UNIVERSITEIT GENT

Cycling for transport: the role of the physical environment

Lieze Mertens

Thesis submitted in fulfillment of the requirements for the degree of

Doctor in Health Sciences

GENT 2016

Supervisor:

Prof. dr. Ilse De Bourdeaudhuij (UGent)

Co-supervisor:

Prof. dr. Benedicte Deforche (UGent)

Supervisory board:

Prof. dr. Nico Van de Weghe (UGent)

dr. Delfien Van Dyck (UGent

Examination board:

Prof. dr. Patrick Calders (UGent)

Prof. dr. Jasper Schipperijn (University of Southern Denmark)

Prof. dr. Bas de Geus (VUB)

Prof. dr. Ben Derudder (UGent)

dr. Nathalie Aelterman (UGent)

Prof. dr. Matthieu Lenoir (UGent)

Acknowledgement:

The original research reported in this doctoral thesis was supported by a project from the Research Foundation Flanders (FWO, Application number: 48560), a Ghent University Special Research Fund (BOF; DC12015000701) and was conducted as part of the SPOTLIGHT project. The SPOTLIGHT project was funded by the Seventh Framework Programme (CORDIS FP7) of the European Commission, HEALTH (FP7-HEALTH-2011-two-stage), grant agreement no. 278186.

TABLE OF CONTENTS

Summary

Regular physical activity can help to increase public health by reducing the risk of many chronic diseases and their risk factors. Unfortunately, one third of the adult population (18 years and over) is insufficiently physically active and does not reach the global health guideline of 150 min/week of moderate-to-vigorous physical activity. Cycling for transport could be an important contributor to integrate physical activity into adults' daily lives. Nevertheless, cycling remains an under-used form of transport. There is a significant potential to increase cycling for transport in the European Union as 40% of all car trips are shorter than 2.5 kilometers and 50% are shorter than 5 kilometers. Therefore, interventions that encourage the incorporation of cycling for transport into the daily lives of adults are required.

It has already been confirmed by the literature that the physical environment is of importance to explain physical activity in adults between 18 and 65 years old, the target population of this thesis. Nonetheless, there are still a lot of inconsistencies regarding the association between the physical environment, especially the micro-environment, and cycling for transport. Micro-environmental factors are small-scaled physical environmental characteristics of a streetscape (such as evenness of the cycle path, speed limit, or vegetation), feasible to modify in existing neighborhoods and thus more practical to target for environmental interventions in comparison to macro-environmental factors (i.e. raw urban planning features, such as residential density or street connectivity). Therefore, the overall aim of this PhD thesis was to get a better insight in how the physical environment, especially the micro-environment, influences cycling for transport among the adult population, and to verify the interplay between socio-demographics, psychosocial and physical environmental factors to explain cycling for transport.

The results of this PhD-thesis indicate that the most important strategy to create supportive micro-environments and to stimulate cycling for transport is to improve the traffic safety for cyclists. This can be done by providing separated cycle paths (even if they are only marked with white lines on the road) or by reducing the authorized speed of the motorized traffic. The most preferred cycle path is a cycle path that is well separated from the motorized traffic of which a hedge as separation is preferred above a curb as separation, and a curb is preferred above a cycle path marked with white lines. Furthermore, policy makers must be informed that in high walkable neighborhoods (i.e. neighborhoods with a high street connectivity, mixed land use, and high residential density) which are positively related to cycling for transport, it is important to pay attention to overlooked environmental factors such as the exposure to air pollution or parked cars that form an obstacle on

the road. The provision of separated cycle paths might help to deal with those environmental factors and consequently can ensure that neighborhoods become safer, healthier and more enjoyable to cycle for transport.

Furthermore, the interaction effects between macro- and micro-environmental factors, as well as the interactions between different micro-environmental factors were examined. Our experimental results suggested that micro-environmental changes have similar outcomes in different macro-environments and therefore gives a first indication about the generalizability of the adjustment of micro-environmental factors in different macro-environments. Since cycle path type was predominantly the most important micro-environmental factor, the relative importance of all other micro-environmental factors was calculated within each type of cycle path. Results indicate that in street settings where no cycle path was provided, micro-environmental factors associated to traffic-related safety (i.e. speed limit, traffic density) prevail. In contrast, when a more separated cycle path was provided, micro-environmental factors related to comfort (i.e. evenness of the cycle path) or aesthetics (i.e. vegetation, general upkeep) appeared to become more important.

Although our subgroup analysis revealed three subgroups of the middle-aged adult population with differences in environmental preferences towards cycling for transport, a good separated cycle path remains the most important environmental factor for all participants. Moreover, our cross-sectional results both for the perceived and the objective physical environment also found only a few significant moderating effects of socio-demographic factors. These results suggest that generic environmental interventions could benefit most population subgroups, even across urban regions in the five different investigated countries (Belgium, the Netherlands, Hungary, France, and UK). Therefore, from our results we can carefully conclude that tailored environmental interventions may not be required in this research context since environmental adaptations (e.g. improving cycle path type) appear to have a favorable effect for the whole adult population.

Samenvatting

Ondanks de vele voordelen die regelmatige fysieke activiteit met zich meebrengt, haalt een derde van de bevolking de richtlijnen voor voldoende beweging niet (150 min/week matig tot zwaar fysiek actief zijn). Fietsen als vorm van transport is een fysieke activiteit die relatief gemakkelijk kan geïntegreerd worden in het dagelijks leven van volwassenen. Zich verplaatsen met de fiets is niet alleen eenvoudig maar brengt ook een tal van gezondheidsvoordelen met zich mee. Toch wordt de fiets op de dag van vandaag nog te weinig gebruikt om zich te verplaatsen. Uit onderzoekt blijkt bovendien dat in Europa 50% van alle ritten korter zijn dan 5 kilometers en zelfs 40% korter dan 2,5 kilometer. Hieruit kunnen we vaststellen dat het fietsen als transport nog aanzienlijk kan toenemen. Interventies die het gebruik van de fiets als transportmiddel promoten zijn dus noodzakelijk.

Er werd reeds aangetoond dat de fysieke omgeving een belangrijke invloed heeft op de fysieke activiteit van volwassenen tussen 18 en 65 jaar, de doelgroep van dit doctoraatsonderzoek. Niettemin zijn er nog heel wat onduidelijkheden met betrekking tot de relatie tussen de omgeving, en in het bijzonder de micro-omgeving, en fietsen als transport. Micro-omgevingsfactoren zijn fysieke kenmerken van een straatbeeld (zoals de effenheid van het fietspad, snelheidsbeperking of het aanwezige groen) die relatief gemakkelijk te veranderen zijn en daardoor ook praktisch relevant zijn om aan te pakken in omgevingsinterventies in vergelijking met de macro-omgeving (= de ruwe structuur van de omgeving zoals de bereikbaarheid van bestemmingen, connectiviteit van de straten of de residentiële dichtheid). Bijgevolg was het algemene doel van dit doctoraatsproefschrift om inzicht te verwerven in hoe de fysieke omgeving, met name de micro-omgeving, gerelateerd is aan fietsen als transport bij volwassenen. Daarnaast werd er ook nagegaan of deze relatie beïnvloed wordt door socio-demografische factoren, psychosociale factoren en omgevingsfactoren.

Resultaten van dit doctoraatsproefschrift tonen aan dat een verkeersveilige omgeving geassocieerd is met meer fietsen als transport. Een belangrijke suggestie voor beleidsmakers is dan ook het verbeteren van de micro-omgevingsfactoren die de verkeersveiligheid bepalen. Dit kan gedaan worden door aandacht te schenken aan een goed afgescheiden fietspad, waarbij een fietspad gemarkeerd met twee evenwijdige, onderbroken, witte lijnen al een meerwaarde is ten opzichte van de afwezigheid van een fietspad. Een fietspad dat fysiek afgescheiden is van het verkeer blijkt het grootste effect te hebben op de mate waarin een straat uitnodigt tot fietsen, waarbij een afscheiding met het verkeer door middel van een haag verkozen wordt boven een afscheiding met

een stoeprand en op zijn beurt ook verkozen wordt boven een fietspad gemarkeerd met witte lijnen. Ook het beperken van de toegestane snelheid van het gemotoriseerd verkeer blijkt een belangrijke strategie te zijn om de verkeersveiligheid te verbeteren. Beleidsmakers moeten daarnaast ook aandacht schenken aan enkele omgevingsfactoren die vaak over het hoofd gezien worden zoals luchtvervuiling en/of geparkeerde auto's die een obstakel vormen voor het verkeer. Hierbij kan de aanwezigheid van afgescheiden fietspaden ook een rol spelen om een buurt veiliger, gezonder en aangenamer te maken om te fietsen.

Vervolgens werden ook interactie-effecten tussen omgevingsfactoren onderzocht in dit doctoraatsproefschrift. Allereerst werd de interactie tussen de micro- en macro-omgeving in kaart gebracht. De experimentele resultaten toonden aan dat onafhankelijk van de kenmerken van de macro-omgeving, dezelfde micro-omgevingsfactoren als belangrijk worden aangeduid voor het creëren van een uitnodigende fietsvriendelijke buurt. Hieruit kan besloten worden dat onafhankelijk van de macro-omgeving, dezelfde micro-omgevingsfactoren onder handen kunnen genomen worden in omgevingsinterventies. Vervolgens werden ook interactie-effecten tussen micro-omgevingsfactoren onderling bestudeerd. Aangezien een goed afgescheiden fietspad veruit de belangrijkste micro-omgevingsfactor bleek te zijn, werd binnen elk type fietspad, de belangrijkheid van de andere micro-omgevingsfactoren onderzocht. Daaruit kon geconcludeerd worden dat in situaties waar er geen afgescheiden fietspad kan voorzien worden (bv. door ruimtelijke of financiële beperkingen), micro-omgevingsfactoren gerelateerd aan veiligheid (zoals het beperken van de snelheid of het verkeersvolume) moeten primeren ten opzichte van micro-omgevingsfactoren met betrekking tot comfort (bv. effenheid van het fietspad) of esthetiek (bv. groen in de straat, algemeen onderhoud van de buurt). Indien er reeds een goed afgescheiden fietspad is voorzien, kan er worden aangeraden om comfort of esthetiek gerelateerde micro-omgevingsfactoren te verbeteren.

Subgroep analyses konden drie subgroepen onderscheiden met verschillende omgevingsvoorkeuren ten opzichte van fietsen als vorm van actief transport. Desondanks bleek voor elke subgroep een afscheiden fietspad steeds veruit de belangrijke micro-omgevingsfactor te zijn. Daarnaast toonden onze cross-sectionele resultaten aan dat er slechts een zeer beperkt aantal significante modererende effecten gevonden werden van socio-demografische factoren (zoals geslacht, leeftijd, opleidingsniveau en woonplaats), op de relatie tussen de fysieke omgeving (objectieve als gepercipieerde omgeving) en fietsen als transport. Deze resultaten suggereren dat algemene omgevingsinterventies baat kunnen hebben voor de meeste subgroepen van de bevolking, zelfs overheen stedelijke gebieden in de vijf onderzochte landen (België, Nederland, Hongarije, Frankrijk en VK). Hieruit kunnen we met enige voorzichtigheid besluiten dat omgevingsinterventies die zich specifiek focussen op een bepaalde doelgroep niet noodzakelijk blijken te zijn in deze onderzoekscontext aangezien omgevingsverandering (bv. verbeteren van het type fietspad) een gunstig effect blijkt te hebben op de volledige volwassen bevolking.

Part 1. General Introduction

1 Introduction

Regular physical activity can help reduce the risk of many chronic diseases and their risk factors, and consequently facilitate global public health. Since active transport (i.e. walking/cycling to go from place to place) can be done on a regular basis, is an inexpensive and very accessible form of physical activity, and is easy to schedule in the daily lives of adults, it might be an important contributor to reach the daily physical activity guidelines for health. Because the intensity of cycling is higher than of walking, it increases the heart rate more [1], and thus provides more health gain in comparison to walking for transport [2]. However, cycling remains an under-used form of transport, even for short-distance trips (<5 km) [3]. Furthermore, the prevalence of cycling for transport declines strongly from childhood to adulthood [4].

Therefore, this thesis focuses on cycling as form of active transport among adults between 18 and 65 years old. It is important to gain understanding of the individual, social and environmental correlates of cycling for transport, and the interplay between these correlates in order to allow communities to implement effective interventions encouraging cycling for transport. Socio-ecological models introduced the importance of the physical environment in addition to individual and social factors affecting health behavior [5]. Since micro-environmental factors (i.e. small-scaled physical environmental characteristics of a streetscape such as evenness of the cycle path, speed limit, or vegetation) instead of macro-environmental factors (i.e. raw urban planning features, such as residential density or street connectivity) are more feasible to modify in existing neighborhoods and thus more practical to target for environmental interventions, this thesis focuses on the association between the micro-environment and cycling for transport.

In this general introduction, an overview of the definition, measuring methods, guidelines, benefits and prevalence of cycling for transport is given. After introducing the core principles of the ecological models, an overview of the different correlates of cycling for transport is provided with special attention to the physical environmental correlates of cycling for transport. Furthermore, the interplay between different correlates will be described: moderating effects of individual factors on the relationship between the physical environment and cycling, as well as interactions between different physical environmental factors. Afterwards, the shortcomings of the existing literature regarding the correlates of cycling for transport will be listed and an innovative experimental approach with manipulated photographs will be introduced. From this background, the problem analysis will be outlined, the content of both chapters of this thesis will be described and the specific sub-aims will be formulated.

2 Health enhancing regular physical activity among adults: cycling for transport

2.1 Definition

In the literature the concepts physical activity, exercise, and physical fitness are often used in the same context, however these terms do not have the same meaning. The worldwide accepted definition of physical activity was defined by Caspersen et al. (1985) as 'any bodily movement produced by skeletal muscles that results in energy expenditure.' On the other hand exercise or sport is a more planned and repetitive activity with the objective to reach improvement or maintenance of the physical fitness. Physical fitness includes health- or skill-related attributes (e.g. cardio-respiratory endurance, muscular strength, reaction time) measured with specific tests (e.g. 12-minute run, handgrip dynamometer) [6] and describes the 'ability to carry out daily tasks with vigor and alertness, without undue fatigue and with ample energy to enjoy leisure-time pursuits and to meet unforeseen emergencies' [6,7]. From a public health perspective, the focus of this thesis will be on the promotion of regular physical activity, and more specifically cycling for transport.

Physical activity can be classified in three main categories of intensity based on the energy expenditure: light, moderate, or vigorous physical activity. The energy expenditure can be expressed as a metabolic equivalent (MET), whereby 1 MET can be defined as the standard resting metabolic rate (3.5 ml O_2/kg/min) and is equivalent to the energy expenditure during sitting quietly [8]. Light-intensity physical activity is equivalent to activities (> 1 MET) that do not exceed 3 MET, such as cooking, slowly walking or billiard. Moderate intensity activities correspond to a value between 3 and 6 MET and are activities such as dancing, brisk walking or light effort cycling. Lastly, vigorous-intensity physical activities apply to all activities that require more than 6 MET, including walking briskly uphill, fast cycling, aerobics or most sports [8–10]. Cycling for transport can therefore generally be considered as a moderate intensity physical activity, except for riding a racing bicycle to go from place to place (i.e. vigorous intensity).

Physical activity can also be subdivided according to the four main domains in which physical activity can occur: occupation, active transport, household and leisure-time. Since this thesis specifies on cycling for transport, the introduction of this thesis will mainly focus on this specific health behavior, belonging to the active transport domain.

2.2 Measuring cycling behavior

Physical activity and accordingly cycling for transport can be measured in different ways. Since physical activity is a complex behavior, it is not easy to measure it precisely. Nevertheless, physical activity has to be measured accurately in order to do high-quality research and to verify intervention effects. In recent literature, a classification based on two types of measurement methods was found: self-report versus objective measurement methods [11]. Each measurement method has its own advantages and disadvantages and is often selected according to the purpose of the measurement, the available time and resources [12]. Both types of measurement methods are explained in detail below.

2.2.1 Self-report measurement methods

Self-report measurement methods (or also known as subjective measurements) rely on individuals' recall of performed physical activities as well as on their perception of the intensity of the activities and includes measurement methods as questionnaires and activity diaries. For example, a 24-hour recall diary is a standard way to collect time use data and allows the respondent to look back and describe his or her activities chronologically [13]. A questionnaire can be administered in interview form (by telephone or face-to-face), or in written form (on paper or electronically). Questionnaires are commonly used because they are cheap and easily usable to administer data from large populations in a short period of time (i.e. cost-efficiently). Furthermore, these self-reported methods can gather information about physical activity conducted in the various domains, and can provide data about the time people were physically active at a certain intensity [11]. However, conducting self-report assessments is associated with a number of limitations as well. Self-reported outcomes may be biased through recall bias (i.e. participants may have difficulty to recall information) or social desirability bias (i.e. participants want to fit with social expectations) [14]. Furthermore, this technique depends on both the subjective interpretation of the questions and the perception of participants regarding their physical activity and may cause under- or overreporting of their physical activity. This under- and overreporting may be affected by several factors such as age, knowledge, complexity of the questions, length of the survey or social desirability [15].

The most frequently used questionnaire worldwide to measure physical activity in large adult groups is the International Physical activity Questionnaire (IPAQ). The IPAQ has different versions, a long (IPAQ-long form) and a short version (IPAQ-short form), telephone- or self-administered [16]. Furthermore, this questionnaire can alternate depending on the reference periods that are used to report physical activity: 'last seven days' or 'usual week'. The IPAQ-long form assesses the different domains in which physical activity can occur together with the duration and intensity of the physical activity, while the IPAQ-short will make no distinction between the different domains of physical activity. The IPAQ was tested in twelve different countries on validity and reliability and showed a good reliability (Spearman's correlation coefficients clustered around 0.80) and fair-to-moderate criterion validity (median $\rho = 0.30$) among adults between 18 and 65 years old. Furthermore, no significant difference in validity and reliability was found between the different versions [17]. Consequently, all different versions of the IPAQ questionnaire can be used for physical activity assessment among adults.

The cycling for transport behavior of individuals can be questioned by using a part of the IPAQ-long form, namely the domain 'transportation physical activity'. One question assesses how many days individuals cycled for at least 10 minutes at a time to go from place to place in the last seven days or in a usual week. Another question assesses how much time individuals usually spend on one of those days to cycle from place to place [16].

2.2.2 Objective measurement methods

Objective measurement methods rely on information obtained by an external person or from solid data coming from a device. Examples of objective measurement methods or tools are direct observation, heart rate monitoring, doubly labelled water method, indirect calorimetry, pedometers, accelerometers, or a global positioning system (GPS) [11]. Although they often meet the disadvantages (e.g. recall bias, social desirability) of self-report methods, they are much more expensive. In the public health context, motion sensors (e.g. pedometers and accelerometers) are commonly used since the usability is greater (i.e. more feasible tools to reach a large sample) in comparison to direct observation or indirect calorimetry [18]. Furthermore, the use of new technologies such as GPS-devices in combination with accelerometers to register physical activity is growing.

Motion sensors objectively register movements of the body. Pedometers are low-priced measurement instruments that can accurately determine the number of steps, allowing use in large-scale studies. However, pedometers are not able to register cycling activities as they only record vertical movements [18,19]. Therefore, these devices can only be used to register walking or running activities, without being able to register the intensity of the activity [18,19]. Accelerometers can be used to overcome this limitation of the pedometer, as these tools can provide valid information about the intensity, duration and frequency of the physical activity [18,19]. The cost of accelerometers is considerably higher than of pedometers, which makes it less feasible to use accelerometers on a large scale. Nevertheless, accelerometers also have some disadvantages which can cause an underestimation of the physical activity or an incorrect interpretation of the data [18,19]. First, these devices are not waterproof, eliminating the registration of water sports (e.g. swimming). Second, accelerometers do not provide information on the context in which activities occur or the type of physical activity [20,21]. Third, these hip worn measurement tools underestimate many types of activities that do not include central body movements, such as cycling because of the limited hip movement while cycling [21–24]. Therefore, these devices cannot be used solely to register cycling for transport.

A more recent tool to objectively register cycling behavior are GPS devices. GPS data provide information about the position and speed of movements. The speed measured with a GPS device can be used to identify the type of transport mode (i.e. walking, cycling, and motorized transport) [25]. Trips with an average speed between 10 and 25 km/h and with a maximum speed of 45 km/h were commonly classified as cycling tips [26]. These values may slightly differ depending on the target population. Nevertheless, there are also some concerns about the use of GPS as a measurement method [27,28] such as the possibility to misclassify the travel mode due to an overlap in speed between different travel modes. For example, in urban areas with dense traffic and slower driving speed, it might be difficult to distinguish the speed of cycling with the speed of the slow driving motorized traffic [25]. Furthermore, incomplete GPS data by losing contact while riding in an urban environment (e.g. tall buildings, tunnels) may also cause inaccurate assessment of cycling. Combining these GPS devices with activity diaries or accelerometers in order to complete the missing information might provide support to overcome these problems. The combination of both devices makes it possible to establish a more accurate detection of the physical activity context and can give a more valid objective estimation of the cycling behavior of individuals [25,29]. However, there are also some concerns of these combined measuring methods: the use of diaries involves a high level of commitment of the participants and using accelerometers induces higher equipment costs, and higher requirements for data collection and analysis [30].

2.3 Physical activity guidelines

The World Health Organization proposed global physical activity guidelines tailored to different age groups (children, adults, elderly) [31]. These recommendations were intend to enhance the primary prevention of non-communicable or chronic diseases (e.g. cardiovascular diseases, cancers, chronic respiratory diseases and diabetes) [31]. The physical activity recommendations for adults are described as follows: “Adults aged 18-64 years should do at least 150 minutes of moderate-intensity aerobic physical activity throughout the week, or at least 75 minutes vigorous-intensity aerobic physical activity throughout the week, or an equivalent combination of moderate- and vigorous-intensity activity. Aerobic activity should be performed in bouts of at least 10 minutes duration. Furthermore, muscle-strengthening activities should be done involving major muscle groups on 2 or more days a week." [31].

2.4 Valuing the benefits of cycling for transport

Regular physical activity can reduce the risk of a lot of chronic diseases (such as cardiovascular disease, coronary heart disease, hypertension, diabetes, stroke, breast and colon cancer); it improves bone and functional health and it also has psychological advantages (reduce the risk of depression and the fear of falling) [32]. Furthermore, as regular physical activity is a key determinant of energy expenditure, it can help to maintain a healthy weight and prevent energy imbalance [31,33]. Consequently, regular physical activity can reduce the risk of mortality by preventing some of the leading causes of death or disability [31,34]. Following the principle of the dose-response relationship, a small increase in dose of physical activity among the least unfit part of the population may ensure a large positive impact on health parameters [9,31]. When adults achieve the minimum recommendation regarding sufficient physical activity, a good health can be obtained or maintained. Additional health benefits can be reached as the amount of physical activity increases since the dose-response relationship suggests that the higher the degree of physical activity, the higher the health benefits. However, from a certain level of physical activity, the health benefits increase less rapidly or flatten [9]. Since the dose-response relationship is not a linear relationship, too much physical activity will again be associated with more health problems.

Since this thesis focuses on cycling for transport, the specific advantages of cycling for transport should be highlighted as well. When performed regularly and at a moderate intensity, cycling for transport can contribute to total physical activity and thus can help to achieve the health benefits of regular physical activity as mentioned above [1,33–36]. Since cycling is more physically intense than walking, it improves the cardiovascular and muscular fitness more [1]. Furthermore, particular for cycling, evidence exists for the positive effect of cycling on reduced mortality and weight gain [37]. In addition, an inverse association between cycling for transport and obesity has been found in different countries [38]. A recent meta-analysis of Kelly et al. (2014) demonstrated the dose-response relation for cycling and showed that the first 100 minutes of cycling per week had the strongest beneficial impact on the risk of all-cause mortality [39]. Furthermore, evidence on the positive impact of cycling for transport on mental health is also available. Cycling to work might decrease stress [40], increase vitality, health-related quality of life [41], improve the cognitive function [1] and the mental well-being (i.e. person's psychological health, mood, and self-perception) [42]. At the same time, cycling for transport also has many other advantages besides their positive health effects. First, cycling implies economic advantages for cyclists such as the reduction of their gasoline purchases [43]. Next, environmental benefits like the reduction of CO_2-emission or the reduced noise are also clearly demonstrated [35,43]. Finally, increasing the proportion of cyclists instead of car drivers could reduce traffic congestion and increases traffic management benefits [44,45].

Unfortunately, some health risks associated to cycling for transport also have to be acknowledged. Cyclists are more likely to suffer from higher injury and fatality rates in comparison to car drivers [46], and might also have a higher exposure to air pollution [47]. Nevertheless, the risks related to cycling for transport appear to be far outweighed by the benefits [34,36,48]. Therefore, previous studies highlighted that an increase in modal share for cyclists will only help to improve their net health cost-benefits [34,35,49–51].

2.5 Prevalence

Despite the known benefits of regular physical activity, about one third of the global adult population (18 years and older) is insufficiently physically active and does not meet the physical activity recommendations [52,53]. In Europe, more than one third (34.8%) of the adults do not reach the minimum World Health Organization recommendations for physical activity for health [54].

Particularly for cycling for transport, available data show that there is still a large opportunity to increase the cycling levels in Europe. In European cities, 40% of all trips are less than 2.5 kilometers, and 50% of all car trips are shorter than 5 kilometers [55–57]. Although this is a feasible distance to cycle, cycling remains an under-used form of transport in comparison to motorized means of transport. In a European study, only 7% and 13% of the adults mentioned that respectively cycling or walking was their main mode of transport, while the majority (53%) of the adults chose the car as their main mode of transport and 22% opted for public transport [3]. In Flanders (Belgium), only 25% and 13% of the trips shorter than 3 and 5 kilometers respectively are traveled by active transport (e.g. walking or cycling) [58].

Despite the many advantages of cycling for transport, cycling remains an under-used form of transport for short-distance trips (>5km) compared to motorized means of transport in Europe [3]. *Consequently, there is a need for interventions to promote cycling for transport. However before these interventions can be developed, it is required to verify the correlates of cycling for transport. In other words, it is important to identify reasons why people do and do not cycle for transport. In the next paragraph,* *different conceptual frameworks representing the correlates of physical activity and more specifically cycling for transport are discussed.*

3 Conceptual frameworks to explain cycling behavior

3.1 The Ecological Model of Active Living

Theoretical frameworks are needed to explain physical activity and should guide research regarding the factors that influence the health behavior. The core concept of ecological models is that a specific health behavior is influenced by correlates at multiple levels: the intrapersonal level, social cultural environmental level, physical environmental level and policy level [59]. Furthermore, since individuals interact with their physical, sociocultural and policy environments [60], ecological models also emphasize the interplay between these different levels to explain the health behavior [5,61]. During the last decade, the most frequently used framework in the public health context to determine the multidimensional correlates of physical activity among adults is 'The Ecological Model of Active Living' by Sallis et al. (2006). This model is presented in Figure 1 [5]. Since this model was constructed around the concept of active living, this ecological model is frequently used in public health research on the four domains of active living, including active transport.

First, in the center of the model the **intrapersonal level** is displayed and consists of the demographical (e.g. age, gender), biological (e.g. physical functioning), and psychological factors (e.g. attitude, self-efficacy) of the individual. Second, around the intrapersonal level, the perception of the physical environment (i.e. **the perceived environment** like the perception of neighborhood safety or neighborhood attractiveness) is presented and should be seen separately from the objective physical environment (i.e. fourth level). On the third level, the four domains of active living (i.e. active transport, occupational activities, active recreation, and household activities) are presented, representing the **behavior** of the individual. This behavior is determined by different environments and policies [62]. Although not literally shown in the framework, an interaction between the individual and the environment to do specific behaviors can be assumed. The fourth level represents the impact of the objective physical environment (i.e. the physical context in which people spend their time) on the behavior and is cited as the **behavior settings (access and characteristics)**. Furthermore, **the policy environment** is considered as the fifth level since it could influence the behavior through a whole series of mechanisms. For example, the public policy level can exert an impact on transport behavior by increasing the taxation of fuel.

Additionally, **the social cultural environment** influences the behavior and cuts across all different levels. For example, the proximal social environment emphasizes the influence of family and peer groups and involves concepts like modeling, social norm and social support. Finally, **the natural and information environment** are two different influences which cover two different levels: the behavior setting and the policy environment. Examples of these correlates are weather, air quality, transport policies, promotion material, and media regulations (see figure 1).

