Previous studies have examined travel mode choice (Clark et al., 2016), bicycle use (Chatterjee et al., 2013; Oakil et al., 2016), and travel distances (Prillwitz et al., 2007) in relation to particular life events including residential relocation. Childbirth, for example, may lead to rearrangements in household maintenance tasks and associate travel (Lanzendorf, 2010). Prillwitz et al. (2007) concluded that childbirth, marriage, separation, retirement, and residential relocation influence vehicle miles traveled. Based on interview data, Chatterjee et al. (2013) found changes in bicycle use across different stages of the life events. Additionally, residential relocation, which usually leads to a change in the built environment context, has been found to trigger changes in travel behavior. Some studies have indicated that people moving to more urbanized areas had a higher likelihood of walking, riding a bike and using public transport than did people moving to suburban/rural areas (Cao and Ermagun, 2017; Scheiner and Holz-Rau, 2013). Job changes may lead to changes in commute distances (Oakil et al., 2014) or changes in travel modes (Van der Waerden et al., 2003).

1.3 Research gaps and conceptual framework

The first research gap addressed in this thesis addresses the links between walking and cycling and population health. Several studies have revealed that walking and cycling levels differ among population subgroups (Babagoli et al., 2019; Heesch et al., 2014; Kwasniewska et al., 2010; Scheepers et al., 2013). However, a review of eleven studies by Beenackers et al. (2012a) suggests that associations between socioeconomic indicators and walking and/or cycling duration are inconsistent among studies. In addition, evidence remains inconclusive about socioeconomic and demographic differences in the health outcomes of walking and cycling. Furthermore, it may be assumed that health benefits from active travel differ across population subgroups (Mueller et al., 2015). However, limited knowledge is available about how differences in walking and cycling translate into inequalities in health benefits stratified by demographic and socioeconomic groups.

The second research gap identified in this thesis concerns the extent to which relationships between the built environment and active travel differ by geographical context. That is to say, the effects of the built environment are often specified at the neighborhood level, neglecting the fact that the built environment outside the neighborhood also influences active travel options. For instance, while a walking- or cycling-friendly neighborhood may in itself stimulate active travel, the effect may be larger if relevant destinations are available within walking or cycling distance outside the neighborhood. This refers to the 'accessibility of destinations' aspect mentioned by Manville (2017). As a consequence, the effect of neighborhood level built environment characteristics may depend on the wider spatial structure, of which municipality size is a key factor. However, the dependence of the effect of the built environment on municipality size has not been addressed in the scientific literature.

Third, the social-ecological model (Sallis et al., 2015) that is widely used in public health studies of physical activity suggests that individual and environmental variables may interact with attitudes on travel behavior. This model proposes that individuals' travel behavior is affected by various groups of key factors: the individual (intrapersonal) level, the social environment (social network, community), the physical (built and natural) environment and the policy environment. The individual level includes personal characteristics that may influence the likelihood of people engaging in active travel, such as one's ability, knowledge, age, gender, education, and attitudes that an individual holds with respect to active and other travel modes. The social environment includes the relationships, the culture and the society with which the individual interacts (e.g., family members, neighbors, or work colleagues). Both the natural and built environments could influence the type and amount of active travel behavior, as indicated in sections 1.1 and 1.2.

Previous studies based on the social-ecological model have investigated the relationships between, on the one hand, the natural and built environment, sociodemographic characteristics, and attitudes toward alternative travel modes and, on the other hand, travel behavior (Heinen et al., 2011; Heinen et al., 2010; Ton et al., 2018). However, the associations between environmental characteristics and travel behavior may be dependent on individual characteristics, including travel mode attitudes. One might argue that a positive attitude toward active travel is more likely to result in more walking or cycling if circumstances are more favorable. For instance, a positive attitude toward walking may have a larger impact in a walking-friendly environment. On the other hand, one may argue that a positive attitude helps to overcome constraints with respect to active travel. In that case, the effect of a positive attitude toward walking would be larger in a less walkable environment. However, research in the domain of walking and cycling has largely ignored the interaction terms of travel-related attitudes with sociodemographic and environmental characteristics. Such interactions may help to clarify inconsistent associations between the environment and cycling. In a broader sense, addressing this gap is in line with the need to develop more focused social-ecological models with more emphasis on specific interaction mechanisms (Beenackers et al., 2013)

Fourth, although many previous studies have investigated the individual and environmental determinants of walking behavior, most are limited to a cross-sectional design (Ghani et al., 2018; Saelens and Handy, 2008; Sugiyama et al., 2019). Mobility studies that have employed longitudinal designs have predominantly focused on car use and the use of public transport and have not addressed changes in walking and cycling. While changes in walking and cycling may stem from interventions in the built environment (especially in infrastructure: see Stappers et al., 2018; Frank et al., 2019), they may also be related to changes in life events, as proposed in the Mobility Biography approach. Such life events may concern household and personal aspects, such as household formation and dissolution and childbirth, as well as the land use and mobility context, as a result of changes in vehicle ownership and residential relocation. In general, there is very limited insight into the role of life events of both kinds on the amount of walking and cycling for both transportation and recreation purposes.

Finally, according to the social-ecological model of active living, physical activity behavior is associated with individual and environmental variables (Sallis et al., 2015). Previous studies have focused on the environmental determinants of transport-related and recreational walking (Frank et al., 2019b; McCormack et al., 2012; Saelens and Handy, 2008). However, transport-related walking (but also cycling) could be further refined into transit-related and non-transit-related transport walking, since these are different behaviors and are potentially affected differently by built environment characteristics (Lee and Moudon, 2006; Saelens and Handy, 2008). Not taking this into account leads to biased outcomes. For example, a pedestrian-friendly environment may provide shorter distances to utilitarian destinations and encourage people to walk for transport within neighborhood without using other travel modes, such as public transport (with associated walking and cycling). In contrast, shorter distance to public transport (e.g., train station and bus stops) is likely positively associated with transit-related transportation walking and cycling, but less walking to utilitarian destinations in the neighborhood. Furthermore, it is possible that engaging in one type of walking has an impact on other types of walking behavior due to time-space constraints. Such relationships may include substitution effects as well as complementarity effects. However, very few studies have investigated correlations between different types of walking.

The conceptual framework of this thesis (Figure 1.1) is based on the social-ecological model (Giles-Corti and Donovan, 2002; Sallis et al., 2006; Sallis et al., 2015) and distinguishes determinants of walking and cycling at different levels. The most common levels include the neighborhood level, where built and natural environment variables commonly used in the literature are assumed to influence walking and cycling, and the individual level, which includes, in addition to sociodemographic variables, individuals' attitudes toward walking and cycling. Both levels influence walking and cycling behavior, leading to health outcomes that are different for different socioeconomic groups. In addition, walking and cycling are split into transport-related, transit-related and recreational to acknowledge that each can be differently affected by the built and natural environment. Apart from the direct effects of neighborhood- and individual-level variables on walking and cycling behavior, the model includes interactions of city-/region-level variables (such as city size) and personal variables (such as attitudes) with built and natural environment variables, acknowledging that the effect of neighborhood built environment factors may be moderated by these factors.

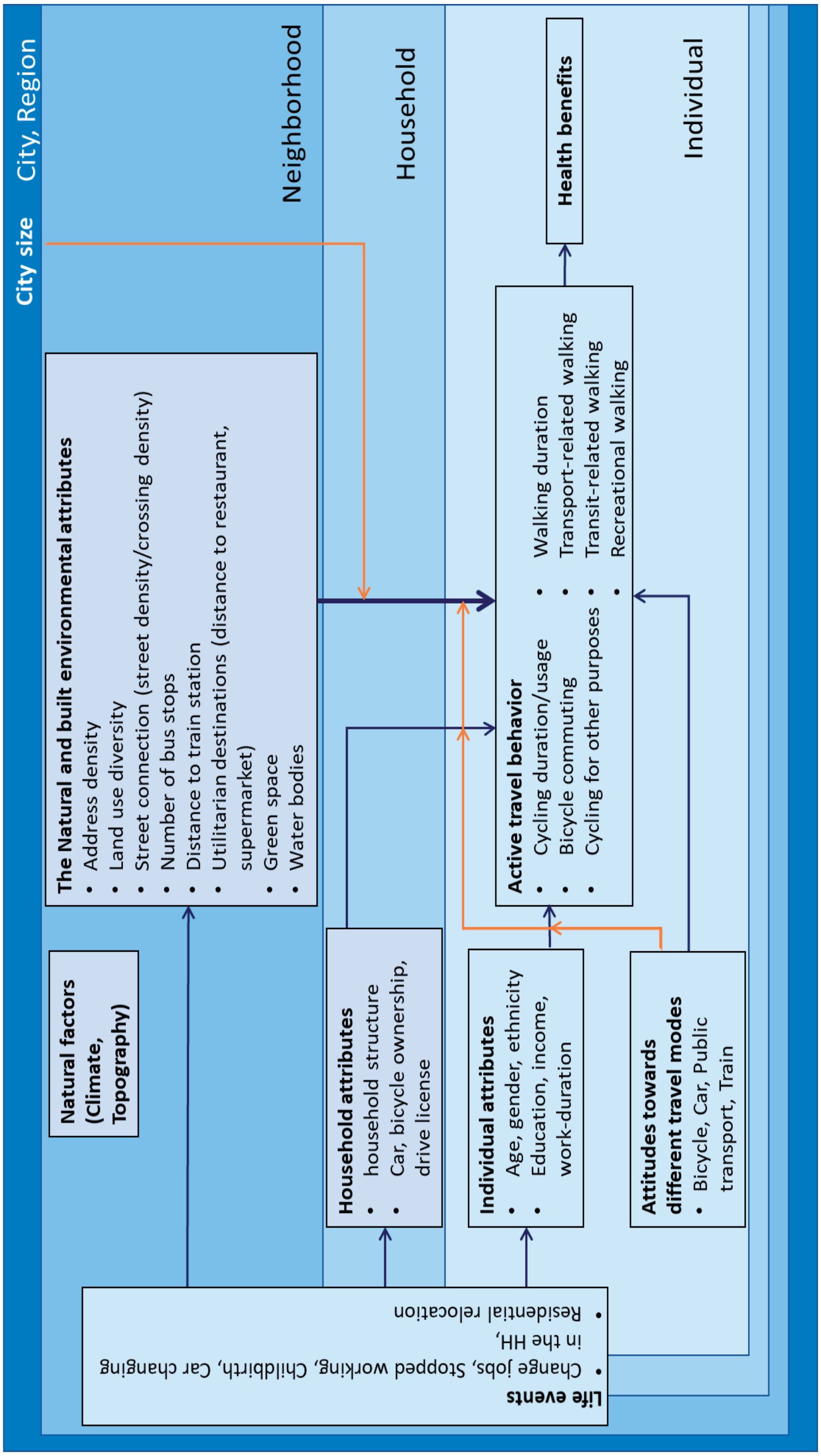

Figure 1.1 Conceptual model

1.4 Research objectives and questions

Despite the increased attention on active travel (i.e., walking and cycling) in the literature, several gaps can be identified, as outlined in section 1.3. The overarching objective of this thesis is to improve our understanding how the individual and environmental factors affect walking and cycling duration and improve public health. As different mechanisms may trigger and influence walking and cycling, we aim to analyze the determinants of walking and cycling separately. Consequently, this thesis addresses the following research questions.

1. *How do the population health benefits of walking and cycling in the Netherlands differ across population subgroups stratified by age, gender, education, income, and ethnicity?*

Walking and cycling are effective means to increase people's daily physical activity. Socioeconomic and demographic differences in walking and cycling exist. Therefore, it is rational to assume that health benefits from active travel differ across population subgroups. However, little is known about how differences in walking and cycling translate into inequalities in health benefits on the population level. Thus, Chapter 2 will quantify these health benefits for different demographic and socioeconomic groups in the Netherlands by using the Health Economic Assessment Tool (HEAT).

2. *To what extent do objectively measured natural and built environment characteristics correlate with cycling duration, and how do environmental characteristics on cycling duration differ by municipality size?*

Cycling for transportation has the potential to increase people's physical activity levels. A growing body of evidence links the natural and built environment to cycling, but studies have been mostly conducted within a single city or region. Chapter 3 covers the entire Netherlands when exploring to what extent associations between environmental characteristics and cycling are context-specific. This chapter will examine the extent to which objectively measured natural and built environment characteristics contribute to cycling duration as well as the differential effect of environmental characteristics on cycling duration by municipality size.

3. *How do interaction effects of travel mode attitudes with sociodemographic and environmental characteristics differ between bicycle commuting and cycling for other purposes?*

Earlier studies focusing on determinants of bicycle usage have generated many insights into the relationships of cycling with intrapersonal, interpersonal, and environmental characteristics. However, it has been reported that associations of built environment characteristics with cycling may also depend on travel-related attitudes. Furthermore, limited evidence exists on how such interaction effects between attitudes, sociodemographic and environmental characteristics may differ across different types of cycling, e.g., cycling for commuting and cycling for other purposes. Chapter 4 fills this gap by investigating whether interactions between travel mode attitudes, urbanization level, and sociodemographic were different for bicycle commuting and cycling for other purposes.

4. *To what extent do life events correlate with changes in transport-related and recreational walking?*

Walking is a common form of physical activity and has a considerable impact on public health. Walking behavior may change over time due to life events including residential relocation. Only a few studies based on longitudinal data have examined the effects of life events on walking behavior. Hence, Chapter 5 provides novel longitudinal insights from the Netherlands for the years 2013 and 2015 regarding the extent to which life events are associated with changes in the transport-related and recreational walking duration.

5. *To what extent are different types of walking correlated, and how are these differently affected by natural and built environment characteristics?*

Walking is a central contributor to adults' physical activity levels while being an environmentally friendly travel mode. Natural and built characteristics of the residential environment may influence the attractiveness of transit use via walking. Whereas previous studies focused on transport-related and recreational walking on weekdays, the present study considers the three types of walking among Dutch adults—transit-related transport walking, non-transit-related transport walking and recreational walking—and assesses to what extent different types of walking are correlated, and how they are differently affected by natural and built environment characteristics on weekdays and weekends.

1.5 Thesis outline

This thesis consists of seven chapters. Chapters 2 to 6 are based on journal papers that have been published or are under consideration in international peer-reviewed journals. This approach results in minor overlaps among the different chapters, especially in the description of the data. The organization of this thesis is briefly described below.

Chapter 2 presents a detailed picture of how the health benefits of walking and cycling differ among population subgroups in the Netherlands using the Health Economic Assessment Tool (HEAT). Chapter 3 investigates the associations between the objectively measured natural and built environment characteristics and cycling duration in the Netherlands. Furthermore, interaction effects between environment characteristics and municipality size on cycling were assessed. Chapter 4 examines interactions effects between travel mode attitudes, urbanization level, and sociodemographic for bicycle commuting and cycling for other purposes based on the Netherlands Mobility Panel (MPN). Chapter 5 investigates the longitudinal influence of life events on changes in transport-related and recreational walking duration. Chapter 6 focuses on the effects of natural and built environment characteristics on different types of walking patterns on weekdays and weekends. Chapter 7 draws overall conclusions, reflects upon the thesis as a whole, and outlines avenues for future research.

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Chapter 2

Socioeconomic and demographic differences in walking and cycling in the Netherlands: how do these translate into differences in health benefits?

This chapter is based on the article Gao, J., Helbich, M., Dijst, M., Kamphuis, C.B.M. (2017) Socioeconomic and demographic differences in walking and cycling in the Netherlands: How do these translate into differences in health benefits? *Journal of Transport & Health.*

Abstract

Walking and cycling are effective means to increase people's daily physical activity. Since little is known about how differences in walking and cycling translate into inequalities in health benefits on the population level, this study estimated these health benefits for demographic and socioeconomic groups in the Netherlands. Population-representative data on walking and cycling among adults (aged 20-90 years) for the period 2010-2014 were analyzed with the Health Economic Assessment Tool (HEAT). Results showed pronounced differences between subgroups, with women, senior citizens (50-79 years), higher socioeconomic groups, and native-Dutch people walking and cycling more than others. Given the relatively high mortality rates and high levels of walking and cycling among senior citizens, it was found that a large number of deaths were prevented in that age group. In lower socioeconomic groups, despite their lower walking and cycling levels, it was found that even more deaths were prevented, given their large population size and higher mortality rates. The proportion of health benefits was found to be greater among the native Dutch because their walking and cycling levels as well as their population size were higher than among non-native groups. The study suggests that policies to increase walking and cycling among lower socioeconomic groups could induce further health benefits in the aggregate and thus help mitigate socioeconomic health inequalities.

Keywords: walking; cycling; Health Economic Assessment Tool; health inequalities; the Netherlands

2.1 Introduction

The Netherlands is well known for the prevalence of walking and cycling for transportation purposes (Pucher and Buehler, 2008). Cycling accounts for approximately a quarter of all journeys and about one-tenth of all kilometers traveled (KiM, 2014). Walking and cycling levels are significantly higher there than in other European countries such as Italy or France (Fishman et al., 2015a; Pucher and Dijkstra, 2003; Scheepers et al., 2013). Nevertheless, there is room for improvement, since about 30% of the commuting trips within five kilometers are still made by car (Engbers and Hendriksen, 2010). The World Health Organization (WHO) recommends more active travel (i.e., walking and cycling) in people's daily life to reduce the risk of non-communicable diseases (Arsenio and Ribeiro, 2015; WHO, 2010). Therefore, policy-makers are advised to develop strategies that stimulate active travel and discourage motorized transport (Fishman et al., 2015a; Kahlmeier et al., 2010).

To make the health benefits of walking and cycling more apparent to policy-makers, the WHO introduced the Health Economic Assessment Tool (HEAT) (Kahlmeier et al., 2014). The tool provides a method to estimate the number of deaths prevented by the beneficial health effects of both walking and cycling. Due to its transparency and simplicity, HEAT turned out to be highly appreciated, especially by non-health experts (Deenihan and Caulfield, 2014). Its value is reflected in the growing number of case studies applying the tool, especially in Western countries (Deenihan and Caulfield, 2014; Fishman et al., 2015b; Olabarria et al., 2013). These studies consistently report pronounced health benefits from walking and cycling at the general population level (i.e., all individuals in a sample without any stratification). Research on health inequalities provides solid evidence that physical and mental health varies significantly across the population taking education and age into account (Umberson and Montez, 2010; Wilkinson and Marmot, 2003). However, the literature remains inconclusive on whether the levels of walking and cycling among different demographic and socioeconomic groups also translate into differential health benefits.

A few mobility studies suggest that walking and cycling levels differ between population subgroups (Adams, 2010; Heesch et al., 2014; Kwasniewska et al., 2010; Scheepers et al., 2013). Kwasniewska et al. (2010) revealed a low prevalence of walking and cycling in high socio-economic groups (i.e., well-educated and higher-income groups) in Poland. Conversely, for the UK and the Netherlands respectively, both Adams (2010) and (Scheepers et al., 2013) found that higher-educated people walk and/or cycle more than groups with low educational attainment. Beenackers et al. (2012) reviewed 11 studies related to socioeconomic inequalities in active transport in Europe. No consistent associations were found between socioeconomic indicators (e.g., income, education, occupation) and active transport or the duration of walking and/or cycling across socioeconomic groups. Additionally, Goodman et al. (2013) showed that well-developed walking and cycling infrastructure was more easily accessible by well-educated individuals with a higher income. Specifically for the Netherlands, Kamphuis et al. (2009) found that adults aged 55-75 years from lower-income and lower-educational groups were less likely to engage in recreational walking, compared to higher income and educational groups.

Regarding age differences, some European studies found that the elderly (age 65+ years) gain more benefits than younger individuals (Edwards and Mason, 2014; Fishman et al., 2015b; Mueller et al., 2015). For Greater Rotterdam, the Netherlands, Böcker et al. (2016) explored how socio-demographics, health, environmental and weather attributes were differentially associated with the walking/cycling behavior of the elderly and non-elderly. In particular, elderly women were more likely to walk and cycle than elderly men. This finding was challenged by Olabarria et al. (2013) and Woodcock et al. (2014), who reported the opposite, namely that men had higher walking and cycling levels than women, while Edwards and Mason (2014) found no gender differences in the U.S.A. Regarding ethnic differences in walking and cycling, another U.S. study found more active travel among migrants than native residents (Garni and Miller, 2008). In countries with relatively high cycling levels such as the Netherlands, however, the natives are significantly more likely to cycle than the non-native population (Pucher and Buehler, 2008).

Previous research has shown that socioeconomic and demographic differences in walking and cycling do exist. In light of these findings, it may be assumed that health benefits from active travel differ across population subgroups (Mueller et al., 2015). However, empirical evidence to support this premise is lacking so far. In a country like the Netherlands, where walking and cycling levels are high (de Vries et al., 2010; Fishman et al., 2015b; Helbich et al., 2016), differences in walking and cycling between population groups may be presumed to be considerable, which could significantly contribute to health inequalities in the population at large. To substantiate that premise, this study applied the HEAT model to estimate how the health benefits of walking and cycling in the Netherlands differ for subgroups stratified by age, gender, education, income, and ethnicity.

2.2 Materials and Methods

2.2.1 Data

Data were collected on the average amount of time spent per person per week (in minutes) on walking and cycling by each population group. Also, the size of population group and the average annual mortality rate of each group were determined. The demographic data were obtained from Statistics Netherlands for the years 2010 to 2014 (CBS, 2016b), while the data on walking and cycling were collected by *National Travel Survey in the Netherlands (NTS)* (OViN, 2015), a travel survey among a nationally representative sample carried out by Statistics Netherlands. To increase the sample size, the data were pooled for 2010-2014, raising the total to 506,933 individuals. The NTS database also contains information about transport modes, trip destinations, travel purposes (e.g. utilitarian vs. recreational trips), as well as the start and end time of the trips. Population counts and average annual mortality rates for age and gender groups were derived from Statistics Netherlands (CBS, 2016c).

Consistent with the approach of Fishman et al. (2015b), population and mortality data from Statistics Netherlands were divided into ten age categories: 20-29, 30-39, 40-49, 50-59, 60-64, 65-69, 70-74, 75-79, 80-84, and 85-90 years. For a more accurate calculation, the broad category of the elderly (aged 60-90) was divided into five-year intervals as their mortality rates are higher than for younger population. Income levels per year were divided into the following three categories (Fishman et al., 2015a): low income (<€20K), middle income (€20K-€40K), and high income (>€40K). Educational attainment was stratified into low (i.e. primary school and lower general secondary school), middle (i.e. upper-division secondary school), and high (i.e. college and university) (CBS, 2016a).

2.2.2 The Health Economic Assessment Tool

HEAT is designed to estimate the health and economic benefit of regular walking and cycling among adults (Kahlmeier et al., 2014). The approach assumes a dose-response function between the number of minutes spent on walking or cycling and all-cause mortality reduction. More precisely, grounded in a meta-analysis by Kelly et al. (2014), HEAT assumes a 10% (95% confidence interval=6%, 13%) reduction in the mortality rate for each 100 minutes of cycling per week, and an 11% (95% confidence interval=4%, 17%) reduction for each 168 minutes walking per week. The following procedure is implemented to estimate the annual prevented number of deaths due to walking for a specific population group. First, the reduced mortality rate for this population group is calculated based on their minutes of walking (e.g. for males 20-29 years, the reduced mortality rate is 11% / 168 minutes * 42 minutes

= 2.7%; see Table 1). Second, the regular number of deaths in this population group is estimated by multiplying the population size and the mortality rate per 100,000 people (e.g. for males 20-29 years, the regular number of deaths is 1,038,353 * 43/100,000 = 447 deaths). Finally, the number of deaths prevented is calculated by multiplying the regular number of deaths by the reduced mortality rate (e.g. for males 20-29 years, this is: 447 * 2.7% = 12 prevented deaths per year). Since the mortality rates were not available for different socioeconomic groups, the age-specific mortality rate was used as a proxy in this study. Specifically, the number of deaths prevented was calculated for each age category of gender and socioeconomic groups and then these results were summed to get the total number of prevented deaths for those groups. A similar procedure was followed to calculate the prevented deaths due to cycling by applying the cycling-specific mortality rate reduction (i.e. a 10% reduction per 100 minutes cycled).

2.3 Results

2.3.1 Walking and cycling levels of different population groups

In general, Dutch adults spent 63 minutes on walking and 75 minutes on cycling per week. The duration of both activities peaks at around 65-69 years and starts to decline at the age of 80 (Figure 2.1). Cycling duration per week for men and women was nearly equal (75 versus 74 minutes). In contrast, women walked more (70 minutes) than men (57 minutes). When stratified by gender and age, the walking (Table 2.1) and cycling duration (Table 2.2) for females was slightly higher than for males aged 20-64 years. In the age group 65+, men cycled and walked more than women.

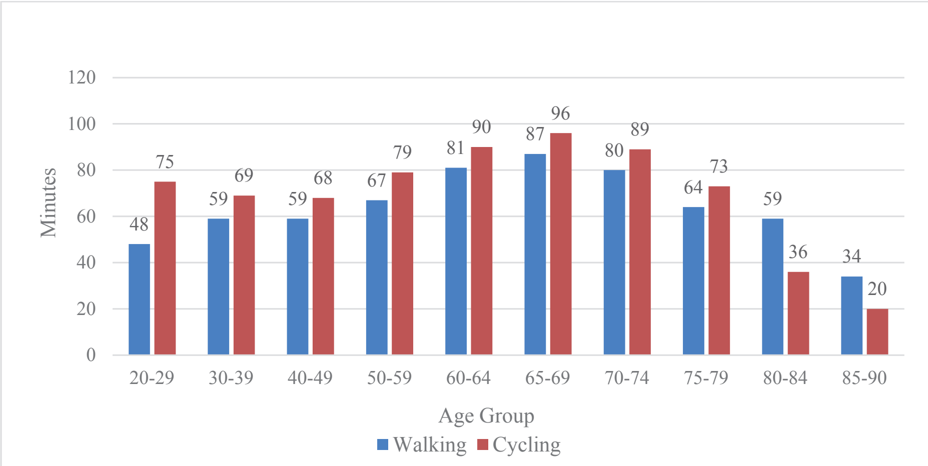

Figure 2.1 : Weekly walking and cycling duration per age group 2010-2014

Table 2.1 Annual number of deaths prevented due to time spent on walking for Dutch males and females, 2010-2014

	Age groups	Average weekly minutes of walking	Population size	Average annual mortality rate per 100,000 population	Mortality rate reduction (%)[a]	Annual number of deaths prevented
Males	20-29	42	1,038,353	43	2.7	12
	30-39	51	1,044,990	65	3.3	23
	40-49	49	1,294,324	156	3.2	64
	50-59	56	1,164,207	456	3.7	194
	60-64	74	535,181	920	4.9	239
	65-69	87	432,409	1,548	5.7	382
	70-74	81	311,312	2,531	5.3	417
	75-79	68	225,325	4,501	4.5	452
	80-84	64	144,144	8,161	4.2	496
	85-90	45	69,578	14,294	2.9	291
	Average	57	-	955	3.7	-
	Total	-	6,259,825	-	-	2,571
Females	20-29	54	1,019,356	21	3.5	7
	30-39	68	1,044,356	44	4.5	20
	40-49	70	1,274,760	126	4.6	73
	50-59	79	1,156,278	347	5.2	207
	60-64	88	532,849	640	5.7	196
	65-69	87	441,219	991	5.7	248
	70-74	79	341,159	1,542	5.2	271
	75-79	61	282,885	2,719	4.0	306
	80-84	55	224,181	5,308	3.6	429
	85-90	28	145,998	10,295	1.9	280
	Average	70	-	835	4.6	-
	Total	-	6,463,039	-	-	2,038

[a] Based on an estimated mortality rate reduction of 11% per 168 minutes of walking per week according to the meta-analysis of Kelly et al. (2014).

[b] Annual number of deaths prevented is calculated for each age group using the HEAT formula: (population size/100,000) * average mortality rate per 100,000 * % mortality rate reduction.

Table 2.2 Annual number of deaths prevented due to cycling for Dutch males and females, 2010-2014

	Age groups	Average weekly minutes of cycling	Population	Average annual mortality rate per 100,000 population	Mortality rate reduction (%)[a]	Annual number of deaths prevented[b]
Males	20-29	74	1,038,353	43	7.4	33
	30-39	68	1,044,990	65	6.8	46
	40-49	62	1,294,324	156	6.2	126
	50-59	77	1,164,207	456	7.7	409
	60-64	89	535,181	920	8.9	439
	65-69	100	432,409	1,548	10.0	669
	70-74	100	311,312	2,531	10.0	791
	75-79	89	225,325	4,501	8.9	899
	80-84	51	144,144	8,161	5.1	604
	85-90	42	69,578	14,294	4.2	418
	Average	75		955	7.5	-
	Total	-	6,259,825	-	-	4,434
Females	20-29	76	1,019,356	21	7.6	16
	30-39	69	1,044,356	44	6.9	32
	40-49	74	1,274,760	126	7.4	119
	50-59	81	1,156,278	347	8.1	326
	60-64	90	532,849	640	9.0	307
	65-69	93	441,219	991	9.3	406
	70-74	79	341,159	1,542	7.9	417
	75-79	60	282,885	2,719	6.0	461
	80-84	27	224,181	5,308	2.7	319
	85-90	10	145,998	10,295	1.0	150
	Average	74	-	835	7.4	-
	Total	-	6,463,039	-	-	2,554

[a] Based on an estimated mortality rate reduction of 10% per 100 minutes of cycling per week according to the meta-analysis of Kelly et al. (2014).

[b] Annual number of deaths prevented is calculated for each age group using the HEAT formula: (population size/100,000) * average mortality rate per 100,000 * % mortality rate reduction.

When socioeconomic groups were compared, it turned out that low-income groups were less likely to walk (31 minutes) and cycle (38 minutes) than higher-income groups (Table 2.3). The prevalence of walking and cycling peaked in the high-income group. This peak is particularly evident from the cycling duration, which was on average 113 minutes per week. Highly educated people also had a higher average weekly walking (79 minutes) and cycling (107 minutes) duration compared to low- and middle-educated groups. In terms of ethnicity, the native Dutch walked (64 minutes on average) and cycled (78 minutes) most, followed by people with a Western background.