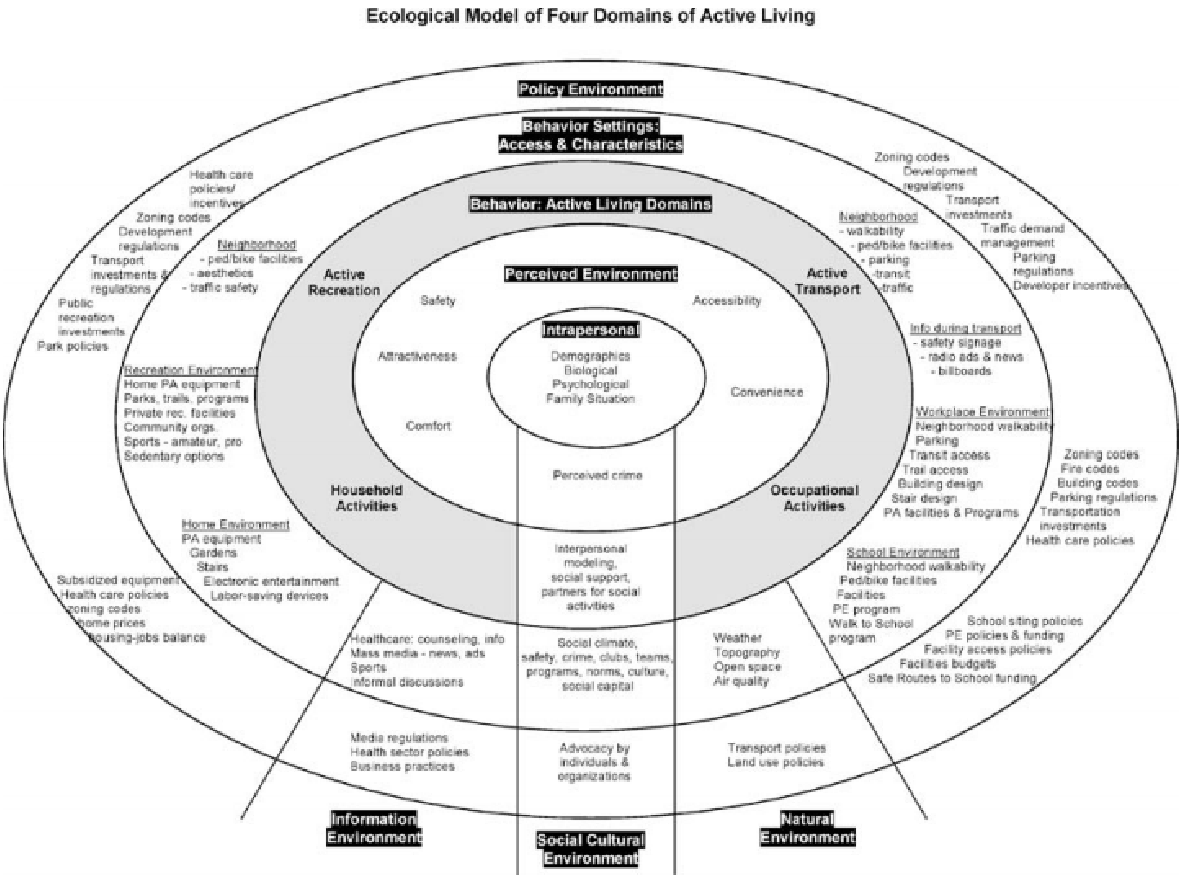

Figure 1. Ecological model of active living from Sallis et al. (2006) [5]

A previous study on physical activity indicated that a large proportion of the variance (42%) could be explained by psychological and social environmental factors compared to an obviously lower proportion of variance (1-8%) explained by physical environmental factors [63]. Nevertheless, there is an indication in the literature that this does not apply for cycling for transport. It seems that transport-related physical activity compared to physical activity for recreation is less dependent of individual decision-making, and might be more likely to be related to physical environmental correlates [64,65]. A better understanding of the physical environmental influences on cycling for transport is needed to elevate cycling to a significant travel mode [66]. Therefore, a more specific conceptual framework to explain cycling for transport is introduced below.

3.2 Conceptual framework for cycling behavior

According to the Ecological Model of Active Living, a conceptual framework to explain cycling behavior was presented in a recent study of Heesch et al. (2015), see figure 2 [66]. This framework highlights the growing interest in the objective physical environment in addition to the individual attributes (e.g. socio-demographic characteristics). In this framework, environmental factors are subdivided in the socio-economic environment (e.g. socio-economic status of a neighborhood), the built environment (e.g. bicycle infrastructure, distance to destinations) and the natural environment (e.g. aesthetics). Furthermore, the cycling behavior is split according to the cycling purpose (i.e. for transport or for recreation), indicating the different environmental influences for the two types of cycling behavior.

The distinction between the objective physical environment and the perceived physical environment is also mentioned by Heesch and colleagues (not shown in the framework). The objective physical environment is associated directly with the cycling behavior, but also indirectly by influencing individuals' perceptions of the physical environment, and in turn influencing the behavior [5,67–73]. Consequently, it is important to distinguish the objective and perceived environmental correlates of cycling for transport [74].

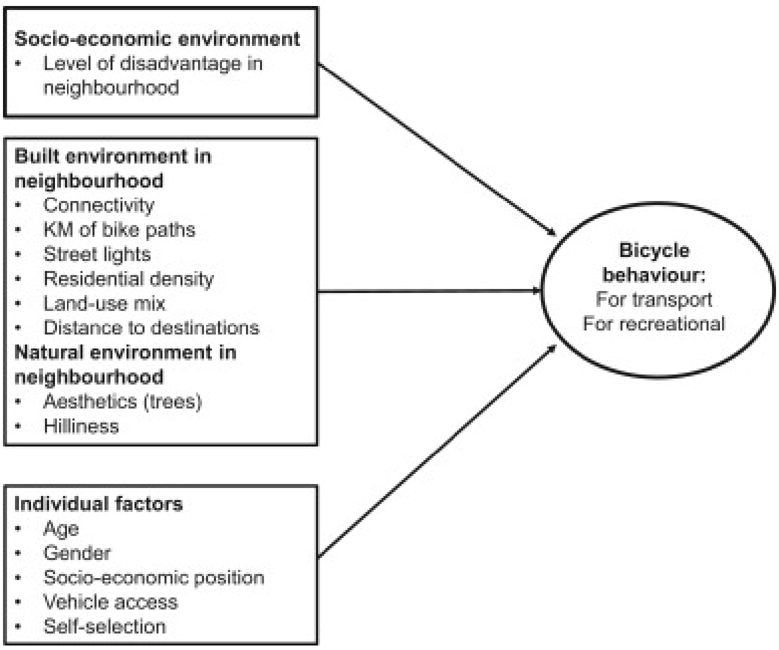

Figure 2. Conceptual framework from Heesch et al. (2015) [66]

3.3 Hierarchy of walking needs

Existing conceptual frameworks to explain cycling are limited and insufficiently detailed. Therefore, we decided to put forward the model “Hierarchy of Walking Needs” which is a walking model but addresses in more detail the environmental influences. Alfonzo (2005) introduced the “Hierarchy of Walking Needs” within the ecological framework in order to illustrate how urban and non-urban form factors may interact to affect walking (see figure 3) [75]. Since it may be assumed that this conceptual framework can also be used to explain the decision-making process to cycle, this framework is explained in further detail below.

The “Hierarchy of Walking Needs” categorizes the various environmental factors associated to walking in a hierarchy (i.e. pyramid). The concept of this pyramid includes that some factors or needs are more fundamental in the decision-making process to walk than others and that the basic or lower order needs should be fulfilled first before higher order needs can be satisfied. The framework postulates that there are five levels of needs within the walking decision-making process, consisting of urban (i.e. the spatial pattern of human activities) and non-urban form factors. Feasibility (i.e. non-urban form variable) is assumed as the most basic level of need within the hierarchy of walking needs and is related to personal limits, including factors such as mobility (e.g. physical condition), time or other responsibilities. It is suggested that if this basic level is not fulfilled, then walking will not occur, irrespective of the satisfaction of the other levels of the hierarchy (i.e. the urban form variables). Furthermore, the basic urban form layer in this hierarchy (i.e. *accessibility*) includes factors such as proximity of destinations and street connectivity. The second urban layer represents environmental factors related to *safety* such as presence of graffiti and litter, or the presence of loitering individuals. The next urban layer refers to *comfort* related environmental factors such as the presence of traffic calming features, width of the sidewalk, or the presence of trees. The upper urban form layer represents the *pleasurability and* consists of factors such as presence of a varied streetscape, presence of public space, or the presence of other people.

Although this framework displays a clear hierarchical structure, several considerations were made. First, it is not essential that lower order urban needs are fully satisfied before proceeding to the next levels of needs. Second, the order of levels can also vary according to the individual. In addition, it might be that different needs simultaneously motivate or inhibit the transport behavior. Therefore, combinations or interaction effects between the different urban layers (i.e. physical environmental factors) are documented in this framework. All these urban layers might interrelate with another urban form layer, representing the possible interactions between physical environmental factors (either factors of the macro- or micro-environment, see below).

Lastly, this framework also highlights the importance of the several inter-processes that act as moderators within the decision-making process to walk, such as correlates on the individual level (e.g. demographics and psychological factors), group level (e.g. cultural factors), and regional level (e.g. climate, topographical factors).

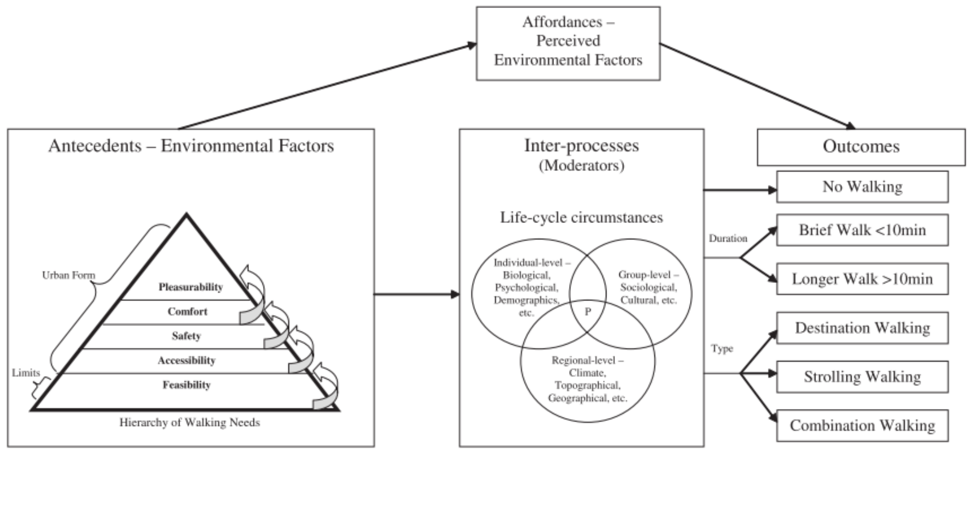

Figure 1: Hierarchy of Walking Needs Within a Social-Ecological Framework

Figure 3. Hierarchy of walking needs within a social-ecological framework from Alfonzo (2005) [75]

Ecological models state that the physical environment, together with social and individual attributes, provides a useful framework to explain physical activity [5]*. However until now, empirical evidence of the different correlates of cycling for transport, is still limited in comparison to other health behaviors like walking or total physical activity* [37,67,76–79]. *In the next paragraph, existing empirical evidence about the correlates of cycling for transport will be given, with the focus on the intrapersonal, interpersonal and physical environmental correlates of cycling for transport, crucial for his PhD thesis.*

4 Correlates of cycling for transport

4.1 Intrapersonal and interpersonal correlates

The most consistent results in the literature regarding the correlates of cycling for transport are found for the socio-demographical factors (i.e. intrapersonal correlates). For example, previous studies in Australia demonstrated that men are more likely to engage in cycling for transport than women, and also travel longer distances by bike [66,80]. Similar results were found in the UK and the USA [81], while in Europe the social distribution of gender in relation to cycling for transport tends to become more equal [3]. In addition, the differences in cycling levels according to age are much more pronounced outside Europe with significant differences between younger and older adults. In Europe, the cycling levels only decline slightly from the age of 25 years old [3,4]. Furthermore, highly educated people often appear to have higher cycling levels than people with a lower educational level [3,81,82], although not all studies found an association between education and cycling for transport [83]. Additionally, cycling levels varied significantly across continents [84], across countries and even across municipalities within the same country. Large differences among various European countries have been found for the amount of individuals using their bicycle as main mode of transport for daily activities with a range from 0% (Malta) to 31.2% (the Netherlands). Other European countries in which more than 10% of the inhabitants use their bicycle as main mode of transport are Belgium (13.4%), Germany (13,1%), Hungary (19.1%), Denmark (19.0%), Finland (12.5%), and Sweden (17.1%) [3]. All other countries do not achieve 10%. These distinctions in cycling levels and cycling-culture among these countries may be related to the different cultural traditions, but this needs to be further examined [85]. Since it is difficult to change socio-demographic correlates of cycling for transport (e.g. gender, age, education, and ethnicity), these factors can be examined as potential moderators in the relationship between other correlates (e.g. physical environmental) and cycling for transport. This might help to identify potential subgroups that are susceptible to low levels of cycling for transport, and might advise tailored interventions promoting cycling for transport. Another potential correlate is the physical fitness level of individuals. As cycling requires a certain basic fitness, balance and agility level, it will make cycling less feasible if physical fitness or mobility limitations occur [75]. Since men and younger adults often have a higher level of physical fitness than women and older adults, this could also help explain the differences in prevalence between these populations [86,87].

In contrast, psychological (i.e. intrapersonal) and social (i.e. interpersonal) correlates of cycling for transport are more changeable than socio-demographic factors. Consequently, clear evidence about the specific psychological and social factors related to cycling for transport in comparison to general physical activity is still limited. Two Belgian studies demonstrated that people who report high levels of modeling (e.g. their relatives who cycle) and social support from family and/or friends (i.e. social factors) were more likely to cycle for transport [63,82]. However, the perceived social benefits or social reasons why people exercise (e.g. being together with family and/or friends) did not appear to be a correlate of cycling for transport [82]. Next, the ecological and economic advantage of cycling for transport could be seen as perceived benefits (i.e. psychological factor) that seem to be associated with cycling for transport [82]. Additionally, several perceived barriers (i.e. psychological factor) such as lack of time, health, extern obstacles, and perspiration when arriving at work were negatively associated with cycling for transport [82,88], and was in line with previous results found for general physical activity [89]. Furthermore, self-efficacy (i.e. the belief of his/her own ability to engage in physical activity or in cycling for transport on a regular basis) turned out to be the most consistent psychological correlate of general physical activity [89], and seems to be important for cycling for transport as well [82].

4.2 Physical environmental correlates

4.2.1 Definition of the physical environment

The physical environment can be seen as the wider built environment and includes both the perceived and the objective physical environment [90]. **The physical environment** is defined as 'objective and perceived characteristics of the physical context in which people spend their time (e.g., home, work and neighborhood), including aspects of urban design, traffic density and speed, distance to and design of venues for physical activity (e.g., parks), crime and safety' [91]. In this thesis, the emphasis is put on the physical environment of the **neighborhood**, which can be defined as 'the area all around one's home that one can walk to in 10-15 minutes, or approximately 1.5 km' [92]. However, there is no consensus in the literature on how to define a neighborhood, and consequently different definitions are used according to the target behavior (walking vs. cycling for transport). Furthermore, this definition is also dependent on which aspect of the physical environment is measured: respondent perceptions of the physical environment or the objective physical environment [93]. An application of a neighborhood definition regarding the perceived physical environment and cycling for transport might be adjusted according to the cycling distance '10 minutes cycling from your home'. Furthermore, self-defined neighborhoods can also be used. Residents can self-define their activity space or neighborhood by drawing the boundaries around their residential address of what they regard as their residential neighborhood [94]. Objective neighborhoods are often defined in a structural manner using census tracts, administrative boundaries, postcode sectors, an actual radius or fixed location [95,96]. Because of the wide variety of geographical neighborhood definitions and its boundaries [95], different results might be obtained, resulting in a report of inconsistent results in this domain [97]. This phenomenon is called the 'modifiable areal unit problem' (MAUP) and needs to be taken into consideration when interpreting the results [98].

The neighborhood physical environment can also be divided depending on the environmental size (i.e. macro and micro) [99]. For each type of environmental influence (e.g. physical, socio-cultural, political), a distinction depending on the environmental size can be made. Specific for the physical environment, the focus of this PhD thesis, the distinction between the physical macro- and micro-environment could be outlined based on previous studies [100–102].

4.2.1.1 The physical macro-environment

The physical **macro-environment** can be seen as 'raw' urban planning features, such as walkability, residential density, street network connectivity, or land use mix diversity [100–102]. This macro-environment corresponds to the basic urban form layer (i.e. accessibility) presented in the "Hierarchy of walking needs" and will be more fundamental in the decision-making process to cycle in comparison to the more upper micro-environmental levels [75]. However, the macro-environment might be difficult to change in existing neighborhoods, because of the size and complexity. The macro-environment is essentially beyond the influence of individuals and even for governments and nongovernmental organizations it is usually difficult to influence these factors because this requires strong collaboration between [99–102].

4.2.1.2 The physical micro-environment

The physical **micro-environment** can be seen as specific characteristics of environmental features within a streetscape, including factors such as evenness of the cycle path, presence of vegetation, safety issues, or upkeep of the streetscape [100–102]. This micro-environment corresponds to the more upper urban form layers (i.e. safety, comfort and pleasurability) presented in the "Hierarchy of walking needs" [75] and might be less fundamental in the decision-making process to cycle in comparison to the basic urban form layer (i.e. accessibility or the macro-environment). Adjusting the micro-environment might be only favorable if the lower urban form layer (i.e. macro-environment) satisfies certain conditions (e.g. close destination, short trip distance). Micro-environmental factors, however, are relatively small-scaled and can be potentially influenced by individuals or local actors which makes those factors more feasible to change [99–102]. Therefore, it seems to be more practical for physical environmental interventions aiming to adjust existing neighborhoods to target the micro- instead of the macro-environment. Nonetheless, the relationship between the more changeable, micro-environment and cycling for transport is less consistent and less thoroughly investigated in comparison to the macro-environment [100,103–107]. A further clarification of both types of correlates (micro- and macro- environmental correlates) and their relation with cycling for transport is given in detail below, after describing different methods to measure the physical environment.

4.2.2 Measuring the physical environment

The physical environment can be measured in two different ways: self-reported vs. objective measurement. According to the conceptual models described previously [5,75], there is a discrepancy between the objective physical environment and the perceived physical environment, but both are important to explain behavior. Perceptions have been suggested to be more closely related to actual behaviors [70,71], while the objective physical environment can either directly or indirectly (through influencing individuals' perceptions) [68] determine the cycling behavior [67,70,71]. Furthermore, previous studies have shown distinct associations between objective and perceived environmental correlates and cycling for transport [108]. Consequently, these two methods assess two distinct dimensions of the physical environment [12,74,109,110]. Therefore, it is important to provide a detailed overview of the different methods of measuring both the perceived and objective physical environment.

4.2.2.1 The perceived physical environment

The self-reported physical environment determined using questionnaires can assess individuals' perceptions of the neighborhood-related physical environment [108,111]. The most commonly used questionnaires to assess perceptions of the physical environment in adults are the Neighborhood Environment Walkability Scale (NEWS) [63,112–114] and the Assessing Levels of Physical Activity and Fitness (ALPHA) [92,115]. Although the NEWS-questionnaire and its abbreviated version (A-NEWS) were developed in the USA, they have been used all over the world and showed a good test-retest reliability, acceptable criterion and concurrent validity [63,112–114,116]. The NEWS-questionnaire (98 items) assesses neighborhood perceptions, including residential density (house type), street connectivity, land use mix (proximity and accessibility), walking/cycling facilities, neighborhood aesthetics, traffic and crime safety, and neighborhood satisfaction. All items, except the residential density and land use mix-diversity subscales, are scaled from 1 (strongly disagree) to 4 (strongly agree), of which higher scores correspond to a more favorable value of the environmental characteristic. For residential density, the frequency of various types of neighborhood residences (e.g. detached single-family residences, apartments more than 13 stories) are assessed with a 5-point scale from 1 (none) to 5 (all). Furthermore, the walking proximity from home to various types of stores and facilities (ranging from 1- to 5- minute walking to ≥ 30 minute walking distance) are assessed to determine the land use mix-diversity [112]. The shortened version (A-NEWS) consists of 49 items.

Later, a specific questionnaire for Europe was developed (i.e. the ALPHA questionnaire) because the physical environment varies considerably among continents [92,115]. This questionnaire was based on the NEWS, and a short version of this questionnaire was developed as well (ALPHA-short). The ALPHA questionnaire pays special attention to the addition of cycling-related questions since the prevalence of cycling is much higher in Europe compared to for example the USA or Australia [117]. The ALPHA questionnaire has a good reliability and predictive validity [115]. The ALPHA (49 items) assesses perceptions of European neighborhoods divided into nine themes: types of residences, distances to local facilities, walking or cycle infrastructure, maintenance of infrastructure, neighborhood safety, pleasantness of the neighborhood, cycling and walking network, home environment, workplace or study environment [92]. The answer categories vary depending on the assessed theme between a five (e.g. none-all), four (e.g. strongly disagree-strongly agree) or two point scale (e.g. yes-no). The ALPHA-short consists of 11 items (minimum one item for each theme) assessed on a two point scale (yes-no) [115].

While neighborhood perceptions may be more closely related to actual behaviors [70,71], the risk of potential biases by recall is greater than when investigating the objective environment [118]. Consequently, it is important to distinguish objective and perceived environmental correlates [74] and to choose the appropriate method depending on the purpose you want to achieve [12].

4.2.2.2 The objective physical environment

The physical environment can be assessed objectively by using existing spatial data (e.g. Geographic Information Systems, GIS), by systematic observations (i.e. field observation audits), or by desk-based audits (e.g. Google Street View (GSV) or Bing Maps). Each method has its advantages and disadvantages and is outlined in detail below.

Geographic information systems (GIS) software is a computer-based tool that is able to operationalize spatial measures of geographical areas (e.g. urban environments), such as measures of proximity, connectivity, density, and other environmental factors. A GIS database consists of several layers with different types of information which can be combined meaningfully through overlay analysis to draw conclusions [119]. Furthermore, GIS can also link and analyze public health data (e.g. household or individual health behavior) in relation to place (i.e. objective environment data) [65,120]. This method usually provides objective information about the macro-environment (such as road network, activity space, density) as more municipalities or cities possess these data in comparison with the micro-environmental data which includes a much higher level of detail [121,122]. Therefore, a disadvantage is that researchers are dependent on the availability of the data from municipalities and cities. Another concern is that an expert is needed to analyze this complex data.

Field observation audits are able to register very detailed features (i.e. micro-environmental factors) because the assessment is conducted by researchers (i.e. coders) who are present on the spot. Furthermore, field observation audits are able to gauge the traffic speed with a radar gun and to measure the cycle path width with a rolling tape measure. In addition, they can also give an indication of other environmental factors like noise or odors [74,122]. Nevertheless, these in-persons audits require a lot of time and effort since the researcher has to visit all specific areas making it difficult to capture large-scale environments. Furthermore, it might also involve some safety concerns [122,123].

Desk-based audits are a recently developed method and can be considered as a good substitute of the field observations [121,123,124]. These remote sensing techniques have the advantage to save time and effort, to efficiently capture large-scale environments in detail, to handle concerns about safety problems and to guarantee a better quality control [122–127]. Compared to the above mentioned GIS-data tool to capture the objective environment, data collection through for example Google Street View can capture large-scale environments in more detail (i.e. micro-environment). Nevertheless, this measuring method also has some disadvantages. Google street view provides images to assess the physical environment, so there is the risk to have some blocked views (e.g. obstacles on the images) or the impossibility to report field audit items as noises, odors, traffic speed and cycle path width [122]. Furthermore, it could be difficult to report temporal environmental factors (e.g. litter, obstacles), or Google Street View data could sometimes be outdated [123,124].

4.2.3 Physical environment correlates of cycling for transport

The macro- and micro-environmental correlates of cycling for transport are described separately below. Only results for adults, the target group of this thesis, are highlighted. Previous research already indicated that the role of the physical environment in relation to general physical activity is of greater importance among the adult population (18-65 years) in comparison to other age groups such as youngsters, adolescents and elderly people [128–131].

4.2.3.1 Macro-environmental correlates

It is assumed that environmental correlates of cycling for transport differ across continents [104] because the physical environment and especially the macro-environment significantly differs across different continents, i.e. the compact structure in Europe vs. less dense structure in America [132]. Furthermore, the active transport culture is much greater in Europe compared to North America and Australia [38]. Therefore, only European results on the association between the macro-environment and cycling for transport will be reported below.

In Europe, consistency in the literature exists about the role of the macro-environment in explaining cycling for transport. A review of Van Holle et al. (2012) reported the perceived and objectively physical environmental correlates of cycling for transport among European adults. A strong positive association was found between walkability, access to shops/services/work, degree of urbanization and cycling for transport in which no distinction in results was found between the objectively or subjectively determined physical environment. In other words, people living in more walkable, urbanized neighborhoods or neighborhoods with better access to shops/services/work tend to cycle more for transport. Furthermore, a negative association was found between hilliness (objectively determined) and cycling for transport. A positive association was found for objective traffic-related safety and cycling for transport and possible positive evidence was found between perceived walking/cycling facilities and cycling for transport. No association was found for objectively determined access to public transport, or access to recreation facilities, for perceived traffic-related safety, perceived aesthetics and objective and perceived crime related safety. Some of these latter environmental factors (e.g. walking/cycling facilities, traffic- and crime-related safety, and aesthetics) can be seen as a collection of different micro-environmental factors commonly assessed by the NEWS questionnaire. For example, the different questions concerning the walking and cycling facilities (e.g. 'There are bicycle or pedestrian trails in or near my neighborhood that are easy to get to', 'Sidewalks are separated from the road/traffic in my neighborhood by parked cars') are usually assembled into one scale representing the overall perception of walking/cycling facilities. Consequently, the biggest concern of the NEWS questionnaire is that these factors are incorporated together which makes it impossible to draw conclusions about the specific effect of some cycling related characteristics. This partly explains the emerging interest to investigate the different specific effects of micro-environmental factors on cycling for transport.

4.2.3.2 Micro-environmental correlates

In contrast to the macro-environment, empirical evidence about the role of the micro-environment for explaining cycling for transport is still restricted and much more inconsistent. Furthermore, evidence is certainly more limited for cycling for transport in comparison to walking for transport or total physical activity [37,76–79]. Some examples of inconsistent results are given below.

The role of the cycling infrastructure (i.e. presence of cycle paths or the type of cycle path) on cycling for transport is inconsistent in the literature. Several studies using self-report methods have demonstrated a positive association [84,133–136], while other studies did not find any association [82,137]. Additionally, environmental factors concerning traffic safety also show some contradicting results. For instance, the presence of perceived traffic calming elements [138] or objectively determined lower road traffic volumes [105] showed a positive association with cycling for transport. However, other studies (objectively or self-report) were unable to find an association [82,134,139] or found an inverse association (i.e. higher volumes of traffic were associated with more cycling for transport) [140,141]. Furthermore, the role of aesthetics (e.g. presence of vegetation, environmental upkeep, and interesting architecture) and cycling for transport is also still unclear. Several studies found positive associations between more greenery and cycling for transport [128,136,142,143], while other studies did not find an association [104,128].

These inconsistencies in the literature are potentially attributed to the different measuring methods that have been used (e.g. objective vs. subjective measures) [68]. A systematic review of Wendel-Vos et al. (2007) indicates that the unclear associations between physical environmental factors and cycling for transport can be restricted by providing standardized definitions of environmental factors and using stronger study designs [103]. A more recent review (2016) concluded the same: improved research methods are needed [144]. Furthermore, specific European results on the relationship between micro-environmental factors and cycling for transport are restricted.

4.3 Interplay between different socio-ecological correlates

Another important issue to which socio-ecological models refer to are people's interactions with their physical environmental and sociocultural surroundings [5,145], recognizing the importance of studying the interplay between different correlates. First, it is important to find out which individual characteristics moderate the relationship between the physical environment and cycling for transport. In addition, investigating the interaction between different environmental factors (i.e. macro vs. micro, or micro vs. micro) might further extend the knowledge about the joint physical environmental influences on cycling for transport.