Table 2.3 Annual health benefits of the time spent walking and cycling for socio-economic groups, 2010-2014

	Groups		Average weekly duration (minutes)	Population	Annual number of deaths prevented[c]
Walking	Income	< 20K euro	31	5,082,285	1,152
		20K-40K euro	80	4,528,951	2,251
		> 40K euro	92	3,111,629	970
	Education	Low	58	4,350,791	2,266
		Middle	57	4,948,923	1,162
		High	79	3,423,151	1,125
	Ethnicity	Dutch	64	10,159,001	3,963
		Western	66	1,291,000	474
		Non-Western	58	1,272,863	144
Cycling	**Income**	< 20K euro	38	5,082,285	1,398
		20K-40K euro	88	4,528,951	3,504
		> 40K euro	113	3,111,629	1,611
	Education	Low	59	4,350,791	3,225
		Middle	65	4,948,923	1,722
		High	107	3,423,151	1,778
	Ethnicity	Dutch	78	10,159,001	6,049
		Western	70	1,291,000	576
		Non-Western	52	1,272,863	140

[c] Annual number of deaths prevented is calculated for each group using the HEAT formula: (population size/100,000) * average mortality rate per 100,000 * % mortality rate reduction .

2.3.2 Health benefits of walking and cycling for different population groups

The number of deaths prevented by walking and cycling was greatest among the age groups of and 80-84 and 75-79 years, respectively (Figure 2.2). Despite the small population size of these elderly compared to younger people, death prevention was much higher among the elderly because of their relatively high levels of walking and cycling and their higher mortality rate. The reduction in mortality rate was a direct result of the average walking and cycling duration for the target group. In terms of cycling duration, the reduction in mortality was similar for men and women, namely 7.5% and 7.4%, respectively. On the other hand, the mortality rate reduction attributed to walking was larger for women (4.6%) than for men (3.7%). Even though men and women had similar walking and cycling durations, the number of deaths prevented among men was larger, since men had higher mortality rates than women across all age groups.

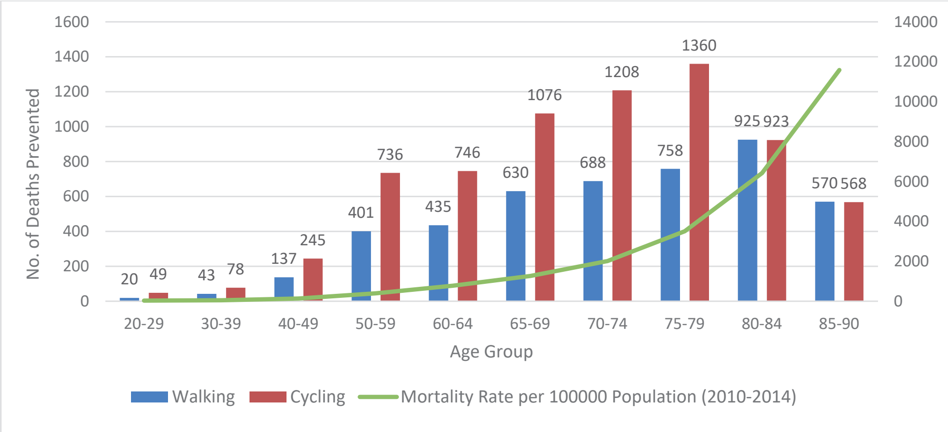

Figure 2.2: Number of death prevented per year and Mortality rate, per age group attributed to walking and cycling 2010-2014

On a population level, the health benefits of walking and cycling were greater among the low-educated than the middle- and high-educated groups. This reflects not only their large share of the population but also the fact that a large proportion of the low-educated group was elderly, an age group with a relatively high mortality rate. High-income groups had lower health benefits from walking than other income groups, caused by their smaller population size. Among the ethnic groups, the native Dutch benefited most from walking and cycling, as they had the highest prevalence of walking and cycling and comprised the largest share of the population. Conversely, the non-native groups had less health benefits due to their small population size (i.e. 10% of the total population) coupled with a lower prevalence of walking and cycling.

2.4 Discussion

2.4.1 Key findings

This is the first study to present a detailed picture of how potential health benefits of walking and cycling differ between population subgroups based on age, gender, and socioeconomic characteristics (i.e. education, income, and ethnicity) in the Netherlands. This study used HEAT to estimate the mortality rate reduction (i.e. a direct result of average walking and/or cycling durations) and the number of deaths prevented by walking and cycling on a population level (i.e. taking the size of the population subgroup and the average mortality rate into account). The results showed large differences in walking and cycling levels between different groups, with women, senior citizens (50-79 years), higher socioeconomic groups, and the native Dutch walking and cycling more than members of the other subgroups. Among senior citizens (50-79 years), as a result of relatively high mortality rates and high walking and cycling levels, a large number of deaths were prevented. In low educated groups, despite their lower walking and cycling levels, more deaths were still prevented than in higher educated groups due to the large population size of the low educated group and their higher mortality rates. Native Dutch people derived more benefit from walking and cycling than the non-natives because of their higher walking and cycling levels and larger population size.

We found that women tend to walk more than men, which is consistent with the results of Olabarria et al. (2013). This may reflect the fact that women are more likely to engage in habitual active travel. A possible explanation may be that women make more trips for utilitarian reasons (household/personal physiological and biological needs-related business (Garrard, 2003). In the Netherlands, women are more likely to work at a part-time job that is closer to home and make shorter, linked journeys (e.g. work, shops, school, and home). Therefore, they may be more likely to walk rather than take the car. Women also have less discretionary time than men, particularly when they combine work and family responsibilities (Garrard et al., 2008). On the other hand, elderly women showed lower levels of cycling compared to elderly men, which is consistent with the findings of previous studies (Curtis et al., 2000; Lee, 2005; Sun et al., 2013). In terms of age groups, we found that people in their early stage of retirement (age 65-75) walk and cycle more than members of other age groups. More free time combined with relatively good health may offer them the opportunity to spend more time on active travel (Fishman et al., 2015b).

With regard to socioeconomic groups, our results revealed that the higher-income and higher-educated groups were the most likely to be active. This is in line with previous studies showing that higher socioeconomic groups are likely to engage in more physical activity (Fishman et al., 2015a; Heinen, 2011; Kitchen et al., 2011; Scheepers et al., 2013). As illustrated by Heinen (2011) and Beenackers et al. (2012), people with high incomes tend to cycle more for leisure and exercise, while low-income groups used the bike mostly for utilitarian purposes. Among different ethnic groups, in line with Harms et al. (2014), people with a non-Western background walked and cycled less than the native Dutch. Indeed, people with an ethnic background usually rely on public transport instead of bicycles, possibly because of a lack of cycling skills, cultural norms that are not in favor of cycling, or since the long distance of their journey to work discourages cycling (Harms, 2007).

Our findings suggested that a large number of prevented deaths in certain population groups does not always reflect high walking and cycling levels but can also stem from a large population size, a high mortality rate or both. Further, some population groups (e.g. elderly) may have lower physical activity levels due to their poorer health status (e.g. their health did not allow them to be physically active) (Moschny et al., 2011). First, despite the small population size compared to younger people, the death prevention of the elderly (age 65+) was much higher due to their higher walking and cycling levels and higher mortality rate. Particularly, elderly men gained higher health benefits than elderly women due to their higher walking and cycling levels. This is consistent with the findings of Mueller et al. (2015) that elderly people are at high risk for chronic degenerative disease, and physical activity can substantially mitigate those diseases. Secondly, while the lowest socioeconomic groups spent less time walking and cycling than other groups, the health benefits accruing to this category as a whole were much higher as a result of its large proportion of the population and high mortality rate. This could also be explained by the fact that a large number of the elderly belong to low socioeconomic groups. Considering ethnicity, the native Dutch as a group benefited more from walking and cycling than the category of non-natives because of their higher walking and cycling levels and their larger share of the population. It may be that people from different educational or cultural backgrounds live in different environmental circumstances, or view the same built environment differently, leading to different walking and/or cycling levels (Sallis et al., 2013).

2.4.2 Strengths and limitations

This is the first study to explore how and to what extent the health benefits of walking and cycling on a population level vary across different subgroups. A major strength is the large sample, being representative for the Dutch population. Its size not only allowed a specific analysis of the inequality of the health benefits of walking and cycling across different subgroups but also provided sufficient evidence to explain each indicator (i.e., population size, duration of walking and cycling, mortality rates) in terms of inequality issues.

However, this study also has some limitations. First, information on all-cause mortality rates for specific socioeconomic groups (i.e. income, education, and ethnicity) was not accessible. Therefore, all-cause mortality rates for each age group were used as a proxy for specific socioeconomic groups, which may induce inaccuracies. Second, our results are likely to underestimate the true total health benefits. Only mortality without prevented morbidity is taken into account in HEAT. Further, HEAT calculations have three components: population size, average mortality rates, and mortality rate reduction due to walking/cycling. According to our results, most deaths are prevented among the low socioeconomic groups. That outcome may be confusing to policy-makers, who could conclude that the low socioeconomic groups have sufficiently high levels of walking and cycling. In fact, their walking and cycling levels are lower than those of high socioeconomic groups, but their 'higher' health benefits merely a reflection of their larger population size and/or higher mortality rates. Thus, increasing the walking and cycling levels of lower socioeconomic groups could still be an effective way to reduce socioeconomic health inequalities. Finally, since the current study pooled the data-set for an entire country, possible variations in walking and cycling levels across different areas of the Netherlands were ignored. Therefore, it would be interesting to explore spatial differences in walking and cycling levels, and how these translate into health benefits, across the country.

2.4.3 Implications for policy

It is important to develop policies and interventions that encourage the population groups with lower walking and cycling levels to do more walking and cycling, as this behavior offers great potential for improving population health and may contribute to mitigating health inequalities. As shown by our results, despite a low level of cycling (59 minutes per week), the annual number of deaths prevented among the low-educated group is already about 3225. If the amount of time they spent cycling could be increased to match that of the high-educated group (i.e. to 107 minutes per week), this would result in an increase of about 40% more prevented deaths among the low-educated group above the current number. Increasing walking and/or cycling levels may thus have enormous aggregate health benefits among these lower socioeconomic groups and could contribute to a reduction of socioeconomic health inequalities. Therefore, policy-makers should focus more on subgroups with a high mortality rate and large population size but low walking and/or cycling levels. With such policies, achievement of mitigating health inequalities between low and high socioeconomic groups should be possible (Mackenbach et al., 2003; Singh and Siahpush, 2002; Stringhini et al., 2010).

2.5 Conclusions

This study is the first to examine how levels of walking and cycling among different income, education, ethnic and age groups translate into inequalities in health benefits on a population level. In the Netherlands, women, senior citizens (50-79 years), higher socioeconomic groups, and the native Dutch showed higher walking and cycling levels than other population subgroups. Our findings suggest that a large number of prevented deaths in some population subgroups does not always reflect high walking and cycling levels, but can also stem from a large population size, a high mortality rate or both. Particularly among senior citizens, as a result of their relatively high mortality rates and high walking and cycling levels, a large number of deaths were prevented. In lower socioeconomic groups, despite their relatively low walking and cycling levels, more deaths were prevented than among higher socioeconomic groups due to the large population size and higher mortality rates of low socioeconomic groups. In aggregate, the native Dutch are associated to more aggregate potential health benefits from walking and cycling than the non-natives because of their higher walking and cycling levels and larger population size. The research outcomes are of fundamental importance for both urban planners and health policymakers. Results show that more attention should be paid to subgroups with a high mortality rate and large population size but low walking and/or cycling levels, which are for instance the lower socioeconomic groups. Urban planners and policy makers should develop strategies and interventions to increase walking and cycling levels among lower socioeconomic groups, which finally may reduce socioeconomic inequalities in health.

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Chapter 3

The role of the natural and built environment in cycling duration in the Netherlands

This chapter is based on the article: Gao, J., Kamphuis, C.B.M, Dijst, M., Helbich, M. (2018) The role of the natural and built environment in cycling duration in the Netherlands. *International Journal of Behavioral Nutrition and Physical Activity 15, 82.*

Abstract

Cycling for transportation has the potential to contribute to an increase in people's physical activity levels. A growing body of evidence links the natural and the built environment to cycling. Whereas previous studies were mostly done within one city or one region, the present study covers the whole of the Netherlands, allowing an investigation of whether associations between environmental characteristics and cycling are context-specific. The study examines the extent to which objectively measured natural and built environment characteristics contribute to cycling duration in the Netherlands, as well as the differential effect of environmental characteristics on cycling duration by municipality size. Our sample from the Dutch National Travel Survey 2010–2014 comprised 110027 people aged 20–89 years, residing in 3163 four-digit postal code areas, nested within 387 municipalities across the whole of the Netherlands. Multilevel Tobit regression models were fitted to assess the associations between the natural and the built environment with average daily cycling duration (in minutes), while adjusting for individual and household characteristics. Interaction effects of natural and built environment characteristics and municipality size on cycling duration were also investigated. Higher address density, more bus stops, and shorter distance from home to the nearest train station were positively related to cycling duration. Respondents were more likely to cycle on days with higher temperatures, less wind, and less precipitation. Interaction tests showed that increased street density and address density were less cycling-promotive in small urban areas compared to medium or large cities. On the other hand, the positive association between number of bus stops and cycling duration was weaker in the largest and medium-sized cities compared to small urban and rural areas. Interactions suggest that relations between environmental characteristics and cycling duration are context-specific (i.e., dependent on circumstances that differ between highly urbanized and less urbanized areas). Our findings need to be replicated in other countries to gain more insight into the interplay between environmental factors and municipality size.

Keywords: Cycling; Natural and built environment; Municipality; Multilevel regression model; the Netherlands

3.1 Introduction

Physical activity provides a range of health benefits and reduces the risks of chronic diseases, such as obesity, diabetes, and high blood pressure (Furie and Desai, 2012; Oja et al., 2011). Cycling for transportation has the potential to contribute to an increase in people's physical activity levels (Rutter et al., 2013), and is an environmentally sustainable mode of transportation (Heesch et al., 2014). As a consequence, national and local governments are eager to promote cycling in order to obtain the associated health benefits (Lee and Moudon, 2004; Mertens et al., 2017; Zhao, 2014). Large variations exist in bicycle use between countries. It was estimated that bicycling accounts for about 1–2% of all trips in North America and Australia (Bauman et al., 2008), which is a much lower percentage than in northern Europe: Figures range from a high of 27% in the Netherlands (all ages) to 18% in Denmark (10-84 years) and around 10% in Finland (6+ years), Germany (all ages), and Belgium (6+ years) (Bassett et al., 2008; Pucher and Buehler, 2008). However, bicycle use varies not only between countries, but also between areas and municipalities within a country (Bonham and Suh, 2008). Although 27% of all trips are made by bicycle in the Netherlands (Fishman et al., 2015b; Harms et al., 2014), there are substantial variations in the share of short-distance (i.e., up to 7.5 kilometers) bicycle trips between Dutch municipalities; for example, the share is 17% in Heerlen[1] and nearly 50% in Groningen[2] (Schaap et al., 2016). These large variations between municipalities possibly correspond to variations in environmental characteristics, but few studies have examined this (de Vries et al., 2010; Mertens et al., 2017).

Studies have shown that cycling duration is related not only to individual attributes (e.g., sociodemographic characteristics), but also to the environment in which people live and move around (Feng, 2016; Handy et al., 2002; Sallis et al., 2006). There is empirical evidence that population and address density, land use, building diversity, and urban design (e.g., street network configurations) affect cycling levels (Buehler and Pucher, 2012; Ewing and Cervero, 2010; Nielsen et al., 2013; Wijk et al., 2017; Zahabi et al., 2016). The effects of population density on cycling behavior might often be indirect. A higher population density is often required to support a greater diversity in local destinations and to reduce distances between places. Higher population density is found to relate to a higher likelihood of bicycle use (Heinen et al., 2010; Zhao, 2014). Similarly, land use diversity, characterized by a mixed land-use, brings origins and destinations closer together and shortens trip

1 Heerlen: 45.53 km^2 , 1,929 people per km^2.
2 Groningen: 83.75 km^2 , 2,572 people per km^2.

distances (Christiansen et al., 2016; Heinen et al., 2010; Helbich, 2017). Mixed-use neighborhoods make trips by bike more convenient (Munshi, 2016). Regarding urban design, a cycling friendly street network and infrastructure characteristics may increase the accessibility of different destinations by bicycle. Studies suggest that people who live in neighborhoods that have been designed to be cycling friendly, which are characterized by higher levels of street connectivity, may increase the likelihood of bicycle use (Buehler and Pucher, 2012; Ewing et al., 2004; Helbich et al., 2016; Munshi, 2016; Wong et al., 2011).

In addition to the built environment factors, natural environment characteristics are also thought to be important (Heesch et al., 2014; Wong et al., 2011). Various studies have investigated the effects of weather on daily bicycle use (Böcker et al., 2015; Heinen et al., 2011b; Thomas et al., 2013), and found that sunshine and warm weather increased the probability of commute cycling, and that cold weather and windy weather were inversely associated with cycling (Böcker and Thorsson, 2014; Heinen et al., 2011a). Weather may influence the relation between environmental determinants and bicycle use (Tucker and Gilliland, 2007). Since cyclists are directly exposed to the elements, high or low temperatures and heavy precipitation may make cyclists hesitant to expose themselves for too long. Therefore, the effects of weather may be inherently related to cycling duration.

Even though these studies contributed significantly to our understanding of how natural and built environments are related to cycling behavior, findings appear to be inconsistent. For example, higher residential densities are related to higher shares of non-motorized travel (e.g., cycling) (Parkin et al., 2008; Zahran et al., 2008), while another study concluded that residential densities do not have a large influence on bicycle use (Rodríguez and Joo, 2004). Additionally, while green space was reported to be positively related to cycling (Lee and Moudon, 2008; Wang et al., 2016), others found no associations (Christiansen et al., 2016). One major concern is that although it has been found that factors promoting or impeding cycling show significant spatial variation, most previous studies were based on the assumption that the relationship between individuals as well as environmental factors and cycling is spatially constant (i.e., built environment variables influence travel behavior in a similar manner everywhere) (Feuillet et al., 2015; Helbich et al., 2014). However, the associations between cycling behavior and the natural and built environment characteristics might vary across areas (Feuillet et al., 2015; Helbich et al., 2014). In addition, previous studies were mostly conducted within only one city or one region, whereas investigations covering a larger area (e.g., a whole country or several countries such as done in the study of (Mertens et al., 2017)) are likely to result in more variation in environmental characteristics. More advanced statistical analyses, including interaction effects, may also uncover complex relationships between the environmental determinants and cycling behavior. For example, it is necessary to examine how the relationships between natural and built environmental determinants and cycling behavior may vary across areas, especially according to the urbanization level, as a previous review study has suggested (Panter et al., 2008). This can offer a better insight into the role of natural and built environment characteristics for cycling across municipalities.

It is well-established that cycling behavior (e.g. duration and frequency) vary depending on people's sociodemographic characteristics (e.g., age, gender, education level) (Goodman et al., 2013; Heesch et al., 2012; Perchoux et al., 2017; Winters et al., 2010) and across geographic scales (Adams et al., 2014; Feuillet et al., 2015). Although sociodemographic characteristics have been shown to be more strongly correlated with travel behavior than environmental factors (Schwanen et al., 2003; Weber and Kwan, 2003), urban form (e.g. municipality size) also seems to explain some variations in travel behavior. From a theoretical perspective, the socio-ecological model suggests a human-environment interplay (Sallis et al., 2006). It is therefore, necessary to examine urban form characteristics such as municipality size as a potential moderator of the relationship between natural and built environmental characteristics and cycling behavior. Such interactions may help to clarify inconsistent associations between environment and cycling.

To sum up, results concerning the associations between cycling duration and the natural and the built environment are contradictory (Fraser and Lock, 2011), research on how natural and built environment characteristics relate to between-area variation in cycling duration is inconclusive, and whether the associations between these environment characteristics and cycling duration differ across settings (e.g., whether they are moderated by municipality size) (Mertens et al., 2017) is unknown. The aim of the present research was to investigate the extent to which objectively measured natural and built environment characteristics contribute to differences in cycling (for all purposes) duration in adults (20–89 years) between 4-digit postal code areas (PC4 areas) and between municipalities across the Netherlands, and to explore interaction effects between environment characteristics and municipality size on cycling. We hypothesized that the associations between cycling duration and natural and the built environment characteristics would vary across areas and be potentially moderated by municipality size. To our knowledge, no previous study has investigated the hypothesized moderating effect of municipality size on the association between natural and the built environment and cycling.

3.2 Materials and Methods

3.2.1 Study design

This study was cross-sectional for the period 2010–2014 and dealt with adults aged 20–89 years residing in 3163 postal code areas (i.e., PC4 level) nested in 387 municipalities across the Netherlands. Figure 3.1 summarizes the underlying conceptual model.

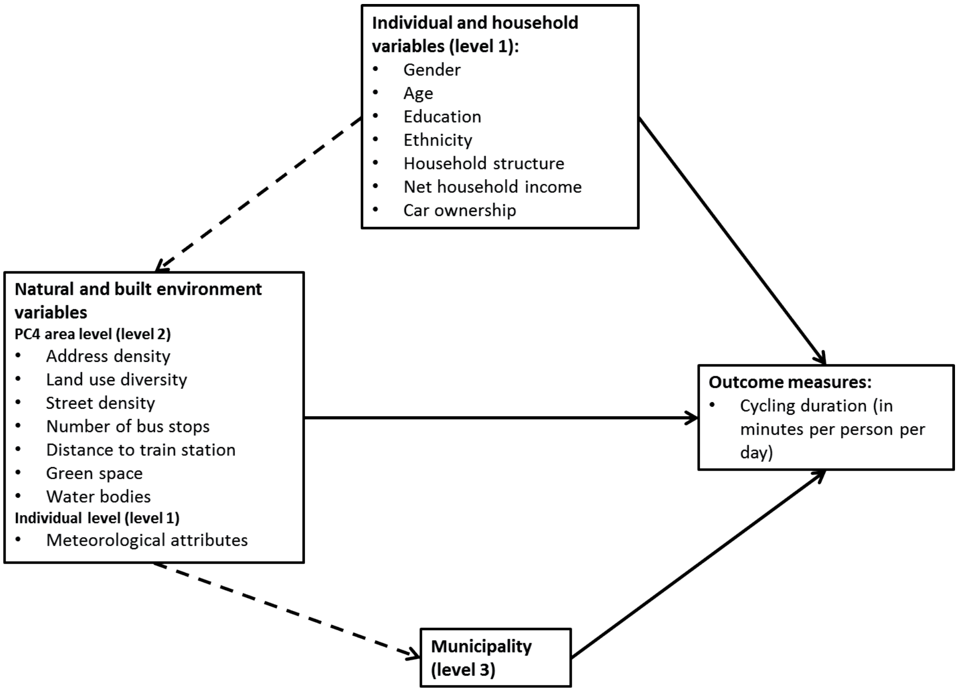

Figure 3.1 Conceptual model

3.2.2 Travel survey data

Data were obtained from the Dutch National Travel Survey (NTS) for the period 2010–2014. The NTS is a continuous survey of approximately 40000 individuals conducted annually by Statistics Netherlands (OViN, 2015). Respondents report their transportation behavior by means of a travel diary for one day. For each trip, travel data include transportation modes, place of origin and destination, time of departure and arrival, and travel purpose. The sample is representative of the Dutch population. The respondents' residential locations were geocoded on a PC4 level, which allowed data linkages with attributes describing the residential environment. Participants without postal code information (n=708) were excluded from the research. This resulted in a final sample of 110027 people aged 20–89 years, residing in 3163 PC4 areas with a mean number of respondents of 34 people (SD=31), nested in 387 municipalities (level 3).

3.2.3 Cycling duration

The outcome variable was total daily cycling duration in minutes per person. This included cycling for all purposes, i.e. travel-related as well as recreational cycling. Cycling duration was calculated based on the travel dairy data.

3.2.4 Built environment variables

The selection of built environment measures was guided by the literature (Winters et al., 2011; Wong et al., 2011). The variables were calculated at the PC4 level using existing spatial data (CBS, 2012, 2014a, b) for the year 2014. Address density refers to the total number of addresses divided by the PC4 area (CBS, 2014a). Land-use diversity is represented by a Shannon entropy index. A value of 0 refers to one land use class per area, and a value of 1 refers to an even distribution of all land use types per area (Cervero and Kockelman, 1997; Helbich, 2017). The operationalization considered the five most relevant land use types for residents' daily activities, namely residential, commercial, industrial, and recreational areas, and public services (e.g., police station, hospital) (CBS, 2014a). Street density (Kadaster, 2012), distance to nearest train station (CBS, 2014b), and number of bus stops per PC4 reflect transportation-related built environment measures. The latter also reflects competition between bicycle and public transportation.

Based on the population of each municipality, municipality size was classified into four classes: the four largest cities, which have > 250000 inhabitants (i.e., Amsterdam, Rotterdam, Den Haag, and Utrecht); medium-sized cities with 100000–250000 inhabitants; small urban areas with 50000–100000 inhabitants; and suburban/rural areas with < 50000 inhabitants (see Figure 2 in the appendix 1) (CBS, 2017).

3.2.5 Natural environment variables

Daily meteorological variables were collected from 33 weather stations across the Netherlands (KNMI, 2017). We obtained weather data from the weather station closest to each participant's residential area for the day on which the travel diary was kept. We matched the trip date with daily measures of maximum air temperature (in °C), precipitation sum (in mm), and average wind speed (in m/s), all of which are frequently used measures (Böcker et al., 2015; Helbich et al., 2014). The proportion of green space (including agricultural and natural areas, man-made greenery (e.g., parks)) and water space per PC4 was abstracted from the most recent Dutch land use database for the year 2012 (Hazeu et al., 2014).

3.2.6 Individual and household characteristics

Individual characteristics were obtained from the National Travel Survey. We categorized net household income per year into low (< €20000), medium (€20000–40000), and high (>€40000) (Fishman et al., 2015a). Educational attainment was stratified into three categories: low (i.e., primary school and lower general secondary school), medium (i.e., upper-division secondary school), and high (i.e., college and university) (CBS, 2016).We also controlled for numerous other demographic characteristics, including age, gender, ethnicity, household structure, and car ownership.

3.2.7 Statistical analyses

Descriptive statistics were used to summarize the data, and Pearson correlation coefficients were used to test for multicollinearity among the covariates. Correlations < -0.8 or > 0.8 are considered problematic (Freedman et al., 1991).

To examine the associations between the built environment variables and cycling duration, we constructed multilevel regression models that allowed variables observed at different hierarchical levels (i.e., individuals nested in PC4 area, nested in municipalities). Unlike basic regressions, multilevel models can capture correlations that arise due to hierarchical data structures (Bottai et al., 2006; Jones and Duncan, 1996; Stawski, 2013). Furthermore, as the outcome variable (cycling duration) could not be negative, and showed an excess of zeros due to a relatively large share of respondents not reporting any cycling trips on the day of the survey, wrongly assuming that data were not censored to zero would have led to wrongly predicting a non-existent negative value. We therefore applied a multilevel Tobit regression model, which can better handle the dependent variables' absence of negative values and excess of zero (Greene, 2003). To facilitate the interpretation of the variance at both PC4 area level and municipality level, we calculated two intraclass correlation coefficients (ICC) (Snijders and Bosker, 1999). The ICC refers to the proportion of total variance in the outcome that is attributable to the PC4 level and municipality level (Merlo et al., 2005). For example, the ICC in level 2 expresses the similarity in cycling duration between persons located in the same PC4. An ICC equal to 100% would imply that all people in a PC4 are have a similar cycling duration, while an ICC equal to 0% imply that people do not share any PC4 area related cycling duration.

Our multilevel regression models were restricted to random intercepts, because the average cluster size was small (i.e., on average 34 people were nested in each PC4 area and eight PC4 areas were nested in each municipality), resulting in reduced power for both random intercepts and slopes model (Snijders, 2005).

We estimated the following models. First, we fitted a three-level random intercept model without explanatory variables (model 1). Second, model 1 was extended with individual and household variables (model 2). Third, model 3 also included both the natural and the built environment variables. Due to varying units, the continuous variables were standardized, and the most frequent category was used as the reference category. Subsequently, interactions between environmental factors and municipality size were tested in separate models, by adding the interaction term based on model 2, which resulted in a total of 10 interaction models. Significance was interpreted using the 95% confidence interval (CI). This interaction approach was based on previous interaction studies (Beenackers et al., 2014; Ding et al., 2012). All models were implemented in Stata 15.

3.3 Results

3.3.1 Descriptive statistics

The sample comprised participants aged from 20 to 89 years, 51.7% were females. Most people aged 40–49 years (21.5%) and 50–59 years (20.8%). About 30.4% of the participants (n=33443) cycled for more than 1 minute per day, the average daily cycling duration was 42.2 minutes per day. Among all participants, the average daily cycling duration was 12.8 minutes. Also, the variations between PC4 areas were larger (average duration = 11.86 minutes, SD=10.86) than they were between municipalities (average duration = 11.81 minutes, SD=3.77). The longest average cycling duration occurred in Groningen, a municipality in the north of the Netherlands (see Figure 3.3 in the appendix 3). Further, descriptive statistics regarding cycling behavior, sociodemographic characteristics, natural and built environment characteristics, and different municipality sizes are presented in Table 3.1. Multicollinearity among the covariates was not a concern, as indicated by the Pearson correlations (see Table 3.5 in the Appendix 2).