4.3.1 Individual moderators of the association between the physical environment and cycling for transport

Individual factors (i.e. socio-demographics and psychological factors) might help to explain how different physical environmental preferences are associated with cycling for transport. Therefore, it is important to get insight in potential individual moderators when investigating associations between the physical environment and cycling for transport [73,146]. This information may help to identify potential subgroups with specific associations between the physical environment and cycling and might advise tailored interventions aiming to promote cycling for transport.

Existing literature already specified some different transportation patterns, needs, and purposes from different subgroups, and usually from under-represented groups (e.g. women or elderly people) [147]. Previous studies indicated that issues of safety, comfort and cycling infrastructure (e.g. cycle paths separated form motorized traffic) seem to be more important among women compared to men regarding their cycling for transport behavior [66,148,149]. A recent study of Aldred et al. (2015) indicated similar findings for older people regarding the importance of separated cycle paths as well as the amount of traffic [147]. Another study focusing on cycling for transport, showed that fun and enjoyment, getting fresh air, building physical activity into a busy lifestyle, confidence in own cycling abilities, seeing other people cycle, encouragement from others, convenient or cheap form of transport, and concerns about the environment were significantly stronger motivators for women compared to men [66]. In addition, women were more likely than men to report following constraints to cycle for transport: inhaling car fumes when cycling, inability to put a bicycle on public transport, weather and climate conditions (e.g. rain or story weather), and lack of fitness or confidence in abilities [66]. A recent study of Poulos et al. (2015) reported both differences between transport and recreational cyclists, as well as differences within these cyclists groups [150]. Among the transport cyclists, results indicated that high intensity cyclists reported higher levels of experience and more confidence on busy main streets resulting in more cycling on the road than their low intensity counterparts [150].

However, these previous studies mainly described the differences in environmental preferences of particular subgroups rather than investigating the moderating effects of the individual factors on the relationship between the physical environment/environmental preferences and behavior. Until now, almost no studies investigated these moderating effects, so there is a strong need to conduct such studies.

4.3.2 Interactions between different environmental factors

Besides the moderating effects of individual factors on the association between the physical environment and cycling for transport, examining the interaction between different physical environmental factors might also help to explain the cycling behavior. The actual environment consists of a combination of several environmental factors; therefore it is interesting for environmental interventions to know which factors interact with each other. For example, the adjustment of two environmental factors simultaneously might cause a better or worse effect on the street’s appeal to cycle for transport.

The “Hierarchy of Walking Needs” (see above section 3.3) highlighted some possible interactions between different environmental factors in the decision-making process to walk [75], and is assumed to be equivalent for explaining the cycling behavior. According to our formulated definitions of the macro- and micro-environment and to the conceptual framework “Hierarchy of walking needs”, a distinction can be made in the possible interactions. First, there could be an **interaction between the macro and the micro-environment** or the basic urban form layer (i.e. accessibility) and the more upper urban form layers (i.e. safety, comfort, pleasurability) [75]. For example, people living in a neighborhood with a good access to destinations are perhaps less dependent on other micro-environmental factors such as evenness of the cycle path. Furthermore, the interrelation between micro- and macro-environmental factors provides an insight about whether specific micro-environmental factors have a different association to cycling for transport depending on the macro-environment. For environmental interventions, it is essential to know how well findings on the importance of micro-environmental factors can be generalized to different macro-environments. Therefore, it is important to verify if in different macro-environments, similar or other micro-environmental factors need to be tackled. Second, **interactions between micro-environmental factors** (i.e. upper urban form layers: safety, comfort, pleasurability) [75] might also occur. For example, the impact of an even cycle path on cycling for transport, might only be important if the cycle path is separated from the motorized traffic. Or only the combination between the presence of trees and a well maintained cycling environment might have an influence on cycling for transport while the isolated effect of both environmental factors has no impact. Therefore, it is important to know whether the association between particular micro-environmental factors and cycling for transport might depend on other micro-environmental factors. Unfortunately, the existing knowledge about the possible environmental interactions to explain cycling for transport is still lacking.

5 An innovative methodology to study physical environment – cycling for transport associations

Accurate empirical evidence about which specific factors of the physical environment need to be modified in environmental interventions is still lacking. Most research has been conducted on the macro-environmental correlates (raw urban planning features) of transport-related cycling in adults of which worldwide rather consistent results have been found. According to the model of “Hierarchy of walking needs”, we might assume that macro-environmental factors like proximity of destinations or street connectivity are more fundamental in the decision-making process to cycle in comparison to micro-environmental factors [75]. Furthermore, environmental interventions focusing on the micro-environment are more likely to succeed if the macro-environment is favorable to cycle. However, it can be assumed that micro-environmental factors (specific features within a streetscape) are more feasible to modify in existing neighborhoods in comparison to macro-environmental factors and therefore are more practical to target for environmental interventions. Unfortunately, the associations between the more changeable, micro-environmental factors, and cycling for transport are less consistent and less thoroughly studied [76,82,103–105,141,151]. These inconsistencies in the current literature can be potentially attributed to the different methodologies used in previous studies.

Although various studies previously investigated the associations between micro-environmental factors and cycling for transport, most research has been limited to describe cross-sectional associations without establishing causal effects [76,118,152,153]. Furthermore, in most current studies, physical environmental perceptions are generally assessed using questionnaires which involve some limitations. First, participants have to recall features of the physical environment while not being in that environment, leading to recall bias [154] and second the lack of standardization in neighborhood definitions increases the inconsistency in associations as well [92]. Moreover, since several physical environmental factors co-occur and cannot be disentangled in real life (but are assessed separately in questionnaires), it is difficult for researchers to identify critical environmental correlates of cycling for transport in descriptive studies. Furthermore, previous studies often merged different environmental factors within questionnaires (e.g. the NEWS questionnaire) into one scale which makes it difficult to draw conclusions about the specific effect of separate cycling related characteristics. New methodologies are required to overcome these shortcomings, to decrease these inconsistencies and to make causal statements [76,118,152,153]. Therefore, an innovative experimental approach is introduced in this thesis to investigate the micro-environmental correlates of cycling for transport by manipulating photographs of physical environments and measuring responses to these experimental environmental changes.

The experimental design using photographs and manipulating environmental factors depicted in these photographs can offer a more in depth insight into "causal" associations, i.e. which micro-environmental changes have the greatest effect on a street's appeal to cycle for transport. The use of photographs offers some solutions for the shortcomings arising from previous research using questionnaires. First, when using photographs participants do not have to recall features of the physical environment which decreases the recall bias and avoids that important environmental factors are neglected or forgotten [154]. Second, there is no need to appoint a definition of the neighborhood since participants evaluate what they see, which can prevent a mismatch between the target environment of the researcher and that of the participant. Third, where questionnaires only have the possibility of asking one item at a time, manipulated photographs make it possible to study the effect of combinations of several environmental factors simultaneously under controlled conditions.

The use of manipulated photographs of environments is a cost-effective approach and enables us to investigate the association between environmental manipulations and a street's appeal to cycle for transport. Of course, the ideal scenario to examine the causal relationships between the physical environment and cycling for transport is to modify actual environments. Unfortunately, it is often not feasible to change the real environment within a research context. Moreover, environmental interventions conducted in real-life settings are usually long-term projects and involve higher costs. Furthermore, the existing quasi-experimental studies investigating the association between the physical environment and cycling for transport showed positive, null, and even counter-intuitive negative associations [155]. It is remarkable that until now, all implemented environmental changes primarily focused on building or improving new cycling infrastructure (i.e. cycle paths). Therefore, more research providing stronger evidence about which environmental factors might help to stimulate cycling for transport is needed. Another approach is recommended to increase the current knowledge about the environmental correlates of cycling for transport.

Manipulating photographs instead of real-life environments allows investigating both the isolating influence of each environmental factor (i.e. control the variation within environmental factors) as well as the combinations between environmental factors (i.e. control the co-variation between environmental factors) [155] which overpowers previous conducted cross-sectional studies. Additionally, using manipulated photographs allows investigating the influences of environmental changes under very controlled conditions and enables us to increase standardization. Furthermore, it has been suggested by previous research that photographs serve as sufficiently representative tools to substitute actual environments [6]. In addition, the validity of responses to color photographs in comparison to on-site responses has already been established [9–11]. Findings obtained from research using manipulated photographs could inform environmental interventions in real life settings about which environmental factors to modify.

The use of manipulated photographs also induces some limitations. First, photographs are unable to study the association with actual cycling behavior, so environmental interventions in real life settings are still needed to identify if changing micro-environmental factors will affect the cycling behavior. Furthermore, another limitation of the photographs is the lack of noise and movement [156] making it difficult to simulate specific micro-environmental factors such as speed limit, or traffic density. Despite these limitations, this cost-effective methodology using manipulated photographs is promising to study the association between micro-environmental factors and a street's appeal to cycle for transport.

6 Problem analysis

Compared to the other continents across the world, cycling for transport is much more common in Europe. Unfortunately, also in Europe cycling remains an under-used form of transport, even for short-distance trips (<5 km) [3]. Half of the trips done by car are shorter than 5 kilometers (i.e. a feasible distance to cycle) and even 40% of all trips are less than 2.5 kilometers [55–57]. Consequently, there is significant unfulfilled potential to increase the cycling levels of the European population. From a public health perspective, it is important to encourage cycling for transport because it can contribute to higher total physical activity levels among adults and reduce the risk of many chronic diseases [33,77,157,158]. Moreover, cycling for transport also has many other advantages, such as environmental, economic and traffic congestion benefits [35,43–45].

In addition to the importance of the individual and social environmental factors, socio-ecological models highlight the importance of the physical environment to explain physical activity. It has already been confirmed by the literature that the physical environment is of importance for adults between 18 and 65 years old [128,129], the target population of this thesis. Nevertheless, there are still a lot of inconsistencies regarding the association between the physical environment and cycling for transport, especially regarding the importance of the micro-environment (i.e. specific characteristics of a street scape).

First, in comparison to leisure-time physical activity, walking or total physical activity, there is limited **consistent evidence on the micro-environmental correlates of cycling for transport** [37,76,103–105,159]. These inconsistencies could be partly explained by different used methodologies (i.e. objective vs. perceived) to assess physical environmental features [160]. Therefore, it is important to distinguish objective and perceived environmental correlates of cycling for transport [74]. On the one hand, it has been suggested that perceptions are more closely related to actual behaviors [70,71]. A recent study of Sahlqvist et al. (2015) suggests that it is very important to improve perceptions of the supportiveness of the physical environment to cycle for transport [161] since it has been demonstrated that perceptions are associated with the uptake and maintenance of active travel [162]. As such, **a better insight in micro-environmental perceptions associated with cycling for transport is needed**. On the other hand, the objective physical environment can either directly or indirectly (through influencing individuals' perceptions) [68] determine cycling behavior [67,70,71]. Potential biases (e.g. recall biases) are not present when assessing the objective environment compared to the perceived environment [118]. Since most previous research investigated the objective environment (e.g. road network, activity space) by using GIS-data, the macro-environment (e.g. road connectivity network, activity space) was mainly investigated [121,122] because GIS-data about the micro-environment is often lacking. Therefore, **knowledge about the association between the objectively determined micro-environment and cycling for transport is still very limited**.

Second, although various studies previously investigated physical environment – cycling for transport relationships, most research has been **limited to describing cross-sectional associations** [76,118,152,153]. On the one hand, it is difficult for scientist to identify critical environmental correlates of cycling for transport in descriptive studies since most physical environmental factors are interrelated and cannot be disentangled in real life (but are assessed separately in questionnaires). On the other hand, natural experiments conducting in real-life setting are usually long-term projects involving higher costs. Therefore, an innovative and cost-effective experimental approach is required to investigate the physical micro-environmental correlates of cycling for transport.

Third, in many actual situations, it is often not possible to change the whole micro-environment at once. Furthermore, it is suggested that **some factors might be more important than other factors** in the decision-making process whether or not to cycle for transport. Therefore, it might be interesting to know which micro-environmental factors should get priority to adapt regarding environmental interventions to increase cycling for transport. To date, it is still unclear which individual impact each micro-environmental factor has on cycling for transport and which micro-environmental factors are more important than other micro-environmental factors to encourage cycling for transport.

Fourth, next to the isolating effects of the environmental correlates of cycling for transport, it is also crucial to know if certain **environmental factors interact with each other**. Since, the actual physical environment consists of a combination of several environmental factors (i.e. micro- and macro-environmental factors), environmental interventions should be aware of possible interaction effects. For interventions, it is essential to know if one intervention can be implemented in different environments. Therefore, it is important to verify if in different macro-environments, similar or other micro-environmental factors need to be tackled. If micro- and macro-environmental factors are interacting, interventions focusing on micro-environmental factors might have to differ depending on the macro-environment. Furthermore, interactions between different micro-environmental factors may also occur. For example, it is possible that the adjustment of two micro-environmental factors simultaneously might cause larger effects regarding the encouragement to cycle for transport. Conversely, it is also likely that the combination of different micro-environmental factors might cause a less beneficial effect. Unfortunately, the current knowledge about the possible environmental interactions (i.e. interaction **between micro- and macro-environmental factors**, as well as the interaction **between different micro-environmental factors**) to explain cycling for transport is lacking.

Fifth, there are already some indications in the existing literature that the association between the physical environment and cycling for transport may differ across **different subgroups**. Mainly the differences in environmental preferences according to gender or age were examined. In addition, these previous studies mainly described the differences in environmental preferences of particular subgroups rather than investigating the moderating effects of the individual factors. Almost no studies previously investigated the moderating effects of individual factors on the association between the physical environment and cycling for transport. Therefore, to provide an empirical basis for developing tailored interventions targeting specific subgroups, it is necessary to find out how these associations differ across different individual characteristics, countries, neighborhood perceptions, transport behavior, cycling skills, concerns or preferences of individuals.

7 Objectives and outline of this thesis

In this section, an description of the overall aim, the different chapters and included study objectives are given below. An schematic overview of the study characteristics, used methods, analyses and chapter aims are presented in Table 1. More details about the different studies and methods can be found in the corresponding chapters in the second part of this thesis.

The **overall aim of this PhD thesis** is to get a better understanding on how the physical environment, especially the micro-environment, is associated with cycling for transport in adults and to investigate the interplay of individual and physical environmental factors on this association.

This thesis is divided into **two main chapters** according to their study approach; a cross-sectional part (chapter 1) and an experimental part (chapter 2) investigating the association between the physical environment and cycling for transport.

The **first chapter** includes **cross-sectional** data in adults (18-65 years) obtained in five different urban regions across Europe, i.e. data from the SPOTLIGHT project. Since cycling for transport is much more prevalent in many European cities compared to the US and Australia [163], it is very relevant to study physical environment – cycling for transport associations across Europe [92]. The SPOTLIGHT project is a cross-European research project and stands for sustainable prevention of obesity through integrated strategies. This project is funded by the European Commission (Seventh Framework Programme) and aims to enhance knowledge on a wide range of correlates of obesity in a systematic way, to investigate the interplay between the different correlates and to discover strong RE-AIM multi-level interventions [164]. This project is subdivided in eight different work packages. The current thesis used data obtained for work package 3 of this SPOTLIGHT project. Data were collected in five urban regions across Europe: Ghent region (Belgium), Randstad region (the Netherlands), Budapest (Hungary), Paris region (France) and greater London (UK). The study design and sampling is further clarified in the methodology section of the included studies.

The **second chapter** introduces an innovative experimental approach to investigate the micro-environmental correlates of cycling for transport by manipulating photographs of physical environments and measuring responses to these experimental environmental changes. Consequently, this chapter includes **experimental data** using manipulated photographs about middle-aged adults obtained in Flanders (Belgium). We chose to focus on a specific age group (45-65 years) because investigating a wider age range might give interference and less accurate results due to too much heterogeneity. This age group was chosen because we argued that adults from this age range evaluate the environment according to their own needs, rather than from the viewpoint of their child(ren)'s need. Furthermore, it has been proven that from the age of 45 years, there is an increased risk of cardiovascular disease, and may partially be attributed to the tendency that the amount of regular physical activity decrease with age [67,165,166]. Older adults (> 65 years) were not included in this research since cycling is more prevalent among adults [4]. Because the use of manipulated photographs is an innovative research line within the transport research, the constructive methodology has been described in detail in the methodology section of the different studies.

Within these chapters, **four subaims** are differentiated. The first aim of this thesis is to describe the direct cross-sectional associations between the physical micro-environment and adult's cycling for transport across five European urban regions (*chapter 1*), along with the analysis of the moderating role of socio-demographic variables. A first study determined t**he perceived micro-environmental correlates of cycling for transport** using a questionnaire within the SPOTLIGHT-project (*chapter 1.1*). A second study uses data collected with the SPOTLIGHT virtual audit tool to discover the **objective micro-environmental correlates of cycling for transport** (*chapter 1.2*). In both studies, the **moderating effects** of age, gender, socio-economic status (SES) and urban region on the association between the physical environment and cycling for transport were examined.

The second aim of this thesis is to investigate the experimental associations between the physical micro-environment and the adults' street's appeal to cycle for transport (*chapter 2*). By manipulating photographs of physical environments and measuring responses to these experimental environmental changes, it was intended to determine the critical micro-environmental correlates of cycling for transport, to identify **the relative importance** of these micro-environmental factors and create an **order of importance** of these factors (*chapter 2.1 and chapter 2.3*).

The third aim is to provide insight regarding the interplay between different physical environmental correlates of cycling for transport since the actual environment consists of a combination of several environmental factors. On the one hand, it is still unclear if environmental interventions have to target different micro-environmental factors in distinct macro-environments (e.g. residential density). On the other hand, interactions between different micro-environmental factors may also occur. Currently it is not possible to provide appropriate guidelines to create more cycling supportive environments depending on the target environment. In addition, there is no information available about which combinations might cause a more beneficial effect or which combinations might create a less beneficial effect to encourage cycling for transport. Therefore, this thesis wants to verify the **interaction effects** between different environmental factors; the interaction between **macro- and micro-environmental**

factors *(chapter 2.2)*, as well as the interaction **between different micro-environmental factors** *(chapter 2.1 and chapter 2.3)*.

The last aim (fourth aim) of this thesis is to explore whether **subgroups exist** with different physical environmental preferences regarding the street's appeal to cycle for transport, since it might be more effective to tailor interventions to specific at risk subgroups instead of developing general interventions [58]. Furthermore, **specific characteristics** of these subgroups are **identified**, based on socio-demographics, transport behavior, psychological and social correlates of cycling for transport, neighborhood environmental perceptions, cycling skills, concerns and preferences of the participants (*chapter 2.4*).

Table 1. Overview of the included studies, aims and methods.

MAIN AIM: To get a better understanding on how the physical environment, especially the micro-environment, is associated with cycling for transport in adults and to investigate the interplay of individual and physical environmental factors on this association.			
CHAPTER 1. CROSS-SECTIONAL RESEARCH			
PROBLEM ANALYSIS: Limited consistent evidence on the micro-environmental correlates of cycling for transport in comparison to leisure-time physical activity, walking or total physical activity. **SUBAIM 1:** To describe the direct cross-sectional associations between the physical micro-environment and adult's cycling for transport across five European urban regions, along with the analysis of the moderating role of socio-demographic variables.			
CHAPTER	**STUDY DESIGN**	**METHODS & ANALYSES**	**CHAPTER AIMS**
Chapter 1.1	- Cross-sectional: SPOTLIGHT project - Random sample of adult inhabitants per three randomly sampled neighbourhoods of each neighbourhood type in each country - Five urban regions across Europe - 4,579 adults between 18 and 65 years - Secondary data-analysis	<u>METHODS</u> - Online questionnaire ▪ Demographic variables ▪ Cycling for transport behavior (IPAQ) ▪ Perceived physical environmental neighbourhood factors (ALPHA) <u>ANALYSES</u> - Descriptives statistics conducted in SPSS - Hurdle models conducted in R (1) ▪ Logistic regression model ▪ Gamma regression model	- To determine which perceived micro-environmental neighbourhood factors are associated with adults' cycling for transport in five urban regions across Europe. - To investigate whether these associations were moderated by socio-demographic variables such as age, gender, SES and urban region (country).
Chapter 1.2	- Cross-sectional: SPOTLIGHT project - Random sample of adult inhabitants per three randomly sampled neighbourhoods of	<u>METHODS</u> - Online questionnaire ▪ Demographic variables ▪ Cycling for transport behavior (IPAQ)	- To identify which objective micro-environmental neighbourhood factors, assessed via a virtual audit, are associated with cycling for transport in adults living in five urban regions across Europe.

	each neighbourhood type in each country - Five urban regions across Europe - 3,904 adults between 18 and 65 years - Total of 59 neighbourhoods, 4486 street segments were virtual audited - Secondary data-analysis	- S-VAT (SPOTLIGHT Virtual Audit Tool) ▪ Objective physical environmental neighbourhood factors ANALYSES - Descriptives statistics conducted in SPSS - Hurdle models conducted in R [1] ▪ Logistic regression model ▪ Gamma regression model	- To investigate whether these associations were moderated by socio-demographic variables such as age, gender, SES and urban region (country).
CHAPTER 2. EXPERIMENTAL RESEARCH			
PROBLEM ANALYSIS: Most research has been limited to describing cross-sectional associations between the physical micro-environment and cycling for transport. Furthermore, it is still unclear which individual impact each micro-environmental factor has on cycling for transport and which micro-environmental factors are more important than other micro-environmental factors to encourage cycling for transport. **SUBAIM 2 :** An innovative and cost-effective experimental approach is required to investigate the physical micro-environmental correlates of cycling for transport and to investigate if some micro-environmental factors are more important than other factors.			
CHAPTER	**STUDY DESIGN**	**METHODS & ANALYSES**	**CHAPTER AIMS**
Chapter 2.1	- Exploratory experimental study using manipulated photographs - 66 Flemish middle-aged adults (45-65 years) - Purposeful convenience sampling stratified by gender	METHODS - Home visit: two step research protocol ▪ Face-to-face interview ▪ Sociodemographic variables ▪ PA level (IPAQ) ▪ Two sorting tasks ▪ Sorting the manipulated panoramic photographs from least (0= not inviting at all) to most (10= very inviting) inviting to cycle for transport. ▪ Qualitative information was collected at the same time to identify the reasons for sorting the photographs in that	- To explore the effect of manipulating photographs of micro-environmental factors on the street's appeal to cycle for transport among middle-aged adults. - To gather qualitative information about which micro-environmental factors are important regarding the street's appeal to cycle for transport

		way. <u>ANALYSES</u> ▪ Quantitative analyses: Multilevel cross-classified modeling in MLwiN ▪ Qualitative analyses: Categorize qualitative data into categories in Nvivo	
Chapter 2.3	- Experimental study using manipulated photographs - 1950 middle-aged adults (45-65 years) - Purposeful convenience sampling and snowball sampling	<u>METHODS</u> - Online questionnaire: two parts ▪ Assessing participants information: ▪ Socio-demographic variables ▪ Cycling for transport behavior (IPAQ) ▪ Choice task with manipulated photographs: Choice based conjoint (CBC) method [2] ▪ Choose which of the two depicted streets (manipulated photographs) they would prefer to cycle along to the house of their friend. ▪ Seven micro-environmental factors were manipulated in each photograph and varied in two to six levels → total of 1944 manipulated photographs ▪ 12 randomly assigned and 2 fixed choice tasks <u>ANALYSES</u> ▪ Descriptives statistics conducted in SPSS ▪ Choice-based conjoint analysis with Hierarchical Bayes estimation (CBC HB) [3] in Sawtooth Software to examine main effects	- To determine the relative importance of micro-environmental factors on the street's appeal to cycle for transport among middle-aged adults. - To create an order of importance of these micro-environmental factors

PROBLEM ANALYSIS: Since, the actual physical environment consists of a combination of several environmental factors (i.e. micro- and macro-environmental factors), it is crucial to know if certain environmental factors interact with each other. Unfortunately, the current knowledge about the possible environmental interactions to explain cycling for transport is lacking.

SUBAIM 3: To provide insight regarding the interplay between different physical environmental correlates of cycling for transport (i.e. interaction between micro- and macro-environmental factors, as well as the interaction between different micro-environmental factors).

CHAPTER	STUDY DESIGN	METHODS & ANALYSES	CHAPTER AIMS

Chapter 2.1	- Exploratory experimental study using manipulated photographs
	
	- 66 Flemish middle-aged adults (45-65 years)
	
	- Purposeful convenience sampling stratified by gender
		<u>METHODS</u>
		- Home visit: two step research protocol
		▪ Face-to-face interview
		  ▪ Sociodemographic variables
		  ▪ PA level (IPAQ)
		▪ Two sorting tasks
		  ▪ Sorting the manipulated panoramic photographs from least (0= not inviting at all) to most (10= very inviting) inviting to cycle for transport.
		  ▪ Qualitative information was collected at the same time to identify the reasons for sorting the photographs in that way.
		
		<u>ANALYSES</u>
		▪ Quantitative analyses:
		Multilevel cross-classified modeling in MLwiN
		▪ Qualitative analyses:
		Categorize qualitative data into categories in Nvivo
			- To explore interactions among micro-environmental factors on the street's appeal to cycle for transport

Chapter 2.2	- Experimental study using manipulated photographs
	
	- 389 middle-aged adults (45-65 years)
	
	- Purposeful convenience
		<u>METHODS</u>
		- Online questionnaire: two parts
		▪ Assessing participants information:
		  ▪ Socio-demographic variables
		  ▪ Cycling for transport behavior (IPAQ)
		
		▪ Choice task with manipulated photographs:
			- To verify the interaction between macro- and micro-environmental factors

	sampling and snowball sampling	Choice based conjoint (CBC) method [2] ▪ Choose which of the two depicted streets (manipulated photographs) they would prefer to cycle along to the house of their friend. ▪ Four environmental factors (one macro- and three micro-environmental factors) and consisted each of three levels → total of 81 (=3^4) manipulated photographs ▪ 14 randomly assigned choice tasks <u>ANALYSES</u> ▪ Descriptives statistics conducted in SPSS ▪ Choice-based conjoint analysis with Hierarchical Bayes estimation (CBC HB) [3] in Sawtooth Software to examine main effects and interaction effects between the macro- and micro-environmental factors	
Chapter 2.3	- Experimental study using manipulated photographs - 1950 middle-aged adults (45-65 years) - Purposeful convenience sampling and snowball sampling	<u>METHODS</u> - Online questionnaire: two parts ▪ Assessing participants information: ▪ Socio-demographic variables ▪ Cycling for transport behavior (IPAQ) ▪ Choice task with manipulated photographs: Choice based conjoint (CBC) method [2] ▪ Choose which of the two depicted streets (manipulated photographs) they would prefer to cycle along to the house of their friend. ▪ Seven micro-environmental factors were manipulated in each photograph and varied in two to six levels → total of 1944 manipulated photographs ▪ 12 randomly assigned and 2 fixed choice tasks <u>ANALYSES</u> ▪ Descriptives statistics conducted in SPSS ▪ Choice-based conjoint analysis with Hierarchical Bayes	- To investigate the effect of combinations of micro-environmental factors by determining the interaction effects among micro-environmental factors on the street's appeal to cycle for transport.

		estimation (CBC HB) [3] in Sawtooth Software to examine interaction effects between the micro-environmental factors	

PROBLEM ANALYSIS: Almost no studies previously investigated the moderating effects of individual factors on the association between the physical environment and cycling for transport, making it difficult to provide an empirical basis for developing tailored interventions targeting specific subgroups.

SUBAIM 4 : To explore whether subgroups exist with different physical environmental preferences regarding the street's appeal to cycle for transport and to identify specific characteristics of these subgroups.

CHAPTER	STUDY DESIGN	METHODS & ANALYSES	CHAPTER AIMS
Chapter 2.4	- Experimental study using manipulated photographs - 1950 middle-aged adults (45-65 years) - Purposeful convenience sampling and snowball sampling	METHODS - Online questionnaire: two parts ▪ Assessing participants information: ▪ Socio-demographic variables ▪ Cycling for transport behavior (IPAQ) ▪ Choice task with manipulated photographs: Choice based conjoint (CBC) method [2] ▪ Choose which of the two depicted streets (manipulated photographs) they would prefer to cycle along to the house of their friend. ▪ Seven micro-environmental factors were manipulated in each photograph and varied in two to six levels → total of 1944 manipulated photographs ▪ 12 randomly assigned and 2 fixed choice tasks ANALYSES ▪ Choice-based conjoint analysis with Hierarchical Bayes estimation (CBC HB) [3] in Sawtooth Software to examine main effects ▪ Latent class analysis [4] to examine subgroups in Sawtooth Software ▪ Chi-square analyses and MANOVAs in SPSS	- To examine whether there are subgroups with different micro-environmental preferences for cycling for transport among middle-aged adults. - To identify the specific characteristics of these subgroups based on socio-demographics, transport behavior, psychosocial determinants of cycling for transport, neighborhood environmental perceptions, cycling skills, concerns and preferences of participants.

(1) Hurdle models are designed to deal with situations where there is an “excessive” number of individuals with a count of zero. Hurdle models were used in our research because the dependent variable (minutes cycling for transport per week) was positively skewed and contained a considerable number of null values (56.3% of the participants did not cycle for transport). Hurdle models create two separate equations; in this case, one equation is for whether people cycle for transport (logistic regression model) and the other is to determine how much time people spent cycling for transport (gamma regression model).

(2) Choice-based conjoint method (CBC) is a method often used in marketing research and aims to identify the relative importance of various components of a product (micro-environmental factors in a street) in the decision process to pursuit the product (cycling for transport in that street). This method allows testing for effects without presenting all the possible combinations. The CBC method using manipulated photographs could identify the relative importance of micro-environmental factors in a street’s appeal to cycle for transport. This methodology allows studying the effects of environmental changes (manipulations) under controlled conditions, i.e. controlling the variation within and between the manipulated micro-environmental factors.

(3) Choice-based conjoint analysis with Hierarchical Bayes estimation (CBC HB) is the most appropriate method to analyze data gained from choice based conjoint. First, the average relative importance of each environmental factor was calculated from the individual utility data gained from Hierarchical Bayes (HB) estimation. Second, the main effect of each level of each environmental factor on the street’s appeal for bicycle transport along the depicted environments was determined using the individual part-worth utilities gained from HB estimation. Third, interaction effects were also derived from part-worth utilities gained from the HB estimation and were selected using the ‘CBC interaction search tool’ of the Sawtooth Software.

(4) Latent class analysis is a model-based approach where the cluster criterion choice is less arbitrary than the standard cluster analysis and shows a higher construct and predictive validity. Participants were assigned to a subgroup based on the highest probability of belonging to a class and not in a discrete manner (all-or-nothing) as with cluster analysis.

8 Publications included in the thesis

CHAPTER 1

Mertens L, Compernolle S, Gheysen F, Deforche B, Brug J, Mackenbach J, Lakerveld J, Oppert J-M, Feuillet T, Glonti K, Bardos H, De Bourdeaudhuij I: Perceived environmental correlates of cycling for transport among adults in five regions of Europe: the SPOTLIGHT project. Obesity reviews (supplement) 2016, 17:53–61.

Mertens L, Compernolle S, Deforche B, Mackenbach JD, Lakerveld J, Brug J, Oppert J-M, Glonti K, Rutter H, Bardos H, De Bourdeaudhuij I, Van Dyck D: Built environmental correlates of cycling for transport across Europe. Health & place. (under revision)

CHAPTER 2

Mertens L, Van Holle V, De Bourdeaudhuij I, Deforche B, Salmon J, Nasar J, Van de Weghe N, Van Dyck D, Van Cauwenberg J: The effect of changing micro-scale physical environmental factors on an environment's invitingness for transportation cycling in adults: an exploratory study using manipulated photographs. The international journal of behavioral nutrition and physical activity 2014, 11:88. DOI 10.1186/s12966-014-0088-x

Mertens L, Van Cauwenberg J, Ghekiere A, Van Holle V, De Bourdeaudhuij I, Deforche B, Nasar J, Van de Weghe N, Van Dyck D: Does the Effect of Micro-Environmental Factors on a Street's Appeal for Adults' Bicycle Transport Vary across Different Macro-Environments? An Experimental Study. PloS one 2015, 10(8): e0136715. doi:10.1371/journal.pone.0136715

Mertens L, Van Dyck D, Ghekiere A, De Bourdeaudhuij I, Deforche B, Van de Weghe N, Van Cauwenberg J: Which environmental factors most strongly influence a street's appeal for bicycle transport among adults? A conjoint study using manipulated photographs. International journal of health geographics 2016, 15(1):31, 1-14. DOI 10.1186/s12942-016-0058-4

Mertens L, Cauwenberg J Van, Ghekiere A, De Bourdeaudhuij I, Deforche B, Van de Weghe N, Van Dyck D: Differences in environmental preferences towards cycling for transport among adults : a latent class analysis. BMC Public Health 2016, 16(782), 1–10. http://doi.org/10.1186/s12889-016-3471-5

9 References

1. Oja P, Titze S, Bauman a, de Geus B, Krenn P, Reger-Nash B, et al. Health benefits of cycling: a systematic review. Scand J Med Sci Sports. 2011;21: 496–509. doi:10.1111/j.1600-0838.2011.01299.x

2. Veisten K, Flügel S, Ramjerdi F, Minken H. Cycling and walking for transport : Estimating net health effects from comparison of different transport mode users ' self-reported physical activity. Health Econ Rev. Springer Open Ltd; 2011;1: 3. doi:10.1186/2191-1991-1-3

3. Eurobarometer F. Future of transport Analytical report. 2011; 1–67. Available: http://ec.europa.eu/public_opinion/flash/fl_312_en.pdf

4. SafetyNet. Pedestrians & Cyclists [Internet]. 2009. Available: http://ec.europa.eu/transport/road_safety/specialist/knowledge/pdf/pedestrians.pdf

5. Sallis JF, Cervero RB, Ascher W, Henderson K a, Kraft MK, Kerr J. An ecological approach to creating active living communities. Annu Rev Public Health. 2006;27: 297–322. doi:10.1146/annurev.publhealth.27.021405.102100

6. Caspersen CJ, Christenson GM. Physical Activity , Exercise , and Physical Fitness : Definitions and Distinctions for Health-Related Research. Public Health Rep. 1985;100: 126–131.

7. Clarke H. Academy approves physical fitness definition. Phys Fit Newsl. 1979;9.

8. Ainsworth BE, Haskell WL, Whitt MC, Irwin ML, Swartz ANNM, Strath SJ, et al. Compendium of Physical Activities : an update of activity codes and MET intensities. Med Sci Sport Exerc. 2000;32: 498–516.

9. Pate RR, Michael Pratt M, Blair SN, Haskell WL, Macera CA, Bouchard C, et al. Physical Activity and Public Health. A Recommendation From the Centers for Disease Control and Prevention and the American College of Sports Medicine. JAMA. 1995;273: 402–407. doi:10.1001/jama.1995.03520290054029.

10. Haskell WL, Lee I-M, Pate RR, Powell KE, Blair SN, Franklin BA, et al. Physical activity and public health: updated recommendation for adults from the American College of Sports Medicine and the American Heart Association. Circulation. Am Heart Assoc; 2007;116:

1081–1093. Available: http://www.ncbi.nlm.nih.gov/pubmed/17671237

11. Warren JM, Ekelund U, Besson H, Mezzani A, Human MRC, Nutrition B. Assessment of physical activity – a review of methodologies with reference to epidemiological research : a report of the exercise physiology section of the European Association of Cardiovascular Prevention and Rehabilitation. 2009; doi:10.1097/HJR.0b013e32832ed875

12. Kweon B-S. Large-Scale Environmental Knowledge: Investigating the Relationship Between Self-Reported and Objectively Measured Physical Environments. Environ Behav. 2006;38: 72–91. doi:10.1177/0013916505280092

13. Phipps PA, Vernon MK. Chapter 7, Twenty-four hours: An Overview of the Recall Diary Method and Data Quality in the American Time Use Survey. In: Belli RF, Stafford FP, Alwin DF, editors. Calendar and Time Diary: Methods in Life Course Research. SAGE Publications; 2009.

14. Adams SA, Matthews CE, Ebbeling CB, Moore CG, Joan E, Fulton J, et al. The Effect of Social Desirability and Social Approval on Self-Reports of Physical Activity. Am J Epidemiol. 2005;161: 389–398. doi:10.1093/aje/kwi054

15. Sallis JF, Saelens BE. Assessment of Physical Activity by Self-Report : Status , Limitations , and Future Directions. Res Q Exerc Sport. 2000;71: 1–14. doi:10.1080/02701367.2000.11082780

16. IPAQ. International physical activity questionnaire (October 2002). Long last 7 days self-administered format. 2002;71. Available: http://www.sdp.univ.fvg.it/sites/default/files/IPAQ_English_self-admin_long.pdf

17. Craig CL, Marshall AL, Sjöström M, Bauman AE, Booth ML, Ainsworth BE, et al. International physical activity questionnaire: 12-country reliability and validity. Med Sci Sports Exerc. 2003;35: 1381–95. doi:10.1249/01.MSS.0000078924.61453.FB

18. Trost SG. Objective Measurement of Physical Activity in Youth : Current Issues , Future Directions. Exerc Sport Sci Rev. 2001;29: 32–36.

19. Kowalski K, Rhodes R, Naylor P, Tuokko H, Macdonald S. Direct and indirect measurement of physical activity in older adults : a systematic review of the literature. Int J Behav Nutr Phys Act. International Journal of Behavioral Nutrition and Physical Activity; 2012;9: 1. doi:10.1186/1479-5868-9-148

20. Murphy SL. Review of physical activity measurement using accelerometers in older adults : Considerations for research design and conduct. Prev Med (Baltim). 2009;48: 108–114. doi:10.1016/j.ypmed.2008.12.001

21. Doherty AR, Kelly P, Kerr J, Marshall S, Oliver M, Hamilton A, et al. Using wearable cameras to categorise type and context of accelerometer-identified episodes of physical activity. Int J Behav Nutr Phys Act. 2013;10: 1–11. Available: http://www.ijbnpa.org/content/10/1/22

22. Robertson W, Stewart-brown S, Wilcock E, Oldfield M, Thorogood M. Utility of Accelerometers to Measure Physical Activity in Children Attending an Obesity Treatment Intervention. J Obes. 2011; 1–8. doi:10.1155/2011/398918

23. Dannecker KL, Sazonova NA, Melanson EL, Sazonov ES, Bowning RC. A comparison of Energy Expenditure Estimation of several physcial activity monitors. Med Sci Sport Exerc. 2014;45: 2105–2112. doi:10.1249/MSS.0b013e318299d2eb.A

24. Hees VT Van, Ekelund U. Novel daily energy expenditure estimation by using objective activity type classification : where do we go from here ? J. 2009;107: 639–640. doi:10.1152/japplphysiol.00150.2009.4.

25. Huss A, Beekhuizen J, Kromhout H, Vermeulen R. Using GPS-derived speed patterns for recognition of transport modes in adults. Int J Health Geogr. 2014;13: 1–8.

26. Bohte W, Maat K. Deriving and validating trip purposes and travel modes for multi-day GPS-based travel surveys: A large-scale application in the Netherlands. Transp Res Part C Emerg Technol. Elsevier Ltd; 2009;17: 285–297. doi:10.1016/j.trc.2008.11.004

27. Dill J, Gliebe J. Understanding and Measuring Bicycling Behavior: a Focus on Travel Time and Route Choice [Internet]. Oregon Transportation Research and education consortium. 2008. Available: http://pdxscholar.library.pdx.edu/cgi/viewcontent.cgi?article=1027&context=usp_fac

28. Carlson J a., Jankowska MM, Meseck K, Godbole S, Natarajan L, Raab F, et al. Validity of PALMS GPS scoring of active and passive travel compared to SenseCam. Med Sci Sports Exerc. 2015;47: 662–667. doi:10.1249/MSS.0000000000000446

29. Ellis K, Godbole S, Marshall S, Lanckriet G, Staudenmayer J, Kerr J. Identifying active travel behaviors in challenging environments using GPS, accelerometers, and machine learning algorithms. Front public Heal. 2014;2: 1–8. doi:10.3389/fpubh.2014.00036

30. Troped PJ, Oliveira MS, Matthews CE, Cromley EK, Melly SJ, Craig BA. Prediction of Activity Mode with Global Positioning System and Accelerometer Data. Med Sci Sport Exerc. 2008;40: 972–978. doi:10.1249/MSS.0b013e318164c407

31. World Health Organization. Global Recommendations on Physical Activity for Health. 2010; 1–60. Available: http://whqlibdoc.who.int/publications/2010/9789241599979_eng.pdf

32. Warburton DER, Nicol CW, Bredin SSD. Review Health benefits of physical activity: the evidence. Can Med Assoc J. 2006;174: 801–809.

33. Wanner M, Götschi T, Martin-Diener E, Kahlmeier S, Martin BW. Active transport, physical activity, and body weight in adults: a systematic review. Am J Prev Med. Elsevier Inc.; 2012;42: 493–502. doi:10.1016/j.amepre.2012.01.030

34. Rojas-Rueda D, de Nazelle A, Tainio M, Nieuwenhuijsen MJ. The health risks and benefits of cycling in urban environments compared with car use: health impact assessment study. BMJ. 2011;343: 1–8. doi:10.1136/bmj.d4521

35. Woodcock J, Edwards P, Tonne C, Armstrong BG, Ashiru O, Banister D, et al. Public health benefits of strategies to reduce greenhouse-gas emissions: urban land transport. Lancet. Elsevier Ltd; 2009;374: 1930–43. doi:10.1016/S0140-6736(09)61714-1

36. Götschi T, Garrard J, Giles-Corti B. Cycling as a Part of Daily Life: A Review of Health Perspectives. Transp Rev. 2015;1647: 1–27. doi:10.1080/01441647.2015.1057877

37. Fraser SDS, Lock K. Cycling for transport and public health: a systematic review of the effect of the environment on cycling. Eur J Public Health. 2010;21: 738–43. doi:10.1093/eurpub/ckq145

38. Bassett DR, Pucher J, Buehler R, Thompson DL, Crouter SE. Walking , Cycling , and Obesity Rates in Europe , North America , and Australia. J Phys Act Health. 2008;5: 795–814.

39. Kelly P, Kahlmeier S, Götschi T, Orsini N, Richards J, Roberts N, et al. Systematic review and meta-analysis of reduction in all-cause mortality from walking and cycling and shape of dose response relationship. Int J Behav Nutr Phys Act. 2014;11: 132. doi:10.1186/s12966-014-0132-x

40. Ohta M, Mizoue T, Mishima N, Ikeda M. Effect of the physical activities in leisure time and commuting to work on mental health. J Occup Health. 2007;49: 46–52.

doi:10.1539/joh.49.46

41. de Geus B, Van Hoof E, Aerts I, Meeusen R. Cycling to work: influence on indexes of health in untrained men and women in Flanders. Coronary heart disease and quality of life. Scand J Med Sci Sports. 2008;18: 498–510.

42. Lee RJ, Sener IN. Transportation planning and quality of life: Where do they intersect? Transp Policy. Elsevier; 2016;48: 146–155. doi:10.1016/j.tranpol.2016.03.004

43. Rabl A, de Nazelle A. Benefits of shift from car to active transport. Transp Policy. Elsevier; 2012;19: 121–131. doi:10.1016/j.tranpol.2011.09.008

44. Rissel CE. Active travel: a climate change mitigation strategy with co-benefits for health. N S W Public Health Bull. 2009;20: 10–3. Available: http://www.ncbi.nlm.nih.gov/pubmed/19261210

45. Bauman A, Rissel C, Garrard J, Ker I, Speidel R, Fishman E. Cycling : getting Australia moving – barriers , facilitators and interventions to get more Australians physically active through cycling. 31st Australas Transp Res forum. 2008; 593–601. Available: http://atrf.info/papers/2008/2008_bauman_rissel_garrard_ker_spiedel_fishman.pdf

46. Teschke K, Harris MA, Reynolds CCO, Winters M, Babul S, Chipman M. Route Infrastructure and the Risk of Injuries to Bicyclists : A Case-Crossover Study. Res Pract. 2012;102: 2336–2343. doi:10.2105/AJPH.2012.300762

47. Panis LI, de Geus B, Vandenbulcke G, Willems H, Degraeuwe B, Bleux N, et al. Exposure to particulate matter in traffic: a comparison of cyclists and car passengers. Atmos Environ. 2010;44: 2263–2270. doi:10.1111/2041-210X.12500

48. de Hartog JJ, Boogaard H, Nijland H, Hoek G. Do the health benefits of cycling outweigh the risks? Environ Health Perspect. 2010;118: 1109–16. doi:10.1289/ehp.0901747

49. Reynolds CCO, Harris MA, Teschke K, Cripton PA, Winters M. The impact of transportation infrastructure on bicycling injuries and crashes : a review of the literature. Environ Heal. 2009;19. doi:10.1186/1476-069X-8-47

50. Tainio M, de Nazelle AJ, Götschi T, Kahlmeier S, Rojas-Rueda D, Nieuwenhuijsen MJ, et al. Can air pollution negate the health benefits of cycling and walking? Prev Med (Baltim). The Authors; 2015;87: 233–236. doi:10.1016/j.ypmed.2016.02.002

51. Mueller N, Rojas-rueda D, Cole-hunter T, Nazelle A De, Dons E, Gerike R, et al. Health impact assessment of active transportation : A systematic review. Prev Med (Baltim). Elsevier Inc.; 2015;76: 103–114. doi:10.1016/j.ypmed.2015.04.010

52. World Health Organization (Regional office for Europe). Factsheets on health-enhancing physical activity in the 28 European union member states of the WHO European region [Internet]. 2015. Available: http://ec.europa.eu/sport/library/factsheets/eu-wide-overview-methods.pdf

53. World Health Organization. Physical activity strategy for the WHO European Region. 2015; 14–17. Available: http://www.euro.who.int/en/who-we-are/governance

54. Hallal PC, Andersen LB, Bull FC, Guthold R, Haskell W. Global physical activity levels: surveillance progress , pitfalls and prospects. Lancet. 2012;380: 247–257.

55. Dekoster J, Schollaert U. Cycling: the way ahead for towns and cities [Internet]. European C. Luxembourg; 1999. doi:10.4135/9781412953993.n184

56. Janssens D, Declercq K, Wets G. Onderzoek Verplaatsingsgedrag Vlaanderen 4.5 (2012-2013). Instituur voor Mobil. 2014; 116. Available: http://www.mobielvlaanderen.be/pdf/ovg45/ovg45-analyse-globaal.pdf

57. Pucher J, Buehler R. Cycling for Everyone : Lessons from Europe. Transp Res Rec J Transp Res Board. 2007;2074: 58–65.

58. Vlaamse overheid Departement Mobiliteit en Openbare Werken. Onderzoek Verplaatsingsgedrag Vlaanderen 4. Brussel: Vlaamse overheid, Departement Mobiliteit en Openbare Werken. Brussel; 2014.

59. Green LW, Potvin L. Ecological Foundations of Health Promotion. Am J Heal Promot. 1996;10: 270–281. doi:10.4278/0890-1171-10.4.270

60. Stokols D. Establishing and Maintaining Healty Environments. Am Psychol. 1992;47: 6–22.

61. McLeroy KR, Bibeau D, Steckler A, Glanz K. An Ecological Perspective on Health Promotion Programs. Health Educ Q. 1988;15: 351–377.

62. Transportation Research Board. Does the Built Environment Influence Physical Activity ? [Internet]. 2005. Available: http://onlinepubs.trb.org/onlinepubs/sr/sr282.pdf

63. De Bourdeaudhuij I, Sallis JF, Saelens BE. Environmental correlates of physical activity in a sample of Belgian adults. Am J Heal Promot. 2003;18: 83–92.

64. De Bourdeaudhuij I, Teixeira PJ, Cardon G, Deforche B. Environmental and psychosocial correlates of physical activity in Portuguese and Belgian adults. Public Health Nutr. 2005;8: 886–895. doi:10.1079/PHN2005735

65. Saelens BE, Sallis JF, Frank LD. Environmental correlates of walking and cycling: findings from the transportation, urban design, and planning literatures. Ann Behav Med. 2003;25: 80–91. Available: http://www.ncbi.nlm.nih.gov/pubmed/12704009

66. Heesch KC, Sahlqvist S, Garrard J. Gender differences in recreational and transport cycling: a cross-sectional mixed-methods comparison of cycling patterns, motivators, and constraints. Int J Behav Nutr Phys Act. International Journal of Behavioral Nutrition and Physical Activity; 2012;9: 106. doi:10.1186/1479-5868-9-106

67. Heesch KC, Giles-corti B, Turrell G. Cycling for transport and recreation : Associations with the socio-economic , natural and built environment. Health Place. Elsevier; 2015;36: 152–161. doi:10.1016/j.healthplace.2015.10.004

68. Ma L. The Objective vs . the Perceived Environment : What Matters for Active Travel. Dissertations and Theses. Paper 2090. 2014.

69. Sallis JF, Owen N, Fisher EB. Ecological models of health behavior. In: Glanz K, Rimer B, Viswanath K, editors. Health behavior and health education: theory, research and practice. San Fransico; 2008. pp. 465–486.

70. Prins RG, Oenema A, van der Horst K, Brug J. Objective and perceived availability of physical activity opportunities: differences in associations with physical activity behavior among urban adolescents. Int J Behav Nutr Phys Act. 2009;6: 70. doi:10.1186/1479-5868-6-70

71. Gebel K, Bauman A, Owen N. Correlates of non-concordance between perceived and objective measures of walkability. Ann Behav Med. 2009;37: 228–38. doi:10.1007/s12160-009-9098-3

72. Winters M, Davidson G, Kao D, Teschke K. Motivators and deterrents of bicycling: comparing influences on decisions to ride. Transportation (Amst). 2010;38: 153–168. doi:10.1007/s11116-010-9284-y

73. Ewing R, Handy S. Measuring the Unmeasurable : Urban Design Qualities Related to Walkability. J urban Des. 2009;14: 65–84. doi:10.1080/13574800802451155

74. Ding D, Gebel K. Built environment, physical activity, and obesity: what have we learned from reviewing the literature? Health Place. Elsevier; 2012;18: 100–5. doi:10.1016/j.healthplace.2011.08.021

75. Alfonzo M a. To Walk or Not to Walk? The Hierarchy of Walking Needs. Environ Behav. 2005;37: 808–836. doi:10.1177/0013916504274016

76. Bauman AE, Reis RS, Sallis JF, Wells JC, Loos RJF, Martin BW. Correlates of physical activity: why are some people physically active and others not? Lancet. 2012;380: 258–71. doi:10.1016/S0140-6736(12)60735-1

77. Pucher J, Dill J, Handy S. Infrastructure, programs, and policies to increase bicycling: an international review. Prev Med (Baltim). 2010;50 Suppl 1: S106–25. doi:10.1016/j.ypmed.2009.07.028

78. Heinen E, Van Wee B, Maat K. Commuting by Bicycle : An Overview of the Literature. 2010;30: 59–96. doi:10.1080/01441640903187001

79. Yang L, Sahlqvist S. Interventions to promote cycling : systematic review. BMJ. 2010;341: 1–10. doi:10.1136/bmj.c5293

80. Munro C, Arnold T. National Cycling Participation Survey 2015: National Results [Internet]. Sydney; 2015. Available: file:///C:/Users/limerten/Downloads/AP-C91-15_National_AustralianCyclingParticipationSurveyResults_2015.pdf

81. Sallis JF, Conway TL, Dillon LI, Frank LD, Adams MA, Cain KL, et al. Environmental and demographic correlates of bicycling. Prev Med (Baltim). 2013;57: 456–460.

82. de Geus B, De Bourdeaudhuij I, Jannes C, Meeusen R. Psychosocial and environmental factors associated with cycling for transport among a working population. Health Educ Res. 2008;23: 697–708. doi:10.1093/her/cym055

83. Handy S, Xing Y. Factors Correlated with Bicycle Commuting : A Study in Six Small US Cities. Int J Sustain Transp. 2011; 0–23. doi:10.1080/15568310903514789

84. Pucher J, Buehler R. Making Cycling Irresistible: Lessons from The Netherlands, Denmark and Germany. Transp Rev. 2008;28: 495–528. doi:10.1080/01441640701806612

85. Rietveld P, Daniel V. Determinants of bicycle use: do municipal policies matter? Transp Res Part A Policy Pract. 2004;38: 531–550. doi:10.1016/j.tra.2004.05.003

86. Van Holle V, Van Cauwenberg J, Van Dyck D, Deforche B, Van de Weghe N, De Bourdeaudhuij I. Relationship between neighborhood walkability and older adults' physical activity: results from the Belgian Environmental Physical Activity Study in Seniors (BEPAS Seniors). Int J Behav Nutr Phys Act. 2014;11: 110. doi:10.1186/s12966-014-0110-3

87. American College of Sports Medicine -. ACSM's Guidelines for Exercise Testing and Prescription the Ninth Edition. Pescatello LS, Riebe D, editors. Lippincott: Williams and Wilkins; 2013.

88. Engbers LH, Hendriksen IJM. Characteristics of a population of commuter cyclists in the Netherlands: perceived barriers and facilitators in the personal, social and physical environment. Int J Behav Nutr Phys Act. BioMed Central Ltd; 2010;7: 1–5. doi:10.1186/1479-5868-7-89

89. Trost SG, Owen N, Bauman AE, Sallis JF, Brown W. Correlates of adults ' participation in physical activity : review and update. 2002; 0–5. doi:10.1249/01.MSS.0000038974.76900.92

90. Saelens BE, Handy SL. Built environment correlates of walking: a review. Med Sci Sports Exerc. 2008;40: S550–66. doi:10.1249/MSS.0b013e31817c67a4

91. Davison KK, Lawson CT. Do attributes in the physical environment influence children ' s physical activity ? A review of the literature. Int J Behav Nutr Phys Act. 2006;3: 1–17. doi:10.1186/1479-Received

92. Spittaels H, Foster C, Oppert J-M, Rutter H, Oja P, Sjöström M, et al. Assessment of environmental correlates of physical activity: development of a European questionnaire. Int J Behav Nutr Phys Act. 2009;6: 39. doi:10.1186/1479-5868-6-39

93. Giles-corti B, Timperio A, Bull F, Pikora T. Correlates : Increased Specificity for Ecological. Exerc Sport Sci Rev. 2005; 175–181.

94. Colabianchi N, Coulton CJ, Hibbert JD, McClure SM, Ievers-Landis CE, Davis EM. Adolescent self-defined neighborhoods and activity spaces: spatial overlap and relations to physical activity and obesity. Health Place. Elsevier; 2014;27: 22–9. doi:10.1016/j.healthplace.2014.01.004

95. Coulton C. Defining Neighborhoods for Research and Policy. Cityscape A J Policy Dev Res. 2012;14: 231–236.

96. Diez Roux A V. Estimating neighborhood health effects: the challenges of causal inference in a complex world. Soc Sci Med. 2004;58: 1953–60. doi:10.1016/S0277-9536(03)00414-3

97. Sherman JE, Spencer J, Preisser JS, Gesler WM, Arcury T a. A suite of methods for representing activity space in a healthcare accessibility study. Int J Health Geogr. 2005;4: 24. doi:10.1186/1476-072X-4-24

98. Flowerdew R, Manley DJ, Sabel CE. Neighbourhood effects on health: does it matter where you draw the boundaries? Soc Sci Med. 2008;66: 1241–55. doi:10.1016/j.socscimed.2007.11.042

99. Swinburn B, Egger G, Raza F. Dissecting Obesogenic Environments: The Development and Application of a Framework for Identifying and Prioritizing Environmental Interventions for Obesity. Prev Med (Baltim). 1999;26: 563–570.

100. Cain KL, Millstein R a, Sallis JF, Conway TL, Gavand K a, Frank LD, et al. Contribution of streetscape audits to explanation of physical activity in four age groups based on the Microscale Audit of Pedestrian Streetscapes (MAPS). Soc Sci Med. Elsevier Ltd; 2014;116: 82–92. doi:10.1016/j.socscimed.2014.06.042

101. Sallis JF, Slymen DJ, Conway TL, Frank LD, Saelens BE, Cain K, et al. Income disparities in perceived neighborhood built and social environment attributes. Health Place. Elsevier; 2011;17: 1274–1283. doi:10.1016/j.healthplace.2011.02.006

102. Bauman AE, Bull FC. Environmental Correlates of Physical Activity And Walking in Adults and Children : A Review of Reviews. 2007;44.

103. Wendel-Vos W, Droomers M, Kremers S, Brug J, van Lenthe F. Potential environmental determinants of physical activity in adults: a systematic review. Obes Rev. 2007;8: 425–40. doi:10.1111/j.1467-789X.2007.00370.x

104. Van Holle V, Deforche B, Van Cauwenberg J, Goubert L, Maes L, Van de Weghe N, et al. Relationship between the physical environment and different domains of physical activity in European adults: a systematic review. BMC Public Health. 2012;12: 807. doi:10.1186/1471-2458-12-807

105. Foster CE, Panter JR, Wareham NJ. Assessing the impact of road traffic on cycling for leisure and cycling to work. Int J Behav Nutr Phys Act. 2011;8: 61. doi:10.1186/1479-5868-8-61

106. Moudon AV, Lee C. Walking and Bicycling : An Evaluation of Environmental Audit Instruments. Am J Heal Promot. 2003;18: 21–38.