Table 3.1: Descriptive statistics

Indicators	Measures	All participants (N=110,027)	
		Mean(S.D.)	% per category
Dependent variables			
Cycling duration (in minutes	≥0 minute per day	12.8(32.6)	
Individual and household variables			
Gender	Male		48.3%
	Female		51.7%
Age	20-29		12.8%
	30-39		16.0%
	40-49		21.5%
	50-59		20.8%
	60-69		17.1%
	70-79		9.1%
	80-89		2.7%
Household structure	Single-person household		17.1%
	Couple without children		36.8%
	Couple with children		40.4%
	Single parent with children		4.5%
Net household income	< €20,000		13.1%
	€20,000–40,000		42.8%
	>€40,000		44.2%
Education	Low		27.4%
	Medium		37.6%
	High		35.1%
Ethnicity	Dutch		94.4%
	Non-Dutch		5.6%
Car ownership	No car		10.8%
	1 car		52.6%
	2 or more cars		36.6%
Built environment variables			
Address density (1,000 addresses per km^2)		1.31(1.54)	
Land use diversity		0.62(0.21)	
Street density (km/km^2)		16.30(8.83)	
Number of bus stops		13(10.58)	
Distance to train station (km)		6.79(7.29)	
Natural environment variables			
Green space (%)		61.59(23.34)	
Water bodies (%)		4.18(6.52)	
Daily max. air temperature (°C)		14.6(7.2)	
Daily precipitation sum (mm)		4.1(1.96)	
Daily average wind speed (m/s)		2.01(4.33)	
Percentage of respondents in each municipality size	Four largest cities		8.6%
	Medium-sized cities		21.3%
	Small urban areas		17.3%
	Suburban/rural areas		52.7%

3.3.2 Multilevel Tobit regression model to explain cycling duration

As shown in Table 3.2, associations between individual and household characteristics and cycling duration were all significant (Model 2) and remained significant after taking environmental characteristics into account (Model 3). The variance in cycling duration decreased from 3.5% (in model 2) to 3.4% (in model 3) at the PC4 area level, indicating that cycling duration variation between PC4 areas could be to a minor extent explained by natural and built environmental characteristics (see Table 3.2). Rather, an alternative reason for the minor difference could be the actual PC4 areas do not correspond with the boundaries that shape the relevant environment for cycling duration (Merlo et al., 2005). For municipalities, the variance in cycling duration remained at 2.2%, also after taking environmental characteristics into account.

The results of model 3 suggest that the built environment variables were largely associated with cycling duration, also when individual and household variables were controlled for. Respondents living in PC4 areas with a higher address density, more bus stops, and shorter distance to the nearest train station tended to cycle longer. A higher temperature was also positively related to cycling duration. Wind speed and precipitation as well as percentage of green showed an inverse correlation with cycling duration. No significant associations were found between cycling duration and the other natural and built environment variables, such as land-use diversity, street density, and water bodies.

Table 3.2: Results of the three-level Tobit regression model for cycling duration

	Model 1 (S.E.)	Model 2 (S.E.)	Model 3 (S.E.)
Intercept	-1.80***(0.02)	-1.18*** (0.03)	-1.13*** (0.04)
Individual and household level			
Age (yrs.)			
20-29 (ref.= 40-49)		-0.13***(0.03)	-0.14***(0.03)
30-39		-0.18***(0.03)	-0.19***(0.03)
50-59		0.20***(0.03)	0.20***(0.03)
60-69		0.35***(0.03)	0.36***(0.03)
70-79		0.13***(0.04)	0.13***(0.04)
80-89		-0.77***(0.06)	-0.76***(0.06)
Gender			
Man (ref.= Female)		-0.28*** (0.02)	-0.28*** (0.02)
Education			
Lower (ref.= medium)		-0.08*** (0.02)	-0.08*** (0.02)
Higher		0.19*** (0.02)	0.18*** (0.02)
Net household income			
< €20,000 (ref.= >€40,000)		-0.14*** (0.03)	-0.14*** (0.03)
€20,000–40,000		-0.10*** (0.02)	-0.10*** (0.02)
Ethnicity			
Other (ref.= Dutch)		-0.83*** (0.04)	-0.85*** (0.04)
Household structure			
Single-person household (ref.= Couple with children)		-0.56*** (0.03)	-0.57*** (0.03)
Couple without children		-0.22*** (0.02)	-0.23*** (0.02)
Single parent with children		-0.43*** (0.04)	-0.43*** (0.04)
Car ownership			
No car (ref.= 1 car)		0.95*** (0.03)	0.93*** (0.03)
2 or more cars		-0.96*** (0.02)	-0.95*** (0.02)
Daily weather conditions			
Daily average wind speed (m/s)		-0.08*** (0.01)	-0.08*** (0.01)
Daily max. air temperature (°C)		0.27*** (0.01)	0.27*** (0.01)
Daily precipitation sum (mm)		-0.07*** (0.01)	-0.08*** (0.01)
4-digit postal code zone level			
Address density (1,000 addresses per km^2)			0.09*** (0.21)
Land use diversity			-0.01 (0.01)
Street density (km/km^2)			-0.02 (0.02)
Number of bus stops			0.02*(0.01)
Distance to train station (km)			-0.06**(0.02)
Percentage of green (%)			-0.04 (0.02)
Percentage of water (%)			-0.02 (0.01)
Level 1: individual and household			
Variance intercept S_1^2	5.29 (0.05)	4.98 (0.04)	4.98 (0.04)
Level 2: 4-digit postal code			
Variance intercept S_2^2	0.11(0.01)	0.07(0.01)	0.06(0.01)
Level 2: ICC	**4.4%**	**3.5%**	**3.4%**
Level 3: Municipality			
Variance intercept S_3^2	0.14(0.02)	0.11(0.01)	0.11(0.01)
Level 3: ICC	**2.5%**	**2.2%**	**2.2%**

Sig. Codes: *$p \leq 0.050$; **$p \leq 0.010$; ***$p \leq 0.001$.

Ten interactions between natural and built environment and municipality size were significant (Table 3.3, Table 3.4). Several associations between environmental characteristics and cycling were weaker in small urban or rural areas than in urbanized areas. Specifically, the positive associations between address density and street density and cycling duration in larger cities were smaller or even negative in small urban areas. This may explain the nonsignificant association between street density and cycling duration when the interaction effects are not considered in model 3. In contrast, the positive association between number of bus stops and cycling duration was weaker in the four largest cities and the medium-sized cities compared to small urban and rural areas. Further, the negative association between distance to train station and cycling duration was strongest in large cities, compared to less urbanized municipalities. More green was inversely related to cycling duration, and this association was most pronounced in the four largest cities

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Table 3.3: Associations of built environment attributes, municipality size, and built environment × municipality size interactions with cycling duration

Municipality size	Address density (1,000 addresses per km²) (AD)		Land use diversity (LD)		Street density (km/km²) (SD)		Number of bus stops (BS)		Distance to train station (km) (DT)	
		β(95%CI)		β(95%CI)		β(95%CI)		β(95%CI)		β(95%CI)
Four largest cities (M1) (ref.= M4)	AD	0.208***(0.11,0.31)	LD	-0.018 (-0.05,0.01)	SD	0.108*** (0.06,0.15)	BS	0.066***(0.03,0.10)	DT	-0.08***(-0.12,-0.04)
	M1	-0.299 (-0.64,0.05)	M1	0.035 (-0.30,0.37)	M1	-0.105 (-0.46,0.25)	M1	0.040 (-0.30,0.38)	M1	-0.196 (-0.56,0.17)
	AD×M1	-0.081 (-0.19,0.03)	LD×M1	0.024 (-0.05,0.10)	SD×M1	-0.037 (-0.15,0.07)	BS×M1	-0.136***(-0.21,-0.06)	DT×M1	-0.398* (-0.73,-0.06)
Medium-sized cities (M2)	AD	0.208***(0.11,0.31)	LD	-0.018 (-0.05,0.01)	SD	0.108*** (0.06,0.15)	BS	0.066***(0.03,0.10)	DT	-0.08***(-0.12,-0.04)
	M2	-0.007 (-0.15,0.16)	M2	0.137 (-0.01,0.28)	M2	0.060 (-0.09,0.21)	M2	0.135 (-0.01,0.28)	M2	0.033 (-0.13,0.20)
	AD×M2	0.101 (-0.22,0.02)	LD×M2	-0.027 (-0.08,0.03)	SD×M2	-0.069 (-0.15,0.01)	BS×M2	-0.065* (-0.12,-0.01)	DT×M2	-0.152 (-0.36,0.06)
Small urban areas (M3)	AD	0.208***(0.11,0.31)	LD	-0.018 (-0.05,0.01)	SD	0.108*** (0.06,0.15)	BS	0.066***(0.03,0.10)	DT	-0.08***(-0.12,-0.04)
	M3	-0.054 (-0.18,0.08)	M3	0.046 (-0.08,0.17)	M3	-0.014 (-0.14,0.11)	M3	0.042 (-0.08,0.17)	M3	0.012 (-0.11,0.14)
	AD×M3	-0.209** (-0.36,-0.06)	LD×M3	0.010 (-0.05,0.07)	SD×M3	-0.108** (-0.19,-0.03)	BS×M3	-0.064 (-0.14,0.01)	DT×M3	-0.034 (-0.16,0.09)

[a]All models adjusted for age, gender, income, education, ethnicity, household structure, and number of cars in the household

M4=Suburban/rural areas are the reference category

Sig. Codes: *p≤ 0.050; **p≤ 0.010; ***p≤ 0.001.

Table 3.4: Associations of natural environment attributes, municipality size, and natural environment × municipality size interactions with cycling duration

Municipality size	Daily average wind speed (m/s) (W)		Daily max air temperature (°C) (T)		Daily precipitation sum (mm) (R)		Percentage of green (%) (G)		Percentage of water (%) (WA)	
		β(95%CI)		**β(95%CI)**		**β(95%CI)**		**β(95%CI)**		**β(95%CI)**
Four largest cities (M1) (ref.= M4)	W	-0.172***(-0.197,-0.146)	T	0.320***(0.30,0.34)	R	-0.105***(-0.13,-0.08)	G	-0.082***(-0.12,-0.04)	WA	-0.025 (-0.06,0.01)
	M1	0.067 (-0.27,0.41)	M1	0.049 (-0.29,0.39)	M1	0.037 (-0.30,0.37)	M1	-0.308 (-0.66,0.04)	M1	0.035 (-0.30,0.37)
	W×M1	0.041 (-0.02,0.10)	T×M1	-0.175***(-0.24,-0.11)	R×M1	-0.012 (-0.05,0.07)	G×M1	-0.187***(-0.30,-0.08)	WA×M1	0.028 (-0.03,0.09)
Medium-sized cities (M2)	W	-0.172***(-0.197,-0.146)	T	0.320***(0.30,0.34)	R	-0.105***(-0.13,-0.08)	G	-0.082***(-0.12,-0.04)	WA	-0.025 (-0.06,0.01)
	M2	0.146 (-0.001, 0.29)	M2	0.148*(0.00,0.29)	M2	0.142 (-0.003,0.29)	M2	0.056 (-0.09,0.21)	M2	0.147* (0.002,0.29)
	W×M2	-0.030 (-0.02, 0.08)	T×M2	-0.058** (-0.10,-0.15)	R×M2	-0.030 (-0.02,0.08)	G×M2	0.001 (-0.07,0.07)	WA×M2	-0.066 (-0.13,0.002)
Small urban areas (M3)	W	-0.172***(-0.197,-0.146)	T	0.320***(0.30,0.34)	R	-0.105***(-0.13,-0.08)	G	-0.082***(-0.12,-0.04)	WA	-0.025 (-0.06,0.01)
	M3	0.045 (-0.08,0.17)	M3	0.055 (-0.07,0.18)	M3	0.050 (-0.07,0.17)	M3	-0.004 (-0.13,0.12)	M3	0.050 (-0.07,0.17)
	W×M3	0.015 (-0.04,0.07)	T×M3	-0.047* (-0.09,0.0001)	R×M3	**0.058* (0.01,0.11)**	G×M3	0.044 (-0.04,0.12)	WA×M3	0.028 (-0.04,0.10)

[a]All models adjusted for age, gender, income, education, ethnicity, household structure, and number of cars in the household
M4=Suburban/rural areas are the reference category
Sig. Codes: *p≤ 0.050; **p≤ 0.010; ***p≤ 0.001.

3.4 Discussion

3.4.1 Key findings

People living in areas with a high address density, more bus stops, and shorter distance to train station cycled longer. Further, cycling duration was positively related to higher temperatures, whereas rain and wind speed were negatively associated with cycling duration. Water bodies did not have a significant relation to cycling duration. Significant interactions of municipality size with built environment characteristics were found. Increased street density and address density appeared to be less cycling-promotive in small urban areas compared to medium or large cities. On the other hand, the positive association between number of bus stops and cycling duration was weaker in the four largest cities and in medium-sized cities compared to small urban and rural areas. This suggests that relations between environmental characteristics and cycling may be dependent on other circumstances (which differ between highly urbanized and less urbanized areas) and are thus context-specific.

3.4.2 Explanation of key findings

When natural and built environment characteristics were included in the models, the variance of cycling duration between PC4 areas declined slightly, but variations at the municipality level could not be explained by environmental characteristics at all. One plausible reason is that because these built environment variables are measured at the PC4 area level, they are inherently more capable of explaining the variance change at the PC4 level than at the municipality level. Another possible explanation is that the low variability in urban design may be typical of Dutch urban areas. The Netherlands is a high-density country with a very good cycling infrastructure and a flat topography. A Dutch walking study also came up with similar findings (Beenackers et al., 2014).

Consistent with previous studies (McCormack and Shiell, 2011; Wang et al., 2016), an association was found between built environment variables and cycling duration: people living in areas with a high address density, more bus stops, and a shorter distance to a train station cycled longer. This may be because, for example, popular destinations, like the city center also have many bus stops. Likewise, people would also be more likely to undertake cycling activities in the city center. In addition, previous studies found that when the distance between a residence and a train station is 1.5–3.7 km, bicycle use increases (Givoni and Rietveld, 2007; Heinen et al., 2010). In the Netherlands, active transportation modes like cycling play a key role in access to and egress from public transportation (e.g., bus stops, train stations): Nearly 50% of all trips between home and train station were conducted by bike (Schaap et al., 2016).

Contrary to previous findings (Ding et al., 2014), in our study land use diversity was not significantly associated with cycling duration. The contrary evidence suggests that mixed-use development in high-density cities may not always have the expected, positive effect on cycling duration. This may be because a high level of land use diversity is associated with heavy traffic, which might eventually weaken people's motivation to cycle (Wang et al., 2016). Also, the non-significant association between street density and cycling duration in this study could be explained by a relatively high level of connectivity, which is in line with previous studies (Eriksson et al., 2012). The percentage of green and water surface was negatively related to cycling duration, which is also in line with other studies (Titze et al., 2010; Winters et al., 2010). This negative effect suggests that whereas people living in attractive residential areas (with green and water areas) tend to remain in and around their houses or gardens, people living in less attractive areas, with relatively little green and/or water, report more cycle trips. Another possible explanation is that most direct routes are through areas with less green and water, as most individuals want to get to their destination as quickly and easily as possible (Winters et al., 2010).

Weather variables were significantly related to cycling duration, which confirms previous Dutch studies (Böcker and Thorsson, 2014; Heinen et al., 2011a; Helbich et al., 2014). High daily precipitation total and high average wind speed had negative effects on cycling, whereas cyclists were more keen to ride when there were high levels of sunshine and high temperatures, as pleasant weather stimulated cycling for recreation (Heinen et al., 2011a).

Most of the built environment characteristics tested had significant main effects on cycling duration, independent of municipality size (Heath et al., 2006). A key finding of the present study was that several associations between built environment characteristics and cycling were stronger in urbanized areas than in small urban or rural areas. Specifically, interactions indicated that the association of address density and street density with cycling duration was weaker in small urban areas compared to larger cities. On the other hand, the positive association between number of bus stops and cycling duration was weaker in the four largest cities and the medium-sized cities compared to small urban and rural areas. One interpretation is that more bus stops means more motorized vehicles on the road, which increases the risk of collisions between bicycles and motorized vehicles, especially in large urban areas (Zhao, 2014). Another possible explanation is that there is competition between public transportation and bicycle use, which is confirmed by previous research (Ettema and Nieuwenhuis, 2017). In addition, the negative association between distance to the nearest train station and cycling duration was stronger in the four largest cities, indicating that a shorter distance to the nearest train station encourages people to cycle more. Regarding the daily maximum temperature, the association with cycling duration was weaker in the four largest cities than in rural areas. A possible explanation is that most Dutch cities have a substantial urban heat island (UHI) that is significantly warmer than the surrounding rural areas due to human activities (Steeneveld et al., 2011).

3.4.3 Strengths and limitations

The study results need to be interpreted in light of some limitations. First, whereas the NTS data for the period 2010–2014 were used, most built environment variables describe the situation in 2014, and for green space and water bodies we used data from 2012. However, the built environment characteristics used are not expected to have changed much over a couple of years. Second, bicycle use was not separately analyzed in terms of trip purpose. However, associations between natural and built environment characteristics and cycling duration differ by trip purpose (Heesch et al., 2015). For example, increasing the tree coverage could increase recreational cycling. It would be interesting for future studies to examine cycling duration for different trip purposes separately. Notably, the relationships between natural and built environment characteristics and cycling duration are complex, and the further investigation of those relationships is needed. Also, future studies should consider not only individual or built environment characteristics associated with cycling behavior, but also personal motivation, travel mode preferences, or mental health, which may vary regarding environmental awareness and/or attitudes toward cycling.

This paper has several key strengths. First, as far as we are aware, this is the first study to examine the extent to which natural and built environment characteristics contribute to inter-PC4 area and inter-municipality differences in cycling behavior in a national Dutch context. Also to the best of our knowledge, no previous studies have investigated municipality size as a moderator between built environment and cycling duration. The uniform and good quality data collocation across years for the whole country reduced the bias during the research and increased the potential for generalizing the results. Second, due to recall biases, measuring aspects of natural and built environment subjectively (e.g., self-report methods) may not accurately assess the association between cycling behavior and the actual natural and built environment characteristics (Kamphuis et al., 2008; Zhou et al., 2013). Therefore, in this study, objective measurements of the natural and built environment were made, which could provide an understanding of how the built environment is constructed regarding policy and urban planning. Third, the hierarchical structure of data, ranging from the individual to the municipality level, was taken into account to correct for possible biases and enable an exploration of variables at different data levels (Stawski, 2013).

Because we focused on the environmental variability between PC4 areas and municipalities, the within-PC4 variability was not considered. If natural and built environment characteristics were measured at a more fine-grained area level, this could increase the variation and the understanding of individual travel behavior. However, it is also important to understand the between-area variation (both PC4 area and municipality level), as policies are mainly based on between-municipality variances. Nonetheless, we maximized variation in natural and built environment characteristics, by including many different PC areas across the whole of the Netherlands, including urban and rural areas. Finally, the interaction effects may suggest that relations between environmental characteristics and cycling duration are context-specific (i.e., dependent on circumstances that differ between urbanized and suburban/rural areas). Other countries may benefit from examining Dutch transportation policies, in order to determine whether there are opportunities to adopt or adapt some of these within their own transportation policy environment.

3.5 Conclusions

Higher address density, more bus stops, and shorter distance from home to the nearest train station were positively related to cycling duration. In addition, significant interaction effects suggest that municipality size may moderate the association between environmental characteristics and cycling duration. Our findings need to be replicated in other countries to gain more insight into the interplay between environment and municipality size.

Abbreviations

PC4 areas: 4-digit postal code areas
NTS: National Travel Survey
ICC: intraclass correlation coefficients
CI: confidence interval
AD: Address density
LD: Land-use diversity
SD: Street density
BS: Number of bus stops
DT: Distance to train station

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Appendix I

Test for correlation between built environment variables

Table 3.5: Pearson correlation between built environment variables (N=110027)

	Address density	Land use diversity	Street density	Number of bus stops	Distance to train station
Address density	1	-.150**	.709**	.035**	-.311**
Land use diversity	-	1	-.226**	.103**	.092**
Street density	-	-	1	-.007*	-.371**
Number of bus stops	-	-	-	1	-.071**
Distance to train station	-	-	-	-	1

Sig. codes: *$p \leq 0.050$; **$p \leq 0.010$

Appendix 2

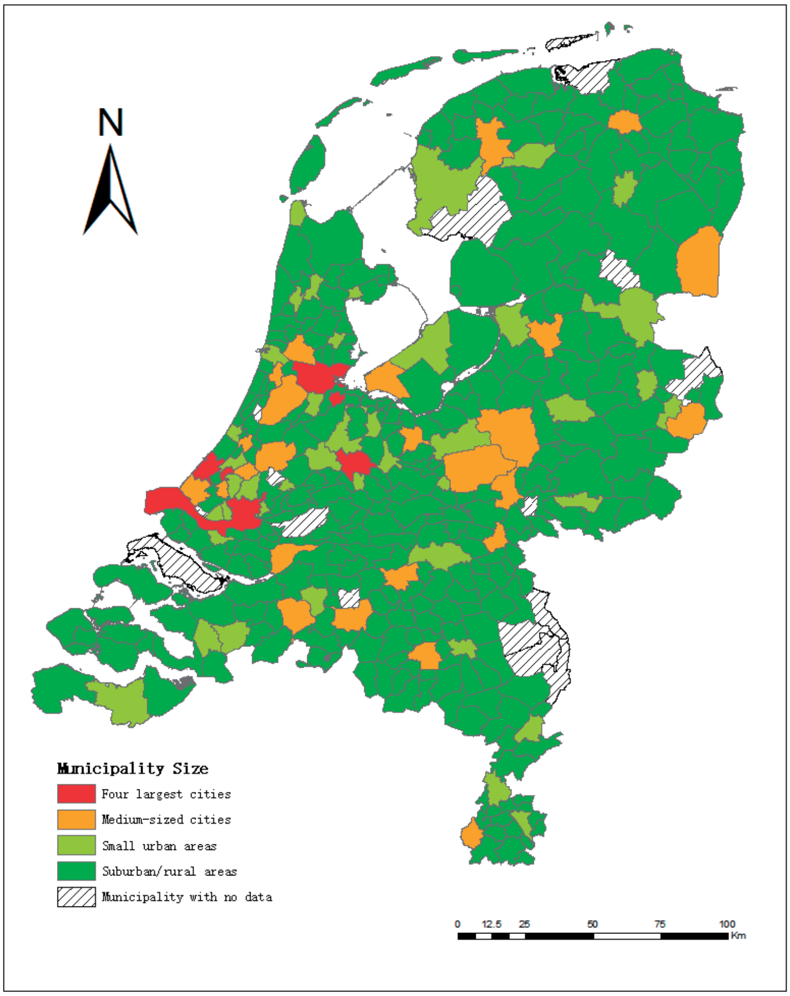

Figure 3.2 Distribution of four types of municipality size in the Netherlands. Municipality size was classified into four classes: the four largest cities, which have > 250000 inhabitants (i.e., Amsterdam, Rotterdam, Den Haag, and Utrecht); medium-sized cities with 100000–250000 inhabitants; small urban areas with 50000–100000 inhabitants; and suburban/rural areas with < 50000 inhabitants.

Appendix 3

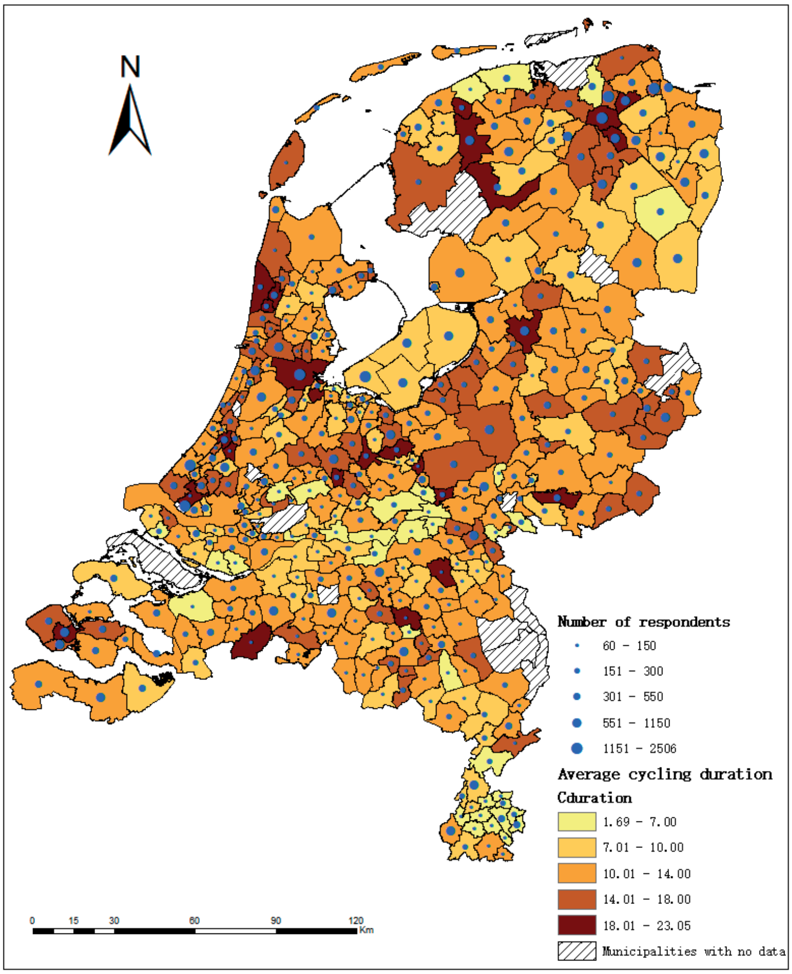

Figure 3.3 Distribution of average cycling duration (in minutes) and number of respondents in each municipality. Number of respondents in each PC4 area was represented as different sizes dots. Average cycling duration was presented in minutes.

Chapter 4

Travel mode attitudes, urban context, and demographics: Do they interact differently for bicycle commuting and cycling for other purposes?

This chapter is based on the article: Gao, J., Ettema, D., Helbich, M., Kamphuis, C.B.M. (2019) Travel mode attitudes, urban context, and demographics: do they interact differently for bicycle commuting and cycling for other purposes? *Transportation.*

Abstract

This study examined whether interactions between travel mode attitudes, urbanization level, and socio-demographics were different for bicycle commuting and cycling for other purposes. Data were obtained from the 2014 wave of the Netherlands Mobility Panel (MPN). In total, 2,673 respondents (18+years) who had recorded at least one trip on the days covered by the survey were included in the sample. Four outcomes were constructed, two of which concerned commuting-related cycling: any commuting-related bicycle usage (yes vs. no) and average cycling duration (in hours per weekday). Likewise, two similar outcome variables concerning cycling for other proposes were constructed. These outcomes were analyzed by means of Tobit regression models (cycling duration) and binary logistic models (any bicycle usage). Attitudinal factors concerning different travel modes, namely bus, car, cycling, and train, were constructed by means of factor analysis. The results showed that a positive attitude toward cycling was positively related to bicycle commuting duration, but this association was less strong among those with a positive attitude toward bus use. Having a positive cycling attitude had a weaker association with both bicycle commuting usage and duration in those who do not always have a car available. Regarding cycling for other purposes, cycling attitude had a stronger positive association with cycling duration among residents of very highly urbanized area, compared to residents of less urbanized areas. The available evidence, though limited, suggests that targeting attitudes can have a measurable impact on bicycling, but not to the same extend among all people.

Keywords: Travel mode attitudes; Urbanization level; Bicycle commuting; Cycling for other purposes, Interactions

4.1 Introduction

Cycling, a clean and active transportation mode has become an increasingly important component of strategies to address issues of public health, climate change, air quality, and inner-city mobility (de Nazelle et al., 2011; Handy et al., 2014; Oja et al., 2011). The extensive literature focusing on how to increase bicycle usage (Dill et al., 2014; Fishman et al., 2015a; Heinen et al., 2011; Pucher and Buehler, 2008; Xing et al., 2010) has generated many insights into the complex relationships between intrapersonal, interpersonal, and environmental aspects. Although many studies have focused on elements of the built environment as determinants of cycling behavior, it has been reported that travel-related attitudes may be equally or more important in increasing the use of bicycles (Curto et al., 2016; Dill et al., 2014; Heinen et al., 2011; Willis et al., 2015). The theory of planned behavior (TPB) developed by Ajzen (1991) is a useful way to explicitly incorporate attitudes and other psychological factors, in addition to the physical environment and sociodemographic characteristics, into models for analyzing cycling behavior (Heinen et al., 2010; Willis et al., 2015).

Thus far, various European studies have directly investigated attitudes toward cycling. For instance, a Dutch study found that attitudes toward cycling are more positive and prominent for cyclists covering longer distances in comparison to those making shorter trips (Heinen et al., 2011). Using a sample drawn from British university employees, Gatersleben and Uzzell (2007) found that regular cyclists had the most positive attitudes toward cycling. An American study (Dill and Voros, 2007) also confirmed the association between positive attitudes toward cycling and transportation cycling. Ewing and Cervero (2010) conducted a meta-analysis of 62 studies on the built environment-travel behavior relation and identify only nine studies that include "attitudinal variables" in predicting walking and cycling behavior. Specifically, these studies consistently reported significant relationships between attitudes and non-motorized travel. Dill et al. (2014) concluded that the built environment and demographics are important in influencing behavior, largely because they influence attitudes, which in turn help predict how often someone bikes or walks from home. Regarding attitudes toward car use, for example, studies found that enjoying cycling had a positive effect on cycling for transportation, whereas not enjoying driving (Dill and Voros, 2007) and limiting driving (Xing et al., 2010) are correlated with cycling for transportation. Regarding commuting, Miller and Handy (2012) found a potential substitutional relationship between cycling and driving. Positive attitudes toward bicycling and negative attitudes toward driving are associated with university employees cycling to work, after controlling for trip distance (Miller and Handy, 2012). The attitudes of people towards transport modes other than car are important for policy makers having the intention to increase transit ridership, walking, or cycling. Nevertheless, the associations between cycling and attitudes toward other travel modes received limited attention to date.