107. Frank LD, Sallis JF, Saelens BE, Leary L, Cain K, Conway TL, et al. The development of a walkability index: application to the Neighborhood Quality of Life Study. Br J Sports Med. 2010;44: 924–33. doi:10.1136/bjsm.2009.058701

108. Ma L, Dill J. Associations between the objective and perceived built environment and bicycling for transportation. J Transp Heal. Elsevier; 2015;2: 248–255. doi:10.1016/j.jth.2015.03.002

109. Mackenbach JD, Rutter H, Compernolle S, Glonti K, Oppert J-M, Charreire H, et al. Obesogenic environments: a systematic review of the association between the physical environment and adult weight status, the SPOTLIGHT project. BMC Public Health. BMC Public Health; 2014;14: 233. doi:10.1186/1471-2458-14-233

110. Kirtland K a., Porter DE, Addy CL, Neet MJ, Williams JE, Sharpe P a., et al. Environmental measures of physical activity supports. Am J Prev Med. 2003;24: 323–331. doi:10.1016/S0749-3797(03)00021-7

111. Brownson RC, Hoehner CM, Day K, Forsyth A, Sallis JF. Measuring the built environment for physical activity: state of the science. Am J Prev Med. 2009;36. doi:10.1016/j.amepre.2009.01.005.Measuring

112. Saelens BE, Sallis JF, Black JB, Chen D. Neighborhood-Based Differences in Physical Activity : An Environment Scale Evaluation. Res Pract. 2003;93: 1552–1558.

113. Cerin E, Saelens BE, Sallis JF, Frank LD. Neighborhood Environment Walkability Scale: Validity and Development of a Short Form. Med Sci Sport Exerc. 2006;38: 1682–1691. doi:10.1249/01.mss.0000227639.83607.4d

114. Cerin E, Macfarlane DJ, Ko H, Chan KA. Measuring perceived neighbourhood walkability in Hong Kong. Cities. 2007;24: 209–217. doi:10.1016/j.cities.2006.12.002

115. Spittaels H, Verloigne M, Gidlow C, Gloanec J, Titze S, Foster C, et al. Measuring physical activity-related environmental factors : reliability and predictive validity of the European

environmental questionnaire ALPHA. Int J Behav Nutr Phys Act. 2010;7: 1–19. Available: http://www.ijbnpa.org/content/7/1/48

116. Leslie E, Saelens B, Frank L, Owen N, Bauman A, Coffee N, et al. Residents ' perceptions of walkability attributes in objectively different neighbourhoods: a pilot study. Health Place. 2005;11: 227–236. doi:10.1016/j.healthplace.2004.05.005

117. Pucher J, Buehler R, Bassett DR, Dannenberg AL. Walking and cycling to health: a comparative analysis of city, state, and international data. Am J Public Health. 2010;100: 1986–92. doi:10.2105/AJPH.2009.189324

118. Sallis JF, Bowles HR, Bauman A, Ainsworth BE, Bull FC, Craig CL, et al. Neighborhood environments and physical activity among adults in 11 countries. Am J Prev Med. 2009;36: 484–490. doi:10.1016/j.amepre.2009.01.031

119. Longley PA, Goodchild MF, Maguire DJ, Rhind DW. Geographical Information Systems and Science. Chichester, England: John Wiley & Sons Ltd; 2005.

120. Croner C, Sperling J, Broome F. Geographic information systems (GIS): new perspectives in understanding human health and environmental relationships. Stat Med. 1996;15: 1961–1977. doi:10.1002/(SICI)1097-0258(19960930)15

121. Curtis JW, Curtis A, Mapes J, Szell AB, Cinderich A. Using google street view for systematic observation of the built environment : analysis of spatio-temporal instability of imagery dates. Int J Health Geogr. 2013;12: 1–10.

122. Rundle AG, Bader MDM, Richards CA, Neckerman KM, Teitler JO. Using Google Street view to audit neighborhood environments. Am J Prev Med. 2011;40: 94–100. doi:10.1016/j.amepre.2010.09.034.Using

123. Vanwolleghem G, Dyck D Van, Ducheyne F, Bourdeaudhuij I De, Cardon G. Assessing the environmental characteristics of cycling routes to school : a study on the reliability and validity of a Google Street View-based audit. Int J Health Geogr. 2014; 1–9.

124. Bethlehem JR, Mackenbach JD, Ben-rebah M, Compernolle S, Glonti K, Bárdos H, et al. The SPOTLIGHT virtual audit tool: a valid and reliable tool to assess obesogenic characteristics of the built environment. Int J Health Geogr. 2014;13: 52. doi:10.1186/1476-072X-13-52

125. Charreire H, Mackenbach JD, Ouasti M, Lakerveld J, Compernolle S. Using remote sensing to

de fi ne environmental characteristics related to physical activity and dietary behaviours : A systematic review (the SPOTLIGHT project). Health Place. Elsevier; 2014;25: 1–9. doi:10.1016/j.healthplace.2013.09.017

126. Mooney SJ, Bader MDM, Lovasi GS, Neckerman KM, Teitler JO, Rundle AG. Practice of Epidemiology Validity of an Ecometric Neighborhood Physical Disorder Measure Constructed by Virtual Street Audit. Am J Epidemiol. 2014;180: 626–635. doi:10.1093/aje/kwu180

127. Odgers CL, Caspi A, Bates CJ, Sampson RJ, Moffitt TE. Using Google Street View : a reliable and cost-effective method. J Child Psychol Psychiatry. 2013;53: 1009–1017. doi:10.1111/j.1469-7610.2012.02565.x.Systematic

128. Van Dyck D, Cerin E, Conway TL, De Bourdeaudhuij I, Owen N, Kerr J, et al. Perceived neighborhood environmental attributes associated with adults' transport-related walking and cicyling: Findings from USA, Australia and Belgium. Int J Behav Nutr Phys Act. 2012;9: 59–68. doi:10.1186/1479-5868-9-70

129. Jongeneel-Grimen B, Busschers W, Droomers M, van Oers H a M, Stronks K, Kunst AE. Change in neighborhood traffic safety: does it matter in terms of physical activity? PLoS One. 2013;8: e62525. doi:10.1371/journal.pone.0062525

130. De Meester F, Van Dyck D, De Bourdeaudhuij I, Deforche B, Sallis JF, Cardon G. Active living neighborhoods: is neighborhood walkability a key element for Belgian adolescents? BMC Public Health. 2012;12: 7.

131. Van Holle V, Van Cauwenberg J, Van Dyck D, Deforche B, Van de Weghe N, De Bourdeaudhuij I, et al. Relationship between neighborhood walkability and older adults ' physical activity : results from the Belgian Environmental Physical Activity Study in Seniors (BEPAS Seniors). Int J Behav Nutr Phys Act. 2014;11: 1–9. doi:10.1186/s12966-014-0110-3

132. Rodrigue J, Comtois C, Slack B. The Geography of Transport Systems. Oxon: Routledge; 2006.

133. Buehler R, Pucher J. Walking and Cycling in Western Europe and the United States. TR NEWS. 2012;280. Available: http://policy.rutgers.edu/faculty/pucher/TRNWesternEurope.pdf

134. Parkin J, Wardman M, Page M. Estimation of the determinants of bicycle mode share for the

journey to work using census data. Transportation (Amst). 2008;35: 93–109. doi:10.1007/s11116-007-9137-5

135. Titze S, Stronegger WJ, Janschitz S, Oja P. Association of built-environment, social-environment and personal factors with bicycling as a mode of transportation among Austrian city dwellers. Prev Med (Baltim). 2008;47: 252–9. doi:10.1016/j.ypmed.2008.02.019

136. Lee C, Moudon AV. Neighbourhood design and physical activity. Build Res informtaion. 2008;36: 395–411.

137. Evenson KR, Herring AH, Huston SL. Evaluating Change in Physical Activity with the Building of a Multi-Use Trail. Am J Prev Med. 2005;28: 177–185. doi:10.1016/j.amepre.2004.10.020

138. Titze S, Giles-Corti B, Knuiman MW, Pikora TJ, Timperio a, Bull FC, et al. Associations Between Intrapersonal and Neighborhood Environmental Characteristics and Cycling for Transport and Recreation in Adults: Baseline Results From the RESIDE Study. J Phys Act Heal. 2010;7: 423–431.

139. Van Dyck D, Cardon G, Deforche B, Giles-Corti B, Sallis JF, Owen N, et al. Environmental and psychosocial correlates of accelerometer-assessed and self-reported physical activity in Belgian adults. Int J Behav Med. 2011;18: 235–45. doi:10.1007/s12529-010-9127-4

140. Titze S, Stronegger WJ, Janschitz S, Oja P. Environmental , Social , and Personal Correlates of Cycling for Transportation in a Student Population. J Phys Act Health. 2007;4: 66–79.

141. Vandenbulcke G, Dujardin C, Thomas I, Geus B De, Degraeuwe B, Meeusen R, et al. Cycle commuting in Belgium: Spatial determinants and “re-cycling” strategies. Transp Res Part A Policy Pract. 2011;45: 118–137. doi:10.1016/j.tra.2010.11.004

142. Zlot AI, Schmid TL. Relationships among community characteristics and walking and bicycling for transportation or recreation. Am J Heal Promot AJHP. 2005;19: 314–317. Available: http://www.ncbi.nlm.nih.gov.offcampus.lib.washington.edu/pubmed/15768927

143. Wendel-vos W, Schuit J, De Niet R, Boshuizen HC, Saris WHM, Kromhout D. Factors of the Physical Environment Associated with Walking and Bicycling. Med Sci Sport Exerc. 2004;36: 725–730. doi:10.1249/01.MSS.0000121955.03461.0A

144. Buehler R, Dill J. Bikeway Networks: A Review of Effects on Cycling. Transp Rev. 2016;36: 9–

27.

145. Panter JR, Jones A. Attitudes and the environment as determinants of active travel in adults: what do and don't we know? J Phys Act Heal. 2010;7: 551–561. Available: http://www.ncbi.nlm.nih.gov/pubmed/20683098

146. Wen M, Hawkley LC, Cacioppo JT. Objective and perceived neighborhood environment, individual SES and psychosocial factors , and self-rated health: An analysis of older adults in Cook County, Illinois. Soc Sci Med. 2006;63: 2575–2590. doi:10.1016/j.socscimed.2006.06.025

147. Aldred R, Woodcock J, Goodman A. Does More Cycling Mean More Diversity in Cycling? Transp Rev. 2015;1647: 1–17. doi:10.1080/01441647.2015.1014451

148. Garrard J, Rose G, Lo SK. Promoting transportation cycling for women: the role of bicycle infrastructure. Prev Med (Baltim). 2008;46: 55–9. doi:10.1016/j.ypmed.2007.07.010

149. Schintler L, Root A, Button K. Women's Travel Patterns and the Environment: An Agenda for Research. Transp Res Rec J Transp Res Board. 2000;1726. doi:10.3141/1726-05

150. Poulos RG, Hatfield J, Rissel C, Flack LK, Murphy S, Grzebieta R, et al. Characteristics , cycling patterns , and crash and injury experiences at baseline of a cohort of transport and recreational cyclists in New South Wales , Australia. Accid Anal Prev. 2015;78: 155–164. doi:10.1016/j.aap.2015.02.008

151. Van Holle V, Van Cauwenberg J, Deforche B, Goubert L, Maes L, Nasar J, et al. Environmental invitingness for transport-related cycling in middle-aged adults: A proof of concept study using photographs. Transp Res Part A Policy Pract. Elsevier Ltd; 2014;69: 432–446. doi:10.1016/j.tra.2014.09.009

152. Ferdinand AO, Sen B, Rahurkar S, Engler S, Menachemi N. The Relationship Between Built Environments and Physical Activity : A Systematic Review. Am J Public Health. 2012;102: 7–13. doi:10.2105/AJPH.2012.300740

153. McCormack GR, Shiell A. In search of causality: a systematic review of the relationship between the built environment and physical activity among adults. Int J Behav Nutr Phys Act. BioMed Central Ltd; 2011;8: 125. doi:10.1186/1479-5868-8-125

154. Carpiano RM. Come take a walk with me: the "go-along" interview as a novel method for

studying the implications of place for health and well-being. Health Place. 2009;15: 263–72. doi:10.1016/j.healthplace.2008.05.003

155. Wells NM, Ashdown SP, Davies EHS, Cowett FD, Yang Y. Environment, Design, and Obesity: Opportunities for Interdisciplinary Collaborative Research. Environ Behav. 2007;39: 6–33. doi:10.1177/0013916506295570

156. Heft H, Nasar JL. Evaluating Environmental Scenes Using Dynamic Versus Static Displays. Environ Behav. 2000;32: 301–322. doi:10.1177/0013916500323001

157. Hamer M, Chida Y. Active commuting and cardiovascular risk: a meta-analytic review. Prev Med (Baltim). 2008;46: 9–13. doi:10.1016/j.ypmed.2007.03.006

158. de Nazelle A, Nieuwenhuijsen MJ, Antó JM, Brauer M, Briggs D, Braun-Fahrlander C, et al. Improving health through policies that promote active travel: A review of evidence to support integrated health impact assessment. Environ Int. 2011;37: 766–777. doi:10.1016/j.envint.2011.02.003

159. McCormack G, Giles-Corti B, Lange a, Smith T, Martin K, Pikora TJ. An update of recent evidence of the relationship between objective and self-report measures of the physical environment and physical activity behaviours. J Sci Med Sport. 2004;7: 81–92. Available: http://www.ncbi.nlm.nih.gov/pubmed/15214606

160. Ding D, Sallis JF, Kerr J, Lee S, Rosenberg DE. Neighborhood environment and physical activity among youth a review. Am J Prev Med. Elsevier Inc.; 2011;41: 442–55. doi:10.1016/j.amepre.2011.06.036

161. Sahlqvist S, Goodman A, Jones T, Powell J, Song Y, Ogilvie D. Mechanisms underpinning use of new walking and cycling infrastructure in different contexts : mixed-method analysis. Int J Behav Nutr Phys Act. 2015;12: 1–15. doi:10.1186/s12966-015-0185-5

162. Panter J, Grif S, Dalton AM, Ogilvie D. Patterns and predictors of changes in active commuting over 12 months. Prev Med (Baltim). 2013;57: 776–784. doi:10.1016/j.ypmed.2013.07.020

163. Pucher J, Dijkstra L. Promoting safe walking and cycling to improve public health: lessons from The Netherlands and Germany. Am J Public Health. 2003;93: 1509–16. Available: http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=1448001&tool=pmcentrez&rendertype=abstract

164. Lakerveld J, Brug J, Bot S, Teixeira PJ, Rutter H, Woodward E, et al. Sustainable prevention of obesity through integrated strategies: The SPOTLIGHT project's conceptual framework and design. BMC Public Health. 2012;12: 793. doi:10.1186/1471-2458-12-793

165. Eurobarometer 72.3. Sport and physical activity. Spec Eurobarom 334. 2010;32: 98. Available: http://www.ncbi.nlm.nih.gov/pubmed/21462450

166. Eurobarometer European commision. Physical activity. 2003;December.

Part 2. Original research

Chapter 1. Cross-sectional studies to investigate the association between the physical environment and cycling for transport (the SPOTLIGHT project)

Chapter 1.1 - Perceived environmental correlates of cycling for transport across five European urban regions

Mertens, L., Compernolle, S., Gheysen, F., Deforche, B., Brug, J., Mackenbach, J. D., Lakerveld, J., Oppert, JM., Feuillet, T., Glonti, K., Bardos, H., & De Bourdeaudhuij, I. (2016). Perceived environmental correlates of cycling for transport among adults in five regions of Europe. Obesity Reviews (Supplement), 17(Suppl.1), 53–61.

obesity reviews

doi: 10.1111/obr.12379

Supplement Article

Perceived environmental correlates of cycling for transport among adults in five regions of Europe

L. Mertens[1], S. Compernolle[1], F. Gheysen[1], B. Deforche[2,3], J. Brug[4], J. D. Mackenbach[4], J. Lakerveld[4], J.-M. Oppert[5,6], T. Feuillet[5], K. Glonti[7], H. Bárdos[8] and I. De Bourdeaudhuij[1]

[1]Department of Movement and Sport Sciences, Faculty of Medicine and Health Sciences, Ghent University, Ghent, Belgium; [2]Department of Public Health, Faculty of Medicine and Health Sciences, Ghent University, Ghent, Belgium; [3]Department of Human Biometry and Biomechanics, Faculty of Physical Education and Physical Therapy, Vrije Universiteit Brussel, Brussels, Belgium; [4]Department of Epidemiology and Biostatistics, EMGO Institute for Health and Care Research, VU University Medical Center, Amsterdam, The Netherlands; [5]Equipe de Recherche en Epidémiologie Nutritionnelle (EREN), Centre de Recherche en Epidémiologie et Statistiques, Inserm (U1153), Inra (U1125), Cnam, COMUE Sorbonne Paris Cité, Université Paris 13, Bobigny, France; [6]Sorbonne Universités, Université Pierre et Marie Curie, Université Paris 06; Institute of Cardiometabolism and Nutrition, Department of Nutrition, Pitié-Salpêtrière Hospital, Assistance Publique-Hôpitaux de Paris, Paris, France; [7]ECOHOST – The Centre for Health and Social Change, London School of Hygiene and Tropical Medicine, London, UK; [8]Department of Preventive Medicine, Faculty of Public Health, University of Debrecen, Debrecen, Hungary

Received 15 December 2015; accepted 16 December 2015

Address for correspondence: Professor I De Bourdeaudhuij, Department of Movement and Sport Sciences, Ghent University, Watersportlaan 2, 9000 Gent, Belgium.
E-mail: Ilse.Debourdeaudhuij@Ugent.be

The copyright line for this article was changed on 30 May 2016 after original online publication

Summary

Regular cycling for transport is an important potential contributor to daily physical activity among adults. Characteristics of the physical environment are likely to influence cycling for transport. The current study investigated associations between perceived physical environmental neighbourhood factors and adults' cycling for transport across five urban regions across Europe, and whether such associations were moderated by age, gender, education and urban region. A total of 4,612 adults from five European regions provided information about their transport-related cycling and their neighbourhood physical environmental perceptions in an online survey. Hurdle models adjusted for the clustering within neighbourhoods were performed to estimate associations between perceived physical environmental neighbourhood factors and odds of engaging in cycling for transport and minutes of cycling for transport per week. Inhabitants of neighbourhoods that were perceived to be polluted, having better street connectivity, having lower traffic speed levels and being less pleasant to walk or cycle in had higher levels of cycling for transport. Moderation analyses revealed only one interaction effect by gender. This study indicates that cycling for transport is associated with a number of perceived physical environmental neighbourhood factors across five urban regions across Europe. Our results indicated that the majority of the outcomes identified were valid for all subgroups of age, gender, education and across regions in the countries included in the study.

Keywords: Built environment, cycling, physical activity, SPOTLIGHT.

Abbreviations: SES, socioeconomic status.

obesity reviews (2016) **17** (Suppl. 1), 53–61

Background

Despite the established health benefits of physical activity (1), a high proportion of European adults do not achieve the public health recommendations for physical activity (2,3). Active transport (e.g. cycling to work and shops or friends) can make a major contribution to daily physical activity (4). Cross-sectional studies indicate that cycling for transport is associated with lower body weight, improved cardiovascular health and lower morbidity in adults (4–7). Besides these health benefits, cycling has many other positive effects such as economic, social and environmental and traffic management advantages (8–17). Physical environments that support cycling can help to increase cycling for transport (18,19). The physical environment can be seen as the wider built environment (20) and is defined as 'objective and perceived characteristics of the physical context in which people spend their time (e.g., home and neighbourhood), including aspects of urban design, traffic density and speed, distance to and design of venues for physical activity (e.g., parks), crime and safety' (21). However, associations between the physical environment and cycling for transport have been less thoroughly investigated than associations with walking, leisure-time physical activity or total physical activity (22,23). Furthermore, a recent study by Kerr *et al.* (2015) emphasizes the importance of investigating perceived environmental neighbourhood factors independently for walking and for cycling for transport, as highly walkable environments may not support cycling for transport (24). In addition, results that are available on cycling for transport are much more inconsistent (22,25–28).

The physical environment can be measured in two main ways: self-reported or objective. These methods assess two distinct dimensions of the physical environment (29–32). For example, a study showed that individuals whose perceptions of the walkability of their neighbourhood were lower than was indicated by objective measures were more likely to decrease their walking for transport than individuals who had a more accurate perception of the walkability of their neighbourhood (33). Furthermore, a recent review found that the consistency of associations between the physical environment and physical activity is strongly influenced by the modes of measurements (objective vs. perceived) (34). Therefore, it is important to distinguish objective and perceived environmental correlates (32) and choose the appropriate data depending on what purpose you want to achieve or which behaviour you want to assess (31). Because neighbourhood perceptions may be more closely related to actual behaviours (35,36), insight into the perceived physical environmental neighbourhood factors associated with cycling behaviour is important.

Demographic factors can influence neighbourhood perceptions as well as cycling behaviour (29). For example, it may be that people from different educational or cultural backgrounds view the same environment differently, leading to different neighbourhood perceptions. However, little is known about whether the association between perceived physical environmental neighbourhood factors and cycling differs between different population subgroups. Previous studies suggest that men, younger adults and highly educated people are more likely to engage in cycling for transport (37–39), and that socio-cultural factors may influence cycling behaviour (40) due to differences in cycling culture across countries (41). Nevertheless, it is unknown if the strength of association between physical neighbourhood environmental characteristics and cycling for transport is moderated by these demographic factors.

Therefore, the current cross-sectional study aimed to determine which perceived physical environmental neighbourhood factors are associated with adults' cycling for transport in five urban regions across Europe. Additionally, the moderating role of demographic variables such as age, gender, SES and country on these associations was investigated.

Methods

Study design and sampling

This study was part of the SPOTLIGHT project (42,43), conducted in five urban regions across Europe: Ghent region (Belgium), Randstad region (the Netherlands), Budapest (Hungary), Paris region (France) and Greater London (UK). Sampling of neighbourhoods and recruitment of participants have been described in detail elsewhere (42). Briefly, neighbourhood sampling was based on a combination of residential density and SES data at the neighbourhood level. This resulted in four types of neighbourhoods: low SES/low residential density, low SES/high residential density, high SES/low residential density and high SES/high residential density. In each country, three neighbourhoods of each neighbourhood type were randomly sampled (i.e. 12 neighbourhoods per country, 60 neighbourhoods in total). Subsequently, per neighbourhood, a random sample of adult inhabitants was invited to participate in an online survey. A total of 6,037 out of 55,893 invited individuals (10.8% response rate) participated in the study between February and September 2014. Only participants aged between 18 and 65 years were included for the present study, because cycling is considerably less prevalent among elderly people (41), resulting in a final sample of 4,579 adults.

Participants answered questions on demographics, neighbourhood perceptions, social environmental factors, health, motivations and barriers for healthy behaviour, obesity-related behaviours and weight and height. The study was approved by the corresponding local ethics committees of participating countries, and all participants in the survey provided informed consent.

Measures

Demographic variables

Self-reported demographic variables included age, gender, country of residence (Belgium, France, Hungary, the Netherlands or UK) and educational level. Higher education was defined as a tertiary education degree (bachelor or master degree); lower education was defined as below a tertiary education (no education, primary, lower secondary or higher secondary).

Cycling for transport

Cycling for transport was measured using the International Physical Activity Questionnaire (long, last seven days self-administrated version) by asking the frequency (number of days in the last seven days) and duration (average time per day) of transport-related cycling (44). Self-reported physical activity assessed by International Physical Activity Questionnaire showed good reliability (Spearman's correlation coefficients clustered around 0.80) and acceptable criterion validity (median $\rho = 0.30$) for adults in a 12-country study (45).

Perceived physical environmental neighbourhood factors

Perceived physical environmental neighbourhood factors were assessed based on the environmental perceptions items from the validated Assessing Levels of Physical Activity environmental questionnaire (46,47) and some additional items. This questionnaire, partly based on the Neighbourhood Environment Walkability Scale questionnaire, was developed from the need to use a standard questionnaire in Europe in which the focus was broader than just walkability (46). The main problem with the globally used Neighbourhood Environment Walkability Scale questionnaire is that characteristics of the European physical environment (e.g. housing density and land use mix) differ markedly from those in the USA or Australia, affecting its suitability in the European context (47). Respondents were asked to what extend they agreed with the following statements (i) there are special lanes, routes or paths for cycling in my neighbourhood; (ii) there is heavy traffic in my neighbourhood related to cycling; (iii) the cycle paths in my neighbourhood are well maintained; (iv) my neighbourhood is a pleasant area for walking or cycling; (v) my neighbourhood is generally free from litter, waste or graffiti; (vi) the air in my neighbourhood is polluted; (vii) the speed of traffic in my neighbourhood is usually low; (viii) the level of crime in my neighbourhood is high and (ix) I have a choice of different routes for walking or cycling in my neighbourhood. All environmental perceptions were rated on a five-point Likert scale ranging from 1 (totally disagree) to 5 (totally agree). For the statistical analyses, items were recoded so that higher scores represented what were hypothesized to be more positive values for a bicycle-friendly environment.

Statistical analyses

Descriptive statistics of sample characteristics were performed using SPSS 22.0 software, and one-way analysis of variance was used to detect differences in cycling levels between different urban regions across Europe. Hurdle models, adjusting for the clustering of participants within neighbourhoods, were performed using the lme4-packages in R version 3.1.2 (48). Hurdle models were used because the dependent variable (minutes cycling for transport per week) was positively skewed and contained a considerable number of null values (56.3% of the participants did not cycle for transport); hereby, violating the assumption of normality and implying that general linear regression analyses could not be performed. Correlations between predictor variables were checked with the variance inflation factor. All values were lower or equal to 1.45, indicating no multicollinearity (49). The first part of hurdle models consisted of analysing associations between the independent variables (i.e. the nine perceived physical environmental neighbourhood factors) and *the odds of participation in cycling for transport among adults* (yes/no cycling for transport in last 7 days) using a logistic regression model: binomial variance and logit link function. The second part of hurdle models consisted of assessing associations between the independent variables and the *amount (*minutes per week*) of cycling for transport among adults who cycled for transport in the last 7 days* (i.e. gamma variance and log link function, selected based on Akaike's information criterion) (48). Hence, the hurdle models resulted in two regression coefficients for each independent variable: an odds ratio (OR) and a gamma regression coefficient. The models were fitted by adaptive Gauss–Hermite quadrature with 25 quadrature points as recommended (48). A hurdle model was chosen over the traditional Tobit model because a hurdle model overpowers the restrictive theory to use the same equation for both outcomes. Hurdle models create two separate equations; in this case, one equation is for whether people cycle for transport and the other is to determine how much time people spent cycling for transport (50,51). In contrast, Tobit models do not make any distinction between the two stages of decision-making (50), making this method less suitable in health applications.

First, a basic model including all main effects of the nine independent variables and four potential moderators (i.e. age, gender, education level and urban regions) were estimated. Second, single interaction models were estimated in which all interaction effects between the perceived physical environmental neighbourhood factors, and the potential moderators were entered separately into the basic model. Third, all single interaction effects from the second step surpassing the statistical threshold of $p < 0.05$ were added simultaneously to the basic model. Non-significant interaction effects were not entered in the final model. Both models are presented in tables, while significant interaction effects observed in the final models are described in the text. Significant interaction terms were probed according to established procedures (52). All analyses were adjusted for type of neighbourhood (i.e. neighbourhood SES and residential density). Level of significance was set at a two-sided α of 0.05.

Results

Descriptive statistics

In total, data from 4,579 adults, aged between 18 and 65 years, were available for the present analyses. More than half of the sample were women (58.5%) and highly educated (57.3%). Furthermore, almost half (43.5%) of the sample cycled for transport in the last 7 days. Other descriptive characteristics of the sample and the descriptive data on neighbourhood perceptions are shown in Table 1. Table 2 shows the significant differences in cycling data in the five different urban regions (overall effect: $F = 125.3$; $p < 0.001$). Participants cycled most for transport in the Randstad region (the Netherlands) and the Ghent region (Belgium), followed by greater Budapest (Hungary), the Paris region (France) and Greater London (UK), where the cycling levels did not differ significantly from those of greater Budapest or the Paris region.