However, attitudes may not always predict travel behavior directly. Some studies also claimed that travel-related attitudes influence travel behavior indirectly through their residential location choice. People might select themselves in neighborhoods facilitating the use of their preferred travel mode (Cao et al., 2009; Schwanen and Mokhtarian, 2005). However, choice of residential environment not always corresponds with the intended travel behavior. That is, for people with very positive or very negative attitude toward cycling, they may cycle or not cycle regardless of the environment. For example, Cao et al. (2006) revealed differences in travel behavior across these two types of neighborhoods (suburban vs. urban areas) were partly attributable to attitudinal factors rather than the built environment. Additionally, people living in suburban areas, may be forced to use the car as destinations are beyond walking or cycling distance (De Vos and Witlox, 2016; Schwanen and Mokhtarian, 2005).

A different perspective on attitudes and behavior is discussed in socio-ecological models, which posit that, theoretically, the effect of attitudes on behavior also depend on other individual characteristics (e.g., age, gender, education, and income) or environmental circumstances (e.g., urbanization levels) (Sallis et al., 2015). Further, ecological models suggest that the combination of individual (i.e., intrapersonal, sociodemographic) and environmental variables will best explain physical activity. That is, individual and environmental variables may have an interaction effect with attitudes on travel behavior. For example, a positive stance toward a certain mode of transportation will result in a higher use of that mode, as long as the use of this mode is not restricted by elements such as urban and suburban neighborhoods (De Vos and Witlox, 2016). Bhat and Guo (2007) examined the interaction effects between density and demographics on cycling behavior. They found that low-income residents living in the areas with a high employment density tend to have a lower propensity to cycle than their counterparts in similar areas. However, these differences might also be due to varying travel-related attitudes. Furthermore, the effect of a certain travel-related attitude on cycling may depend on preferences regarding other transportation modes. It has been suggested that car users who also use other modes, such as the bicycle, may develop different attitudes toward cycling compared to those who solely use a car (Diana and Mokhtarian, 2009). Although theories suggest that attitude toward cycling moderate the effects of socio-demographics and environmental factors on cycling behavior, empirical studies in the domain of cycling have largely ignored the interaction terms of travel-related attitudes with sociodemographic and environment characteristics.

Despite the recognition of the socio-ecological nature of travel behavior (Sallis et al., 2015), only a few scholars have studied the interaction effects of attitudes with sociodemographic and environmental characteristics, and their findings are inconsistent (Beenackers et al., 2013; Beenackers et al., 2014; Carlson et al., 2012; Ding et al., 2012). In general, both compensatory and synergetic interaction mechanisms can be at play. For example, a compensatory mechanism was found in that having a positive attitude toward walking makes the effects of urban form layout less important to leisure-time walking (Beenackers et al., 2014). On the contrary, the synergetic mechanism showed that the environment is more important to physical activity among those who have more positive psychological characteristics (Carlson et al., 2012). Likewise, the mechanism assumes a synergy between interpersonal and built environment characteristics and attitudes toward cycling. For example, it may be assumed that retired people who have more free time and a positive attitude toward cycling will cycle more. In contrast, a positive attitude toward cycling in people who have a car, could lead to less cycling than in people with no car available. This may indicate that interaction effects are likely to be complex and behavior-specific. Besides, regarding competitive mechanism, attitudes toward different modes also have an effect on cycling behavior, although most studies have neglected interactions between cycling attitudes and attitudes toward other travel modes. To our knowledge, only a few studies investigated the interaction effect between the built and social environment on cycling without considering cycling attitudes (Bourke et al., 2018; D'Haese et al., 2016; Wang et al., 2017). A Belgian study on children found an interaction effect between support from friends and neighborhood walkability on cycling in leisure time (D'Haese et al., 2016). This study also showed that friend support moderated the relationship between walkability and cycling in leisure time; however the effect size of this interaction was minor.

The interaction effects of travel-related attitudes with trip characteristics may differ by trip purpose. Different mechanisms may trigger and influence cycling for these different purposes (Scheepers et al., 2013), especially for bicycle commuting and cycling for other purposes (Barnes and Krizek, 2005), as trips to work typically comprise a significant portion of a worker's total weekly trips (Stinson and Bhat, 2004). For example, commuting cyclists are much more sensitive to factors such as travel time due to busy activity agendas than people in leisure time. In addition, since bicycle commuting is a form of non-discretionary travel, it is likely to be impacted by different factors than those impacting trips for other purposes (Heinen et al., 2010). For instance, commuters may have fixed work hours, nonflexible options for their departure time, route choice, and few feasible commute mode choices, so a strong motivation is needed for them to switch to or sustain cycling.

So far, while some studies showed that cycling attitudes are also strongly associated with cycling distance and the choice of bicycle commuting (Handy et al., 2010; Heinen et al., 2011), there has been limited investigation of how the interaction effects of attitudes with sociodemographic and environmental characteristics vary across bicycle commuting and other purposes.

Hence, the aim of the present study was to fill this gap by investigating the extent to which the relation between sociodemographic characteristics, urbanization level, and attitude toward alternative travel modes on the one hand and cycling behavior (bicycle commuting and cycling for other purposes) on the other hand interacts with attitudes toward cycling. The conceptual framework for this study (Figure 4.1) is partly based on previous studies (Willis et al., 2015; Xing et al., 2018).

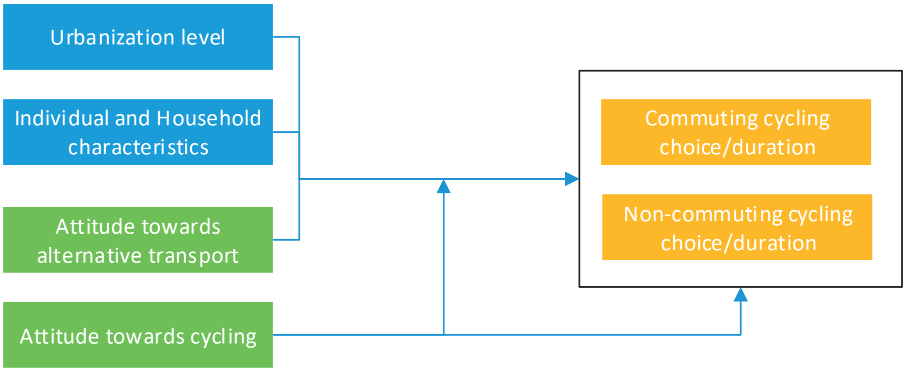

Figure 4.1 Conceptual framework

4.2 Materials and methods

4.2.1 Data source and sample

Data were obtained from the Netherlands Mobility Panel (MPN), which was set up to establish short- and long-term dynamics in the travel behavior of individuals and households, and to determine how changes in personal and household characteristics and in other travel-related factors (e.g., reduced taxes on sustainable transportation, or changes in land use) correlate with changes in travel behavior (Hoogendoorn-Lanser et al., 2015). Socioeconomic attributes for individuals and their households were collected through individual questionnaires. Participants with a completed questionnaire were also invited to keep an online trip diary for three successive days (including weekend days). For each respondent, the diary provides information about all trips the respondent made (e.g., transportation modes, trip duration, distances, trip purposes, travel companionship and delays).

The present study is based on data from the panel survey 2014 of MPN, as this wave had a particular focus on travel-related attitudes. The sample selected for this study only includes participants who recorded travel data and were aged over 17 years (the age at which it is legal to drive a car in the Netherlands) (N=4,978). Participants who did not complete the questionnaire were excluded (N=872). Participants with no opinion about attitudes toward travel modes were also excluded (N=1,152). Also, only regular day-to-day trips were selected, which means that holidays trips and trips abroad were excluded (N=164). Finally, the weekends were excluded (N=117), because the decision structures related to weekday and weekend trips are different (Yang et al., 2016). As a consequence, the subsample on which the analyses presented in this paper are based comprised 2,673 respondents.

4.2.2 Outcome variables

To describe cycling patterns, four outcome variables were determined. Two outcome variables concerned bicycle commuting i.e., trips to and from a place of work or study. For bicycle commuting, we investigated both whether participants used their bike at all for commuting (i.e., any bicycle usage, yes vs. no) and the average daily bicycle commuting duration in hours per day (cycling duration; continuous variable). Likewise, the other two outcome variables (bicycle usage and average daily cycling duration in hours per day) for other purposes were identified. Bicycle usage represented whether participants chose to cycle at all. Daily cycling duration represents how many minutes people cycle per day, an indicator of the mobility of people going about their day-to-day lives.

4.2.3 Travel mode attitudes

The MPN 2014 measured respondents' attitudes toward driving, cycling, trains, and buses. For each travel mode respondents indicated to what extent they regard it as comfortable, relaxing, time saving, flexible, and pleasurable, and their personal impression of the travel mode. The attitudes represent the degrees to which people favor the respective modes. The items were measured by a 5-point Likert scale ranging from 1 (=strongly disagree) to 5 (=strongly agree). The questionnaire contained 28 statements on various attitudinal dimensions. Principal components analysis (PCA) with an orthogonal rotation (i.e., varimax method) was used to reduce the dimensionality of the subset of attitude measures and create continuous linear composite factors for analysis (Bryant and Yarnold, 1995; Härdle and Simar, 2007).

4.2.4 Sociodemographic and spatial context characteristics

Individual characteristics were based on self-reports from MPN 2014 and were considered done previously (de Haas et al., 2018; Gao et al., 2018). Age was divided into six categories: 18–29, 30–39, 40–49, 50–59, 60–69, and 70–80 years. We categorized gross household income per year into low (<€26,000), medium (€26,000–65,000), and high (>€65,000). Educational attainment was stratified into three categories: low (primary school and lower general secondary school), medium (upper-division secondary school), and high (college and university) (CBS, 2016). Due to the low proportion of the other categories (i.e., unemployed, retired, and housewife/husband) among the sample, the employment status was classified into three groups: employed, student, and retired or other unemployed. We also controlled for numerous other key variables, including gender, presence of children within household (under 12 years old), and car availability (i.e., always a car available, not always a car available, and no car).

There is some evidence of associations between cycling behavior and built environment characteristics such as accessibility of employment, population density and residential location (Ewing and Cervero, 2010; Wong et al., 2011). Among them, population density can be considered as a key element of availability of local destinations (e.g., shops and services) and is related to other built environmental attributes such as housing type, street pattern, access to public transport, hence people's travel behavior (Cervero and Kockelman, 1997). Therefore, in this study, the spatial context was measured by urbanization level, which was classified into four categories according to the population density: very highly urbanized (>2,500 inhabitants/km^2), highly urbanized (1,500–2,500 inhabitants/km^2), moderately urbanized (1,000–1,500 inhabitants/km^2), less urbanized /rural areas (<1,000 inhabitants/km^2).

4.2.5 Statistical analyses

Descriptive statistics were used to summarize the data. Pearson correlation coefficients were used to assess multicollinearity among the covariates. Correlations larger than ± 0.8 are considered problematic (Freedman et al., 1991). We added the correlation table as an appendix (Table 5).

Multivariate regression analyses were performed to relate the sociodemographic variables, urbanization level, and travel mode attitudinal factors to measures of cycling duration and daily bicycle usage for commuting and other purposes. Cycling duration was investigated in a Tobit regression analysis, as it better handled the dependent variables' lack of negative values and excess of zeros due to people not making any cycling trips on the days covered by the survey (Greene, 2003). For daily bicycle usage, a binary logistic model was used. Because we were dealing with data consisting of data for multiple days for one person, the data may have violated the independence assumption. The estimation of equal robust standard errors per participant corrected for intragroup correlation (Wooldridge, 2010).

Separate models for commuting and other purposes cycling duration and bicycle usage were used to test the interaction of each of the included variables with cycling attitudinal factors. The first set (models 1a/2a/3a/4a) contained all the sociodemographic variables, urbanization level variable, and the individual travel mode attitudinal factors. Subsequently, to explore the interactions, the second set (models 1b/2b/3b/4b) was estimated for each outcome variable that added the interactions with attitudes toward cycling based on the first model. All models were estimated using STATA/SE 15.0 (StataCorp, College Station, Texas).

4.3 Results

4.3.1 Descriptive analysis

Table 4.1 presents descriptive statistics for the total sample, as well as descriptive statistics for respondents who engaged in bicycle commuting and cycling for other purposes separately. Of the sample, 52.9% reported any cycling during the survey days, and the average daily cycling duration was 0.27 hours and 1.1 cycling trips per day among all participants. The mean number of bicycle commuting trips for those cycling was 1.5, which was less than cycling trips for other purposes (2.1). Specifically, about 21.8% of the total sample engaged in bicycle commuting, while 38.3% of respondents reported cycling for other purposes (e.g., of the latter category, 54.1% was related to shopping, 58.1% to leisure, and 36.9% to other purposes, as some participants engaged in multiple non-commuting trips). Women made up 54.2% of the total sample but accounted for 59.8% of all individuals who reported any bicycle commuting and for 62.8% of all individuals who reported cycling for other purposes. Thus, women were more likely to cycle than the men, especially for non-commuting purposes, which is consistent with a previous study (Garrard et al., 2008). More young adults reported bicycle commuting (35.3% for the category 18–29 years), while more elderly people reported cycling for other purposes (24.4% for the category 60+ years). Individuals who reported bicycle commuting were less likely to have dependent children in their households (15.6%) or to always have a car available (41.4%), and were more likely to be students (22.3%) have low household incomes (26.7%) and live in highly or very highly urbanized areas. Individuals who reported cycling for other purposes were more likely to be retired or unemployed (37.1%), and to not always have a car available (29.2%) or never have a car available (17%).

Table 4.1 Descriptive Statistics

Variables	**Total Sample (N=2,673)**	**Respondents Reporting any Bicycle Commuting (N=584)**	**Respondents Reporting any Cycling for Other Purposes (N=1,023)**
Dependent Variables			
Mean cycling duration (hours) (SD)	0.27 (0.52)	0.44 (0.43)	0.46 (0.62)
Mean number of cycling trips (SD)	1.1 (1.6)	1.5 (0.8)	2.1 (1.5)
Socioeconomic characteristics			
Age			
18–29	24.4%	35.3%	22.7%
30–39	15.2%	13%	13.8%
40–49	21.4%	20%	19.3%
50–59	20.6%	22.9%	20.1%
60–69	10.7%	6.8%	14.2%
70+	7.8%	1.9%	10.2%
Gender			
Male	45.8%	40.2%	37.2%
Female	54.2%	59.8%	62.8%
Education			
Low	21.5%	19.5%	22.6%
Medium	40.1%	40.4%	38.5%
High	38.4%	40.1%	38.9%
Gross household income			
<€26,000	19.4%	26.7%	23.3%
€26,000–65,000	56.6%	50.2%	55.2%
>€65,000	24%	23.1%	21.5%
Children <12 years			
No	80.7%	84.4%	81.3%
Yes	19.3%	15.6%	18.7%
Employment status			
Multiple occupations including paid labor	61.5%	68.5%	50.7%
Student	11.2%	22.3%	12.1%
Retired and other unemployed	27.3%	9.2%	37.1%
Car availability			
Always a car available	64.4%	41.4%	53.8%
Not always a car available	22.6%	38.2%	29.2%
No car available	13.1%	20.4%	17%
Municipal urbanization level			
Very highly urbanized	18.9%	25%	22.1%
Highly urbanized	28.6%	31.7%	28.2%
Moderately urbanized	23.6%	23.8%	25.1%
Less urbanized / rural areas	28.8%	19.5%	24.6%

4.3.2 Factor analysis on attitudinal factors

Exploratory factor analysis was used to identify the attitudinal factors related to different travel modes. Items with low communalities (<0.5) were iteratively excluded, leaving 25 of 28 attitudinal characteristics to test for underlying constructs. Four factors (i.e., attitude toward bus/cycling/car/train) contributed 61.36% to the cumulative variance, and this provided interpretable factors. All Cronbach's alpha coefficients showed high reliability (α=0.8) (Hair et al., 2009), indicating that internal consistencies are acceptable, and it was therefore acceptable to use each factor instead of the original indicators (Table 4.2).

Table 4.2 Factors Score of the Attitudes toward Characteristics of Travel Mode

Factor	Statement Variable	Component			
		1	2	3	4
Bus / tram / metro attitudes factor	Travelling by bus / tram / metro is pleasurable.	0.811			
	Travelling by bus / tram / metro is comfortable.	0.805			
	Travelling by bus / tram / metro provides flexibility.	0.783			
	Travelling by bus / tram/ metro saves me time.	0.764			
α=0.896	Travelling by bus/ tram/ metro is relaxing.	0.777			
	Personal impression of the bus / tram / metro.	0.614			
	Travelling by car is pleasurable.		0.829		
Car attitudes factor	Travelling by car is comfortable.		0.820		
	Travelling by car is relaxing.		0.755		
	Travelling by car provides flexibility.		0.710		
	Travelling by car is safe.		0.699		
α=0.865	Personal impression of the car.		0.685		
	Travelling by car saves me time.		0.709		
	Cycling is pleasurable.			0.852	
Cycling attitudes factor	Cycling is relaxing.			0.838	
	Cycling is comfortable.			0.805	
	Cycling provides flexibility.			0.713	
	Personal impression of the bicycle, e-bike.			0.670	
α=0.856	Cycling is safe.			0.595	
	Cycling saves me time.			0.602	
Train attitudes factor	Travelling by train is relaxing.				0.769
	Travelling by train is comfortable.				0.745
	Travelling by train is pleasurable.				0.742
	Travelling by train is safe.				0.699
α=0.873	Personal impression of the train.				0.669

The KMO value was 0.891. The significance of Bartlett spherical test was 0.000.
Values below 0.5 are not reported.
α= Cronbach's Alpha

Chapter 4

4.3.3 Multivariate regression analysis

4.3.3.1 Bicycle commuting

As shown in Table 4.3, both the estimated models 1b and 2b, with a McFadden pseudo-R^2 of 0.185 for bicycle commuting usage and 0.166 for bicycle commuting duration, fit the data moderately, compared to models 1a and 2a, separately. This indicated the reasonability of considering interactions between attitude toward cycling and other environmental and individual characteristics.

Regarding both bicycle commuting usage and duration, two significant interactions were observed in regression models (model 1b and 2b). Among those with children less than 12 years of age, a positive attitude toward cycling was less strongly associated with bicycle commuting usage and duration than among those with no young children in the household. One possible explanation is that the presence of children in a household may mean that commuters are more time pressed, as they have to take care of children in the morning and pick them up from school in the afternoon, or have to combine other childcare-related activities. This interaction could indicate the existence of the compensatory mechanism proposed in the introduction. Another compensatory mechanism was also found: the negative effect of car availability on cycling is weaker for those with a positive attitude towards cycling. This indicates that commuters with a car available need a stronger motivation to cycle, as commuting travel is a form of non-discretionary travel, and acquiring a car would probably increase the range of choice options of the commuters (Oakil et al., 2016; Piatkowski and Marshall, 2015), and thus influence bicycle usage (Fu and Farber, 2017).

Having a positive cycling attitude had a weaker association with bicycle commuting among those with a positive attitude toward using buses, compared to those with a less positive attitude toward using buses. This suggests a competition between these travel modes. In particular, the relationship between attitude (toward cycling) and behavior (cycling) is weaker if an alternative behavior (take the bus) is more attractive. As no other study could be identified that investigated the interaction effects of cycling attitude and attitudes toward other transportation modes on bicycle commuting, it is hard to compare results. However, one possible explanation is that in a short commuting distance, both riding a bus and cycling are attractive to commuters, thus leading to a competitive relationship (Ettema and Nieuwenhuis, 2017). For instance, a well-served public transportation infrastructure around the workplace indeed helps to increase the use of buses, and thus decreases the likelihood of bicycle commuting.

Table 4.3 Results for Bicycle Commuting Usage and Duration

Variables	Bicycle Commuting Usage		Bicycle Commuting Duration	
	Model 1a	Model 1b	Model 2a	Model 2b
	Coef. (S.E.)	Coef. (S.E.)	Coef. (S.E.)	Coef. (S.E.)
Constant	-1.968*** (0.256)	-2.010***(0.263)	-0.803***(0.103)	-0.819***(0.104)
Age				
18–29 (ref.)				
30–39	0.0655 (0.206)	0.0546 (0.213)	0.038 (0.0793)	0.045 (0.0804)
40–49	0.403** (0.190)	0.343* (0.202)	0.165** (0.0735)	0.155** (0.0762)
50–59	0.507*** (0.188)	0.462** (0.198)	0.213*** (0.0727)	0.195*** (0.0753)
60–69	0.589** (0.267)	0.604** (0.281)	0.283*** (0.100)	0.276*** (0.104)
70+	0.211 (0.402)	0.158 (0.434)	0.106 (0.143)	0.101 (0.148)
Gender				
Male (ref.)				
Female	0.288*** (0.107)	0.309*** (0.113)	0.077* (0.0412)	0.09** (0.0427)
Education				
Low (ref.)				
Medium	-0.00126 (0.146)	0.00119 (0.149)	-0.034 (0.0558)	-0.034 (0.0563)
High	0.0125 (0.157)	0.0304 (0.165)	0.018 (0.0597)	0.025 (0.0616)
Gross household income				
<€26,000 (ref.)				
€26,000–65,000	-0.458*** (0.140)	-0.486*** (0.144)	-0.164*** (0.0538)	-0.173*** (0.0549)
>€65,000	-0.541*** (0.168)	-0.576*** (0.176)	-0.167*** (0.0641)	-0.177*** (0.0661)
Children <12 years				
No (ref.)				
Yes	-0.186 (0.156)	-0.0955 (0.162)	-0.079 (0.0601)	-0.055 (0.0614)
Employment status				
Multiple occupations including paid labor (ref.)				
Student	0.720*** (0.200)	0.692*** (0.205)	0.269*** (0.0770)	0.266*** (0.0777)
Retired and other unemployed	-1.792*** (0.201)	-1.756*** (0.213)	-0.705*** (0.0749)	-0.681*** (0.0776)
Car availability				
Always a car available (ref.)				
Not always a car available	1.019*** (0.127)	1.101*** (0.133)	0.397*** (0.0500)	0.412*** (0.0517)
No car available	0.831*** (0.165)	0.868*** (0.171)	0.340*** (0.0641)	0.341*** (0.0651)
Municipality level				
Very highly urbanized	0.576*** (0.164)	0.548*** (0.172)	0.197*** (0.0631)	0.187*** (0.0651)
Highly urbanized	0.499*** (0.146)	0.491*** (0.153)	0.171*** (0.0559)	0.167*** (0.0574)
Moderately urbanized	0.565*** (0.152)	0.588*** (0.157)	0.179*** (0.0583)	0.194*** (0.0594)

Less urbanized / rural area (ref.)				
Attitudinal factors				
FBus[a]	-0.0207 (0.0547)	-0.0161 (0.0588)	0.003 (0.0209)	0.008 (0.0219)
Fcycle[b]	0.555*** (0.0628)	0.531* (0.300)	0.208*** (0.0243)	0.161 (0.111)
FCar[c]	-0.265***(0.0543)	-0.251*** (0.0576)	-0.086*** (0.0209)	-0.084*** (0.0219)
FTrain[d]	-0.0525 (0.0533)	-0.0630 (0.0579)	-0.034* (0.0204)	-0.033 (0.0218)
Interaction terms				
Age×Fcycle				
18–29 (ref.)				
30–39		-0.0386 (0.241)		-0.073 (0.0920)
40–49		0.189 (0.226)		0.039 (0.0845)
50–59		0.163 (0.231)		0.068 (0.0864)
60–69		0.00542 (0.310)		0.033 (0.115)
70+		0.204 (0.466)		0.052 (0.161)
Gender×Fcycle				
Male (ref.)				
Female		-0.0729 (0.129)		-0.059 (0.0485)
Education×Fcycle				
Low (ref.)				
Medium		0.156 (0.163)		0.101 (0.0617)
High		0.115 (0.181)		0.094 (0.0677)
Income×Fcycle				
<€26,000 (ref.)				
€26,000–65,000		0.0603 (0.164)		0.049 (0.0610)
>€65,000		0.147 (0.208)		0.084 (0.0768)
Children <12 years ×Fcycle				
No (ref.)				
Yes		-0.376** (0.183)		-0.143** (0.0699)
Employment Status ×Fcycle				
Multiple occupations including paid labor (ref.)				
Student		-0.0565 (0.227)		-0.019 (0.0851)
Retired and other unemployed		-0.158 (0.242)		-0.064 (0.0887)
Car availability ×Fcycle				
Always a car available (ref.)				
Not always a car available		-0.332** (0.152)		-0.106* (0.0573)
No car available		-0.0566 (0.196)		-0.015 (0.0721)

Urbanization level×Fcycle				
Very highly urbanized		0.185 (0.191)		0.093 (0.0726)
Highly urbanized		0.0455 (0.171)		0.028 (0.0643)
Moderately urbanized		-0.0367 (0.181)		-0.039 (0.0688)
Less urbanized / rural area (ref.)				
Fbus×Fcycle		-0.0572 (0.0626)		-0.038* (0.0231)
Fcar×Fcycle		-0.0479 (0.0622)		-0.006 (0.0231)
Ftrain×Fcycle		0.0373 (0.0573)		0.005 (0.0217)
Model fit				
Log-likelihood	-1154.8988	-1144.2881	-1288.9280	-1275.0898
Ps.R2 (McFadden)	0.177	0.185	0.156	0.166

Sig. Codes: *p≤ 0.1; **p≤ 0.05; ***p≤ 0.01.

[a]: Factor of Attitudes toward Bus

[b]: Factor of Attitudes toward Cycling

[c]: Factor of Attitudes toward Car

[d]: Factor of Attitudes toward Train

4.3.3.2 Cycling for other purposes

Overall, the estimated multivariate models show a reasonable fit, according to the significant likelihood ratio Chi^2 values and the McFadden pseudo-R^2 measures. Specifically, after adding interaction variables in models 3b/4b, the McFadden pseudo-R^2 is improved from 0.118 (model 3a) to 0.131 (model 3b) for cycling for other purposes model, and from 0.098 (model 4a) to 0.106 (model 4b) for model for cycling duration (see Table 4.4).

With respect to cycling usage and duration for other purposes, considering the interaction terms (models 3b and 4b), the results show that having a positive attitude toward cycling had a stronger effect on bicycle usage for other purposes among the middle aged (50–59), senior citizens (60–69, 70+), and women. In particular, with regard to age groups, elderly participants (60–69, 70+) with a positive attitude toward cycling, cycled most. This suggests that senior citizens (60–69) and the elderly (70+) have more time to spend on cycling (Fishman et al., 2015b; Gao et al., 2017) and that cycling is an essential means of transportation for them. Also, the interactions of cycling duration for other purposes and elderly age groups suggest that the synergetic mechanism proposed in the introduction, indicating that people in advantageous situations (i.e., retired, with plenty of time), a positive attitude toward cycling encourages them to cycle more. In addition, women with a positive attitude toward cycling were found to participate in more cycling trips than men. This is because in the Netherlands, women are more likely to have a part-time job that is closer to home, and to make shorter, linked journeys to, for example, pick up/drop off children or go shopping. Therefore, they may be more likely to make more cycling trips, which is in line with previous studies (Gao et al., 2017; Garrard et al., 2008). Car is less available to women due to the same reasons, which is another possible explanation of the stronger effect of attitude on cycling for women. The interaction between cycling attitude and gender suggests another synergistic effect; if one assumes that woman's activity patterns or car allocation processes in households encourage cycling among women.

Having a positive attitude toward cycling was related to more cycling for other purposes among residents of very highly urbanized area compared to those living in less urbanized areas. This indicates that a positive cycling attitude increases the duration of cycling for other purposes in very highly urbanized areas (synergetic mechanism). Finally, for individuals who live in more urbanized municipalities, their daily activities (e.g., shopping, recreation, and visiting friends) may be more convenient than they are for people living in less urbanized areas, and therefore people who have positive attitude towards cycling they may prefer to cycle.