Main and moderated associations for the odds of cycling for transport

From the logistic model (Table 3), low perceived traffic speed, high perceived choice between different routes to walk/cycle and high perceived air pollution in the neighbourhood were positively associated with the odds of engaging in cycling for transport. A one-unit increase of 'low traffic speed' (i.e. a lower perception of traffic speed) in the neighbourhood was associated with 10% higher odds of having cycled for transport in the last 7 days. Furthermore, a one-unit increase in perception of amount of choices between different routes to walk or cycle was associated with 38% higher odds of having cycled in the last 7 days. Lastly, a one-unit increase of 'no air pollution' (i.e. lower self-reported air pollution) was associated with 19% lower odds of having cycled in the last 7 days.

The association of perceived air pollution with engaging in cycling for transport was significantly moderated by gender ($p = 0.007$). Men reporting (higher levels of 'no air pollution') less air pollution in their neighbourhood were less likely to have cycled in the last 7 days (OR = 0.84; 95% CI = 0.75, 0.95), while there was no significant association observed among women (OR = 0.93; 95% CI = 0.84, 1.04). No other moderation effects were found to be significant.

Main and moderated associations for minutes of cycling for transport

In the gamma model (Table 3), perceived pleasantness of the environment in relation to walking or cycling as well as perceived less air pollution were negatively associated with minutes per week cycling for transport among those who indicated to have cycled in the last seven days. A one-unit higher perceived pleasant environment to walk or cycle was associated with 10% fewer minutes of cycling for transport per week. Participants who agreed more strongly with the statement that their neighbourhood had low levels of air pollution cycled less for transport in the last week. In other words, a one-unit increase of 'no air pollution' (i.e. lower self-reported air pollution) was associated with 6% less time (minutes) of cycling for transport per week among those who cycled for transport. No moderation effects were found to be significant.

Discussion

In total, five significant associations (out of the 18 associations tested) between the physical environment and cycling for transport by adults were found. Low perceived traffic speed, higher perceived amount of choices between different routes to walk or cycle and higher perceived air pollution were positively associated with the odds of engaging in cycling for transport. Furthermore, a less pleasant environment to walk or cycle and higher perceived air pollution were associated with more minutes of cycling for transport in the last week. For only one of these associations (air pollution and the odds of engaging in cycling for transport), some evidence for moderation by gender was found. The small number of associations between the physical environment and cycling for transport were not as expected since previous studies using manipulated photographs (53,54) found significant associations between several physical environmental factors (e.g. presence of cycle paths, good maintained cycle paths and even cycle paths) and the street's appeal to cycle for transport. A possible explanation for these different outcomes is the fact that the previous research did not investigate actual cycling behaviour but focused on small-scaled street-setting features (i.e. micro-environmental factors). In the present study, both micro-

Table 1 Descriptive characteristics of the participants ($n = 4,579$)

Characteristics	
Age in years (M ± SD) ($n = 4,517$)	45.2 ± 12.4
Women (%) ($n = 4,538$)	58.6
Urban regions (country) (%) ($n = 4,579$)	
- Ghent region (Belgium)	30.0
- Paris region (France)	15.0
- Greater Budapest (Hungary)	16.2
- Randstad region (Netherlands)	24.9
- Greater London (UK)	14.0
Level of education (%) ($n = 4,146$)	
- Lower	43.0
- Higher	57.0
Type of neighbourhood (%) ($n = 4,505$)	
- H-SES/H-dens	25.1
- H-SES/L-dens	25.4
- L-SES/H-dens	22.2
- L-SES/L-dens	27.3
Current cycling for transport level ($n = 4,579$)	
- Cycling for transport in the last week (%)	43.7
- Min/week among those who cycled (M ± SD)	288.3 ± 272.4
Perceived physical environmental neighbourhood factors	
- Presence of cycle paths (M ± SD) ($n = 4,215$)	3.6 ± 1.3
- Good maintained cycle paths (M ± SD) ($n = 3,932$)	3.3 ± 1.2
- Pleasant environment to walk/cycle (M ± SD) ($n = 4,320$)	3.8 ± 1.1
- Free from litter, graffiti and trash (M ± SD) ($n = 4,330$)	3.2 ± 1.3
- Low traffic speed (M ± SD) ($n = 4,297$)	2.8 ± 1.2
- Choice between different routes to walk/cycle (M ± SD) ($n = 4,275$)	3.9 ± 1.0
- No busy traffic (M ± SD) ($n = 4,312$)	2.4 ± 1.2
- No air pollution (M ± SD) ($n = 4,265$)	3.0 ± 1.2
- Low level of crime (M ± SD) ($n = 4,270$)	3.4 ± 1.1

H-dens = high residential density; H-SES = high socioeconomic status; L-dens = low residential density; L-SES = low socioeconomic status; M = mean; SD = standard deviation.

environmental and macro-environmental factors were included. Macro-environmental factors are regarded as 'raw' urban planning features (e.g. connectivity of the street network, residential density and land use mix diversity), which are more complex to modify compared with the reconfiguration of micro-environmental factors (55). From our study, it might be concluded that macro-environmental factors (e.g. air pollution and choice between different routes to walk/cycle), despite their difficult changeability, appear to be more important than the micro-environmental factors.

First, low perceived traffic speed was positively associated with the odds of engaging in cycling for transport. In the literature, there is overall consensus that safety of cyclists can be increased by reducing the speed of motorized traffic on secondary roads (56). In the Netherlands, Denmark and Germany, the overall bicycle network was greatly enhanced by traffic-calming interventions in cities, reducing the speed limit to 30 km/h in most residential streets (57). Research has indicated that safer and less stressful cycling routes are preferable to streets with fast-moving traffic for children, older people and women; (56) our findings did not indicate moderation by gender or age, although we only considered the age range of 18 to 65 years in this analysis.

Second, higher perceived air pollution was associated with higher odds of engaging in cycling for transport and more minutes of cycling for transport in the last week. This finding may be explained by the fact that cyclists are more exposed to, and therefore may be more aware of air pollution (i.e. reverse causality). The same counter-intuitive result was found in a recent cross-sectional study by Feuillet *et al.*, (58) in which air pollution was positively associated with active transport. It may also be that there are additional benefits to using a bicycle in neighbourhoods with high levels of air pollution, as a result of greater traffic density e.g. using your bike in such a car-traffic dense neighbourhood may save time. This association was only significant among men. It may be that cycling for transport is more influenced by the instrumental component (e.g. because it is efficient) in men than women, while for women, the emotional and safety component remains more important (e.g. cycling for transport has to be fun and enjoyable as well) (37,59,60).

Furthermore, our results indicated that higher perceived street connectivity (i.e. choice between different routes to walk or cycle) was positively related with the odds of engaging in cycling for transport, but not with minutes of cycling for transport in the last week. Previous research has also identified an association between perceived street connectivity and cycling for transport (26,61–63). The same contrasting result for the association between cycling for transport and perceived street connectivity (i.e. a positive association with the odds of engaging but no association with minutes of cycling) was also found in a recent study of Kerr *et al.* (2015) (24). A possible explanation for this split association might be that highly connected neighbourhoods cause interrupted cycling and result in only short cycling trips

Table 2 Cycling levels for the different urban regions

	n	Cycling for transport in the last week (%)	Min/week cycling for transport (M ± SD)
a. Ghent region (Belgium)	1,373	56.7	188.8 ± 283.2 [b,c,e]
b. Paris region (France)	687	13.4	28.3 ± 108.0 [a,c,d]
c. Greater Budapest (Hungary)	740	30.9	68.2 ± 159.0 [a,c,d]
d. Randstad region (the Netherlands)	1,138	71.1	193.1 ± 242.7 [b,c,e]
e. Greater London (UK)	641	14.4	43.8 ± 150.4 [a,d]

The superscript letters indicate which urban regions significantly differ from each other ($p < 0.05$).

Table 3 Main and moderated associations for the odds of cycling for transport (Logistic model) and for minutes cycling for transport (Gamma model)

	Logistic model† (n = 3,338; AIC = 3870.7)		Gamma model‡ (n = 1,628; AIC = 1526.4)	
Main effects	OR of engaging in cycling for transport (95% CI)	p-value	Exp B§ (95% CI)	p-value
Presence of cycle paths	1.10 (1.00, 1.21)	0.051	1.04 (0.98, 1.10)	0.225
Good maintained cycle paths	0.97 (0.89, 1.07)	0.534	0.97 (0.92, 1.03)^	0.362
Pleasant environment to walk/cycle	1.00 (0.90, 1.11)	0.993	0.90 (0.82, 0.99)* ^	0.028
Free from litter, graffiti and trash	0.94 (0.86, 1.01)	0.103	0.99 (0.95, 1.04)	0.763
Low traffic speed	1.10 (1.01, 1.19)*	0.028	1.04 (0.99, 1.10)	0.097
Choice between different routes to walk/cycle	1.38 (1.15, 1.65)*** ^	<0.001	1.00 (0.90, 1.11)	0.943
No busy traffic	1.08 (1.00, 1.17)	0.058	1.00 (0.95, 1.05)	0.979
No air pollution	0.81 (0.72, 0.90)*** ^	<0.001	0.94 (0.90, 0.99)*	0.044
Low level of crime	1.03 (0.95, 1.12)	0.505	1.00 (0.95, 1.06)	0.964
Moderating effects				
No air pollution x gender	1.19 (1.05, 1.36)*	0.007		
Choice between different routes x regions	0.94 (0.88, 1.00)	0.063		
Free from litter, graffiti and trash x age			1.00 (0.950, 1.06)	0.163
Good maintained cycle paths x age			1.00 (1.00, 1.01)	0.054
No busy traffic x age			1.00 (1.00, 1.00)	0.992
No air pollution x age			1.00 (1.00, 1.01)	0.107
Pleasant environment to walk/cycle x education			1.12 (1.00, 1.26)	0.051
Choice between different routes x education			1.06 (0.93, 1.21)	0.375

^variable which is significantly moderated;
†The logistic model estimates the association between the independent variables (physical environmental factors) and the odds of engaging in cycling for transport;
‡The gamma model estimates the association between the independent variables (physical environmental factors) and the amount of minutes cycling for transport among those who cycled for transport in the last seven days;
§Exp B, exponent of B, all gamma models were fitted using a log link function, the exponent of B can be interpreted as the proportional increase of the dependent variable with a one-unit increase in the independent variable;
*$p < 0.05$,
**$p < 0.01$,
***$p < 0.001$;
OR = odds ratio; CI = confidence interval; AIC, Akaike's information criterion.

(24). Lastly, a more pleasant environment for walking or cycling was associated with fewer minutes of cycling per week. Again, this may be the result of reverse causality, i.e. people who cycled more in their neighbourhood may have been more aware of the less pleasant attributes for walking or cycling in their neighbourhood.

If these results are replicated by other (longitudinal or experimental) studies, this might indicate that interventions focusing on reducing traffic speed in city centres would promote increased levels of cycling. Despite the fact that our study showed no negative association between perceived air pollution and cycling for transport, policymakers should be aware of the problem concerning air pollution in those dense areas and should be encouraged to reduce exposure to air pollution for cyclists to improve public health (64,65). Only few moderating effects were found in this study, which indicates that despite significant differences in cycling levels across regions, generic interventions could benefit most population subgroups, even across regions in the different countries included in the present study.

Strengths of this study include the large study sample, distributed across five different countries in Europe. This study addresses a clear evidence gap because there is very limited evidence on the perceived neighbourhood environment correlates of cycling for transport compared with the correlates for walking, leisure-time physical activity or total physical activity. In addition, it is also important for future research to investigate the importance of the objective environment regarding cycling for transport because these environments (objective vs. perceived) are related differently to physical activity (32). A recent review of Ding *et al.*(34) suggests that future studies, if possible, should combine both objective and perceived measurement modes in one study, to compare and contrast the impact of these methods.

A limitation of the current study was the cross-sectional design, which precluded determination of causality. Longitudinal designs enable causal inference with regard to the impact of physical environmental factors on cycling for transport (22,66). Furthermore, the response rate (around 10.8%) was low with the lowest response rates observed in low SES neighbourhoods in comparison with high SES neighbourhoods, which calls into question the external validity and the potential for bias for this study. In addition, this might be a possible explanation for the few moderating effects found in this analysis.

Conclusions

This study indicated that cycling for transport is significantly associated with different perceived physical environmental neighbourhood factors, i.e. more polluted neighbourhoods, better connected neighbourhoods, lower traffic speed levels and neighbourhoods that are less pleasant to walk or cycle in, in five urban regions across Europe. Our results indicated that the majority of the outcomes from the present study were valid for all subgroups, even across regions in the different countries included in the present study.

Authors' contributions

The WP3 SPOTLIGHT group (S. C., J. L., J. M., H. B., H. R., K. G. and J. M. O.) developed the questionnaire, research protocol and conducted the data collection. L. M. performed the data analysis and drafted the manuscript supervised by S. C., F. G., B. D., I. D. B. All other co-authors critically reviewed and revised versions of the manuscript, and each of them read and approved the final manuscript.

Declaration of interests

The authors have no conflicts of interest to declare.

Acknowledgements

The SPOTLIGHT project was funded by the Seventh Framework Programme (CORDIS FP7) of the European Commission, HEALTH (FP7-HEALTH-2011-two-stage), grant agreement no. 278186. The content of this article reflects only the authors' views, and the European Commission is not liable for any use that may be made of the information contained therein.

References

1. World Health Organization. Global Recommendations on Physical Activity for Health. 2010. URL: http://whqlibdoc.who.int/publications/2010/9789241599979_eng.pdf.
2. Eurobarometer 72.3. Sport and physical activity. *Special Eurobarometer 334* 2010;**32**:98. URL: http://www.ncbi.nlm.nih.gov/pubmed/21462450.
3. World Health Organization. Global status report on noncommunicable diseases. 2014. URL: http://apps.who.int/iris/bitstream/10665/148114/1/9789241564854_eng.pdf.
4. Wanner M, Götschi T, Martin-Diener E, Kahlmeier S, Martin BW. Active transport, physical activity, and body weight in adults: a systematic review. *Am J Prev Med* 2012; **42**: 493–502. DOI: 10.1016/j.amepre.2012.01.030.
5. Pucher J, Dill J, Handy S. Infrastructure, programs, and policies to increase bicycling: an international review. *Prev Med* 2010; **50**: S106–S125. DOI: 10.1016/j.ypmed.2009.07.028.
6. Hamer M, Chida Y. Active commuting and cardiovascular risk: a meta-analytic review. *Prev Med* 2008; **46**: 9–13. DOI: 10.1016/j.ypmed.2007.03.006.
7. De Nazelle A, Nieuwenhuijsen MJ, Antó JM *et al*. Improving health through policies that promote active travel: a review of evidence to support integrated health impact assessment. *Environ Int* 2011; **37**: 766–777. DOI: 10.1016/j.envint.2011.02.003.
8. World Health Organization. Interventions on diet and physical activity: what works (summary report). 2009. URL: http://www.who.int/dietphysicalactivity/summary-report-09.pdf.
9. Rojas-Rueda D, de Nazelle A, Tainio M, Nieuwenhuijsen MJ. The health risks and benefits of cycling in urban environments compared with car use: health impact assessment study. *BMJ* 2011; **343**: d4521. DOI: 10.1136/bmj.d4521.
10. De Hartog JJ, Boogaard H, Nijland H, Hoek G. Do the health benefits of cycling outweigh the risks? *Environ Health Perspect* 2010; **118**: 1109–1116. DOI: 10.1289/ehp.0901747.
11. Oja P, Titze S, Bauman A *et al*. Health benefits of cycling: a systematic review. *Scand J Med Sci Sports* 2011; **21**: 496–509. DOI: 10.1111/j.1600-0838.2011.01299.x.
12. Rissel CE. Active travel: a climate change mitigation strategy with co-benefits for health. *N S W Public Health Bull* 2009; **20**:10–13. URL: http://www.ncbi.nlm.nih.gov/pubmed/19261210.
13. Woodcock J, Edwards P, Tonne C *et al*. Public health benefits of strategies to reduce greenhouse-gas emissions: urban land transport. *Lancet* 2009; **374**: 1930–1943. DOI: 10.1016/S0140-6736(09)61714-1.
14. Woodcock J, Banister D, Edwards P, Prentice A, Roberts I. Energy and health 3 – energy and transport. *Lancet* 2007; **370**:1078–1088. Available at: http://discovery.ucl.ac.uk/1004053/.
15. Department of Health- Physical activity- Health improvement and prevention. At least five a week. 2004. URL: http://www.bhfactive.org.uk/sites/Exercise-Referral-Toolkit/downloads/resources/cmos-report-at-least-five-a-week.pdf.
16. Pucher J, Buehler R, Bassett DR, Dannenberg AL. Walking and cycling to health: a comparative analysis of city, state, and international data. *Am J Public Health* 2010; **100**: 1986–1992. DOI: 10.2105/AJPH.2009.189324.
17. Rabl A, de Nazelle A. Benefits of shift from car to active transport. *Transport Policy* 2012; **19**: 121–131. DOI: 10.1016/j.tranpol.2011.09.008.
18. U.S. Department of Health and Social Services. The Surgeon General's Call to Action to Prevent and Decrease Overweight and Obesity, 2001. URL: http://www.cdc.gov/nccdphp/dnpa/pdf/CalltoAction.pdf.
19. Sallis JF, Cervero RB, Ascher W, Henderson KA, Kraft MK, Kerr J. An ecological approach to creating active living communities. *Annu Rev Public Health* 2006; **27**: 297–322. DOI: 10.1146/annurev.publhealth.27.021405.102100.
20. Saelens BE, Handy SL. Built environment correlates of walking: a review. *Med Sci Sports Exerc* 2008; **40**: S550–S566. DOI: 10.1249/MSS.0b013e31817c67a4.
21. Davison KK, Lawson CT. Do attributes in the physical environment influence children's physical activity? A review of the literature. *Int J Behav Nut Phys Activity* 2006; **3** 1479–5868 (Electronic): 19.
22. Bauman AE, Reis RS, Sallis JF, Wells JC, Loos RJF, Martin BW. Correlates of physical activity: why are some people physically active and others not? *Lancet* 2012; **380**: 258–271. DOI: 10.1016/S0140-6736(12)60735-1.
23. Fraser SDS, Lock K. Cycling for transport and public health: a systematic review of the effect of the environment on cycling. *Eur J Public Health* 2010; **21**: 738–743. DOI: 10.1093/eurpub/ckq145.
24. Kerr J, Emond JA, Badland H *et al*. Perceived neighborhood environmental attributes associated with walking and cycling for

transport among adult residents of 17 cities in 12 countries: the IPEN study. *Environ Health Perspect* 2015. DOI: 10.1289/ehp.1409466.

25. Foster CE, Panter JR, Wareham NJ. Assessing the impact of road traffic on cycling for leisure and cycling to work. *Int J Behav Nut Phys Activity* 2011; **8**: 61. DOI: 10.1186/1479-5868-8-61.

26. Van Holle V, Deforche B, Van Cauwenberg J *et al.* Relationship between the physical environment and different domains of physical activity in European adults: a systematic review. *BMC Public Health* 2012; **12**: 807. DOI: 10.1186/1471-2458-12-807.

27. Wendel-Vos W, Droomers M, Kremers S, Brug J, van Lenthe F. Potential environmental determinants of physical activity in adults: a systematic review. *Obesity Reviews* 2007; **8**: 425–440. DOI: 10.1111/j.1467-789X.2007.00370.x.

28. McCormack G, Giles-Corti B, Lange A, Smith T, Martin K, Pikora TJ. An update of recent evidence of the relationship between objective and self-report measures of the physical environment and physical activity behaviours. *J Sci Med Sport / Sports Med Australia* 2004; 7:81–92. Available at: http://www.ncbi.nlm.nih.gov/pubmed/15214606.

29. Mackenbach JD, Rutter H, Compernolle S *et al.* Obesogenic environments: a systematic review of the association between the physical environment and adult weight status, the SPOTLIGHT project. *BMC Public Health* 2014; **14**: 233. DOI: 10.1186/1471-2458-14-233.

30. Kirtland KA, Porter DE, Addy CL *et al.* Environmental measures of physical activity supports. *Am J Prev Med* 2003; **24**: 323–331. DOI: 10.1016/S0749-3797(03)00021-7.

31. Kweon B-S. Large-scale environmental knowledge: investigating the relationship between self-reported and objectively measured physical environments. *Env Behav* 2006; **38**: 72–91. DOI: 10.1177/0013916505280092.

32. Ding D, Gebel K. Built environment, physical activity, and obesity: what have we learned from reviewing the literature? *Health Place* 2012; **18**: 100–105. DOI: 10.1016/j.healthplace.2011.08.021.

33. Gebel K, Bauman AE, Sugiyama T, Owen N. Mismatch between perceived and objectively assessed neighborhood walkability attributes: prospective relationships with walking and weight gain. *Health Place* 2011; **17**: 519–524. DOI: 10.1016/j.healthplace.2010.12.008.

34. Ding D, Sallis JF, Kerr J, Lee S, Rosenberg DE. Neighborhood environment and physical activity among youth a review. *Am J Prev Med* 2011; **41**: 442–455. DOI: 10.1016/j.amepre.2011.06.036.

35. Prins RG, Oenema A, van der Horst K, Brug J. Objective and perceived availability of physical activity opportunities: differences in associations with physical activity behavior among urban adolescents. *Int J Behav Nutr Phys Act* 2009; **6**: 70. DOI: 10.1186/1479-5868-6-70.

36. Gebel K, Bauman A, Owen N. Correlates of non-concordance between perceived and objective measures of walkability. *Annals Behav Med: Pub Soc Behav Med* 2009; **37**: 228–238. DOI: 10.1007/s12160-009-9098-3.

37. Heesch KC, Sahlqvist S, Garrard J. Gender differences in recreational and transport cycling: a cross-sectional mixed-methods comparison of cycling patterns, motivators, and constraints. *Int J Behav Nut Phys Activity* 2012; **9**: 106. DOI: 10.1186/1479-5868-9-106.

38. Eurobarometer F. Future of transport analytical report. 2011; (March):1–67.

39. Sallis JF, Conway TL, Dillon LI *et al.* Environmental and demographic correlates of bicycling. *Prev Med* 2013; **57**: 456–460.

40. Rietveld P, Daniel V. Determinants of bicycle use: do municipal policies matter? *Trans Res A: Policy Practice* 2004; **38**: 531–550. DOI: 10.1016/j.tra.2004.05.003.

41. SafetyNet. Pedestrians & cyclists. 2009. URL: http://ec.europa.eu/transport/road_safety/specialist/knowledge/pdf/pedestrians.pdf.

42. Lakerveld J, Ben Rebah M, Mackenbach J, Charreire H *et al.* Obesity-related behaviours and BMI in five urban regions across Europe: sampling design and results from the SPOTLIGHT cross-sectional survey. *BMJ Open* 2015; **5**: e008505.

43. Lakerveld J, Brug J, Bot S *et al.* Sustainable prevention of obesity through integrated strategies: The SPOTLIGHT project's conceptual framework and design. *BMC Public Health* 2012; **12**: 793. DOI: 10.1186/1471-2458-12-793.

44. IPAQ. International physical activity questionnaire (October 2002). Long last 7 days self-administered format. 2002; 71(October). Available at: http://www.sdp.univ.fvg.it/sites/default/files/IPAQ_English_self-admin_long.pdf.

45. Craig CL, Marshall AL, Sjöström M *et al.* International physical activity questionnaire: 12-country reliability and validity. *Med Sci Sports Exerc* 2003; **35**: 1381–1395. DOI: 10.1249/01.MSS.0000078924.61453.FB.

46. Spittaels H, Foster C, Oppert J-M *et al.* Assessment of environmental correlates of physical activity: development of a European questionnaire. *Int J Behav Nut Phys Activity* 2009; **6**: 39. DOI: 10.1186/1479-5868-6-39.

47. Spittaels H, Verloigne M, Gidlow C *et al.* Measuring physical activity-related environmental factors: reliability and predictive validity of the European environmental questionnaire ALPHA. 2010.

48. Bolker BM, Brooks ME, Clark CJ *et al.* Generalized linear mixed models: a practical guide for ecology and evolution. *Trends Ecol Evol* 2009; **24**: 127–135. DOI: 10.1016/j.tree.2008.10.008.

49. Field A. Discovering statistics using IBM SPSS statistics. SAGE Publications Ltd; 2013:952.

50. Wodjao TB. A double-hurdle model of computer and internet use in American households. Job market paper presented at the International Association of Time Use Research (IATUR) Conference 2007 (October 177–19, 2007), Washington, D.C., USA.

51. Mullahy J. Specification and testing in some modified count data models, *Journal of Econometrics* 1986; **33**: 341–365.

52. Aiken LS, West SG, Pitts SC. Multiple linear regression. In: Handbook of Psychology. John Wiley & Sons, Inc.: Hoboken, New Jersey, 2003 Four:19, pp. 481–507.

53. Ghekiere A, Deforche B, Mertens L *et al.* Creating cycling-friendly environments for children: which micro-scale factors are most important? An experimental study using manipulated photographs. *Plos One* 2015; **12**: e0143302. DOI: 10.1371/journal.pone.0143302.

54. Mertens L, Van Holle V, De Bourdeaudhuij I *et al.* The effect of changing micro-scale physical environmental factors on an environment's invitingness for transportation cycling in adults: an exploratory study using manipulated photographs. *Int J Behav Nut Phys Activity* 2014; **11**: 88. DOI: 10.1186/s12966-014-0088-x.

55. Mertens L, Van Cauwenberg J, Ghekiere A *et al.* Does the effect of micro-environmental factors on a street's appeal for adults' bicycle transport vary across different macro-environments? An experimental study. *PLoS One* 2015; **10**: e0136715. DOI: 10.1371/journal.pone.0136715.

56. John P, Buehler R. Cycling for everyone: lessons from Europe. *J Transp Res Board* 2007; **2074**: 58–65.

57. Dutch bicycling federation. Continuous and integral: the cycling policies of Groningen and other European cycling cities. *Fietsberaad* 2006; **7**: 1–89. URL: http://www.cycling-embassy.org.uk/sites/cycling-embassy.org.uk/files/documents/060608_Fietsberaad.pdf.

58. Feuillet T, Charreire H, Menai M *et al.* Spatial heterogeneity of the relationships between environmental characteristics and active commuting: towards a locally varying social ecological model. *Int J Health Geogr* 2015; **14**: 12. DOI: 10.1186/s12942-015-0002-z.

59. Twaddle H, Hall F, Bracic B. Latent bicycle commuting demand and effects of gender on commuter cycling and accident rates. *Transp Res Record: J Transp Res Board* 2010; **2190** October 2015: 28–36. DOI: 10.3141/2190-04.
60. Schintler L, Root A, Button K. Women's travel patterns and the environment: an agenda for research. *Transp Res Record: J Transp Res Board* 2000; **1726** 0361–1981. DOI: 10.3141/1726-05.
61. Van Dyck D, Cardon G, Deforche B *et al.* Environmental and psychosocial correlates of accelerometer-assessed and self-reported physical activity in Belgian adults. *Int J Behav Med* 2011; **18**: 235–245. DOI: 10.1007/s12529-010-9127-4.
62. Saelens BE, Sallis JF, Frank LD. Environmental correlates of walking and cycling: findings from the transportation, urban design, and planning literatures. *Annals Behav Med: Publication Soc Behav Med* 2003;**25**:80–91. URL: http://www.ncbi.nlm.nih.gov/pubmed/12704009.
63. Van Dyck D, Cerin E, Conway TL *et al.* Perceived neighborhood environmental attributes associated with adults' transport-related walking and cycling: findings from the USA, Australia and Belgium. *Int J Behav Nutr Phys Activity* 2012; **9**: 70. DOI: 10.1186/1479-5868-9-70.
64. European Cyclists' Federation asbl. Cycle more often 2 cool down the planet! Quantifying CO2 savings of cycling. 2011. URL: http://www.ecf.com/wp-content/uploads/ECF_CO2_WEB.pdf.
65. European Cyclists' Federation asbl. Cycling and urban air quality cycling and a study of European experiences. 2014. URL: http://www.ecf.com/wp-content/uploads/150119-Cycling-and-Urban-Air-Quality-A-study-of-European-Experiences_web.pdf.
66. Ferdinand AO, Sen B, Rahurkar S, Engler S, Menachemi N. The relationship between built environments and physical activity: a systematic review. *Am J Public Health* 2012; **102**: 7–13. DOI: 10.2105/AJPH.2012.300740.