Table 4.4 Results for Cycling Usage and Duration for Other Purposes

Variables	Bicycle Usage		Cycling Duration	
	Model 3a	Model 3b	Model 4a	Model 4b
	Coef. (S.E.)	Coef. (S.E.)	Coef. (S.E.)	Coef. (S.E.)
Constant	-1.757*** (0.213)	-1.758*** (0.213)	-0.761*** (0.093)	-0.762*** (0.093)
Age				
18–29 (ref.)				
30–39	0.153 (0.177)	0.126 (0.177)	0.035 (0.077)	0.025 (0.076)
40–49	0.182 (0.164)	0.182 (0.165)	0.096 (0.071)	0.098 (0.071)
50–59	0.387** (0.164)	0.380** (0.165)	0.175** (0.071)	0.168** (0.071)
60–69	0.557*** (0.205)	0.534** (0.210)	0.327*** (0.086)	0.301*** (0.087)
70+	0.553** (0.234)	0.533** (0.242)	0.198** (0.098)	0.165* (0.099)
Gender				
Male (ref.)				
Female	0.533*** (0.090)	0.521*** (0.092)	0.135*** (0.039)	0.135*** (0.039)
Education				
Low (ref.)				
Medium	-0.0496 (0.119)	-0.0468 (0.121)	-0.046 (0.050)	-0.037 (0.050)
High	-0.000373 (0.127)	-0.0115 (0.131)	-0.043 (0.054)	-0.031 (0.055)
Gross household income				
<€26,000 (ref.)				
€26,000–65,000	-0.0944 (0.117)	-0.116 (0.119)	-0.091* (0.050)	-0.101** (0.050)
>€65,000	-0.0735 (0.143)	-0.0279 (0.144)	-0.085 (0.061)	-0.073 (0.061)

Children <12 years				
No (ref.)				
Yes	0.310** (0.130)	0.330** (0.131)	0.215*** (0.056)	0.223*** (0.056)
Employment status				
Multiple occupations including paid labor (ref.)				
Student	0.422** (0.185)	0.406** (0.185)	0.171** (0.080)	0.166** (0.080)
Retired and other unemployed	0.698*** (0.129)	0.695*** (0.133)	0.379*** (0.054)	0.376*** (0.055)
Car availability				
Always a car available (ref.)				
No always a car available	0.723*** (0.111)	0.756*** (0.115)	0.241*** (0.048)	0.255*** (0.049)
No car available	0.591*** (0.143)	0.644*** (0.145)	0.251*** (0.060)	0.277*** (0.061)
Municipality level				
Very highly urbanized	0.423*** (0.134)	0.434*** (0.137)	0.192*** (0.057)	0.183*** (0.058)
Highly urbanized	0.141 (0.117)	0.158 (0.119)	0.039 (0.050)	0.041 (0.051)
Moderately urbanized	0.347*** (0.121)	0.329*** (0.124)	0.135*** (0.052)	0.132** (0.052)
Less urbanized / rural area (ref.)				
Attitudinal factors				
FBus[a]	0.0297 (0.046)	0.0217 (0.048)	0.034* (0.019)	0.032 (0.020)
Fcycle[b]	0.582*** (0.051)	-0.0185 (0.228)	0.240*** (0.019)	0.115 (0.020)
FCar[c]	-0.187***(0.046)	-0.193***(0.048)	-0.075*** (0.022)	-0.073*** (0.097)
FTrain[d]	0.129*** (0.045)	0.133*** (0.048)	0.03 (0.019)	0.031 (0.020)
Interaction terms				
Age×Fcycle				
18–29 (ref.)				
30–39		0.177 (0.196)		0.050 (0.085)
40–49		0.201 (0.179)		0.045 (0.078)
50–59		0.318* (0.185)		0.099 (0.079)
60–69		0.515** (0.239)		0.186*** (0.095)
70+		0.623** (0.280)		0.224** (0.111)
Gender×Fcycle				
Male (ref.)				
Female		0.212** (0.105)		0.012 (0.044)
Education×Fcycle				
Low (ref.)				
Medium		-0.141 (0.136)		-0.118** (0.056)
High		0.0139 (0.149)		-0.073 (0.061)
Income×Fcycle				

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<€26,000 (ref.)				
€26,000–65,000		0.233* (0.134)		0.096* (0.055)
>€65,000		-0.128 (0.166)		0.009 (0.071)
Children <12 years ×Fcycle				
No (ref.)				
Yes		-0.156 (0.145)		-0.069 (0.062)
Employment Status ×Fcycle				
Multiple occupations including paid labor (ref.)				
Student		0.269 (0.200)		0.104 (0.087)
Retired and other unemployed		0.152 (0.151)		0.039 (0.061)
Car availability ×Fcycle				
Always a car available (ref.)				
Not always a car available		0.0978 (0.135)		-0.008 (0.057)
No car available		-0.142 (0.156)		-0.082 (0.063)
Urbanization level×Fcycle				
Very highly urbanized		0.213 (0.151)		0.133** (0.063)
Highly urbanized		0.105 (0.133)		0.043 (0.056)
Moderately urbanized		0.292** (0.146)		0.082 (0.060)
Less urbanized / rural area (ref.)				
Fbus×Fcycle		0.0144 (0.051)		-0.0002 (0.021)
FCar×Fcycle		-0.0190 (0.051)		-0.012 (0.021)
FTrain×Fcycle		-0.0288 (0.046)		-0.014 (0.020)
Model fit				
Log-likelihood	-1568.0429	-1546.1000	-1974.0220	-1955.7158
Ps.R2 (McFadden)	0.1184	0.131	0.098	0.106

Sig. Codes: *p≤ 0.1; **p≤ 0.05; ***p≤ 0.01.
[a]: Factor of Attitudes toward Bus
[b]: Factor of Attitudes toward Cycling
[c]: Factor of Attitudes toward Car
[d]: Factor of Attitudes toward Train

4.4 Conclusions

Although cycling behavior is often believed to be influenced by both environmental and individual factors, little is known about the interaction effects of travel mode attitudes in the association between demographic characteristics, urbanization level, and cycling behavior. The present study therefore examined the interaction effects of attitude toward cycling and sociodemographic characteristics and urbanization level on cycling duration/usage for commuting and other purposes among Dutch adults. Our findings provide partial support for the interactions between environmental and individual factors in relation to cycling behavior, as postulated by socio-ecological models (Sallis et al., 2015). The results showed that a positive attitude toward cycling was positively related to bicycle commuting duration, and that this association was less strong among those with a positive attitude toward the use of buses. Having a positive cycling attitude had a weaker positive effect on both bicycle commuting usage and duration in those who not always have a car available. Regarding cycling for other purposes, cycling attitude had a stronger positive association with cycling duration among residents of very highly urbanized area, compared to residents of less urbanized areas. The middle aged, the elderly and women with a positive attitude toward cycling were more likely to cycle in their day-to-day lives than their counterparts without a positive attitude toward cycling.

Overall, the study provides evidence for competitive mechanisms in which a positive cycling attitude is positively related to bicycle commuting duration, while this association is less strong among those with a positive attitude toward bus use. It also suggests the existence of synergetic mechanisms, in which a positive cycling attitude reinforces favorable cycling conditions (urban areas) or groups likely to cycle (elderly and women). On the other hand, compensatory mechanisms were found in that having a positive attitude toward cycling, had a weaker positive effect on bicycle commuting usage and duration among those who not always have a car available. While both competitive and synergetic mechanisms seem to exist, they translate into cycling behavior to only a limited extent.

To our knowledge, our study is the first to investigate the interaction effects of attitude toward cycling and sociodemographic characteristics, urbanization level, and attitude toward alternative travel modes on bicycle commuting and cycling for other purposes. The inclusion of attitudes toward other transportation modes is one of its strengths, indicating the possible competition between cycling and riding a bus. Another strength is the comparison of the usage and duration of bicycle commuting with that of cycling for other purposes. This makes the results more generalizable and indicates differences in correlates by cycling purpose, because the behavior of and decisions made by cyclists differ depending on trip purpose, especially for commuting and other purposes. Obviously, although the results are promising, they should be confirmed in future studies.

However, this study also has some limitations. First, data covering one year cannot be used to identify directionality in the relationship between attitudes and cycling patterns. Longitudinal studies measuring people's attitudes before and after changes in relation to cycling behavior would be valuable in understanding the relationships among attitudes, environmental factors, and cycling behavior. A second study limitation is that more nuanced physical environmental characteristics are needed, such as of the cycling infrastructure, which may be in relation to cycling behavior and attitudes. Furthermore, since cycling levels vary substantially among countries, additional research is needed to determine to what extent the impact of cycling attitude depends on the specific local context.

For policy making, our results highlight the complex link between attitudinal and contextual factors, showing that, to optimize interventions to increase bicycle use, both factors should be targeted simultaneously. A better understanding of the interactions between attitudinal factors and contextual factors could be beneficial for the tailoring of intervention strategies to specific population groups, as well as may contribute to the development of multi-level interventions (Ding et al., 2012). For example, the available evidence, suggests that targeting attitudes (e.g., via social marketing campaigns) can have a measurable impact on cycling (Pucher et al., 2010), but the effect may differ between specific geographical or socio-demographic strata. Further, this work points to target groups that deserve attentions in future studies (e.g., families with young children) to find out which barriers they face for bicycling, and how these could be overcome. Our findings contribute to the knowledge of how multiple factors may reciprocate to influence an individual's decision to cycle.

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Chapter 4

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Appendix

Table 4.5 Pearson correlation between independent variables (*N*= 2,673)

	Age	Gender	Education	Gross household income	Children <12 years	Employment status	Car availability	Municipal urbanization level	Fbus[a]	Fcar[c]	Fcycle[b]	Ftrain[d]
Age	1	-.085**	-0.026	.055**	-.152**	.270**	-.252**	.069**	0.017	-.075**	.060**	.128**
Gender	-	1	-.046*	-.112**	0.026	.078**	.084**	-0.019	.060**	-.062**	0.020	-0.021
Education	-	-	1	.202**	.122**	-.228**	-.125**	-.123**	-.112**	-0.033	.115**	.096**
Gross household income	-	-	-	1	.107**	-.244**	-.191**	.089**	-.089**	.115**	0.016	0.027
Children <12 years	-	-	-	-	1	-.193**	-.077**	.087**	-.143**	.041*	-0.001	-.093**
Employment status	-	-	-	-	-	1	.134**	0.011	.155**	-.097**	-0.015	.048*
Car availability	-	-	-	-	-	-	1	-.151**	.160**	-.248**	0.010	.050**
Municipal urbanization level	-	-	-	-	-	-	-	1	-.123**	.083**	-0.011	-0.013
Fbus[a]	-	-	-	-	-	-	-	-	1	0.000	0.000	0.000
Fcar[c]	-	-	-	-	-	-	-	-	-	1	0.000	0.000
Fcycle[b]	-	-	-	-	-	-	-	-	-	-	1	0.000
Ftrain[d]	-	-	-	-	-	-	-	-	-	-	-	1

Sig. codes: *p≤ 0.050; **p≤ 0.010

[a]: Factor of Attitudes toward Bus

[b]: Factor of Attitudes toward Cycling

[c]: Factor of Attitudes toward Car

[d]: Factor of Attitudes toward Train

Chapter 5

Longitudinal changes in transport-related and recreational walking: the role of life events

This chapter is based on the accepted article Gao, J., Kamphuis, C.B.M., Ettema, D., Helbich, M. Longitudinal changes in transport-related and recreational walking: the role of life events.
Transportation Research Part D: Transport and Environment

Abstract

Walking is a common form of physical activity and has a considerable impact on public health. Walking behavior may change over time due to life events including residential relocation. Only a few studies based on longitudinal data have examined the impacts of life events on walking behavior. By analyzing longitudinal panel data from the Netherlands Mobility Panel (MPN) for the years 2013 and 2015, this study examines to what extent life events lead to changes in the transport-related and recreational walking duration. In total, 1,185 respondents aged 18 and older who completed both survey waves were included in our sample. Multilevel mixed-effects Tobit regression models were fitted and showed that both childbirth and relocation to less urbanized areas were related to an increase in transport-related walking over time. No significant associations of life events with recreational walking were observed. Findings suggest that transport-related walking has a higher likelihood to be influenced by changes in the household composition and residential relocation than recreational walking. Further longitudinal research is needed to verify our findings and gain insight into underlying mechanisms explaining these relationships.

Key words: Longitudinal data; walking; residential relocation; life event; The Netherlands

5.1 Introduction

Walking is considered as one of important forms of physical activity (Bentley et al., 2018; Christian et al., 2017). A change in travel behavior toward walking is beneficial for population health (Scheiner and Holz-Rau, 2013b) as well as the environment given that walking is carbon-neutral and a nonpolluting travel mode (Sallis et al., 2016). Increases in walking behavior could be promoted by specific interventions (e.g., the creation of walking groups in residential neighborhoods or improvements in walking infrastructure) (Bentley et al., 2018; Giles-Corti et al., 2013; Knuiman et al., 2014), but changes may also occur as a response to life events such as childbirth (Lanzendorf, 2010).

Although many aspects of travel behavior are largely habitual until daily needs and living conditions disrupting the routine, life events may substantially affect people's travel (Bamberg et al., 2003; Schäfer et al., 2012; Scheiner and Holz-Rau, 2013a). Rooted in the Mobility Biography framework, this thinking addresses temporal stability and changes in people's travel behavior by acknowledging their routines (Müggenburg et al., 2015; Scheiner, 2007). The concept assumes that the existence of key events is related to travel behavior regarding different life course trajectories. Two main elements characterize the trajectories: on the one hand people's routine travel behavior over time until something leads to disrupt the routine; on the other hand key events that trigger one to reconsider individual's behavior and break habit, probably resulting to behavior change (Scheiner, 2007). Three domains of life events were centered upon in this framework: (1) households and family biographies (e.g., childbirth, and divorce) (Lanzendorf, 2010); (2) employment biographies comprising job or education changes (Busch-Geertsema and Lanzendorf, 2017; Oakil et al., 2011); and (3) residential biographies including residential relocation (Lin et al., 2018; Prillwitz et al., 2007; Wells and Yang, 2008).

Several studies address everyday travel behavior as a routine activity that may be affected by changes in these three life domains (Clark et al., 2016; Janke and Handy, 2019; Scheiner and Holz-Rau, 2013b; Van der Waerden et al., 2003). Childbirth, for example, may lead to rearrangements in household maintenance tasks (Lanzendorf, 2010). After childbirth, parents may increase their walking behavior, as they may substitute cycling by walking with a stroller. Regarding the second domain of life events, changing jobs may lead to an in- or de-crease in commute distance which may affect travel mode choice (Oakil et al., 2011; Van der Waerden et al., 2003). Additionally, retirement may disrupt daily routines and social networks leading to re-arrangements of lifestyle choices. These shifts in routines may change walking behavior (Jones et al., 2018), resulting a new activity pattern until another life event happens (Lanzendorf, 2003).

Previous studies have focused on the impact of life events on changes in travel mode including car, public transport and bicycle (Chatterjee et al., 2013; Clark et al., 2016; Klein and Smart, 2019; Oakil et al., 2011; Scheiner and Holz-Rau, 2013b). Regarding cycling behaviour, for instance, life events, such as residential relocation, job changes, and changes in household structure, have been shown to be crucial (Chatterjee et al., 2013; Janke and Handy, 2019; Jones, 2013; Oakil et al., 2016). Oakil et al. (2016) found that job changes increased likelihood of cycling commuting while childbirth reduced it. With respect to other travel modes, changes in income, changes in the household structure, and a childbirth etc., are related with changes in car ownership (Klein and Smart, 2019; Oakil et al., 2018). However, the importance of life events on walking remains unclear. Because life events have been largely ignored in empirical walking studies may bias transport models due to unobserved confounding and spurious relationships.

Changes in the third life domain, i.e. those caused by residential relocation may also lead to changes in travel behavior (Müggenburg et al., 2015). When moving to a different place, the transport options available, the accessibility of shops and facilities, and the neighborhood 'walkability' may differ between the old and new residential neighborhood, which may lead to changes in people's walking behavior (Giles-Corti et al., 2013). People moving to suburban and rural areas showed an increase in travel distance and time (Næss, 2005; Prillwitz et al., 2007; Scheiner and Holz-Rau, 2013a). Scheiner and Holz-Rau (2013a) found that suburbanization increased car use and decreased the usage of other travel modes (i.e., public transport, walking, and cycling). However, existing knowledge about walking behavior is mainly based on cross-sectional studies, failing to address causal relations. Only longitudinal study designs can incorporate the temporal order and the examination of changes within the individual due to life events (including residential relocation) on walking behavior. Within-person relationships are not confounded by time-constant factors (e.g., gender) and other confounders (e.g., self-selection factors) (Fitzmaurice et al., 2012). Walking and longitudinal relations with life events has received minor attention (Jones et al., 2014). Giles-Corti et al. (2013) showed that significant longitudinal associations between changes in built environment after relocation and walking for transport and recreation, however, without considering other life events (e.g., childbirth, job changes, and stopped working).

To address these knowledge gaps, this study is the first to provide longitudinal evidence regarding the effects of life events (i.e., regarding household composition, employment, and residential relocation) on transport-related and recreational walking behavior by using longitudinal panel data from 2013 and 2015.

5.2 Materials and methods

5.2.1 Research design and study population

Data were obtained from the Netherlands Mobility Panel (MPN) (Hoogendoorn-Lanser et al., 2015), a longitudinal household panel of approximately 2,500 households followed-up yearly from 2013 onward. Every year, the household members (aged older than 12 years) recorded their mobility using a travel diary for three successive days (September to November). Respondents reported demographics and socio-economic characteristics.

The 2013-and 2015-wave were considered for this analysis. These waves were chosen because they included all variables of interest for this study. Our sample included participants over 17 years (i.e., the legal driving age in the Netherlands) who recorded travel data (N=1,673). Participants who did not finish the whole questionnaire (N=427) and those who provided no data on transport-related and recreational walking across the waves (N=61) were excluded. In total, our data include 1,185 respondents, residing in 922 households nested in 87 Dutch municipalities. The mean number of respondents per municipality was 27 (SD=17).

5.2.2 Data

5.2.2.1 Walking duration

Per wave participants recorded their trips and travel-related characteristics (i.e., mode, distance, travel time and purpose). Because walking for transport (i.e., walking to the bus, to the car, to work, or to go from place to place) differs from recreational walking (i.e., walking for pleasure, or with a dog) in terms of flexibility and discretionary nature, both purposes were considered separately (Heinen et al., 2011; Mirzaei et al., 2018). Participants were asked whether they were engaged in each walking purpose during the survey days, and if so, how many minutes it took per day. We considered the average transport-related and recreational walking duration as outcome variables measured per person per day in minutes.

5.2.2.2 Life events and residential relocation

The occurrence of life events is tracked through the annual survey. Along with the mobility biographies (Lanzendorf, 2003), respondents in 2015 were asked 'have you ever experienced the following events (i.e., childbirth, getting a job, starting work, and stop working) in the past 24 months?' (1=Yes; 0=No). Due to the low frequency of getting a job and start working, both life events were grouped together as "changes in the job situation" and represented by a dummy variable. Moving status in both 2013 and 2015 was determined by means of changes in the residential address within the Netherlands. By combining data on residential postcode with the level of address density (CBS, 2014, 2015a), this variable was coded into two dummy variables: someone moved to a more urbanized area and a less urbanized areas, with no change in population density as reference group. Additionally, we incorporated car number changes in the household by aggregating two dummy variables (i.e., car disposal, and car acquisition).

5.2.2.3 Control variables

Numerous covariates on an individual and household level were selected according to previous studies (de Haas et al., 2018; Gao et al., 2018). Specifically, we considered age with six categories (i.e., 18-29, 30-39, 40-49, 50-59, 60-69, and ≥70 years). Gross annual household income and educational level were grouped into low, middle, and high (CBS, 2016). Employment status was incorporated as employed, and retired or other unemployed. Other control variables were gender, number of children (aged ≤12 years) per household, working hours, drivers' license, and number of cars per household. All these covariates were measured in 2013.

Informed by the literature (Handy et al., 2002; Wong et al., 2011) but constrained by data availability, the following variables describe the residential environment on the four-digit postal code level (PC4 level) for 2013 and 2015 (CBS, 2013, 2015b). Address density means the total number of addresses per km^2. Distances (in km) from the center of each postal code area to the following nearest destinations were determined: train station, supermarket, and major transfer station. To preserve respondents' privacy, environmental variables were blurred adding 1% a random noise by data owner—Netherlands Institute for Transport Policy Analysis.

5.2.3 Statistical analyses

Repeated walking duration was recorded for individuals in our cohort. Therefore, we examined the longitudinal associations between life events and residential relocation on changes in both transport-related and recreational walking duration in 2013 and 2015 by means of two-level mixed-effects regression models. The two-level regression design was necessary because we expected within-subject correlations and for people within the same household. A significant proportion of the participants did not report walking in 2013 and 2015, resulting in positively skewed outcome variables. Because the response was further censored to zero, multilevel mixed-effects Tobit regressions were fitted, which can deal with absence of negative values in the dependent variable and excess of zero (Greene, 2003). Further, multilevel regression models with only a random intercept were used, due to the small size of average cluster (i.e., 1.29 people averagely were nested in each household) (Snijders, 2005).

Following two models for each walking purpose were estimated. Our base model (Model 1) included only sociodemographic and residential environmental variables. Model 2 additionally added life events and residential relocation. All modes were adjusted for time in years, and the time-vary control variables (Table 1). Goodness-of-fit across the models is assessed through the Chi-square statistics, log likelihood ratio test, and the deviance statistic. As the estimated parameters do not directly quantify the absolute differences in minutes of walking compared to a reference group, the average marginal effects have been determined for easy interpretation. For a continuous variable, it refers to an additional minute of walking if the continuous variable increased by one unit. On the other hand, for a categorical variable, it means that the estimated average change in walking duration for each level of the categorical variables. The analyses were performed with Stata SE 15.1 (StataCorp, College Station, TX).

5.3 Results

Table 5.1 reports the descriptive statistics. About 31% and 26% of the participants in 2013 and 2015 respectively engaged in any transport-related walking over the three successive days during which they kept a travel diary, while 22.5% (2013) and 20.5% (2015) reported any walking for recreation. The mean daily transport-related walking duration was 2.8 minutes in 2013 and 2.3 minutes in 2015. Recreational walking decreased from 3.3 minutes (2013) to 2.8 minutes (2015). Participants were aged from 18 and older years and 53.9% were females. The frequency of life events was low. Changing jobs occurred most frequently with 9.8%, whereas stopped working (3%) and childbirth (3.7%) were less frequent. Approximately 3.7% of respondents relocated to less urbanized areas, whereas 7% moved to denser areas. Participants reported 5.9% of car disposal whereas 5.5% of household obtained car. Life event co-occurred rarely. For instance, childbirth co-occurred with moving to less urban areas only in 0.3% of cases.

Table 5.1 Socio-demographic and behavioral characteristics of participants for 2013 and 2015.

Indicators	2013 (N=1,185)	2015 (N=1,185)
Dependent variables		
Mean transport walking (min.) (SD)	2.8 (6.69)	2.5 (6.19)
Mean recreational walking (min.) (SD)	3.3 (8.79)	2.8 (7.86)
Life events		
Change jobs	-	9.8%
Stopped working	-	3.0%
Childbirth	-	3.7%
Car changing in the HH	-	
Car disposal	-	5.9%
Car acquisition	-	5.5%
Residential relocation		
Move to less urban areas	-	3.7%
Move to more urban areas	-	7%
Control variables		
Age (years)		
18-29	14.8%	-
30-39	18.5%	-
40-49	18.6%	-
50-59	18.2%	-
60-69	18.2%	-
70+	11.6%	-
Gender		
Male	46.1%	-
Female	53.9%	-
Education		
Low	22.2%	-
Medium	39.4%	-

High	38.4%	-
Gross household income		
<26K euro	20.8%	-
26K-65K euro	48.9%	-
>65K euro	17.4%	-
Unknown	12.9%	-
Diver licenses		
No	11.5%	-
Yes	88.5%	-
Employment status		
Multiple occupations	63.5%	-
Retired and other unemployed	36.5%	-
Working hours		
< 12 hours	6.9%	-
12-35 hours	21.6%	-
35+ hours	30.0%	-
Unemployed	41.4%	-
Children <12 years		
No	84.1%	-
Yes	15.9%	-
Number of cars in the HH		
no car	17.9%	-
1 car	49.8%	-
2 and more cars	32.3%	-
Residential environment variables		
Address density (1,000 addresses per km2)	1.66(1.63)	1.68(1.61)
Distance to nearest train station (km)	4.50(4.93)	4.65(4.99)
Distance to major transfer station (km)	9.73(8.25)	9.97(8.26)
Distance to nearest supermarket (km)	1.03(0.69)	1.06(0.71)

The regression results are summarized in Table 5.2. Chi-square tests indicate that Model 2 significantly exceed Mode1 ($p < 0.05$). Therefore, we focus on Model 2, where the average marginal effect of walking for transport decreased on average by 0.25 min/day ($p = 0.009$). Childbirth was significantly related with transport-related walking on average the marginal effect increased by 1.54 min/day ($p = 0.041$). Moving to less urbanized areas was positively associated with transport-related walking. The average marginal effect increased by 1.64 min/day ($p = 0.061$). Moving from less to more urbanized areas was insignificant. The increase in transport walking duration was significantly larger for residents who live in areas with a shorter distance to both a supermarket and a major transfer station.

For recreational walking, similar models were fitted. As no significant associations appeared between life events and recreational walking, the results are reported in the appendix (Table A1) Nonetheless, the average marginal effect of recreational walking decreased by 0.24 min/day ($p = 0.071$) (Model 1) after taking life events and residential relocation into account (Model 2; 0.32 min/day ($p = 0.042$)).

Table 5.2 Results for transport walking duration

Variables	Model 1 Coef.	Std. err.	Model 2 Coef.	Std. err.	Average margins effects (model 2)	Delta-method Std. err.
Constant	-7.140**	3.237	-7.053**	3.263		
Time (0=2013)	-0.768**	0.337	-0.980***	0.374	-0.249***	0.095
Life events						
Change jobs			-0.247	1.818	-0.063	0.462
Stop working			1.150	3.160	0.293	0.804
Childbirth			6.040**	2.960	1.536**	0.753
Car changing in the HH						
Car acquisition			0.971	2.314	0.252	0.610
Car disposal			-4.420	2.658	-1.035	0.572
Residential relocation						
Move to less urban areas			5.773**	2.785	1.644*	0.884
Move to more urban areas			-3.039	2.325	-0.731	0.528
Sociodemographic variables						
Age 18-29 (ref.)						
30-39	3.127*	1.726	2.912*	1.731	0.699*	0.411
40-49	1.371	1.750	1.661	1.757	0.389	0.408
50-59	1.732	1.803	1.949	1.816	0.459	0.424
60-69	4.930**	1.996	5.053**	2.013	1.267**	0.499
70+	5.193**	2.261	5.330**	2.282	1.345**	0.582
Gender Male (ref.)						
Female	3.780***	0.884	3.717***	0.881	0.936***	0.220
Education Low (ref.)						
Medium	1.281	1.208	1.290	1.206	0.318	0.295
High	2.509*	1.302	2.388*	1.304	0.602*	0.325
Gross household income <26K euro (ref.)						
26K-65K euro	-0.404	1.237	-0.489	1.239	-0.126	0.320
>65K euro	-0.540	1.675	-0.681	1.682	-0.174	0.430
Unknown	-1.481	1.685	-1.535	1.689	-0.387	0.422
Employment status Multiple occupations (ref.)						
Retired and other unemployed	-0.364	2.404	-0.083	2.409	-0.021	0.612
Working hours < 12 hours (ref.)						
12-35 hours	-0.068	1.980	0.068	1.982	0.017	0.498
35+ hours	-2.105	1.928	-2.051	1.929	-0.495	0.477
Unemployed	1.955	2.712	1.881	2.716	0.491	0.702

Children <12 years No (ref.)						
Yes	0.672	1.604	0.487	1.612	0.125	0.416
Diver licenses No (ref.)						
Yes	-2.570*	1.356	-2.491*	1.355	-0.658	0.372
Number of cars in the HH No car (ref.)						
1 car	-2.092**	1.023	-1.842*	1.022	-0.488*	0.276
2 and more cars	-4.120***	1.181	-3.570***	1.198	-0.915***	0.311
Residential environment						
Address density	0.572	0.354	0.593*	0.356	0.151*	0.091
Distance to nearest train station	0.006	0.134	0.015	0.134	0.004	0.034
Distance to nearest supermarket	-2.004**	0.970	-2.324**	0.976	-0.591**	0.248
Distance to nearest major transfer station	-0.182**	0.080	-0.185**	0.080	-0.047**	0.020
Between-individual variance	91.163	11.229	93.038	11.352		
Within individual variance	135.894	9.714	132.651	9.503		
Model fit						
Log-likelihood	-3449.46		-3442.35			
Wald Chi-square	(24) 131.66		(31) 143.00			
LR test	14.21**					

*** p<0.01, ** p<0.05, * p<0.1
LR=Likelihood-ratio test

5.4 Discussion

5.4.1 Key findings

This longitudinal study is among the few complementing the largely cross-sectional knowledge base on the effects of life events on transport-related and recreational walking duration. We found that childbirth positively affected transport-related walking over time, consistent with existing studies (Hirsch et al., 2014; Hou et al., 2010; Lanzendorf, 2010). Contrary to our expectation as well as previous studies (Prillwitz et al., 2007; Scheiner and Holz-Rau, 2013a), we found that relocation to less urbanized areas was significantly related with increases in transport-related walking duration. Life events seem to influence transport-related walking to some extent, but no significant longitudinal relationship was observed between life events and recreational walking duration.

5.4.2 Explanation of key findings

The descriptive analyses showed that both transport-related and recreational walking duration slightly decreased over time. Showing low frequency of life events occurring simultaneously with residential relocation, our findings suggest that childbirth and residential relocation (i.e., to less urbanized areas) are positive and significant determinants of the changes in transport-related walking duration. Consistent with previous studies (Lanzendorf, 2010; Scheiner, 2014), childbirth specifically plays an important role in transport-related walking. One possible reason is that in the Netherlands, approximately 27% of short trips (< 5 km) are made by bike, and it is likely that a considerable share of these bike trips is replaced by walking, simply because it is not easy to take a baby on a bike. For example, newborn babies not only need a full-time caretaker, but also would travel in a stroller for shopping or other child-related maintenances activities such as visiting doctors. Thus, caretakers would have to adjust their daily activities and schedules accordingly. Additionally, women considered it dangerous to drive a car with a baby on board, as drivers' attention may be divided between the baby and traffic (Lanzendorf, 2010). Another partner-related reason was that one of family members need to use the car during working would make car travel unavailable for the partner.

However, other life events including job changes and stopped working showed no significant associations with changes in transport-related walking. One possible interpretation is that the observation of participants is in a relatively short period. Changes in walking behavior can be delayed because of life events (Oakil et al., 2014). For instance, after retirement, people may need time to adapt their 'new' lifestyle whereby they may walk or cycle more for transport and/or recreation, rather than immediately changing their travel behavior and only to a minor extent, even if circumstances in the environment change dramatically. Further, as previous studies mainly focused on the effect of travel mode on life events, the biographical life events may not have a significant impact on all travel behavior measures, such as walking durations (Scheiner and Holz-Rau, 2013b). Weak effects of life events also suggest a considerable amount remains unknown about predicting walking duration. For instance, it is possible that changes in walking routes occurred during the study period that may have facilitated or inhibited transport-related walking duration but were not captured in the survey.

Regarding residential relocation, the effect of moving to a lower density area did not meet our expectation and our results were contrary to those from previous studies (Giles-Corti et al., 2013; Handy et al., 2008; Hirsch et al., 2014). While these studies were conducted in countries with lower population density, such as the US, and Australia, the Netherlands is among the most densely populated countries, so individuals relocating to less urbanized areas could be still within an acceptable range of walking distances. It is thus possible to walk to daily utilitarian destinations and bus stops. Additionally, our findings suggest that moving to inner-city neighborhoods may not have the anticipated positive impact on transport-related walking duration. This finding is congruent with a previous study (Prillwitz et al., 2006), where relocated residence from one regional main area to another had a strong effect on car acquisition. This probably because a highly urbanized area is related with heavy congestion, which might discourage frequency of residents' walking behavior (Wang et al., 2016). To encourage walking in more urbanized areas, enhancing pedestrian conditions such as pavement cleanliness, road lights, and connectivity would facilitate residents to use an improved pedestrian environment (Kelly et al., 2011).

The lack of associations between life events, and recreational walking, confirms both cross-sectional (Lee and Moudon, 2006; Lovasi et al., 2008; Pikora et al., 2006), and a longitudinal studies (Hirsch et al., 2014), suggesting that transport-related and recreational walking are different behaviors (Kang et al., 2017). This indicates that life events can influence routines and mandatory activities, such as work and school, more strongly than discretionary activities. Also, compared to recreational walking, transport-related walking has higher participation rates and frequency. Another possible reason is that this study omits the factors which may encourage recreational walking (e.g., aesthetic quality, sidewalk and street lamp availability). Different relationships of residential environment characteristics with transport-related and recreational walking highlight that it is important to incorporate different environmental features of different travel behavior (Hirsch et al., 2014; Lee and Moudon, 2006). It is also possible that recreational walking is influenced by attributes beyond the built environment, such as safety or social features, which could still be the characteristics of residential areas.

5.4.3 Strengths and limitations

A primary strength of this study is that it is one of the few longitudinal study designs. Additionally, our study is based on a national sample including both movers and non-movers to avoid the unobserved preferences regarding both choice of residential relocation and travel behavior. Our study also has some limitations. First, the low frequency of life events is due to the sample being constrained by two waves. The low frequency of life events did not allow us to add lag effects into our model, nor to examine combined or independent effects of different live events when two or more occur at the same time. Additional data are needed to analyze effects of life events in-depth. Also, we were not able to incorporate different travel characteristics between weekdays and weekends due to limited sample size. Second, while we considered built environmental characteristics at the postal code level, 'micro' characteristics known to be important for walking (e.g., aesthetics, presence of walking trails) were not included. Third, our outcome measured of minutes spent transport-related and recreational walking is self-reported and thus may be prone to recall bias (Bentley et al., 2018; Turrell et al., 2014). For example, the large proportion of non-walkers observed is probably due to underreporting of short daily walking including retrieving the mail or going to the grocery store. This restriction may also bias the estimated relationship between life events such as residential relocation and walking for transport and recreation. Tracking people through Global Positioning System seems promising to objectively collect data on walking behavior.

5.5 Conclusion

This study provided longitudinal evidence of the effect of life events on changes in walking over time. Our study adds to the literature by showing that changes in transport-related walking behavior are positively associated with childbirth, and moving to less urbanized areas. Life events, however, were not associated with recreational walking, whereas travel-related walking has a higher likelihood to be influenced by changes in household composition and residential relocation. Additionally, although we investigated direct links between life events and walking duration, these links may also be moderated by changes in activity patterns, destination choice, associated distances, and other variables. Further longitudinal research is needed to verify our findings and gain insight into the underlying mechanisms explaining these relationships.

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Appendix

Table A1 Results for recreational walking duration

Variables	Model 1 Coef.	Std. err.	Model 2 Coef.	Std. err.	Average margins effects (model 2)	Delta-method Std. Err.
Constant	-22.24***	-5.77	-22.27***	-5.82		
Time (0=2013)	-1.07*	-0.60	-0.89*	-0.67	-0.20*	0.15
Life events						
Change jobs			-1.65	-3.44	-0.37	0.77
Stop working			1.87	-5.56	0.42	1.24
Childbirth			0.45	-6.02	0.10	1.35
Car changing in the HH						
Car acquisition			0.37	-4.19	0.08	0.94
Car disposal			1.89	-4.24	0.43	0.99
Residential relocation						
Move to less urban areas			2.97	-5.12	0.69	1.22
Move to more urban areas			-4.16	-4.26	-0.89	0.87
Sociodemographic variables						
Age 18-29 (ref.)						
30-39	-1.83	-3.14	-1.88	-3.15	-0.39	0.66
40-49	-0.11	-3.14	-0.13	-3.16	-0.03	0.68
50-59	4.46	-3.10	4.39	-3.12	0.99	0.69
60-69	4.97	-3.54	4.82	-3.57	1.09	0.80
70+	2.51	-4.06	2.39	-4.09	0.53	0.90
Gender Male (ref.)						
Female	0.06	-1.57	0.05	-1.57	0.01	0.35
Education Low (ref.)						
Medium	2.63	-2.16	2.61	-2.16	0.55	0.45
High	7.04***	-2.31	7.07***	-2.32	1.57***	0.51
Gross household income <26K euro (ref.)						
26K-65K euro	0.45	-2.26	0.51	-2.26	0.12	0.52
>65K euro	-2.69	-3.03	-2.75	-3.04	-0.61	0.67
Unknown	-3.91	-3.11	-3.83	-3.12	-0.83	0.67
Employment status Multiple occupations (ref.)						
Retired and other unemployed	-0.36	-4.38	-0.33	-4.40	-0.07	0.98

Working hours						
< 12 hours (ref.)						
12-35 hours	0.03	-3.46	0.15	-3.47	0.03	0.79
35+ hours	-4.12	-3.34	-4.06	-3.34	-0.89	0.75
Unemployed	0.29	-4.84	0.39	-4.85	0.09	1.11
Children <12 years No (ref.)						
Yes	-6.18**	-2.99	-6.23**	-3.00	-1.32**	0.60
Diver licenses No (ref.)						
Yes	-4.03	-2.46	-4.00	-2.47	-0.93	0.59
Number of cars in the HH						
No car (ref.)						
1 car	1.50	-1.92	1.47	-1.92	0.33	0.42
2 and more cars	1.85	-2.13	1.76	-2.17	0.39	0.48
Residential environment						
Address density	0.78	-0.64	0.80	-0.65	0.18	0.14
Distance to nearest train station	0.28	-0.22	0.28	-0.22	0.06	0.05
Distance to nearest supermarket	0.15	-1.55	0.02	-1.56	0.00	0.35
Distance to nearest major transfer station	-0.06	-0.14	-0.07	-0.14	-0.01	0.03
Between-individual variance	2511.061		2512.072			
Within individual variance	3306.042		3304.395			
Model fit						
Log-likelihood	-3567.935		-3566.96			
Wald Chi-square	(24) 45.90		(31) 47.54			
LR test	1.95					

*** p<0.01, ** p<0.05, * p<0.1
LR=Likelihood-ratio test

Chapter 5

Chapter 6

What is walkability? How the built environment differently influences transport walking, recreational walking, and transit-related walking?

This chapter is based on a manuscript under review for a peer-reviewed journal:
Co-authors: Dick Ettema, Marco Helbich and Carlijn B.M. Kamphuis

Abstract

Residential environments are associated with people's walking behavior. Transit-related, non-transit-related, and recreational walking may be affected differently on weekdays and weekends, but empirical evidence is scarce. We examined the extent to which different types of walking correlated with natural and built environmental characteristics and how these characteristics were affected differently by weekdays and weekends. Our sample comprised 92,298 people aged 18 years and older from the Dutch National Travel Survey 2010-2014. Multivariate Tobit regression models assessed the associations between the natural and built environment and the three types of walking behavior (in average minutes per day); these models were also able to address correlations between the three types of walking behavior (e.g., compensation effects). Our results showed that denser residential areas encouraged both longer transit-related and non-transit-related transport walking, whereas lower density neighborhoods were positively associated with increased recreational walking on weekdays. Shorter distances to public transport were only significantly associated with transit-related transport walking. Crossing density was only significantly associated with transit-related transport walking on weekdays but was uncorrelated during weekends. However, proximity to facilities was not associated with non-transit-related transport walking on weekends. No significant associations were found on weekends. Our findings suggest that recreational walking may be less dependent on residential environmental attributes than transport-related walking is. Some compensation effects between different types of walking may be relevant: during weekends, recreational walking was inversely correlated with transit-related transport walking. Residential environments may have different effects on different types of walking behavior, suggesting that one size does not fit all and facilitating the efforts of policy makers and urban planners to target neighborhoods with specific environmental characteristics.

Keywords: Transit-related transport walking, Non-transit-related transport walking, Recreational walking, Natural and built environment, Multivariate Tobit regression model, The Netherlands

6.1 Introduction

Walking is considered a travel mode that contributes to physical activity and health (Bentley et al., 2018; Saelens and Handy, 2008) and that does not generate emissions of pollutants and greenhouse gases. Hence, policy makers in cities around the world aim to create walking-friendly environment via urban and transport planning. This approach requires that they have a proper insight into the mechanisms by which the built environment influences walking behavior. According to the ecological model of active living, physical activity, including walking, is associated with individual and environmental variables (Sallis et al., 2015). Various studies have addressed the extent to which neighborhood characteristics influence walking (Frank et al., 2019; McCormack et al., 2012; Saelens and Handy, 2008; Vale et al., 2016), distinguishing between transport-related walking (walking to reach a destination for a specific purpose) and recreational walking (walking for relaxation). In addition, using public transport has been positively associated with both total walking and transport-related walking duration mainly because walking is an important way to access and egress trains, metro and bus stops (Lachapelle and Pinto, 2016). For example, in the Netherlands, active travel to and from public transport is significant (e.g., 30% of trips access transport vs. 9% egress transport by bike, and 25% of trips access transport vs. 49% egress transport by walking) (Fishman et al., 2015; KiM, 2010; Shelat et al., 2018). Hence, a proper understanding of built environmental factors associated with walking to and from public transport stops may help to stimulate this specific type of transport-related walking (Humphrey, 2005; Xiao et al., 2019).

Some previous studies have shown that the built environments may have an impact on the use of public transport and whether people are willing to walk to public transport (Cervero, 2001; Lachapelle and Noland, 2012; Wasfi et al., 2013). For example, those living in suburban areas were less likely to use public transport (Susilo and Maat, 2007) and reported longer work commute distances than those living in urban areas (Badland et al., 2012). In neighborhoods that were more dense and diverse, the average distance to the closest public transport stop tends to be shorter, as more potential users can be found within the public transport stop catchment area, which sustains a more dense public transport network, with more lines potentially accessible from a given location (Nielsen, 2005). Note that the effect of the built environment on the amount of walking to and from public transport stops is twofold: both the distance to public transport and the attractiveness of the environment for walking, which is related to issues such as greenness, safety and presence of facilities, matter.

Although frequently disregarded, walking for different purposes may be induced by different mechanisms (Giles-Corti et al., 2013; Kang et al., 2017; Lee and Moudon, 2006; Saelens and Handy, 2008). Many studies have not addressed walking to and from public transit as a separate category and have instead merged it into transport-related walking. However, built environmental factors have different relationships with different types of walking behavior (Lee and Moudon, 2006; Saelens and Handy, 2008);, ignoring this difference may lead to biased estimates of their effects. For example, some existing reviews found that transport-related walking was related to address/population density, land-use diversity, street network, and accessibility of daily destinations (Saelens and Handy, 2008; Smith et al., 2017; Sugiyama et al., 2012), while recreational walking is related to aesthetic quality and, sidewalk and street lamp availability.

Furthermore, most studies have mainly focused on associations between built environmental factors and walking and do not take correlations between different types of walking into account (Menai et al., 2015). It is possible that engaging in one type of walking may cause people to engage in other types of walking behavior due to time-space constraints. Compensation effects may exist between different types of walking behavior. For example, people may start walking to and from public transport and subsequently decrease or even quit their morning recreational walking. Quantifying more precisely the relationships between the natural and built environment and different types of walking can inform decisions about transportation investments. Such investments could encourage more active travel and improve public health.

In addition, the effects of the natural and built environment attributes with different types of walking behavior may differ by weekdays and weekends, as the decision structures related to weekday and weekend trips are different (Gim, 2018; Ho and Mulley, 2013; Yang et al., 2016). For example, during weekdays, people, especially commuters, are much more sensitive to travel time due to busy agendas, and fixed time schedules than they are during weekends. Thus, it is necessary to consider and analyze different types of walking behavior on both weekdays and weekends simultaneously. However, most existing studies have focused on understanding walking behavior on weekdays.

Therefore, to fill these research gaps this study aims to examine: 1) the extent to which the natural and built environment affects different types of walking, 2) how these effects differ over weekdays and weekends, and 3) the correlations between different types of walking. Three walking types were considered among Dutch adults—transit-related transport walking, non-transit related transport walking and recreational walking.

6.2 Literature review

Findings from both public health and transport literature (Bentley et al., 2018; Christian et al., 2017; Christiansen et al., 2016; Ghani et al., 2018; McCormack et al., 2008), and reviews (McCormack and Shiell, 2011; Saelens and Handy, 2008; Smith et al., 2017; Wang et al., 2016) have indicated that there is substantial evidence that the built environment has an impact on transport-related walking and recreational walking. Built environmental factors include but are not limited to, density, land use diversity, urban design (e.g., street network configurations), distance to transit, and destination accessibility (Cervero et al., 2009). Walkability is a measure of how conducive an area is to walking. It refers to an aggregated score, including residential density, street density, and land use diversity (Frank et al., 2010). For example, shorter distances to destination could encourage walking (Ewing and Cervero, 2010). Likewise, land use diversity can shorten travel distance and increase walking frequency (Lachapelle and Pinto, 2016). Frank et al. (2007) found that both transport-related and recreational walking trips were positively associated with a more walkable neighborhood. In contrast, Pikora et al. (2006) found that the availability of shops and public transport were less important in predicting recreational walking compared to transport-related walking. Moreover, recreational walking is associated with access to pubic open space, recreational facilities, and neighborhood attractiveness (Giles-Corti et al., 2013). A review by McCormack and Shiell (2011) found that the built environment had a larger impact on transport-related walking compared with recreational walking.

In addition, public transport use, which often involves walking, is also influenced by the surrounding environment that leads an individual to incorporate more walking into their daily life (Lachapelle and Noland, 2012). For example, public transport stops being available in proximity to housing not only supports public transport usage but also increases accessibility to destinations beyond residential areas. Additionally, people would walk farther to public transport stops when high walkability factors were available, including easy access to utilitarian destinations and high street connectivity (Daniels and Mulley, 2013). In contrast, Lachapelle et al. (2011) found that public transport users also walked more to services and destinations near their homes and workplaces compared with non-transit users, irrespective of residential environment. The placement of frequent public transport stops may slow down the travel speed of public transport, thereby decreasing the spatial coverage of transit reachable within a given travel time limit (Murray and Wu, 2003).

In addition to the built environment, the natural environment, including green and blue space, influences walking behavior (Daniels and Mulley, 2013; Liu et al., 2019), but the evidence is mixed. Burke et al. (2006) concluded that natural environments have little influence on the propensity of walking. Tilt et al. (2007) found that living in greener neighborhoods were related with more walking trips, whereas greenness was negatively correlated with active travel mode usage in the Netherlands (Fishman et al., 2015; Gao et al., 2018). Furthermore, regarding weather conditions, for trips that involve walking to and from public transport, rain is a constraining factor (Walton and Sunseri, 2010), while higher temperatures and strong winds increase bus ridership (Tao et al., 2018). Regarding travel mode choice, Saneinejad et al. (2012) found that rain, temperatures below 15 °C and strong winds would be more likely to increase the amount that people walk but reduce cycling. However, no significant associations were found with transit use.

In summary, natural and built environment attributes play an important role in walking duration, although the specific factors that correlated with different patterns of walking have yet to be determined. To do so, a conceptual model composed of the three intertwined relationships among different types of walking behavior is presented (see Figure 6.1).

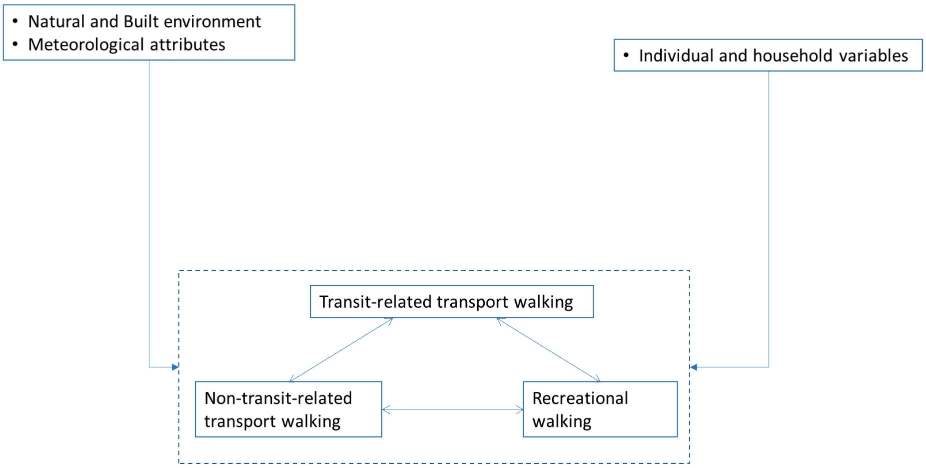

Figure 6.1 Conceptual model

6.3 Materials and methods

6.3.1 Study population

Data were obtained from the Dutch National Travel Survey (NTS) for the period 2010-2014 (CBS, 2011-2015). The NTS is a cross-sectional and continuous survey of approximately 40,000 individuals conducted annually by Statistics Netherlands. Respondents report their transportation behavior by means of a travel diary for one day. For each trip, travel data include transportation modes, place of origin and destination, time of departure and arrival, and travel purpose. The sample is representative of the Dutch population. The respondents' residential locations were geocoded on a 4-digit postal code (PC4) level, which allowed data linkages with attributes describing the residential environment.

The sample only includes participants who recorded travel data and were over 17 years of age (the age at which it is legal to drive a car in the Netherlands) (N=129,142). People with 'Unknown' and/or missing values of socioeconomic characteristics were not included (25,446).The respondents' residential locations were geocoded on a PC4 level, describing residential environmental attributes. Respondents missing information for postal code and built environmental attributes were excluded (n=11,398). After data cleaning, the sample comprised 92,298 people. Specifically, on weekdays, there was a sample of 73,729 people residing in 2,874 PC4 areas with a mean number of respondents per PC4 of 26 people (SD = 25) nested in 388 municipalities. On weekends, there was a sample of 18,569 people residing in 2,529 PC4 areas with a mean number of respondents of 7 people (SD = 5) nested in 386 municipalities.

6.3.2 Data

6.3.2.1 Walking duration

Three outcome variables were constructed, namely, total transit-related transport walking duration, non-transit-related transport walking duration and recreational walking duration in minutes per person. Episode data were used to create variables for participation and duration of walk trips by purpose. Transit-related transport walking duration only included walking trips that are part of combined walking and transit trip. Non-transit-related transport walking included trips to and from or between shops, facilities or work. Additionally, recreational walking included walking for pleasure or with the dog. All walking durations were calculated based on the travel diary data.

6.3.2.2 Built environment variables

The selection of the built environment measures was guided by the literature (Ewing and Cervero, 2010; Wong et al., 2011), but constrained by data availability: density, diversity, destination accessibility and distance to train station were considered. The variables were calculated at the PC4 level using existing spatial data (CBS, 2012, 2014a, b). Address density refers to the total number of addresses per km^2 in the PC4 (CBS, 2014a). Land-use diversity is represented by the Shannon entropy index. A value of 0 refers to one land use class per area, and a value of 1 refers to an even distribution of all land use types per area (Cervero and Kockelman, 1997). The operationalization considered the five most relevant land use types for residents' daily activities, namely, residential, commercial, industrial, and recreational areas, and public services (e.g., police station, hospital) (CBS, 2014b). Intersection density (Kadaster, 2012), distance to nearest train station, supermarket, and restaurant (calculated by road) (CBS, 2014b), and number of bus stops per PC4 reflect transportation-related built environment measures (i.e., accessibility of destinations and distance to public transport).

6.3.2.3 Natural environment variables and weather

Daily meteorological variables were collected from 33 weather stations across the Netherlands (KNMI, 2017). We obtained weather data from the weather station closet to each participant's residential area for the day on which the travel diary was kept. We matched the trip date with daily measures of maximum air temperature (in °C), precipitation total (in mm), and average wind speed (in m/s), which are all frequently used measures (Böcker et al., 2015; Helbich et al., 2014). The proportion of green space (including agricultural and natural areas, man-made greenery (e.g., park)) and water space per PC4 was abstracted from the most recent Dutch land use database for the year 2012 (Hazeu et al., 2014).

6.3.2.4 Individual and household characteristics

Individual characteristics were obtained from the National Travel Survey. Age was divided into four categories: 18-24, 25-34, 35-64, and ≥ 65 years. We categorized net household income per year into low (< €20,000), medium (€20,000 – 40,000), and high (> €40,000) (Gao et al., 2018). Education attainment was stratified into three categories: low (i.e., primary school and lower general secondary school), medium (i.e., upper-division secondary school), and high (i.e., college and university) (CBS, 2016). Employment status was incorporated as employed (work 12-30 hours; work more than 30 hours), student, unemployed, retired, and other. Other controls were gender, household structure, number of cars per household, car ownership, and driver's licenses.

6.3.3 Statistical analyses

We first display the distribution of the variables across transit users and non-transit users by weekdays and weekends. The significance of the difference between sample of transit users and non-transit users was tested using Chi squared tests for categorical variables in weekdays and weekends respectively. Pearson correlation coefficients were used to test for multicollinearity among the covariates. Correlations < - 0.8 or > 0.8 are considered problematic (Freedman et al., 1991).

Next, multivariate Tobit models were used to model the associations between the natural and the built environment variables and three types of walking duration (i.e., transit-related transport walking, non-transit-related transport walking, and recreational walking). Unlike employing a traditional Tobit model to each walking behavior separately, the applied Tobit model is able to address correlation among three types of walking behavior (Anastasopoulos et al., 2012; Huang, 1999; Zhang et al., 2017). This is important because if different types of walking duration are modeled independently, significant estimation error could be introduced since unobserved effects at the individual level are likely to be shared across walking behavior types. The correlation between the dependent variables is represented as an endogeneity relationship, which implies that a change in the endogenous variable leads to a change in the dependent variables. It is thus assumed that each type of walking behavior is affected by a change in other types of walking behavior, and vice versa. Furthermore, a large proportion of participants report no walking during the survey day, which means that the outcome variables are censored. Therefore, the multivariate Tobit model was employed (Barslund, 2015). Moreover, by estimating the cross-equation error correlations and the variance of the error terms, this model can reveal the relation between the different types of walking duration.

We estimated the following models for both weekdays and weekends. First, base models only included individual and household characteristics. Second, full models were extended with the natural and built environmental variables. Due to varying units, continuous independent variables were z-score transformed. The alpha level was set at 0.01. All models were implemented in Stata SE 15.1 (StataCorp, College Station, TX).

6.4 Results

6.4.1 Descriptive statistics

Examining the type of walking behavior, the overall walking duration for transit users (23.69 min/day) was longer than for non-transit users (10.85 min/day). Among all participants, average total walking duration was longer on weekends (14.95 min/day), compared to weekdays (10.9 min/day). Approximately 6.9% of participants (n = 6,195) who were transit users reported an average daily walking duration was 23.35 min on weekdays, and 25.12 min on weekends. Although there were fewer transit users on weekends (4.4% of the weekend sample) than on weekdays (7.3% of the weekday-sample), people engaged in longer transit-related transport walking on weekends (18 min/day) than on weekdays (16.82 min/day). In contrast, for both non-transit-related transport walking and recreational walking, non-transit users walked for a longer duration than transit users. In particular, non-transit users engaged in more recreational walking than transit users (see Figure 6.2).

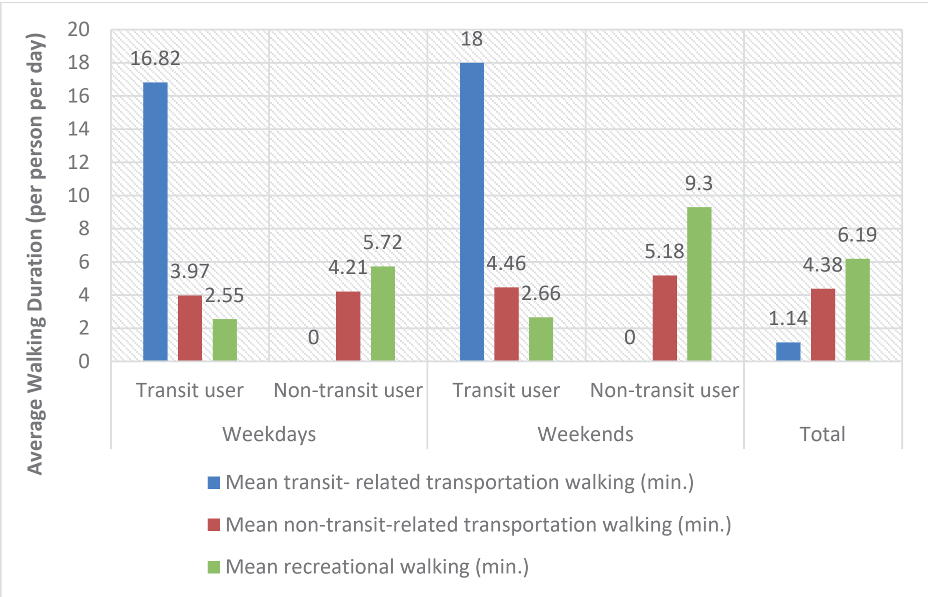

Figure 6.2 Distribution of walking duration

Summary statistics for the sample and subgroups of transit users and non-users are presented in Table 6.1. There were significant differences between transit users and non-transit users (all Chi square tests between users and non-users of $p < 0.05$). On both weekdays and weekends, compared to non-transit users, transit users were younger and had lower incomes; they were also composed of a higher percentage of women, single individual households, and households lacking driver's licenses or cars. There were fewer transit users on the weekends compared to weekdays. Regarding weekdays, transit users had a higher proportion of students and participants who worked more than 30 hours per week. Regarding contextual factors, for transit users, the mean address density, crossing density, and number of bus stops of residential areas were greater, compared to non-transit users on both weekdays and weekends. Additionally, destination accessibility (i.e., distance to supermarkets, restaurants, and a train station) was better for transit users. Transit users reported living in areas with less green space, compared to residential areas of non-transit users.

Table 6.1 Descriptive Statistics

		Weekdays (N_1 = 73,729)			Weekends (N_2 = 18,569)		
Sociodemographic variables	**Total sample, %**	**Transit user, %**	**Non-transit user, %**	**Chi square test (users vs. non-users)**	**Transit user, %**	**Non-transit user, %**	**Chi square test (users vs. non-users)**
Sample size *n*	92,298	7.28	92.7%		4.44	95.6	
Age (years)				0.000			0.000
18-24	6.4	23.7	5.1		18.2	5.7	
25-34	14.1	18.7	13.6		19.2	14.3	
35-64	59.2	46.4	60.2		46.9	59.6	
65+	20.3	11.2	21.1		15.8	20.4	
Gender				0.000			0.039
Male	48.7	45.2	48.9		45.2	48.9	
Female	51.3	54.8	51.1		54.8	51.1	
Education				0.000			0.001
Low	5.3	4.0	5.3		6.2	5.4	
Medium	60.4	51.5	61.1		53.9	60.5	
High	34.4	44.5	33.6		39.9	34.0	
Gross household income				0.004			0.000
<20K euro	31.2	33.0	31.1		40.1	30.9	
20K-40K euro	58.2	56.2	58.5		51.9	58.1	
>40K euro	10.5	10.8	10.4		8.0	11.0	
Social Participation				0.000			0.000
Work (12-30h)	17.7	14.4	18.0		13.1	18.1	
Work (>= 30h)	44.3	47.5	44.3		42.5	43.6	
Student	3.5	18.9	2.2		14.9	3.0	
Unemployed	12.1	7.5	12.3		12.0	12.7	

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Retired	22.4	11.7	23.2		17.5	22.6	
Household structure				0.000			0.000
Single-person HH	17.7	26.0	17.1		34.5	16.7	
Couple without children	37.6	28.3	38.5		26.5	37.5	
Couple with children	40.2	38.6	40.1		29.0	41.4	
Single parent with children	4.5	7.1	4.3		9.9	4.4	
Number of cars in the HH				0.000			0.000
no car	10.6	31.7	8.8		43.6	9.7	
1 car	52.8	48.8	53.1		39.5	53.8	
2 and more cars	36.5	19.6	38.1		16.8	36.6	
Diver licenses				0.000			0.000
No	10.6	26.1	9.3		33.9	10.1	
Yes	89.4	73.9	90.7		66.1	89.9	
Bicycle ownership				0.000			0.000
No	14.1	15.8	14.0		21.0	13.6	
Yes	85.9	84.2	86.0		79.0	86.4	
Built environmental variables							
Address density (per 1000 addresses km2)	1.36 (1.60)	2.29 (2.15)	1.25 (1.50)		2.92 (2.53)	1.43 (1.63)	
Land use diversity	0.61 (0.16)	0.60 (0.15)	0.61 (0.16)		0.60 (0.15)	0.61 (0.16)	
Cross density (N per km2)	105.77 (80.41)	143.19 (80.07)	101.34 (79.58)		156.07 (78.37)	109.21 (79.91)	
Number of bus stop	17.78 (11.54)	18.56 (12.02)	17.61 (11.52)		20.60 (14.01)	18.08 (11.31)	
Distance to supermarket (km)	0.95 (0.78)	0.76 (0.55)	0.98 (0.81)		0.68 (0.50)	0.91 (0.69)	
Distance to restaurant (km)	0.90 (0.74)	0.71 (0.59)	0.93 (0.78)		0.59 (0.49)	0.84 (0.63)	
Distance to train station (km)	6.09 (7.58)	3.78 (4.95)	6.53 (8.09)		3.32 (4.00)	5.25 (5.93)	
Natural environmental variables							
Percentage of Green (%)	54.56 (22.68)	43.79 (21.72)	56.12 (22.61)		37.95 (20.88)	52.59 (21.93)	
Percentage of Blue space (%)	4.11 (6.33)	4.06 (6.46)	4.08 (6.27)		4.40 (6.45)	4.27 (6.49)	
Weather variables							
Daily max. Air temperature (°C)							
< 0 °C	3.5%	3.9%	3.6%		1.9%	2.9%	
0-10 °C	30.0%	30.4%	29.7%		29.1%	31%	

10 - 20 °C	45.0%	46.1%	45.1%	48.1%	44.3%
20 - 25 °C	16.2%	15.3%	16.3%	15.6%	15.9%
> 25 °C	5.3%	4.2%	5.3%	5.2%	6.0%
Daily precipitation sum (mm)	2.17 (4.64)	13.43 (7.20)	13.72 (7.37)	2.28 (4.17)	2.23 (4.60)
Daily average wind speed (m/s)	4.22 (2.03)	2.21 (4.84)	2.16 (4.63)	4.49 (2.17)	4.16 (2.03)

6.4.2 Multivariate Tobit regression model results

Multicollinearity among the covariates was not a concern, as indicated by the Pearson correlations (see Table A1 in the Appendices). The correlation showed that instead of a trade-off effect, recreational walking is positively correlated with non-transit-related transport walking on weekdays (see Table 6.2). In contrast, the correlations on weekends showed an inverse correlation between recreational walking and transit-related transport walking (see Table 6.3).