Chapter 1.2 - Objective environmental correlates of cycling for transport across five European urban regions

Mertens, L., Compernolle, S., Deforche, B., Mackenbach, J. D., Lakerveld, J., Brug, J., Oppert, JM., Glonti, K., Rutter, H., Bardos, H., De Bourdeaudhuij, I., & Van Dyck, D. Built environmental correlates of cycling for transport across Europe. *Health & Place*. (under revision)

Built environmental correlates of cycling for transport across Europe

Lieze Mertens[1], Sofie Compernolle[1], Benedicte Deforche[2,3], Joreintje D. Mackenbach[4], Jeroen Lakerveld[4], Johannes Brug[4], Célina Roda[5], Thierry Feuillet[5], Jean-Michel Oppert[5,6], Ketevan Glonti[7], Harry Rutter[7], Helga Bardos[8], Ilse De Bourdeaudhuij[1§], Delfien Van Dyck[1]

[1] Department of Movement and Sport Sciences, Faculty of Medicine and Health Sciences, Ghent University, Watersportlaan 2, B-9000 Ghent, Belgium

[2] Department of Public Health, Faculty of Medicine and Health Sciences, Ghent University, De Pintelaan 185, 4k3, B-9000 Ghent, Belgium

[3] Department of Human Biometry and Biomechanics, Faculty of Physical Education and Physical Therapy, Vrije Universiteit Brussel, Pleinlaan 2, B-1050 Brussels, Belgium

[4] Department of Epidemiology and Biostatistics, the EMGO Institute for Health and Care Research, VU University Medical Center, Amsterdam, the Netherlands

[5] Équipe de Recherche en Épidémiologie Nutritionnelle (EREN), Université Paris 13, Centre de Recherche en Épidémiologie et Statistiques, Inserm (U1153), Inra (U1125), Cnam, COMUE Sorbonne Paris Cité, F-93017 Bobigny, France

[6] Université Pierre et Marie Curie-Paris 6, Department of Nutrition Pitié-Salpêtrière Hospital (AP-HP), Centre for Research on Human Nutrition Ile-de-France (CRNH IdF), Institute of Cardiometabolism and Nutrition (ICAN), Paris, France

[7] ECOHOST – The Centre for Health and Social Change, London School of Hygiene and Tropical Medicine, London, UK

[8] Department of Preventive Medicine, Faculty of Public Health, University of Debrecen, Hungary

[§] Corresponding author

Address for correspondence: Prof. Dr. Ilse De Bourdeaudhuij, Department of Movement and Sport Sciences, Ghent University, Watersportlaan 2, 9000 Gent, Belgium

E-mail: Ilse.Debourdeaudhuij@Ugent.be

Competing interests: The authors declare that they have no competing interests.

Abstract

This cross-sectional study aimed to determine which objective built environmental factors, identified using a virtual neighbourhood audit, were associated with cycling for transport in adults living in five urban regions across Europe. The moderating role of age, gender, socio-economic status and country on these associations was also investigated. Overall, results showed that people living in neighbourhoods with a preponderance of speed limits below 30 km/h, many bicycle lanes, with less traffic calming devices, more trees, more litter and many parked cars forming an obstacle on the road were more likely to cycle for transport than people living in areas with lower prevalence of these factors. Evidence was only found for seven out of 56 possible moderators of these associations. These results suggest that reducing speed limits for motorized vehicles and the provision of more bicycle lanes may be effective interventions to promote cycling in Europe.

Keywords: Active transport, Built Environment, Cycling, Google Street View, Virtual audit

Highlights:

- Speed limits below 30km/h were associated with more cycling for transport
- The presence of bicycle lanes was associated with more cycling for transport
- These associations were similar across different subgroups

Background

Regular physical activity (PA) can reduce the risk of chronic diseases, such as cardiovascular diseases, type 2 diabetes, and certain types of cancer (World Health Organization, 2010), and is an important part of treatment and rehabilitation of chronic conditions (World Health Organization, 2015). However, more than one third of the global adult population does not meet the PA public health recommendations of 150 min/week moderate to vigorous PA (World Health Organization, 2015, 2010). Cycling for transport has the potential to contribute to increased PA levels among adults, since it is an accessible and inexpensive form of activity that can be incorporated in everyday life throughout adult life (Menai et al., 2015; Oja et al., 2011; Pucher et al., 2010a; Rabl and de Nazelle, 2012; World Health Organization, 2010). Additionally, cycling may also lead to economic benefits, reduced CO_2-emissions, noise and air pollution, and reduced traffic congestion (Rabl and de Nazelle, 2012). Nevertheless, cycling remains an under-used form of transport compared to motorized modes in most countries (Eurobarometer, 2011). There are plentiful opportunities to increase cycling levels in European cities, given that around 40% of all trips are less than 2.5 kilometres, and 50% of all car trips are shorter than 5 kilometres (Dekoster and Schollaert, 1999; Janssens et al., 2014; Pucher and Buehler, 2007). These distances could be covered by bicycle by most adults or by most people, and cycling may often be even quicker than driving in some urban areas (Ministry of Transport/ Public Works and Water Management, 2009; Rudinger et al., 2006). Communities and cities can contribute to increasing cycling levels in adults by providing cycling-friendly environments (Buehler and Pucher, 2012; Commission of the European Communities, 2007). Next to individual-level factors (such as socio-demographics, abilities and motivations), socio-ecological models emphasise the importance of the physical or built environment in explaining behavior change (Sallis et al., 2006), or more specifically cycling for transport. Therefore, it is necessary to identify the most relevant physical environmental correlates of cycling for transport.

Both objective and perceived attributes of the built environment have been found to be important for cycling for transport and have previously shown distinct associations with cycling for transport (Heesch et al., 2012; Ma and Dill, 2015). Since, these two methods assess two distinct dimensions of the physical environment (Ding and Gebel, 2012; Kirtland et al., 2003; Kweon, 2006; Mackenbach et al., 2014), it is important to distinguish the objective and perceived environmental correlates of cycling for transport. Self-reported outcomes (i.e. perceived attributes of the built environment) may be biased through recall bias (i.e. participants may have difficulty to recall information) or social desirability bias (i.e. participants want to fit with social expectations) (Adams et al., 2005). Since objective measurement methods rely on information obtained by an external person or from solid data coming from a device, they often meet the disadvantages (e.g. recall bias, social desirability) of self-report methods (Sallis et al., 2009). The objective built environment is directly and indirectly (i.e. by influencing individual's perceptions of the built environment) associated with the cycling behavior (Ewing and Handy, 2009; Gebel et al., 2009; Heesch et al., 2015; Ma, 2014; Prins et al., 2009; Sallis et al., 2008, 2006; Winters et al., 2010). Most previous studies have used existing spatial data (e.g. based on Geographic Information Systems, GIS) to examine the objective built environment in relation to cycling for transport (Brownson et al., 2009; Ma and Dill, 2015). However, these studies were only able to draw conclusions about the macro-environment (i.e. raw urban planning features, such as street connectivity or residential density) because GIS-data about the micro-environment are often lacking. Nevertheless, the micro-environment is more feasible to adjust in environmental interventions since these factors are relatively small-scaled (e.g. speed limits, or vegetation) and only influenced by local actors or individuals, while adjustments to the macro-environment requires extensive collaboration between authorities (Cain et al., 2014; Swinburn et al., 1999). Consequently, evidence about the association between the objectively determined micro-environment and cycling for transport is still scarce and less consistent in comparison to the association with the macro-environment (Van Holle et al., 2014). For example, a study by Parkin et al. found that objectively measured traffic volumes were negatively related with cycling for transport (Parkin et al., 2008), while other studies have not found an association between objectively determined traffic volume and cycling for transport (Foster et al., 2011; Moudon et al., 2005). Another study has shown that the impact of traffic volume on cycling differed substantially between regions within the same country (Vandenbulcke et al., 2011). Furthermore, the role of aesthetics (e.g. presence of vegetation, trees, litter) to explain cycling for transport is inconclusive. Several studies have found positive associations between greenery and cycling for transport (Lee and Moudon, 2008; Wendel-vos et al., 2004), while other studies have not found an association between aesthetics and cycling for transport (Van Holle et al., 2012). Therefore, there is a need for empirical evidence about the association between objectively determined detailed environmental characteristics and cycling for transport.

The use of desk-based rating of the built environment using remote imaging sources such as Google Street View (GSV) or Bing Maps is now increasing (Bethlehem et al., 2014; Charreire et al., 2014; Curtis et al., 2013; Vanwolleghem et al., 2014). These remote sensing techniques can capture large-scale environments in detail efficiently, and in a way that is both standardized and quality controlled (Bethlehem et al., 2014; Charreire et al., 2014; Mooney et al., 2014; Odgers et al., 2013). Another important advantage of using a virtual audit tool is the possibility of obtaining harmonized data across different countries. Since this is a relatively new methodology, empirical evidence on the relation between objectively determined built environmental factors using virtual audits and cycling for transport is still scarce (Bauman et al., 2012; Fraser and Lock, 2010; Heinen et al., 2010; Pucher et al., 2010b; Yang and Sahlqvist, 2010).

Furthermore, previous research has already demonstrated that cycling for transport varies depending on gender, age, education level or country (Eurobarometer, 2011; Heesch et al., 2012; Rietveld and Daniel, 2004; SafetyNet, 2009; Sallis et al., 2013). Therefore, it might be necessary to include these socio-demographics as moderators in studies investigating the physical environment (Ewing and Handy, 2009; Wen et al., 2006), as these factors might help to clarify certain inconsistent associations between objective built environmental factors and cycling for transport."

This cross-sectional study aimed to identify which objective physical environmental neighbourhood factors, assessed via a virtual audit, are associated with cycling for transport in adults living in five urban regions across Europe. We also investigated whether these associations were moderated by socio-demographic variables such as age, gender, socio-economic status (SES) and urban region.

Methods

Study design and sampling

This study was part of the SPOTLIGHT project, a cross-European research project that aimed to enhance knowledge about the wide range of determinants of obesity, and provide an evidence-based model for effective integrated intervention approaches (Lakerveld et al., 2015, 2012). Research was conducted in five large cities (urban regions) of five European countries which were defined as study areas: Ghent region (Belgium), Paris region (France), greater Budapest (Hungary), Randstad region (The Netherlands) and Greater London (the United Kingdom). Neighbourhoods were considered according to local administrative boundaries in each country except for Hungary because their districts are much larger than the equivalent administrative areas of the other countries. Therefore, the study areas were defined as 1 km^2 areas in greater Budapest to guarantee comparability between study areas. The average study area of a neighbourhood (across all five countries) was 1.5 km^2 with a mean population density of 2700 inhabitants per neighbourhood (Lakerveld et al., 2015). The neighbourhood sampling was based on a combination of residential density and socioeconomic status (SES) data at the neighbourhood level. This resulted in four types of neighbourhoods: low SES/low residential density, low SES/high residential density, high SES/low residential density and high SES/high residential density. In each country, three neighbourhoods of each neighbourhood type were randomly sampled (i.e. 12 neighbourhoods per country, 60 neighbourhoods in total). Subsequently, a random sample of adult inhabitants (age $\geq$ 18 years) was invited to participate in an online survey. The survey contained questions on demographics, neighbourhood perceptions, social environmental factors, health, motivations and barriers for healthy behavior, obesity-related behaviors and weight and height. A total of 6,037 (10.8%, out of 55893 invited persons) individuals participated in the study between February and September 2014. The study was approved by the corresponding local ethics committees of participating countries and all survey participants provided informed consent.

Measures

Demographic variables

The following demographic variables were reported: age, gender, educational level and country of residence (Belgium, France, Hungary, the Netherlands, or United Kingdom). Educational level of participants was divided into two categories to enable comparison between the country-specific education systems: lower education (no education, primary, lower secondary or higher secondary) and higher education (bachelor or master degree). Furthermore, age was split into two groups using the median of the study population: younger adults (18-46 years) and older adults (46-65 years).

Cycling for transport

Self-reported cycling for transport was measured using an adapted form of the last seven day self-administrated long version of the International Physical Activity Questionnaire (IPAQ) (IPAQ, 2002). In this questionnaire the amount (number of days in the last seven days) and duration (average time/day) of transport-related cycling was assessed (IPAQ, 2002). The IPAQ showed good reliability (Spearman's correlation coefficients clustered around 0.80) and acceptable criterion validity (median $\rho = 0.30$) for adults carried out in a 12-country study (Craig et al., 2003).

Objective physical environmental neighbourhood factors

An objective assessment of physical environmental neighbourhood characteristics was conducted using the SPOTLIGHT Virtual Audit Tool (S-VAT). A detailed description of the development of the S-VAT is reported elsewhere (Bethlehem et al., 2014). The S-VAT consists of 40 different physical environment items related to walking infrastructure (e.g. maintenance of sidewalks), cycling infrastructure (e.g. presence and type of bicycle lanes), public transport (e.g. presence or type of public transport), aesthetics (e.g. presence of green space), land use-mix (e.g. type of residential buildings), grocery stores (e.g. presence of supermarkets), food outlets (e.g. presence of fast-food restaurants) and recreational facilities (e.g. presence of swimming pool), and was judged in all street segments of the covered neighbourhoods. In one neighbourhood in Hungary no Google Street View (GSV) data were available at the time of the virtual audit, resulting in a total of 59 neighbourhoods in the study. In total, 4486 street segments were audited. The virtual audit was conducted by trained researchers of the

SPOTLIGHT project team. A Standard Operating Procedure (SOP) was developed to assist in scoring by defining environmental characteristics and street segments, or by providing clear instructions for data extraction and storage and is available open access (Bethlehem et al., 2014). The physical environmental factors determined from the street segment level were aggregated to the neighbourhood level by accumulating the outcomes for the street segments within each neighbourhood (Feuillet et al., 2016). For example, if 100 of the 500 street segments of a neighbourhood were qualified as ‘no bicycle lanes', then the feature ‘no bicycle lanes present’ was quantified as 0.20 in this neighbourhood. The S-VAT tool proved to have good to high criterion validity, and intra-observer and inter-observer reliability (Bethlehem et al., 2014).

In this study only environmental factors related to cycling infrastructure (eight items) and aesthetics (four out of nine items) were included. A selection of the relevant predictor variables (objective neighbourhood factors) was based on the prevalence of the items and on the variance inflation factor (VIF), ensuring no multicollinearity between these factors (VIF < 2) (Field, 2013). These selection methodologies were used by previous research (Handy and Xing, 2011; Ma and Dill, 2015; Wahlgren and Schantz, 2012; Wen et al., 2006). When collinearity occurred, the variables with the strongest correlations with the dependent variable were retained. This resulted in the eliminating of the following five environmental factors: type of street, presence of graffiti, obstacles on bicycle lanes, type of bicycle lanes, and public bicycle facilities. Finally, seven environmental factors were included in the analyses: presence of traffic calming features (such as speed humps, traffic island, roundabouts or traffic lights), speed limit ≤ 30 km/h, absence of bicycle lanes, cars that form an obstacle on the road, presence of green and water areas, presence of trees, presence of litter. Cars that form an obstacle on the road are defined in this study as cars parked on the road and/or partly on the sidewalk regardless of whether this is done legally or illegally. If cars are parked on the sidewalk and/or on cycle path and cyclists and/or pedestrians have to manoeuvre around these cars, they form an obstacle. For the included environmental factors, the inter-observer reliability ranged from 46.1% agreement (Cohen’s kappa, k=0.010) to 99.2% agreement (k=1.00), the intra-observer reliability results ranged from 76.6 % agreement (k=0.520) to 99.2 % agreement (k=0.973) and the criterion validity from 60.2

% agreement (k=0.168) to 98.4% agreement (k=0.947) (Bethlehem et al., 2014). The lowest percentages agreement and Cohen's kappa scores arose from the environmental factor 'litter', due to the subjectively of the judgements by the auditor, or the possible difficulty to virtually assess this item because of obstructions on the road (e.g. cars, trees) which could block the view of the images (Bethlehem et al., 2014). A detailed overview of all percentage agreement and Kappa statistics for all included SPOTLIGHT-VAT items is provided in a previous paper of the SPOTLIGHT study (Bethlehem et al., 2014).

Statistical analyses

Individuals who could not be allocated to one of the 59 selected neighbourhoods were excluded from the analyses, resulting in a sample of 5,205 participants. As we were interested in the cycling behaviors of adults of working age (i.e. 18-65 years) only, the study population included 3,904 adults.

Descriptive statistics of the sample were obtained using SPSS 22.0 software. To examine the main associations between objective physical environmental factors and cycling for transport, and the moderating effects of age, gender, educational level and urban region, complete case regression analyses were conducted in R (version 3.1.2) (Bolker et al., 2009) with Package 'lme4' (Douglas et al., 2016). Since the dependent variable (minutes cycling for transport per week) included an excessive number of null values (51.6%), Hurdle models were fitted for all analyses. Hurdle models consist of two parts: a logistic regression model (binomial variance and logit link function), estimating the odds of participation in cycling for transport (yes/no) and a gamma regression model (gamma variance and log link function), estimating the amount of minutes cycling for transport among those who cycled for transport in the last seven days (minutes/week). The need to model both behaviors separately has also been suggested by previous research (Ma and Dill, 2015). The models were fitted by Adaptive Gauss-Hermite Quadrature with 25 quadrature points as recommended (Bolker et al., 2009) and the Akaike's Information Criterion (AIC) minimization was used to select the most appropriate variance and link function causing the best model fit. These Hurdle models resulted in two regression coefficients for each predictor or independent variable: an odds ratio (OR) and a gamma regression coefficient.

For each model separately, a basic model was estimated including all main effects of the seven independent variables (objectively measured neighbourhoods factors) together with the four potential moderators (i.e. age, gender, educational level and urban regions), adjusted for neighbourhood type (i.e. neighbourhood SES and residential density) and for the clustering of participants within neighbourhoods. In a second step, each single interaction effect between a neighbourhood factor and a potential moderator was added to the basic model. Since there were seven neighbourhood factors and four potential moderators, 28 possible models were fitted for each part of the Hurdle model. The interaction effects that were found to be significant ($p<0.05$) in the previous step were then added to the basic model. Finally, in order to simplify this final model, non-significant interaction effects were removed from the model. To calculate the estimates for each category, stratified analyses were performed. These steps were followed for each part of the Hurdle models, namely the logistic regression model and the gamma regression model. Level of significance was set at a two-sided α of 0.05.

Results

Descriptive statistics

The characteristics of the study population and the presence of objectively measured physical environmental neighbourhood factors are presented in Table 1.

Table 1. Descriptive characteristics of the participants (n = 3,904).

Characteristics	
Age in years (M (SD)) (n=3,904)	45.5 (12.3)
Women (%) (n=3,887)	58.0
Urban regions (country) (%) (n=3,904)	
- Ghent region (Belgium)	31.9
- Paris region (France)	14.4
- Greater Budapest (Hungary)	15.0
- Randstad region (Netherlands)	28.2
- Greater London (UK)	10.5

Level of education (%) (n=3,552)	
- Lower	38.3
- Higher	52.7
Type of neighbourhood (%) (n=3,904)	
- H-SES/H-dens	26.9
- H-SES/L-dens	22.1
- L-SES/H-dens	26.5
- L-SES/L-dens	24.5
Current cycling for transport level (n=3,730)	
- Cycling for transport in the last week (%)	48.4
- Min/week among those who cycled (M (SD))	139.4 (237.9)
***Objective built environmental neighbourhood factors* (n=3,904)[a]**	
- Traffic calming features (M (SD))	0.36 (0.24)
- Speed limit ≤ 30 km/h (M (SD))	0.45 (0.32)
- No bicycle lanes (M (SD))	0.83 (0.14)
- Cars form obstacle on the road (M (SD))	0.30 (0.23)
- Presence of green and water areas (M (SD))	0.37 (0.34)
- Presence of trees (M (SD))	0.82 (0.23)
- Presence of litter (M (SD))	0.19 (0.25)

M= mean; SD= standard deviation; H-SES= high socio-economic status; L-SES= low socio-economic status; H-dens= high residential density; L-dens= low residential density; [a]= percentages of street segments in the neighbourhoods in which these characteristics are present

Main and moderated associations for the odds of cycling for transport

Table 2 shows the results of the logistic regression model adjusted for age, gender, education level, neighbourhood type, urban region and for the clustering of participants within neighbourhood. Living in a neighbourhood with more traffic calming features, or fewer bicycle lanes, was associated with being less likely to engage in cycling for transport in the last seven days. On the other hand, living in a neighbourhood with more streets where the speed limit is ≤ 30 km/h, more parked cars that form an obstacle on the road, more trees, or more litter were all associated with being more likely to engage in cycling for transport.

The significant moderating effects found for this model are presented in Table 3. The association of presence of traffic calming features with engaging in cycling for transport was significantly moderated by urban region ($p<0.001$), and turned out to be only significant for the Ghent region in Belgium ($p<0.05$). Residents from the Ghent region living in a neighbourhood with more traffic calming features were more likely to engage in cycling for transport than those living in a neighbourhood with fewer traffic calming features (OR= 16.00, 95% CI=1.16, 220.82). However in the Paris region, greater Budapest, the Randstad region and Greater London no significant association was found between the presence of traffic calming features and the odds of cycling for transport. Another significant moderating effect by urban region was found for the association between presence of litter and the odds of engaging in cycling for transport: the effect of litter was only significant in the Paris Region and not in the Ghent region, greater Budapest, the Randstad region, and Greater London. Residents of the Paris region living in a neighbourhood with more litter were less likely to engage in cycling for transport than residents of the Paris region living in a neighbourhood with less litter (OR= 0.04, 95% CI=0.00, 0.06).

Age moderated the association between cars that form an obstacle on the road and the odds of engaging in cycling for transport ($p<0.001$). This effect was significant for both younger adults (18-45 years) and older adults (46-65 years) from this sample but was stronger in the younger population. Younger adults living in a neighbourhood with more cars that form an obstacle on the road were more likely to engage in cycling for transport (OR= 14.03, 95% CI= 4.30, 45.76) in comparison to older adults (OR=6.45, 95% CI= 1.64, 25.32).

The association of presence of trees with engaging in cycling for transport was significantly moderated by education ($p<0.001$), and turned out to be only significant for people with a low education level and not significant for people with a high education level. People with a low education level living in a neighbourhood with more trees were more likely to engage in cycling for transport (OR= 15.93, 95% CI= 3.57, 71.11).

Lastly, the association of presence of green and water areas with engaging in cycling for transport was significantly moderated by gender ($p<0.05$). However, this effect was not significant for either men or women.

Table 2. Main associations for the odds of cycling for transport (Logistic model) and for minutes cycling for transport (Gamma model).

	Logistic model[1] (n=3514; AIC=3999.9)	**Gamma model**[2] (n= 1713; AIC=1641.6)
Main effects	*OR (95% CI)*	*Exp* β[3] *(95% CI)*
Traffic calming features	0.02 (0.00, 0.31)**^	0.90 (0.63, 1.28)
Speed limit ≤30km/h	6.68 (1.57, 28.39)*	1.13 (0.79, 1.62)
No bicycle lanes	0.09 (0.01, 0.68)*	0.80 (0.46, 1.38)
Cars form an obstacle on the road	14.56 (4.26, 49.80)***^	1.61 (1.04, 2.51)*^
Green and water areas	0.67 (0.24, 1.87)^	1.08 (0.88, 1.33)
Trees	15.65 (3.58, 68.37)***^	0.68 (0.49, 0.93)*
Litter	37.37 (2.91, 479 .59)**^	0.99 (0.71, 1.39)^

*p< 0.05, **p< 0.01, ***p< 0.001; OR= odds ratio of engaging in cycling for transport; CI= confidence interval; ^= variable which is significantly moderated; [1] The logistic model estimates the association between the independent variables (physical environmental factors) and the odds of engaging in cycling for transport; [2] The gamma model estimates the association between the independent variables (physical environmental factors) and the amount of minutes cycling for transport among those who cycled for transport in the last seven days; [3] Exp β = exponent of β, all gamma models were fitted using a log link function, the exponent of β can be interpreted as the proportional increase of the dependent variable with one percentage increase in the independent variable; AIC= Akaike's Information Criterion

Main and moderated associations for minutes of cycling for transport

The results of the gamma model are shown in Table 2. Living in a neighbourhood with more cars that form an obstacle on the road was associated with more minutes of cycling for transport per week (exp(β)= 1.61, 95% CI= 1.04, 2.51). Living in a neighbourhood with more trees was associated with fewer minutes of cycling for transport per week (exp(β)= 0.68, 95% CI= 0.49, 0.93).

The significant moderating effects found for the gamma model are presented in Table 3 as well. The association of cars that form an obstacle on the road with the amount of cycling for transport was significantly moderated by urban region (p<0.01). In stratified analyses, the association was non-significant in all urban regions included. Finally, the association between the presence of litter with the amount of cycling for transport among those who indicated to have cycled in the last seven days was significantly moderated by gender (p<0.05). However, this association appeared not to be significant in the analyses stratified by gender.

Table 3. Moderating associations for the odds of cycling for transport (Logistic model) and for minutes cycling for transport (Gamma model).

	Logistic model[1] (n=3,514 ; AIC=3999.9)	**Gamma model**[2] (n= 1,713 ; AIC=1641.6)
Moderating effects	*OR (95% CI)*	*Exp* β[3] *(95% CI)*
Traffic calming features x regions*	***2.19 (1.40, 3.41)****	
- Ghent region (Belgium)	16.00 (1.16, 220.82)*	
- Paris region (France)	0.59 (0.05, 6.87)	
- Greater Budapest (Hungary)	0.00 (0.00, 1.08 e12)	
- Randstad region (Netherlands)	1.65 (0.30, 9.24)	
- Greater London (UK)	5.17 (0.01, 4792.44)	
Cars form an obstacle on the road x age*	***0.23 (0.10, 0.51)****	
- Younger adults (18-46 years)	14.03 (4.30, 45.76)***	
- Older adults (46-65 years)	6.45 (1.64, 25.32)**	
Green and water areas x gender*	***0.42 (0.20, 0.85)****	
- Men	0.96 (0.40, 2.30)	
- Women	1.11 (0.32, 3.81)	
Trees x education**	***0.19 (0.07, 0.52)*****	
- Low educational level	15.92 (3.57, 71.11)***	
- High educational level	3.76 (0.91, 14.52)	
Litter x regions**	***15.15 (4.59, 50.07)*****	
- Ghent region (Belgium)	0.04 (0.00, 1.53)	
- Paris region (France)	0.04 (0.00, 0.07)*	
- Greater Budapest (Hungary)	0.00 (0.00, 7.31 e9)	
- Randstad region (Netherlands)	0.17 (0.03, 1.15)	
- Greater London (UK)	3.40 (0.13, 80.62)	
Cars form an obstacle on the road x regions**		***1.59 (1.14, 2.22)*****
- Ghent region (Belgium)		2.25 (0.55, 9.20)
- Paris region (France)		7.19 (0.00, 5.64 e9)
- Greater Budapest (Hungary)		78.77 (0.24, 26347.81)
- Randstad region (Netherlands)		0.82 (0.41, 1.65)
- Greater London (UK)		0.97 (0.01, 90.27)
Litter x gender*		***0.78 (0.64, 0.96)****
- Men		1.07 (0.74, 1.56)
- Women		1.38 (0.92, 2.07)

*p< 0.05, **p< 0.01, ***p< 0.001; OR= odds ratio of engaging in cycling for transport; CI= confidence interval; [1] The logistic model estimates the association between the independent variables (physical environmental factors) and the odds of engaging in cycling for transport; [2] The gamma model estimates the association between the independent variables (physical environmental factors) and the amount of minutes cycling for transport among those who cycled for transport in the last seven days; [3] Exp β= exponent of β, all gamma models were fitted using a log link function, the exponent of β can be interpreted as the proportional increase of the dependent variable with one percentage in the independent variable; AIC= Akaike's Information Criterion

Discussion

We investigated the association between objectively measured built environment characteristics and cycling for transport in and across five urban regions across Europe among adults. Furthermore, we explored the moderating role of age, gender, education and urban region on these associations.

Overall, results showed that living in neighbourhoods with more streets where speed limits are ≤ 30 km/h, with more bicycle lanes, with traffic calming devices being absent, more trees present, more litter present and with more parked cars that form an obstacle on the road was associated with being more likely to engage in cycling for transport. Previous studies have indicated that cyclists find it important to have restrictive speeds for motorized traffic when they have to share the road (Mertens et al., 2016b, 2015; Pucher and Buehler, 2008, 2007; Titze et al., 2010). Moreover, zones where the maximum speed is limited to 30 km/h are proved to reduce the number and severity of bicycle crashes (Grundy et al., 2009). In addition to speed limits of <30 km/h, the presence of bicycle lanes in the neighbourhood was also associated with higher odds of cycling for transport. This finding supports results from previous studies (Fraser and Lock, 2010; Ma and Dill, 2015; Mertens et al., 2016b; Winters et al., 2010).