As indicated in Table 6.2, individuals living in PC4 areas with a higher address density, higher crossing density, and shorter distance to the nearest train station were more likely to engage in transit walking. Regarding non-transit-related transport walking, respondents living in PC4 areas with a higher address density and shorter distances to the nearest supermarket and restaurant tended to walk longer for transport. A lower temperature was positively related to non-transit-related walking duration compared to the normal temperature in the Netherlands (i.e., 10-20°C). The percentage of green showed an inverse association with walking duration. No significant associations were found between non-transit-related walking duration and the other natural and built environment variables, such as crossing density, distance to the nearest train station, wind speed, precipitation and water bodies. In contrast, recreational walking was less prevalent in higher address density areas compared to less urbanized areas.

Table 6.2 Results for different walking behavior on weekdays

Variables	Model Transit-related transport walk	S.E.	Model Non-transit-related transport walking	S.E.	Model Recreational walking	S.E.
Constant	-37.17***	(3.72)	-45.75***	(3.20)	-208.84***	(7.34)
Age (years)						
18-24 (ref.)						
25-34	-19.20***	(1.60)	3.67	(1.98)	31.73***	(4.87)
35-64	-23.20***	(1.53)	-1.49	(1.91)	46.86***	(4.64)
65+	-23.50***	(2.79)	-3.85	(2.72)	34.40***	(5.99)
Gender						
Male (ref.)						
Female	3.78***	(0.85)	9.53***	(0.81)	2.99	(1.61)
Education						
Low (ref.)						
Medium	4.33	(1.92)	-0.81	(1.48)	6.50	(3.36)
High	14.87***	(2.19)	3.23	(1.58)	11.38***	(3.58)
Gross household income						
<20K euro (ref.)						
20K-40K euro	9.35***	(1.03)	0.61	(0.83)	1.49	(1.67)
>40K euro	14.84***	(1.63)	0.67	(1.49)	-5.61	(2.86)
Social Participation						
Work (12-30h) (ref.)						
Work (>= 30h)	6.44***	(1.25)	-8.39***	(1.09)	-17.16***	(2.13)
Student	30.68***	(2.29)	-4.56	(2.58)	-13.09	(5.87)
Unemployed	-8.24***	(1.69)	10.85***	(1.29)	18.69***	(2.52)
Retired	-10.49***	(2.52)	12.48***	(2.18)	17.30***	(4.14)
Household structure						
Single-person HH (ref.)						
Couple without children	3.00	(1.28)	-2.93**	(1.06)	14.45***	(2.24)
Couple with children	8.62***	(1.38)	-4.57***	(1.20)	8.960***	(2.45)
Single parent with children	1.73	(1.90)	-7.26***	(1.88)	-1.89	(3.96)
Number of cars in the HH						
no car (ref.)						
1 car	-23.30***	(1.59)	-13.33***	(1.29)	-6.11	(3.02)
2 and more cars	-42.95***	(2.37)	-23.05***	(1.59)	-8.32	(3.42)
Diver licenses						
No (ref.)						
Yes	-16.03***	(1.30)	-7.55***	(1.17)	4.79	(2.82)

Bicycle ownership						
No (ref.)						
Yes	-5.10***	(1.06)	-3.102***	(0.94)	10.80***	(2.11)
Daily weather conditions						
Daily average wind speed (m/s)	1.22**	(0.41)	0.46	(0.37)	-1.42	(0.75)
Daily max. air temperature (°C)						
10 - 20 °C (ref.)						
< 0 °C	4.10	(1.92)	15.50***	(1.79)	3.70	(3.74)
0-10 °C	0.72	(0.92)	2.77***	(0.81)	-1.25	(1.65)
20 - 25 °C	-1.08	(1.09)	-0.73	(1.03)	-1.00	(2.13)
> 25 °C	-3.82	(1.85)	0.81	(1.55)	-5.16	(3.34)
Daily precipitation sum (mm)	-0.38	(0.41)	-0.36	(0.36)	-1.09	(0.79)
4-digit postal code zone level						
Address density (1000 addresses per km^2)	2.08**	(0.66)	4.72***	(0.59)	-6.33***	(1.36)
Land use diversity	0.50	(0.56)	0.93	(0.41)	0.59	(0.72)
Crossing density (N/km^2)	2.86**	(0.96)	-1.53	(0.69)	0.99	(1.35)
Number of bus stops	0.32	(0.56)	0.72	(0.40)	-1.56	(0.77)
Distance to train station (km)	-5.18***	(0.76)	0.38	(0.41)	0.42	(0.88)
Distance to supermarket (km)	-0.02	(0.64)	-2.54***	(0.58)	-1.89	(0.87)
Distance to restaurant (km)	-0.21	(0.60)	-2.68***	(0.56)	-0.76	(0.83)
Percentage of green (%)	-1.27	(1.06)	-3.87***	(0.75)	-0.80	(1.41)
Percentage of water (%)	-0.54	(0.57)	0.68	(0.36)	0.35	(0.65)
Summary statistics						
Sigma	46.02***	(1.87)	61.42***	(1.69)	112.75***	(1.65)
Rho correlation						
Recreational walking and Transit walking	-0.01	(0.01)				
Recreational walking and Transport-related walking	0.09***	(0.01				
Transit walking and Transport-related walking	0.01	(0.01)				
Wild Chi-squared (102)	2910.28***					
LR test	105.36***					
Total Observations	73,729					

*** p<0.001, ** p<0.010

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On weekends, higher address density and more bus stops within a residential PC4 area were positively associated with longer transit-related transport walking duration. The percentage of green space showed an inverse association with transit-related transport walking duration. No significant associations were found among meteorological attributes. Similarly, a higher address density in a residential PC4 area was more likely to engage in non-transit-related transport walking for longer duration of time. The percentage of green was negatively associated with non-transit-related transport walking duration. No significant association was found between the built environment and recreational walking, but lower temperature (i.e., below 0 °C) was more likely to encourage recreational walking.

Table 6.3 Results for different walking behaviors on weekends

Variables	**Model Transit-related transport walk**	**S.E.**	**Model Non-transit-related transport walking**	**S.E.**	**Model Recreational walking**	**S.E.**
Constant	-66.32***	(9.99)	-49.32***	(6.25)	-239.01***	(16.30)
Age (years)						
18-24 (ref.)						
25-34	-13.14	(5.36)	4.30	(3.76)	32.34***	(10.00)
35-64	-17.03***	(5.12)	5.03	(3.57)	47.56***	(9.67)
65+	-32.55***	(8.47)	-1.92	(5.05)	49.48***	(12.76)
Gender						
Male (ref.)						
Female	4.16	(2.85)	5.32***	(1.57)	9.81**	(3.65)
Education						
Low (ref.)						
Medium	6.26	(5.51)	2.23	(3.18)	9.59	(7.35)
High	17.10**	(6.15)	5.49	(3.44)	12.40	(7.74)
Gross household income						
<20K euro (ref.)						
20K-40K euro	7.73**	(2.99)	-4.81**	(1.75)	6.30	(3.80)
>40K euro	5.26	(4.77)	-4.74	(3.05)	2.45	(6.39)
Social Participation						
Work (12-30h) (ref.)						
Work (>= 30h)	4.41	(4.14)	1.64	(2.19)	-7.92	(4.89)
Student	25.43***	(6.14)	-4.12	(4.88)	-18.76	(13.88)
Unemployed	-0.71	(5.12)	3.48	(2.60)	15.17**	(5.81)
Retired	5.30	(7.26)	11.55**	(3.94)	11.84	(9.12)

Household structure						
Single-person HH (ref.)						
Couple without children	-3.71	(3.31)	-4.69	(2.05)	24.73***	(5.27)
Couple with children	-7.19	(3.83)	-6.24**	(2.30)	10.19	(5.59)
Single parent with children	3.93	(4.88)	-7.17	(3.58)	12.32	(8.40)
Number of cars in the HH						
no car (ref.)						
1 car	-29.11***	(4.39)	-11.46***	(2.58)	-2.35	(6.85)
2 and more cars	-38.39***	(5.71)	-20.43***	(3.13)	-12.20	(7.99)
Diver licenses						
No (ref.)						
Yes	-28.95***	(4.41)	-10.35***	(2.39)	-3.10	(5.82)
Bicycle ownership						
No (ref.)						
Yes	-9.38**	(3.20)	-2.35	(2.06)	13.44**	(4.75)
Daily weather conditions						
Daily average wind speed (m/s)	2.47	(1.09)	0.28	(0.72)	0.68	(1.58)
Daily max. air temperature (°C)						
10 - 20 °C (ref.)						
< 0 °C	-12.97	(7.58)	10.69	(4.21)	30.65***	(8.46)
0-10 °C	0.09	(2.75)	4.85**	(1.65)	7.33	(3.65)
20 - 25 °C	-4.78	(3.77)	-2.75	(2.17)	-10.13	(4.84)
> 25 °C	-2.55	(5.59)	-2.78	(3.08)	-4.30	(7.14)
Daily precipitation sum (mm)	-0.29	(1.18)	-0.55	(0.80)	-3.95	(1.70)
4-digit postal code zone level						
Address density (1000 addresses per km^2)	4.27**	(1.41)	5.41***	(0.93)	-6.07	(2.67)
Land use diversity	-1.10	(1.34)	0.95	(0.82)	-3.63	(1.70)
Crossing density (N/km^2)	-2.56	(2.02)	-0.84	(1.27)	-4.81	(2.75)
Number of bus stops	4.88***	(1.33)	0.16	(0.77)	0.36	(1.64)
Distance to train station (km)	-5.42	(2.98)	1.77	(1.14)	-2.43	(2.17)
Distance to supermarket (km)	-1.19	(2.50)	-2.41	(1.15)	2.46	(2.14)
Distance to restaurant (km)	1.16	(2.64)	-2.21	(1.17)	-4.58	(2.40)
Percentage of green (%)	-10.19***	(2.62)	-3.85**	(1.44)	-2.54	(2.99)
Percentage of water (%)	-0.54	(1.08)	0.38	(0.74)	-0.14	(1.47)
Summary statistics						
Sigma	62.10***	(5.45)	66.02***	(2.59)	138.75***	(4.19)
Rho correlation						
Recreational walking and Transit walking	-0.13***	(0.04)				

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Recreational walking and Transport-related walking	-0.03	(0.02)
Transit walking and Transport-related walking	-0.06	(0.03)
Wild Chi-squared (102)	890.27***	
LR test	25.97***	
Total Observations	18,569	

*** p<0.001, ** p<0.010

6.5 Discussion

6.5.1 Correlations between different types of walking

Our findings reveal that the relationship differs across different types of walking behavior as well as between weekdays and weekends. During weekdays, recreational walking is positively correlated with non-transit-related transport walking, suggesting a complementary relationship. Apparently, an underlying positive attitude toward walking leads to more walking for both categories but not for transit-related transport walking. Transit-related transport walking is more strongly influenced by other characteristics, such as accessibility of destinations to transit. This is also likely because during weekends, recreational walking is reversely correlated with transit-related transport walking, suggesting a trade-off between these two types of walking behavior. One possible explanation is that recreational walking could take place outside the residential area, whereas transit-related transport walking would start from a residential area. This also reflects differences in spatial and temporal distribution of utilitarian and recreational walking, confirming their contextual differences (Kang et al., 2017).

6.5.2 The built and natural environment

Consistent with earlier studies (Adams et al., 2013; Lee and Moudon, 2006; Saelens and Handy, 2008), the results confirmed that different built environmental characteristics are related to different types of walking behavior. Transportation walking (including (non-) transit-related transport walking) was more frequently related with built environment than recreation walking, which is in line with previous reviews (Panter and Jones, 2010; Saelens and Handy, 2008; Van Holle et al., 2012). Specifically, residential areas with a higher address density encouraged both longer transit-related and non-transit-related transport walking, whereas a less address density is positively associated with longer recreational walking on weekdays. Because people would prefer to walk for recreation (e.g., walking for leisure, brisk walking and walking a dog, etc.) in a public open space, leafy suburbs with less address density provide attractive destinations and pleasant routes. Recreational walking is not necessarily undertaken in residential neighborhoods, as a recreational built environment (e.g., parks) may compete with other land use characteristics, such as living and commercial areas (Van Holle et al., 2012). An interesting contrast is found that greenness had a negative effect on (non-) transit-related transport walking, which is in line with previous Dutch studies (Fishman et al., 2015; Gao et al., 2018). The results might seem counterintuitive, because one may expect it to be more pleasant to walk in green areas. A possible explanation is that a higher percentage of green space may be characterized by a lower level of safety, as large green space is more likely to serve as a hiding place for criminal activity, thereby leading to feelings of insecurity (Kuo and Sullivan, 2001). A shorter distance to public transport only matters for transit-related transport walking. Proximity to utilitarian facilities only matter for non-transit-related transport walking. This means that utilitarian destinations were consistently considered important indicators of a walk-friendly environment (Heinen et al., 2010; Lee and Moudon, 2006; McCormack et al., 2012).

Regarding differences between weekdays and weekends, crossing density was significantly associated with transit-related transport walking on weekdays. This indicates that not only distance to public transport matters, but also the ease, in terms of routes choices, with which one can get to a transit stop, given that crossing density relates to the ease of travel between two points (Adams et al., 2013). By contrast, on weekends, this is not the case, which is probably due to fewer tight constraints and the use of public transport for recreational reasons. Moreover, proximity to facilities does not matter for non-transit-related transport walking on weekends. It is possible that most people take utilitarian trips during week. This is also probably because if the utilitarian destinations of people were within walkable distance, it would not be necessary to use public transport to meet their daily needs. This idea therefore suggests distinction between pedestrian-friendly environment and transit-friendly environment (Ewing and Cervero, 2001). Without proper access to public transport, individuals probably need to use alternative travel modes, such as cars, even when destinations are within walking distance (Lachapelle and Pinto, 2016; Morency et al., 2007). Therefore, pedestrian-friendly environment design should include easy transit access so people can reach their destinations and return home, and transit-friendly areas must be augmented with a variety of nearby destinations. However, no significant associations were found on weekends, which is consistent with previous cross-sectional evidence (Lee and Moudon, 2006; Lovasi et al., 2008; Pikora et al., 2006), and a longitudinal study (Hirsch et al., 2014). McCormack et al. (2012) concluded that a supportive neighborhood built environment is necessary, but insufficient to increase recreational walking alone. People would engage in recreational walking outside residential areas. Another possible explanation is that recreational walking is affected by factors outside the built environment, such as safety or social features, which could still be neighborhood-level characteristics but are constrained by data availability in this study.

Another important factor for walking behavior is formed by weather conditions. In contrast to existing international (Aaheim and Hauge, 2005; Tucker and Gilliland, 2007) and Dutch cycling studies alike (Böcker et al., 2015; Gao et al., 2018) maximum daily air temperature, especially a lower temperature (i.e., <0 °C, and 0-10 °C), had a positive effect on recreational walking on weekends, and non-transit-related transport walking for both weekdays and weekends, suggesting that lower temperature has little impact on people's walking behavior. This is probably because the Netherlands has a moderate climate with mild temperatures, and substantially low temperatures did not prevent people from walking outside.

6.5.3 Strengths and limitations

To our knowledge, no prior study has examined the relationships of distinct types of walking behavior at a nationwide level. In addition to transport-related and recreational walking, we examined associations with transit-related transport walking. The national representative dataset across years for the entire country increased the possibility of generalizing the results. Further, multivariate Tobit models were employed to investigate correlations between three types of walking behavior but also to account for the large amount of non-walking participation. Although we lack a pedestrian infrastructure, such as sidewalks in good condition, nearly every street in the Netherlands is walkable. This consideration is less important for pedestrian infrastructure in countries such as the Netherlands that have a mature walking and cycling infrastructure.

Our study also has some limitations. First, self-reported walking information is another limitation in this cross-sectional study. This may result in over-reporting or under-reporting of walking duration (Turrell et al., 2014; Wasfi et al., 2016). For example, the large number of non-walkers observed is probably due to underreporting of short daily walking, such as retrieving the mail or going to the grocery store. Second, our study did not take into consideration the type and characteristics of transit services, such as the frequency of services. Previous studies have suggested that the characteristics of public transport service is an important factor if people are encouraged to use it (Djurhuus et al., 2014; Wasfi et al., 2013). Third, the natural and the built environmental variables were clustered at the PC4 level, although a more fine-grained area level should be considered. This could increase the variation and understanding of walking behavior.

6.6 Conclusions

This study is among the first nation-wide studies to examine the associations between natural and built environmental characteristics and different types of walking behavior on both weekdays and weekends, while also considering the correlation between these types of walking duration. Our empirical evidence suggests that residential built environment attributes are independently related to different types of walking behavior. We found that residential areas with a higher address density appeared to be positively associated with (non-) transit-related transport walking, whereas a lower address density was positively related with recreational walking. Access to public transport was only significantly associated with transit-related transport walking. On the other hand, proximity to utilitarian facilities only matters for non-transit-related transport walking. Regarding differences between weekdays and weekends, crossing density was only significantly associated with transit-related transport walking on weekdays. Proximity to facilities does not matter for non-transit-related transport walking on weekends. In addition, the results revealed some compensation effects between different types of walking: during weekends, recreational walking was inversely correlated with transit-related transport walking, indicating that compensation effects may exist between different types of walking behavior. These findings suggest that one size does not fit all and will contribute to an understanding of different types of walking, which may support the promotion of mixed-use development to encourage transit users to walk longer. Further, it is also important to remember that walking is not the only form of physical activity. It is possible that participants, who report a decrease in walking behavior, could have increased cycling behavior or take part in more sports. Future research should consider substituting walking for other physical activities.

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Appendix

Table A1 Pearson correlation between built environment variables (*N*= 92,298)

	Address density	Land use diversity	Intersection density	Number of bus stops	Distance to train station	Distance to large supermarket	Distance to restaurant
Address density	1	-.151**	.688**	.049**	-.317**	-.372**	-.388**
Land use diversity	-	1	-.265**	.093**	.106**	.113**	.079**
Intersection density	-	-	1	-.019**	-.350**	-.402**	-.354**
Number of bus stops	-	-	-	1	-.062**	-.184**	-.166**
Distance to train station	-	-	-	-	1	.247**	.208**
Distance to large supermarket	-	-	-	-	-	1	.493**
Distance to restaurant	-	-	-	-	-	-	1

Chapter 7

Discussion and conclusions

7.1 Introduction

Walking and cycling provide substantial health benefits as a result of increased physical activity (Mueller et al., 2015). Several studies have demonstrated that characteristics of the built environment have a significant relationship with walking and cycling (Saelens and Handy, 2008; Smith et al., 2017; Wang et al., 2016). Specifically, reviews have shown that areas with higher population (address) density, land-use diversity, and street connectivity show more active travel (McCormack and Shiell, 2011; Saelens and Handy, 2008).

However, the current body of knowledge has some important limitations. A first limitation is that previous studies provide evidence that socioeconomic and demographic differences in walking and cycling exist (Adams, 2010; Kamphuis et al., 2009; Pucher and Buehler, 2008; Scheepers et al., 2013), but the results are still inconclusive.. Empirical evidence is lacking to support the assumption that population health benefits from walking and cycling differ across population subgroups (Mueller et al., 2015). It remains unclear how differences in walking and cycling translate into inequalities in health benefits on the population level.

A second limitation of most earlier studies is that they consider the relationship between built environmental factors and walking and cycling as homogenous across contexts (e.g., built environment variables influence travel behavior in a similar manner everywhere) and population groups (e.g., age groups, low and high socioeconomic groups) (Feuillet et al., 2015). However, it is likely that these associations differ across population segments and across geographical contexts. Built environment characteristics that support walking for parents with children may not necessarily support walking among elderly adults (Stappers et al., 2018). For instance, a systematic review by McGrath et al. (2015) found a positive association of walkability attributes as well as the availability of parks among adolescents. In contrast, negative relationships were observed for younger children. A review by Cerin et al. (2017) concluded that built environments seemed to have a stronger relationship with transport-related walking among elderly adults than among younger groups. With respect to the geographical context, it is noted that built environmental characteristics do not (only) have a direct, independent effect on active travel, but their impacts may also depend on the presence of other built environment factors. For instance, the impact of the availability of walking or cycling infrastructure on active travel may depend on the proximity of destinations, including shops and schools, or on traffic safety, and will therefore differ across urban areas.

A third limitation concerns the cross-sectional nature of the majority of studies addressing the built environment and walking or cycling. Scarce longitudinal evidence suggests that the effect of land use characteristics on walking and cycling is smaller than that found in cross-sectional studies (Stappers et al., 2018; Van Wee and Handy, 2014). Furthermore, increasing active travel may also occur as a response to life events (e.g., childbirth, residential relocation) (Lanzendorf, 2003, 2010). However, the importance of life events on walking/cycling remains unclear. Likewise, the changes in the built environment due to relocation have primarily been studied for motorized travel (Klein and Smart, 2019; Oakil et al., 2018) but not yet for walking or cycling.

Fourth, other studies frequently either considered walking and cycling as a single category in relation to the built environment or, at best, distinguish between transportation and recreational walking (Lee and Moudon, 2006; Saelens and Handy, 2008). Using public transport has been positively associated with total and transport-related walking duration, as walking is a major choice to access and egress public transport (Lachapelle and Noland, 2012; Lachapelle and Pinto, 2016). The role of walking and cycling as part of trips (also including other travel modes) is under-researched (exceptions are (Brand et al., 2014; Shelat et al., 2018)). Thus, the role of walking and cycling as modes of access and egress is central with respect to how they are influenced by built environment.

This thesis addressed these shortcomings. Improved conceptualizations of the relationship between the built environment and walking and cycling were tested empirically with existing data sets. This chapter describes the main findings from these studies and discusses the implications for theory, the empirical body of knowledge on land use and transport policy.

7.2 Main findings

This thesis has addressed the aforementioned research gaps and contributed novel evidence on the relationship between the built environment, walking, and cycling. This section summarizes the main findings.

1. *How do the population health benefits of walking and cycling in the Netherlands differ for population subgroups stratified by age, gender, education, income, and ethnicity?*

Previous studies have shown that socioeconomic and demographic differences in walking and cycling exist. In light of these findings, it may be assumed that health benefits from active travel on a population level differ across population subgroups (Mueller et al., 2015). However, the empirical evidence in support of this premise is weak. In Chapter 2, the Health Economic Assessment Tool (HEAT) as developed by the World Health Organization (WHO) (Kahlmeier et al., 2014), was used to quantify the population health benefits for demographic and socioeconomic groups in the Netherlands.

The results showed large differences in walking and cycling levels among different population subgroups. Women, older citizens (50-79 years), high socioeconomic groups, and native Dutch people reported more walking and cycling than members of the other subgroups. However, despite lower walking and cycling levels among low socioeconomic groups (e.g., low-educated groups or low-income groups), more deaths were prevented in this population group than in higher socioeconomic groups due to the large population size and their higher initial mortality rates. Hence, a large number of prevented deaths in certain population groups does not always reflect high walking and cycling levels but rather can also stem from a large population size, a high mortality rate or both. Eventually, although larger population-level health benefits are gained among low than among high socioeconomic groups at the population group level, the individual-level health benefits remain lower, leading to larger health inequality between low and high socioeconomic groups. With respect to ethnicity, native Dutch people gained more benefits from walking and cycling than nonnatives. An explanation for lower walking and cycling among low socioeconomic groups and nonnative Dutch people may be that these groups live in different environmental circumstances, view the same built environment differently, or are influenced by factors other than those in the *built environment* (e.g., rather by a different sociocultural background or worse economic circumstances), leading to lower walking and/or cycling level (Sallis et al., 2013).

2. *To what extent do objectively measured natural and built environment characteristics influence cycling duration, and how does the effect of environmental characteristics on cycling duration differ by municipality size?*

Chapter 3 investigated the extent to which the inconsistency in the effects of built environmental characteristics on cycling behavior is related to municipality size (i.e., the spatial context) using nationwide data for the Netherlands.

The results showed that individuals living in 4-digit postal code areas (PC4 areas) with higher address density, more bus stops, and a shorter distance from home to the nearest train station show a longer cycling duration. Contrary to previous findings (Ding et al., 2014), land use diversity was not significantly associated with cycling duration. This result suggests that mixed-use development in high-density cities may not always have the expected, positive effect on cycling duration. A possible explanation is the low variability in land use mix, which is typical in the Netherlands (Beenackers et al., 2014; Wijk et al., 2017).

Moreover, our results imply that relationships between environmental characteristics and cycling duration are context-specific (i.e., dependent on circumstances that differ between highly urbanized and less urbanized areas). Specifically, we found that increased street density and address density appeared to be less conducive to cycling in small cities than in medium or large cities. A potential explanation is that larger cities have more destinations accessible within a larger area, leading to longer cycling duration. The positive association between the number of bus stops and cycling duration was weaker in the largest and medium-sized cities than in small urban and rural areas. It seems that cycling is more important in smaller municipalities, or that it takes longer to cycle to a bus stop. Taken together, the findings show that the effects of built environment characteristics on cycling may depend on the specific geographical context, in this case, the size of the municipality.

3. *How do interaction effects of travel mode attitudes with sociodemographic and environmental characteristics differ between bicycle commuting and cycling for other purposes?*

One of the core principles of social-ecological models is that "influences interact across the multiple levels" (Glanz et al., 2008; Sallis et al., 2015). In other words, how individual factors affect active travel behavior may depend on environmental characteristics and vice versa. Although previous studies have shown that both individual factors (e.g., attitudes toward travel modes (Ton et al., 2019; Xing et al., 2018) and built environmental characteristics (Ewing and Cervero, 2010; Heinen et al., 2010) are associated with active travel behaviors, evidence for interaction effects between attitudes toward travel modes and the built environment on active travel is still limited. In Chapter 4, interactions between travel mode attitudes, urbanization level and sociodemographic characteristics in relation to bicycle commuting and cycling for other purposes (e.g., leisure, visiting) were investigated. The findings partially support the hypothesis of interactions between environmental and individual factors in relation to cycling behavior (Sallis et al., 2015). The results showed that a positive attitude toward cycling was positively related to bicycle commuting duration, whereas this association was less strong among those with a positive attitude toward bus use. Regarding cycling for other purposes, cycling attitude had a stronger positive relationship with cycling duration among residents of very highly urbanized areas than among residents of less urbanized areas.

The study suggests the existence of synergetic mechanisms, in which a positive cycling attitude reinforces favorable environmental conditions for cycling (such as higher urbanization levels) or groups likely to cycle (elderly adults and women). Compensatory mechanisms were found in that having a positive attitude toward cycling had a weaker positive effect on bicycle commuting for those in favorable cycling conditions (such as not having access to a car). These findings may indicate that both mechanisms exist for some specific combination of cycling attitudes and individual and environmental factors.

4. *To what extent do life events lead to changes in transport-related and recreational walking?*

Chapter 5 explored the extent to which life events lead to changes in transport-related and recreational walking using longitudinal panel data for the years 2013 and 2015. Multilevel mixed-effects Tobit regression models were estimated, which showed that an increase in transport-related walking over time was related to both childbirth and relocation to less urbanized areas. No significant effects of life events on recreational walking were observed.

This longitudinal study is among the few complementing the largely cross-sectional knowledge base on the effects of life events on transport-related and recreational walking. Childbirth and residential relocation were central determinants of transport-related walking. Specifically, relocation to less urbanized areas was significantly associated with increases in transport-related walking duration. This finding seems to contrast with those of other, cross-sectional studies reporting higher walking rates in more urbanized areas. It could be that the role of the built environment is different in the context of residential relocations than found in cross-sectional studies. Moving to a less urbanized area may provide better opportunities for walking because higher levels of urbanization are associated with more traffic (Wang et al., 2016). In addition, Dutch rural areas refer to more attractive social environments with higher socioeconomic status and safer neighborhoods (Hoekman et al., 2017). No significant longitudinal relationship was observed between life events and recreational walking.

5. *To what extent are different types of walking correlated, and how are these differently affected by natural and built environment characteristics?*

Whereas previous studies largely focused on transport-related and recreational walking (mostly measured on weekdays), Chapter 6 considered three types of walking—transit-related transport walking, non-transit-related transport walking and recreational walking—and investigated these three outcomes on both weekdays and weekends. We examined to what extent these three types of walking were correlated (e.g., do people who heavily engage in transit-related transport walking engage less in recreational walking?) and how natural and built environment characteristics correlated with the three types of walking on both weekdays and weekends. It is important to distinguish between weekdays and weekends, as the decision structures are different (Gim, 2018; Ho and Mulley, 2013; Yang et al., 2016). For example, on weekends, people have more free time for several discretionary (e.g., leisure and social) activities than on weekdays, which are characterized by more fixed time schedules. The results indicate that the three types of walking behavior appear to be correlated. During weekdays, recreational walking was positively correlated with non-transit-related transport walking, whereas recreational walking was inversely correlated with transit-related transport walking on weekends. This finding may suggest that a compensation effect may exist between different types of walking behavior between weekdays and weekends.

Furthermore, the results confirmed that different built environment characteristics were related to different types of walking behavior. Residential areas with a higher address density, a highly connected street network, a shorter distance to nearest train station, and more bus stops encouraged longer transit-related transport walking. Shorter distances to utilitarian destinations were more important for non-transit-related transport walking during weekdays. A lower address density is positively associated with increased recreational walking on weekdays, while no significant associations with the built environment were found on weekends. Regarding differences between weekdays and weekends, street network density is only significantly related to transit-related transport walking on weekdays. This finding indicated that not only distance to public transport matters but also the ease, in terms of routes, with which one can arrive there. On weekends, this is less important, probably because of less tight constraints. In contrast, shorter distances to utilitarian destinations were more important for non-transit-related transport walking on weekdays than on weekends. This is because on weekdays, commuters with fixed time schedules are more sensitive to travel time.

7.3 Theoretical and methodological reflections

Based on the insightful conclusions from the empirical studies presented above, this session discusses three major issues that may contribute to further theoretical implications.

7.3.1 Human-environment interplay and its associations with active travel behavior

The social-ecological model proposes that people's travel behavior is affected by factors at multiple levels, such as intrapersonal, interpersonal, social, and environmental factors (Sallis et al., 2015), and that factors at different levels may interact. This thesis found support for such an interaction. For example, interactions with municipality size imply that relationships between environmental characteristics and cycling duration are context-specific (Chapter 3). These relationships depend on circumstances that differ between highly urbanized and less urbanized areas. With respect to attitudes toward travel modes, the relationship between attitude (toward cycling) and behavior (cycling) is weaker if an alternative behavior (the bus) is more attractive (Chapter 4). Additionally, a positive attitude toward cycling appeared to stimulate cycling for reasons other than commuting more in more urbanized areas. These examples indicate that interactions among environmental characteristics and attitudes may only exist in specific combinations and may vary for different combinations.

Although this thesis provides evidence for the interactions among factors at different levels in the social-ecological model, there is room for additional research regarding interactions that are important in understanding walking and cycling behavior. In this respect, interactions within the built environment and social interactions would be of particular importance. In general, the findings not only provide support for the relevant interactions among different levels of the social-ecological model, but also raise theoretical questions regarding the underlying mechanisms. For instance, understanding the extent to which travel attitudes would have compensatory or synergetic effects would be important to better understand the effect of both built environment characteristics and attitudes on travel.

Although previous findings indicating that built environmental characteristics shape people's travel behavior were confirmed (Heinen et al., 2010; McCormack and Shiell, 2011; Wang et al., 2016), the presented model estimations may be biased because only built environment characteristics within residential PC4 areas were incorporated. Starting from home, people only cycle for a few minutes through their own residential area, and then enter different places beyond their own residential area along the cycling route. Although home-based walking trips will often take place within the residential PC4 area, pedestrians will not be exposed to the whole PC4 area, suggesting that using the average characteristics of the area introduces bias to the results. Therefore, both for cycling and walking, the use of en-route buffers may be more accurate than the use of administrative areas in representing the determinants of local environments (Böcker et al., 2015; Perchoux et al., 2013). This approach, however, requires the use of precise tracking data of trips, which is rarely available.

However, residential PC4 areas may not necessarily fully represent the relevant environment influencing daily activities and travel behavior. The influential context may differ for individuals in the same neighborhood, which is also referred to as the uncertain geographic context problem (UGCoP) (Kwan, 2012). It arises due to the spatial and temporal uncertainty regarding where and how much time people spend in each daily activity location. For example, although individuals live in the same PC4 area, they may experience social and environmental influences from many different contexts (e.g., work places, school). However, it is difficult to determine the "true causally relevant" geographic context for individual walking and cycling behavior due to the "selective daily mobility bias" (Chaix et al., 2013). Specifically, the causality between environmental attributes and travel behavior may be confounded by unmeasured factors, such as people's motivations and intentions (Chaix et al., 2013). People with a positive attitude toward cycling may be more likely to actually be in environments that are cycling-friendly. They are therefore more "exposed" to cycling-friendly environments, but this will only be partially the reason why they cycle. One way to approximate the true causal environment would be by considering people's anchor points (i.e., home or workplace) (Chaix et al., 2012) and determining the environmental attributes of the surroundings of these anchor points and the corridors connecting them. GPS tracking data of people's activity and trip patterns may then shed light on the behavior in response to this approximated "true causally relevant" area.

In addition, a major challenge in this type of research is that people's daily activities are not only shaped by place-related factors, but also by temporal constraints (Gatrell, 2011). Time geography may be useful to investigate human activities given people's space-time constraints (Hägerstrand, 1970; Shaw and Yu, 2009). Unlike predicting travel behavior directly, time geography mainly focuses on evaluating the people's daily activities given spatial and temporal constraints. Individuals' daily activity patterns are constrained threefold due to capability constraints (physiological, instrumental, and cognitive limitations), coupling constraints (requirement for people to join others and material artifacts), and authority constraints (laws, rules and norms). Given these constraints, individuals interact with places and social contexts based on their perceptions, attitudes and experiences. This means that the associations of the neighborhood built environment will be moderated by daily scheduling constraints.

Tracking activity and travel patterns with the Global Positioning System (GPS) are regarded as a useful tool for measuring participants' daily activities and travel over time and across space and for investigating the influence of the built environment. Combining GPS with detailed environmental data using GIS techniques provides a more detailed and comprehensive representation of the context in which walking and cycling take place (Chaix et al., 2013). In addition to spatial and temporal contextual influences on travel behavior, the social context is should be considered by combining GPS approaches with ecological momentary assessments (EMAs) (Kwan, 2012). EMAs aims to record real-time data about people's perceptions and experiences, behaviors and features of the surrounding environment (Birenboim, 2018). The integration of these data sources could display a more complete picture to describe how daily activities influence peoples' travel behavior (Kwan, 2012).

7.3.2 The impact of life events on walking and cycling

The mobility biography approach was developed to address temporal stability and changes in people's travel routines (Müggenburg et al., 2015; Scheiner, 2007). The concept assumes that the experience of life events is related to people's travel behavior. This thesis showed that changes in walking duration were associated with life events (e.g., childbirth and residential relocation) (Chapter 5). Despite this evidence, it needs to be stressed that trajectories in people's mobility biographies may be more complex than modeled in this thesis. First, life events may co-occur in people's daily life. For example, residential relocation may be accompanied by marriage, childbirth, or job changes. It is therefore difficult to disentangle which life events most heavily affect changes in walking behavior. Additionally, the possibility exists that specific combinations of life events trigger specific changes in travel behavior. Future research needs to separate independent events from co-occurring events. Additionally, lagged effects of life events on travel behavior may exist, as people may need time to adapt to their 'new' living circumstances through a learning process over time, rather than immediately changing their travel behavior. Considering lagged effects in the analysis may provide deeper insight into the extent to which life events play a role in changes in active travel behavior.

Second, similar life events may implicitly have different impacts on walking behavior for different population subgroups. Such an aspect was not considered in this study. It could be that the effects of life events vary between men and women due to differences in their social role, household responsibilities, and preferences. Moreover, according to time geography, space-time constraints of daily activities may differ between men and women as well (Schwanen et al., 2008). Women may experience more spatial and temporal fixed constraints than men do due to multiple daily activities (e.g., by combining childcare, household, and employment duties). On the other hand, men may place stronger emphasis on job-related matters (Halford, 2006; Schwanen et al., 2008). As women usually spend more time on childcare, they may increase their walking behavior after childbirth as they spend more time behind a stroller. Making a link between gender, life events and travel may contribute to an improved interpretation of the influences of life events on changes in walking behavior.

Residential relocation is another important life event, that can provide a new social and environmental context with new travel mode options (Cao et al., 2009; De Vos et al., 2018; Oakil et al., 2016). However, moving to a less urbanized neighborhood may not have the anticipated negative impact on transport-related walking duration and may be associated with an increase in walking (Chapter 5). It is possible that moving to a less urbanized area is more often done by groups with a positive attitude toward walking, who value a greener and safe environment. Additionally, self-selection has been found to have a serious impact on travel behavior by travel mode attitudes and preferences. People with a positive attitude toward walking and cycling are more likely to live in a walkable neighborhood (De Vos et al., 2018). Cao (2015) found that people in suburban areas have a more positive attitude toward public transport compared with people living in urban areas. However, people may not always be able to fully self-select because residential choice is affected by factors such as income, household circumstances, and health care. Therefore, when the influence of residential relocation on travel behavior is considered, both travel mode attitudes and self-selection should be taken into account to reduce inaccurate modeling results.

7.3.3 Substitution and complementarity of walking types

In Chapter 6, both environmental determinants and correlations among walking types appeared to be important for people's daily walking duration. The findings revealed complementary relationships between non-transit-related transport and recreational walking on weekdays. That is, those walking for non-transit-related transport also walk more for recreation and vice versa. This finding may be related to a general positive attitude toward walking, thus stimulating both forms of walking. On weekends, recreational walking was inversely correlated with transit-related transport walking. This suggests a trade-off between recreational walking and the use of transit (with walking as an access mode), based on preferences and opportunities.

This substitution effect may be related to the existence of time constraints that necessitate a choice between activities given an available time budget for out-of-home leisure activities. However, it is also important to remember that walking is not the only form of physical activity. People may substitute walking for other types of physical activities, such as cycling or sports participation. Hence, instead of increasing overall physical activity, it is possible that an increase in walking can, at least to some extent, shift from one form to another form of physical activity. Longitudinal studies (Brown et al., 2015), including a variety of (physical) activities, could provide a more definitive answer regarding the extent to which an increase in transport-related/recreational walking or cycling is compensated by a reduction in other forms of active travel and for which target groups.

7.4 Policy implications

This research revealed several individual and environmental factors that affect cycling or walking behavior for different purposes. This subsection provides examples and ideas as to how this knowledge can be used in policies and interventions to encourage walking and cycling.

Since disparities exist in walking and cycling levels among population subgroups, tailored policy and programs are needed, especially for disadvantaged subgroups (Chapter 2). The different walking and cycling levels among different population subgroups (i.e., high vs. low socioeconomic groups) offer information that could be used for designing interventions tailored to promote walking and cycling in a particular population. Policy makers should pay more attention to subgroups with lower health status and a large population size but low walking and/or cycling levels. This focus suggests the use of interventions in areas with concentrations of disadvantaged subgroups; these interventions may include not only those related to the physical environment, but also those pertaining to people's attitudes, social capital, and social and cultural norms. In line with the social-ecological model (Sallis et al., 2015), a combination of factors will determine walking and cycling behavior, suggesting a multidimensional approach, which should also include local communities.

Chapter 3 suggests that relationships between environmental characteristics and cycling duration are context-specific. Unlike suburban/rural areas, in large urban areas, people's daily activity spaces are larger. Moreover, in the Netherlands, more jobs are available in the central areas of large cities such as Amsterdam than in medium- or small-sized cities (Wiersma et al., 2016). Cycling might be further promoted by enlarging the activity space of cyclists living in smaller municipalities, by improving cycling infrastructure. In particular, the advance of the e-bike makes this a promising direction. By travelling at higher speeds (with the same or less physical effort) on faster infrastructure, individuals can more easily reach jobs and facilities by bicycle (de Kruijf et al., 2018; Guidon et al., 2019). This travel mode may especially reduce car traffic on interlocal connections. Therefore, initial efforts for developing cycling highways at the regional level need to be continued and extended.

It is of great importance to intervene in transport infrastructure and the built environment to encourage walking and cycling, but it may not be sufficient to increase active travel durably. Chapter 4 implied that individual attitudes and social norms should support cycling, implying that interventions should also provide a positive experience during walking and cycling. Walking and cycling levels can be promoted via media campaigns and incentives at multiple levels (e.g., individual, corporate, local, and regional) (Ding et al., 2012). This type of strategy not only provides information that is intended to motivate individual behavior change, but also focuses on the provision of institutional and environmental support to sustain changes in active travel behavior over time. For example, targeting attitudes through methods such as social marketing campaigns can send more positive and appealing messages publicly to improve the public image of cycling.

Furthermore, smartphone apps are able to record data in relation to the health aspects of active travel. This is an efficient way to make cyclists aware that to a certain extent, individual behavior can contribute to environmental benefits. Furthermore, the use of walking/cycling app data by local authorities for both policymakers and urban planning is a rising area of interest. More specifically, the Alipay app, which is already used in China, provides carbon emission reduction information by individuals' walking duration and other carbon emission reduction behavior (for example, using a shared bicycle, taking public transit). Furthermore, Alipay promises to plant trees under individuals' names when their carbon emission reduction accumulates to some value. Such measures promote the engagement of more people in active travel.

Chapter 6 revealed that the determinants of walking differed by different types of walking behavior and thus underlined that one size does not fit all, suggesting that different types of walking behavior are not necessarily influenced by the same built environmental characteristics. Policies focusing on creating 'walking-friendly' environments likely require a combination of environmental improvements to encourage walking for different purposes. The same holds for cycling, where transportation cyclists have clearly different demands than recreational cyclists do. This finding calls for differentiation between walking and cycling networks, allowing pedestrians and cyclists with different purposes to choose their desired routes while avoiding conflicts between road users with different purposes and demands. The sharp increase in cycling in Dutch cities makes such an approach increasingly necessary.

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Appendix

Summary
Samenvatting
Curriculum Vitae

Summary

From a public health perspective, the promotion of cycling and walking is increasingly recognized as an important way to increase overall physical activity. From a transport and planning perspective, switching from car use to cycling or walking may help to mitigate the adverse effects caused by motorized travel, as it leads to reductions in CO_2 emissions, noise pollution, air pollution, and traffic congestion. In the Netherlands, although approximately 25% of all trips are made by bike, about 33% of all trips within 7.5 kilometers are still made by car. Hence, there is room for stimulating active travel, especially in dense Dutch urban areas, where cycling is potentially quicker than driving for short trips (up to 7 kilometers). While existing studies have already identified determinants of walking and cycling, many studies have implicitly assumed a one-size-fits-all approach, assuming that determinants have a similar effect across population segments and geographies. However, indications exist that the impacts of environmental determinants differ between these groups and contexts.

To fill this gap, the main objective is to identify *how determinants of walking/cycling differ by geographical context, population segment (defined by life stage or preference) and type of walking/cycling, thus paving the way for more diverse policies aimed at specific segments of cyclists/pedestrians.*

Applying different analytical approaches and using different data sets, this thesis provides evidence that determinants such as socio-demographics, built environment, attitudes, and life events have an impact on walking and cycling behavior, but also that these impacts may differ between population segments, geographical settings and types of walking/cycling.

Using the Health Economic Assessment Tool (HEAT), Chapter 2 quantified the population health benefits for different demographic and socioeconomic groups in the Netherlands. The results showed large differences in walking and cycling levels among different population subgroups. However, despite lower walking and cycling levels among low socioeconomic groups (e.g., low-educated groups or low-income groups), more deaths were prevented in this population group than in higher socioeconomic groups due to the large population size and their higher initial mortality rates. Hence, a large number of prevented deaths in certain population groups does not necessarily reflect high walking and cycling levels but rather can also stem from a large population size, a high mortality rate or both.

Chapter 3 investigated the extent to which differences in the effects of built environmental characteristics on cycling behavior are related to municipality size (i.e., the spatial context) using nationwide data for the Netherlands. The results showed that municipality size may moderate the association between environmental characteristics and cycling duration. Chapter 4 explored interactions between travel mode attitudes, urbanization level and sociodemographic characteristics in relation to bicycle commuting and cycling for other purposes (e.g., leisure, or social trips). The findings suggest the existence of synergetic mechanisms, in which a positive cycling attitude reinforces favorable environmental conditions for cycling (such as higher urbanization levels) or groups likely to cycle (elderly adults and women). Compensatory mechanisms were found in that having a positive attitude toward cycling had a weaker positive effect on bicycle commuting for those in favorable cycling conditions (such as not having access to a car). These findings may indicate that both mechanisms exist for some specific combination of cycling attitudes and individual and environmental factors.

Existing knowledge about walking behavior is mainly based on cross-sectional studies, failing to address causal relations. Chapter 5 fills this gap by providing longitudinal evidence regarding the effects of life events (i.e., regarding household composition, employment, and residential relocation) on transport-related and recreational walking behavior. Childbirth and residential relocation were central determinants of transport-related walking. Specifically, relocation to less urbanized areas was significantly associated with increases in transport-related walking duration. No significant longitudinal relationship was observed between life events and recreational walking.

Chapter 6 further considered three types of walking —transit-related transport walking, non-transit-related transport walking and recreational walking—and investigated these three outcomes on both weekdays and weekends. Residential areas with a higher address density, a more connected street network, a shorter distance to the nearest train station, and more bus stops encouraged transit-related transport walking. Shorter distances to utilitarian destinations were more important for non-transit-related transport walking during weekdays. A lower address density is positively associated with increased recreational walking on weekdays, while no significant associations with the built environment were found on weekends.

This dissertation has various theoretical implications that call for further research. First, although this study provided evidence for the interactions among factors at different levels in the social-ecological model (Chapter 3 and 4), there is room for additional research regarding interactions that are important in understanding walking and cycling behavior. In this respect, interactions between the built environment and social interactions would be of particular importance. In general, the findings not only provide support for interactions among different levels of the social-ecological model, but also raise theoretical questions regarding the underlying mechanisms. For instance, understanding the extent to which travel attitudes would have compensatory or synergetic effects would be important to better understand the effect of both built environment characteristics and attitudes on travel.

Second, while this thesis provided evidence for the influence of the built environment on walking and cycling, the built environment was defined around the residential location. This neglects that people will mostly travel outside their neighborhood as part of their daily activity patterns, and are subsequently influenced by the built environment at other places. Investigating the role of this wider built environment requires tracking of people's whereabouts using methods such as GPS tracking. This raise at the same time theoretical causality issues: to what extent is the dynamic built environment that people interact with during their daily activity patterns the reason of their travel behavior, or the result of their decision to visit places via specific trajectories?

Third, the mobility biography approach was developed to address temporal stability and changes in people's travel routines across their life span. Despite the evidence found in this dissertation (Chapter 5), it needs to be stressed that trajectories in people's mobility biographies may be more complex than modeled in this thesis. Firstly, life events may co-occur in people's daily life. For example, residential relocation may be accompanied by marriage, childbirth, or job changes. It is therefore difficult to disentangle which life events most heavily affect changes in walking behavior. Secondly, similar life events may have different impacts on walking behavior for different population subgroups. For instance, it could be that the effects of life events vary between men and women due to differences in their social role, household responsibilities, and preferences. Making a link between gender, life events and travel may contribute to an improved interpretation of the influences of life events on changes in walking behavior.

Finally, both substitution (recreational walking was inversely correlated with transit-related transport walking on weekends) and complementarity (between non-transit-related transport and recreational walking on weekdays) effects are confirmed among different walking types in this study (Chapter 6). The complementarity effect may be related to a general positive attitude toward walking, thus stimulating both forms of walking. And the substitution effect may be related to the existence of time constraints that necessitate a choice between activities given an available time budget for out-of-home leisure activities. However, it is also important to remember that walking is not the only form of physical activity. People may substitute walking for other types of physical activities, such as cycling or sports participation. Hence, instead of increasing overall physical activity, it is possible that an increase in walking can, at least to some extent, shift from one form to another form of physical activity.

Samenvatting

Voor de volksgezondheid wordt het stimuleren van fietsen en wandelen in toenemende mate erkent als een belangrijke manier om algemene fysieke activiteit te verhogen. Vanuit het transport en planning perspectief is het overschakelen van autogebruik naar fietsen of wandelen een manier om de negatieve effecten van gemotoriseerd vervoer tegen te gaan, omdat het leidt tot een afname van CO_2 uitstoot, geluidshinder, luchtvervuiling en verkeersoptoppingen. Hoewel in Nederland 25% van de reizen met de fiets worden gedaan, worden rond de 33% van alle reizen van minder dan 7,5 kilometer nog steeds met de auto gedaan. Er is dus ruimte voor het stimuleren van actief vervoer in Nederlandse stedelijke gebieden met een hoge bevolkingsdichtheid, waar fietsen potentieel een sneller alternatief is voor de auto voor korte tripjes (tot 7 kilometer). Hoewel bestaande studies de determinanten van wandelen en fietsen al hebben aangetoond hebben veel studies impliciet een eenvormige aanpak die er van uit gaat effecten vergelijkbaar zijn tussen verschillende bevolkingsgroepen en gebieden. Er zijn echter aanwijzingen dat de invloed van omgevingsfactoren kunnen verschillen tussen groepen en contexten.

Om deze kloof in de literatuur te dichten, is het objectief om te identificeren *hoe determinanten van wandelen/fietsen verschillen tussen geografische contexten, bevolkingsgroepen (gedefinieerd aan de hand van levensfase of voorkeuren) en het type wandelen/fietsen, om zodoende meer divers beleid mogelijk te maken gericht op specifieke segmenten fietsers/wandelaars.*

Door verschillende analytische benadering en verschillende datasets te gebruikten, toont deze dissertatie aan dat loop- en fietsgedrag wordt beïnvloed door sociaal-demografische factoren, de gebouwde omgeving, attitudes en levensgebeurtenissen, maar dat de invloed van deze factoren verschillen tussen bevolkingsgroepen, geografische contexten en types van wandelen/fietsen.

Gebruik makend van de Health Economic Assessment Tool (HEAT), kwantificeert hoofdstuk 2 de voordelen voor de volksgezondheid voor verschillende demografische en sociaaleconomische groepen in Nederland. De resultaten laten zien dat er grote verschillen zijn in de mate van wandelen en fietsen tussen verschillende subgroepen van de bevolking. Echter, ondanks een lagere mate van wandelen en fietsen onder lage sociaaleconomische groepen (bijv. laag opgeleide groepen of lage inkomensgroepen), meer sterfgevallen werden voorkomen in deze bevolkingsgroep dan in de hogere sociaaleconomische groepen, vanwege de hogere bevolkingsgrootte en hogere initiële mortaliteit. Hieruit volgt dat een groter aantal voorkomen sterfgevallen niet noodzakelijk een hogere mate van wandelen en fietsen reflecteren, maar ook kan worden veroorzaakt door hogere bevolkingsgrootte, hogere mortaliteit of beide.

Hoofdstuk 3 onderzoekt de mate waarin verschillen in de effecten van de kenmerken van de gebouwde omgeving op fietsgedrag gerelateerd zijn aan de grootte van de gemeente (d.w.z. de ruimtelijke context), gebruik makend van landelijk dekkende data uit Nederland. De resultaten laten zien dat de grootte van de gemeente de associatie tussen kenmerken van de gebouwde omgeving en fietsgedrag modereert. Hoofdstuk 4 onderzoekt de interacties tussen attitudes over transportmodus, de mate van urbanisatie en sociaaldemografische kenmerken in relatie tot woon-werk verkeer op de fiets en fietsen voor andere doeleinden (bijv. vrijetijd of sociale tripjes). De uitkomsten suggereren dat er synergetische mechanismes zijn waarin positieve attitudes over fietsen worden versterkt door positieve omgevingskenmerken voor fietsen (zoals een hogere mate van urbanisatie) of voor groepen waarvan het waarschijnlijker is dat ze fietsen (ouderen en vrouwen). Compensatiemechanismes werden gevonden omdat het hebben van een positieve attitude ten opzichte van fietsen een zwakker positief effect op woon-werk verkeer met de fiets had voor mensen met positieve omgevingskenmerken voor fietsen (zoals geen toegang tot een auto hebben). Deze uitkomsten laten zien dat beide mechanismes kunnen bestaan voor specifieke combinaties van attitudes over fietsen en individuele en omgevingskenmerken.

Bestaande kennis over wandelgedrag is hoofdzakelijk gebaseerd op cross-sectionele studies die geen causale verbanden kunnen aantonen. Hoofdstuk 5 vult deze kloof door van longitudinaal bewijs te voorzien over de effecten van levensgebeurtenissen (bijv. met betrekking tot huishoudenssamenstelling, werk en verhuizing) op wandelgedrag voor transport of recreatie. De geboorte van een kind en verhuizingen waren centrale determinanten voor wandelgedrag voor transport. In het bijzonder een verhuizing naar een gebied met een lagere mate van urbanisatie was significant geassocieerd met een toename in wandelgedrag voor transport. Er werd geen significante longitudinale relatie gevonden tussen levensgebeurtenissen en wandelen voor recreatie.

Hoofdstuk 6 ging dieper in op drie types van wandelen: wandelen naar openbaar vervoer, wandelen niet naar openbaar vervoer en recreatief wandelen, en bekijkt deze drie uitkomsten zowel op werkdagen als in weekenden. Woongebieden met een hogere bevolkingsdichtheid, een beter verbonden straatnetwerk, een kortere afstand tot het dichtstbijzijnde treinstation en meer bushaltes, stimuleerden wandelen naar openbaar vervoer. Kortere afstanden naar praktische bestemmingen waren belangrijk voor wandelen niet naar openbaar vervoer gedurende werkdagen. Een lagere adressendichtheid heeft een positieve associatie met een toename in recreatief wandelen gedurende werkdagen, terwijl er geen significantie associatie is met de gebouwde omgeving in weekenden.

Deze dissertatie heft verschillende theoretische implicaties voor vervolgonderzoek. Ten eerste, hoewel deze studie bewijs aanvoert voor de interacties tussen verschillende factoren op verschillende niveaus in het sociaalecologische model (hoofdstukken 3 en 4), is er ruimte voor vervolgonderzoek met betrekking tot de interacties die belangrijk zijn voor wandel- en fietsgedrag. In het bijzonder zijn interacties tussen de gebouwde omgeving en sociale interacties belangrijk. In het algemeen ondersteunen de resultaten niet alleen het idee van interacties tussen verschillende niveaus van het sociaalecologische model, maar roepen ook theoretische vragen op met betrekking tot de onderliggende mechanismes. Bijvoorbeeld, een beter begrip over hoe attitudes met betrekking tot reizen compensatie of synergetische effecten hebben is belangrijk voor een beter begrip over de effecten van zowel de gebouwde omgeving als attitudes met betrekking tot reizen.

Ten tweede, hoewel deze dissertatie bewijs aanvoert voor de invloed van de gebouwde omgeving op wandelen en fietsen, is de gebouwde omgeving gedefinieerd als het gebied rond de residentiele locatie. Dit verwaarloost het feit dat mensen voornamelijk reizen buiten hun eigen buurt als onderdeel van hun dagelijks activiteitenpatroon, en daardoor dus worden beïnvloed door de gebouwde omgeving in andere plaatsen. Om de rol van een wijdere gebouwde omgeving te onderzoeken, is het noodzakelijk om mensen te volgen met behulp van bijvoorbeeld GPS tracking. Dit leidt echter wel tot theoretische causaliteitsproblemen: in welke mate is de dynamische gebouwde omgeving waarmee mensen interacteren gedurende hun dagelijkse activiteitenpatroon de reden voor hun reisgedrag of juist het gevolg van hun beslissing om plaatsen te bezoeken via specifieke routes?

Ten derde, de benadering die kijkt naar mobiliteitbiografieën is ontwikkeld om temporele stabiliteit en verandering in mensen hun reisroutines gedurende hun levensloop te bespreken. Ondanks het bewijs gevonden in deze dissertatie (hoofdstuk 5), moet het worden benadrukt dat trajecten in mensen hun mobiliteitbiografieën mogelijk complexer zijn dan zoals ze gemodelleerd zijn in deze dissertatie. Ten eerste, levensgebeurtenissen kunnen samenvallen in het leven van mensen. Bijvoorbeeld een verhuizing kan samengaan met trouwen, de geboorte van een kind of het veranderen van baan. Het is daardoor moeilijk uit elkaar te trekken welke levensgebeurtenissen het zwaarst wegen voor wandelgedrag. Ten tweede, vergelijkbare levensgebeurtenissen kunnen een verschillende invloed hebben op het wandelgedrag van verschillende bevolkingsgroepen. Bijvoorbeeld, het is mogelijk dat de effecten van levensgebeurtenissen verschillen tussen mannen en vrouwen, vanwege verschillen in hun sociale rol, taken in het huishouden en voorkeuren. De link tussen gender, levensgebeurtenissen en reisgedrag kan helpen bij een verbeterede interpretatie van de invloed van levensgebeurtenissen op veranderingen in wandelgedrag.

Tot slot, zowel substitutie (recreatief wandelen was omgekeerd gecorreleerd met wandelen naar openbaar vervoer in het weekend) als complementaire effecten (tussen wandelen niet naar openbaar vervoer en recreatief wandelen in het weekend) werden gevonden voor verschillende types van wandelen in deze studie (hoofdstuk 6). Het complementaire effect kan gerelateerd zijn aan een algemene positieve attitude ten opzichte van wandelen, waarmee het beide vormen van wandelen stimuleert. Het substitutie effect kan gerelateerd zijn aan het bestaan van tijdsrestricties die leiden tot een keuze tussen bepaalde activiteiten aan de hand van een beschikbaar tijdsbudget voor vrijetijdsbesteding buitenshuis. Het is echter ook belangrijk om te herinneren dat wandelen niet de enige vorm van fysieke activiteit is. Mensen kunnen wandelen vervangen voor andere types van fysieke activiteit, zoals fietsen of sporten. Hieruit volgt dat in plaats van een toename in totale fysieke activiteit, het mogelijk is dat een toename in wandelen, tenminste voor een deel, kan voortkomen uit een verschuiving van ee andere vorm van fysieke activiteit.

Curriculum Vitae

Jie Gao was born on 1 July 1989 in Shaanxi province, China. In 2012, she received her Bachelor of Engineering in Transportation from Chang'an University, China. After that, she continued her Master of Engineering in Transport Planning and Management at Chang'an University (2012-2015). During this period, she also enrolled in the Master of Science program at Faculty of ITC of the University of Twente and obtained her Master of Urban Planning and Management in March 2014. In October 2015, she started her PhD research on active travel and public health in the department of Human Geography and Spatial Planning at Utrecht University. Her works are published in a variety of peer-reviewed journals, including Transportation, Journal of Transport & Health, and International Journal of Behavioral Nutrition and Physical Activity.