The presence of parked cars that form an obstacle on the road was associated with higher odds of engaging in cycling for transport and also with more minutes cycling for transport per week. However, previous qualitative research demonstrated that cyclists experience these obstacles as disturbing, since they do not allow a good overview of the traffic situation and could be dangerous because of the possibility of suddenly opening doors (Ghekiere et al., 2014). A possible explanation for this finding might be the fact that the cycling levels are higher in busy urban neighbourhoods with high levels of car use as well as bicycle use (Douglas et al., 2011; Van Holle et al., 2012). Consequently, people will cycle in such neighbourhoods despite of the parked cars even if they bother them. Additionally, the association was significantly moderated by age: the association was stronger for the younger adults (18-46 years) compared to the older adults (46-65 years) and could be possibly explained by the fact that younger adults are more likely to feel safe to cycle in these traffic dense neighbourhoods, and are thus more likely to cycle in them.

The environmental factors mentioned above appeared to be rather general predictors, with the same direction of associations across age groups, gender, educational level, or urban region (with the exception of a few associations). If supported by evidence from (quasi-) experimental or longitudinal studies this is promising for future interventions, as focusing on these specific factors would not disadvantage specific subgroups. For example, if these results are duplicated by other studies that allow more for causal inference, adapting speed limits to ≤ 30 km/h and providing clear and unobstructed cycling lanes might help to encourage more population groups to cycle for transport.

However, for some other environmental factors, moderating effects of socio-demographic variables were found. People living in a neighbourhood with more trees were more likely to engage in cycling for transport, but this was only significant for individuals with a low educational level, while in general the presence of trees was associated with fewer minutes cycling for transport per week among those who had cycled in the last seven days. Furthermore, the main effect of providing traffic calming features and the presence of litter showed respectively a positive and negative association with cycling for transport. However, a significantly moderated effect by urban region was found; providing traffic calming features may increase the likelihood of cycling for transport in the Ghent region and removing litter may help in the Paris region. No association with the other regions was detected. A possible explanation of the moderated effect is that the associations of the other countries are in the opposite direction, but not strong enough to be significant. Examining a larger sample in each subgroup (e.g. educational level) or each urban region might give more clarity about association in these smaller subgroups. These findings need further exploration and future studies should replicate these findings to confirm the importance of specific built environmental features for some subgroups.

A previous study indicated that the objective physical environment had the greatest influence on the decision about whether or not to cycle and not on the amount or duration of cycling (Ma and Dill, 2015). Consequently, it might be that environmental factors in the residential neighbourhood are less important when individuals cycle longer distances, since they are likely to travel through and to other neighbourhoods. Therefore, future studies examining the built environmental determinants of the amount of cycling will also need to look at the physical environmental factors of the neighbourhoods adjacent to the one a person lives in. Another possibility is to assess also the work environment of individuals in addition to their residential environment (Chaix et al., 2012; Kestens et al., 2010; Perchoux et al., 2013). Since the cycling environment of an individual is often larger than the determined residential neighbourhood, it needs to be investigated further which neighbourhood definition is most relevant to map the activity space regarding cycling for transport of an individual.

In a previously conducted study (Mertens et al., 2016a) within the SPOTLIGHT project, we investigated the perceived environment related to cycling. Although most of the perceived measures were not comparable to the objective measures, we did find that perceived lower traffic speeds were associated with higher odds of cycling for transport. These results are comparable with findings in this study, showing that objectively assessed traffic speed levels of 30 km/h or less were associated with higher odds of cycling. However, people's perceptions of their environment may not always match with objective characteristics of the environment in which they live (Gebel et al., 2011; Ma and Dill, 2015; Roda et al., 2016). For example, in the current study the objectively measured attribute 'no bicycle lanes' was positively associated with the odds of engaging in cycling, however, the perceived attribute 'presence of bicycle lanes' previously showed no association with cycling for transport (Mertens et al., 2016a). Nevertheless, both objective and perceived attributes of the built environment have been found to be important for cycling for transport and future research is needed to provide more insight about this association.

Strengths of this study include a large study sample of European adults living in five urban regions was used, enabling the possibility to perform inter-country comparisons. Additionally, the use of the validated GSV tool which can capture the objective physical environment in detail (Bethlehem et al., 2014; Curtis et al., 2013; Rundle et al., 2011). However, the use of GSV images also has some disadvantages, such as the risk of some obstructed views (e.g. obstacles on the images) or the impossibility to report field audit items such as noises, odours, traffic speeds and cycle path widths (Rundle et al., 2011). In addition, there were some locations where there was a mismatch in the dates of the GSV data, with the oldest images dated from 2008, and the field audits conducted in 2014 (Bethlehem et al., 2014). Furthermore some other limitations should be acknowledged. First, the cross-sectional study design does not support causal inferences, and does not exclude the problem of self-selection (e.g. Do people cycle more because they live in a cycling-friendly environment, or do they choose to live in a cycling-friendly environment because they like to cycle?) (Transportation Research Board, 2005). Therefore, stronger experimental or longitudinal designs are needed to close this research gap (Bauman et al., 2012; Sallis et al., 2013). Furthermore, our present findings need to be confirmed by studies with those stronger designs since they enable causal interference with regard to the impact of the objective physical environmental factors on cycling for transport (Bauman et al., 2012; Ferdinand et al., 2012). Second, several moderating effects turned out not to be significant when looking only at the subgroups. Consequently, examining a larger sample might give more clarity about associations in these smaller subgroups. Third, some pronounced high or low odds ratios are possible due to a small variance in built environmental factors or in the behavior between the five urban regions. Fourth, the results including the objective environmental factor ‘litter’ should be interpreted with some caution, since this factor has the lowest percentages agreement and Cohen’s kappa scores (Bethlehem et al., 2014). Fifth, the low response rate of (10%), while common in large European surveys (Neill et al., 1995), means that generalization of these results should be approached with caution. Furthermore, since most participants come from Belgium and the Netherlands, we have to be careful when applying those general results to each country separately. Lastly, we have to be aware of the modifiable Areal Unit Problem (MAUP) which is a result of the definition of data collection units. In the SPOTLIGHT project, neighbourhoods were defined according to local administrative boundaries, but results (objective physical environment – cycling for transport) could be entirely different if the ‘neighbourhood’ was defined differently (i.e. MAUP). We suggested that future studies examining the built environmental determinants of the amount of cycling should also look at the physical environmental factors of the adjacent neighbourhoods in which one lives or other neighbourhoods (e.g. work environment of individuals) as cyclists often travel longer distances than only their residential neighbourhood. Since the cycling environment of an individual is often larger than the determined residential neighbourhood, it needs to be investigated further which neighbourhood definition is most relevant to map the activity space regarding cycling for transport of an individual. Taking into consideration the MAUP, it would be even better to objectively determine the activity space of an individual, for example with the use of GPS devices. These devices make it possible to investigate which cycling routes participants' actual take (e.g. the shortest route, the safest route or the prettiest route) and to compare the objective environmental factors along these routes.

Conclusions

People living in neighbourhoods with a preponderance of speed limits below 30 km/h, many bicycle lanes, with traffic calming devices being absent, more trees present, more litter present and many parked cars forming an obstacle on the road were more likely to cycle for transport than people living in areas with lower prevalence of these factors. Among people who reported cycling in the previous seven days, those living in neighbourhoods with more parked cars (as road obstacles), and neighbourhoods with fewer trees, reported more time per week spent cycling for transport. Moderating effects were only found for seven out of 56 examined possible moderators. If supported by evidence from large-scale (quasi-) experimental or longitudinal studies this is promising for future interventions, as focusing on these specific factors could be positive for everyone, or could be more favourable for some subgroups in comparison to others, without disadvantaging those others. Consequently, our study results suggest the need to test in future studies that the provision of bicycle lanes and reducing speed limits for motorized vehicles may be effective interventions to promote cycling in Europe. Future studies examining the built environmental determinants of the amount of cycling should also look at the physical environmental factors of the adjacent neighbourhoods in which one interacts and of the work environments.

Acknowledgements

This work is part of the SPOTLIGHT project funded by the Seventh Framework Programme (CORDIS FP7) of the European Commission, HEALTH (FP7-HEALTH-2011-two-stage), Grant agreement No.278186. The content of this article reflects only the authors' views and the European Commission is not liable for any use that may be made of the information contained therein.

Authors' contributions

The WP3 SPOTLIGHT group (SC, JL, JM, HB, HR, KG and JMO) developed the questionnaire, research protocol and conducted the data collection. LM performed the data analysis and drafted the manuscript supervised by SC, FG, BD, IDB. All other co-authors critically reviewed and revised versions of the manuscript and each of them read and approved the final manuscript.

Competing interests

The authors declare that they have no competing interests.

References

Bauman, A.E., Reis, R.S., Sallis, J.F., Wells, J.C., Loos, R.J.F., Martin, B.W., 2012. Correlates of physical activity: why are some people physically active and others not? Lancet 380, 258–71. doi:10.1016/S0140-6736(12)60735-1

Bethlehem, J.R., Mackenbach, J.D., Ben-rebah, M., Compernolle, S., Glonti, K., Bárdos, H., Rutter, H.R., Charreire, H., Oppert, J., Brug, J., Lakerveld, J., 2014. The SPOTLIGHT virtual audit tool: a valid and reliable tool to assess obesogenic characteristics of the built environment. Int. J. Health Geogr. 13, 52. doi:10.1186/1476-072X-13-52

Bolker, B.M., Brooks, M.E., Clark, C.J., Geange, S.W., Poulsen, J.R., Stevens, M.H.H., White, J.-S.S., 2009. Generalized linear mixed models: a practical guide for ecology and evolution. Trends Ecol. Evol. 24, 127–35. doi:10.1016/j.tree.2008.10.008

Brownson, R.C., Hoehner, C.M., Day, K., Forsyth, A., Sallis, J.F., 2009. Measuring the built environment for physical activity: state of the science. Am. J. Prev. Med. 36. doi:10.1016/j.amepre.2009.01.005.Measuring

Buehler, R., Pucher, J., 2012. Walking and Cycling in Western Europe and the United States. TR NEWS 280.

Cain, K.L., Millstein, R. a, Sallis, J.F., Conway, T.L., Gavand, K. a, Frank, L.D., Saelens, B.E., Geremia, C.M., Chapman, J., Adams, M. a, Glanz, K., King, A.C., 2014. Contribution of streetscape audits to explanation of physical activity in four age groups based on the Microscale Audit of Pedestrian Streetscapes (MAPS). Soc. Sci. Med. 116, 82–92. doi:10.1016/j.socscimed.2014.06.042

Chaix, B., Kestens, Y., Perchoux, C., Karusisi, N., Merlo, J., Labadi, K., 2012. An Interactive Mapping Tool to Assess Individual Mobility Patterns in Neighborhood Studies. Am. J. Prev. Med. 43, 440–450.

Charreire, H., Mackenbach, J.D., Ouasti, M., Lakerveld, J., Compernolle, S., 2014. Using remote sensing to de fi ne environmental characteristics related to physical activity and dietary behaviours : A systematic review (the SPOTLIGHT project). Health Place 25, 1–9. doi:10.1016/j.healthplace.2013.09.017

Commission of the European Communities, 2007. GREEN PAPER Towards a new culture for urban mobility. Brussels.

Craig, C.L., Marshall, A.L., Sjöström, M., Bauman, A.E., Booth, M.L., Ainsworth, B.E., Pratt, M., Ekelund, U., Yngve, A., Sallis, J.F., Oja, P., 2003. International physical activity questionnaire: 12-country reliability and validity. Med. Sci. Sports Exerc. 35, 1381–95. doi:10.1249/01.MSS.0000078924.61453.FB

Curtis, J.W., Curtis, A., Mapes, J., Szell, A.B., Cinderich, A., 2013. Using google street view for systematic observation of the built environment : analysis of spatio-temporal instability of imagery dates. Int. J. Health Geogr. 12, 1–10.

Dekoster, J., Schollaert, U., 1999. Cycling: the way ahead for towns and cities, European C. ed. Luxembourg. doi:10.4135/9781412953993.n184

Ding, D., Gebel, K., 2012. Built environment, physical activity, and obesity: what have we learned from reviewing the literature? Health Place 18, 100–5. doi:10.1016/j.healthplace.2011.08.021

Douglas, A., Bolker, B., Walker, S., Singmann, H., Dai, B., Ben, M., 2016. Package “lme4.”

Douglas, M.J., Watkins, S.J., Gorman, D.R., Higgins, M., 2011. Are cars the new tobacco ? J. Public Health (Bangkok). 33, 160–169. doi:10.1093/pubmed/fdr032

Eurobarometer, F., 2011. Future of transport Analytical report 1–67.

Ewing, R., Handy, S., 2009. Measuring the Unmeasurable : Urban Design Qualities Related to Walkability. J. urban Des. 14, 65–84. doi:10.1080/13574800802451155

Ferdinand, A.O., Sen, B., Rahurkar, S., Engler, S., Menachemi, N., 2012. The Relationship Between Built Environments and Physical Activity : A Systematic Review. Am. J. Public Health 102, 7–13. doi:10.2105/AJPH.2012.300740

Feuillet, T., Charreire, H., Roda, C., Ben-Rebah, M., Mackenbach, J., Compernolle, S., Glonti, K., Bardos, H., Rutter, H., De Bourdeaudhuij, I., McKee, M., Brug, J., Lakerveld, J., Oppert, J.-M., 2016. Neighbourhood typology based on virtual audit of environmental obesogenic characteristics. Obes. Rev. doi:10.1111/obr.12378

Field, A., 2013. Discovering Statistics using IBM SPSS Statistics. SAGE Publications Ltd.

Foster, C.E., Panter, J.R., Wareham, N.J., 2011. Assessing the impact of road traffic on cycling for leisure and cycling to work. Int. J. Behav. Nutr. Phys. Act. 8, 61. doi:10.1186/1479-5868-8-61

Fraser, S.D.S., Lock, K., 2010. Cycling for transport and public health: a systematic review of the effect of the environment on cycling. Eur. J. Public Health 21, 738–43. doi:10.1093/eurpub/ckq145

Gebel, K., Bauman, A., Owen, N., 2009. Correlates of non-concordance between perceived and objective measures of walkability. Ann. Behav. Med. 37, 228–38. doi:10.1007/s12160-009-9098-3

Gebel, K., Bauman, A.E., Sugiyama, T., Owen, N., 2011. Mismatch between perceived and objectively assessed neighborhood walkability attributes: prospective relationships with walking and weight gain. Health Place 17, 519–24. doi:10.1016/j.healthplace.2010.12.008

Ghekiere, A., Van Cauwenberg, J., de Geus, B., Clarys, P., Cardon, G., Salmon, J., De Bourdeaudhuij, I., Deforche, B., 2014. Critical environmental factors for transportation cycling in children: a qualitative study using bike-along interviews. PLoS One 9, e106696. doi:10.1371/journal.pone.0106696

Grundy, C., Steinbach, R., Edwards, P., Green, J., Armstrong, B., Wilkinson, P., 2009. Effect of 20 mph traffic speed zones on road injuries in London, 1986-2006: controlled interrupted time series analysis. BMJ 339, b4469. doi:10.1136/bmj.b4469

Handy, S., Xing, Y., 2011. Factors Correlated with Bicycle Commuting : A Study in Six Small US Cities. Int. J. Sustain. Transp. 0–23. doi:10.1080/15568310903514789

Heesch, K.C., Giles-corti, B., Turrell, G., 2015. Cycling for transport and recreation : Associations with the socio-economic , natural and built environment. Health Place 36, 152–161. doi:10.1016/j.healthplace.2015.10.004

Heesch, K.C., Sahlqvist, S., Garrard, J., 2012. Gender differences in recreational and transport cycling: a cross-sectional mixed-methods comparison of cycling patterns, motivators, and constraints. Int. J. Behav. Nutr. Phys. Act. 9, 106. doi:10.1186/1479-5868-9-106

Heinen, E., Van Wee, B., Maat, K., 2010. Commuting by Bicycle : An Overview of the Literature 30, 59–96. doi:10.1080/01441640903187001

IPAQ, 2002. International physical activity questionnaire (October 2002). Long last 7 days self-administered format 71.

Janssens, D., Declercq, K., Wets, G., 2014. Onderzoek Verplaatsingsgedrag Vlaanderen 4.5 (2012-2013). Instituur voor Mobil. 116.

Kestens, Y., Lebel, A., Daniel, M., Thériault, M., Pampalon, R., 2010. Using experienced activity spaces to measure foodscape exposure. Health Place 16, 1094–1103.

Kirtland, K. a., Porter, D.E., Addy, C.L., Neet, M.J., Williams, J.E., Sharpe, P. a., Neff, L.J., Kimsey, C.D., Ainsworth, B.E., 2003. Environmental measures of physical activity supports. Am. J. Prev. Med. 24, 323–331. doi:10.1016/S0749-3797(03)00021-7

Kweon, B.-S., 2006. Large-Scale Environmental Knowledge: Investigating the Relationship Between Self-Reported and Objectively Measured Physical Environments. Environ. Behav. 38, 72–91. doi:10.1177/0013916505280092

Lakerveld, J., Ben Rebah, M Mackenbach, J., Charreire, H., Compernolle, S., Glonti, K., Bardos, H., Rutter, H., De Bourdeaudhuij, I., Brug, J., Oppert, J.-M., 2015. Obesity-related behaviours and BMI in five urban regions across Europe: sampling design and results from the SPOTLIGHT cross-sectional survey. BMJ Open 5, 1–9. doi:10.1136/bmjopen-2015-008505

Lakerveld, J., Brug, J., Bot, S., Teixeira, P.J., Rutter, H., Woodward, E., Samdal, O., Stockley, L., De Bourdeaudhuij, I., van Assema, P., Robertson, A., Lobstein, T., Oppert, J.-M., Adány, R., Nijpels, G., 2012. Sustainable prevention of obesity through integrated strategies: The SPOTLIGHT project's conceptual framework and design. BMC Public Health 12, 793. doi:10.1186/1471-2458-12-793

Lee, C., Moudon, A.V., 2008. Neighbourhood design and physical activity. Build. Res. informtaion 36, 395–411.

Ma, L., 2014. The Objective vs . the Perceived Environment : What Matters for Active Travel. Diss. Theses. Pap. 2090.

Ma, L., Dill, J., 2015. Associations between the objective and perceived built environment and bicycling for transportation. J. Transp. Heal. 2, 248–255.

doi:10.1016/j.jth.2015.03.002

Mackenbach, J.D., Rutter, H., Compernolle, S., Glonti, K., Oppert, J.-M., Charreire, H., De Bourdeaudhuij, I., Brug, J., Nijpels, G., Lakerveld, J., 2014. Obesogenic environments: a systematic review of the association between the physical environment and adult weight status, the SPOTLIGHT project. BMC Public Health 14, 233. doi:10.1186/1471-2458-14-233

Menai, M., Charreire, H., Feuillet, T., Salze, P., Weber, C., Enaux, C., Andreeva, V.A., Hercberg, S., Nazare, J., Perchoux, C., Simon, C., 2015. Walking and cycling for commuting , leisure and errands : relations with individual characteristics and leisure-time physical activity in a cross-sectional survey (the ACTI-Cités project). Int. J. Behav. Nutr. Phys. Act. 1–10. doi:10.1186/s12966-015-0310-5

Mertens, L., Compernolle, S., Gheysen, F., Deforche, B., Brug, J., Mackenbach, J., Lakerveld, J., Oppert, J.-M., Feuillet, T., Glonti, K., Bardos, H., De Bourdeaudhuij, I., 2016a. Perceived environmental correlates of cycling for transport among adults in five regions of Europe: the SPOTLIGHT project. Obes. Rev. 17, 53–61.

Mertens, L., Van Cauwenberg, J., Ghekiere, A., Van Holle, V., De Bourdeaudhuij, I., Deforche, B., Nasar, J., Van De Weghe, N., Van Dyck, D., 2015. Does the Effect of Micro-Environmental Factors on a Street's Appeal for Adults' Bicycle Transport Vary across Different Macro-Environments? An Experimental Study. PLoS One 10, 1–17. doi:10.1371/journal.pone.0136715

Mertens, L., Van Dyck, D., Ghekiere, A., De Bourdeaudhuij, I., Deforche, B., Van de Weghe, N., Van Cauwenberg, J., 2016b. Which environmental factors most strongly influence a street's appeal for bicycle transport among adults? A conjoint study using manipulated photographs. Int. J. Health Geogr.

Ministry of Transport/ Public Works and Water Management, 2009. Cycling in the Netherlands 77.

Mooney, S.J., Bader, M.D.M., Lovasi, G.S., Neckerman, K.M., Teitler, J.O., Rundle, A.G., 2014. Practice of Epidemiology Validity of an Ecometric Neighborhood Physical Disorder Measure Constructed by Virtual Street Audit. Am. J. Epidemiol. 180, 626–635. doi:10.1093/aje/kwu180

Moudon, A.V., Lee, C., Cheadle, A.D., Collier, C.W., Johnson, D., Schmid, T.L., Weather, R.D., 2005. Cycling and the built environment, a US perspective. Transp. Res. Part D Transp. Environ. 10, 245–261. doi:10.1016/j.trd.2005.04.001

Neill, T.W.O., Marsden, D., Matthis, C., Raspe, H., Silman, A.J., 1995. Survey response rates : national and regional differences in a European multicentre study of vertebral osteoporosis 87–93.

Odgers, C.L., Caspi, A., Bates, C.J., Sampson, R.J., Moffitt, T.E., 2013. Using Google Street View : a reliable and cost-effective method. J Child Psychol Psychiatry 53, 1009–1017. doi:10.1111/j.1469-7610.2012.02565.x.Systematic

Oja, P., Titze, S., Bauman, a, de Geus, B., Krenn, P., Reger-Nash, B., Kohlberger, T., 2011. Health benefits of cycling: a systematic review. Scand. J. Med. Sci. Sports 21, 496–509. doi:10.1111/j.1600-0838.2011.01299.x

Parkin, J., Wardman, M., Page, M., 2008. Estimation of the determinants of bicycle mode share for the journey to work using census data. Transportation (Amst). 35, 93–109. doi:10.1007/s11116-007-9137-5

Perchoux, C., Chaix, B., Cummins, S., Kestens, Y., 2013. Conceptualization and measurement of environmental exposure in epidemiology: Accounting for activity space related to daily mobility. Health Place 21, 86–93.

Prins, R.G., Oenema, A., van der Horst, K., Brug, J., 2009. Objective and perceived availability of physical activity opportunities: differences in associations with physical activity behavior among urban adolescents. Int. J. Behav. Nutr. Phys. Act. 6, 70. doi:10.1186/1479-5868-6-70

Pucher, J., Buehler, R., 2008. Making Cycling Irresistible: Lessons from The Netherlands, Denmark and Germany. Transp. Rev. 28, 495–528. doi:10.1080/01441640701806612

Pucher, J., Buehler, R., 2007. Cycling for Everyone : Lessons from Europe. Transp. Res. Rec. J. Transp. Res. Board 2074, 58–65.

Pucher, J., Buehler, R., Bassett, D.R., Dannenberg, A.L., 2010a. Walking and cycling to health: a comparative analysis of city, state, and international data. Am. J. Public Health 100, 1986–92. doi:10.2105/AJPH.2009.189324

Pucher, J., Dill, J., Handy, S., 2010b. Infrastructure, programs, and policies to increase bicycling: an international review. Prev. Med. (Baltim). 50 Suppl 1, S106–25. doi:10.1016/j.ypmed.2009.07.028

Rabl, A., de Nazelle, A., 2012. Benefits of shift from car to active transport. Transp. Policy 19, 121–131. doi:10.1016/j.tranpol.2011.09.008

Rietveld, P., Daniel, V., 2004. Determinants of bicycle use: do municipal policies matter? Transp. Res. Part A Policy Pract. 38, 531–550. doi:10.1016/j.tra.2004.05.003

Roda, C., Charreire, H., Feuillet, T., Mackenbach, J.D., Compernolle, S., Glonti, K., Rebah, M. Ben, Bárdos, H., Rutter, H., Mckee, M., Bourdeaudhuij, I. De, Brug, J., Lakerveld, J., Oppert, J., 2016. Mismatch between perceived and objectively measured environmental obesogenic features in European neighbourhoods. Obes. Rev. 17, 31–41. doi:10.1111/obr.12376

Rudinger, G., Donaghy, K., Poppelreuter, S., 2006. Societal trends , mobility behaviour and sustainable transport in Europe and North America.

Rundle, A.G., Bader, M.D.M., Richards, C.A., Neckerman, K.M., Teitler, J.O., 2011. Using Google Street view to audit neighborhood environments. Am. J. Prev. Med. 40, 94–100. doi:10.1016/j.amepre.2010.09.034.Using

SafetyNet, 2009. Pedestrians & Cyclists.

Sallis, J.F., Bowles, H.R., Bauman, A., Ainsworth, B.E., Bull, F.C., Craig, C.L., Sjöström, M., De Bourdeaudhuij, I., Lefevre, J., Matsudo, V., Matsudo, S., Macfarlane, D.J., Gomez, L.F., Inoue, S., Murase, N., Volbekiene, V., McLean, G., Carr, H., Heggebo, L.K., Tomten, H., Bergman, P., 2009. Neighborhood environments and physical activity among adults in 11 countries. Am. J. Prev. Med. 36, 484–490. doi:10.1016/j.amepre.2009.01.031

Sallis, J.F., Cervero, R.B., Ascher, W., Henderson, K. a, Kraft, M.K., Kerr, J., 2006. An ecological approach to creating active living communities. Annu. Rev. Public Health 27, 297–322. doi:10.1146/annurev.publhealth.27.021405.102100

Sallis, J.F., Conway, T.L., Dillon, L.I., Frank, L.D., Adams, M.A., Cain, K.L., Saelens, B.E., 2013. Environmental and demographic correlates of bicycling. Prev. Med. (Baltim). 57, 456–460.

Sallis, J.F., Owen, N., Fisher, E.B., 2008. Ecological models of health behavior, in: Glanz, K., Rimer, B., Viswanath, K. (Eds.), Health Behavior and Health Education: Theory, Research and Practice. San Fransico, pp. 465–486.

Swinburn, B., Egger, G., Raza, F., 1999. Dissecting Obesogenic Environments: The Development and Application of a Framework for Identifying and Prioritizing Environmental Interventions for Obesity. Prev. Med. (Baltim). 26, 563–570.

Titze, S., Giles-Corti, B., Knuiman, M.W., Pikora, T.J., Timperio, a, Bull, F.C., Van Niel, K., 2010. Associations Between Intrapersonal and Neighborhood Environmental Characteristics and Cycling for Transport and Recreation in Adults: Baseline Results From the RESIDE Study. J Phys Act Heal. 7, 423–431.

Transportation Research Board, 2005. Does the Built Environment Influence Physical Activity ?

Van Holle, V., Deforche, B., Van Cauwenberg, J., Goubert, L., Maes, L., Van de Weghe, N., De Bourdeaudhuij, I., 2012. Relationship between the physical environment and different domains of physical activity in European adults: a systematic review. BMC Public Health 12, 807. doi:10.1186/1471-2458-12-807

Van Holle, V., Van Cauwenberg, J., Deforche, B., Goubert, L., Maes, L., Nasar, J., Van de Weghe, N., Salmon, J., De Bourdeaudhuij, I., 2014. Environmental invitingness for transport-related cycling in middle-aged adults: A proof of concept study using photographs. Transp. Res. Part A Policy Pract. 69, 432–446. doi:10.1016/j.tra.2014.09.009

Vandenbulcke, G., Dujardin, C., Thomas, I., Geus, B. De, Degraeuwe, B., Meeusen, R., Panis, L.I., 2011. Cycle commuting in Belgium: Spatial determinants and "re-cycling" strategies. Transp. Res. Part A Policy Pract. 45, 118–137. doi:10.1016/j.tra.2010.11.004

Vanwolleghem, G., Dyck, D. Van, Ducheyne, F., Bourdeaudhuij, I. De, Cardon, G., 2014. Assessing the environmental characteristics of cycling routes to school : a study on the reliability and validity of a Google Street View-based audit. Int. J. Health Geogr. 1–9.

Wahlgren, L., Schantz, P., 2012. Exploring bikeability in a metropolitan setting: stimulating and hindering factors in commuting route environments. BMC Public Health 12, 168. doi:10.1186/1471-2458-12-168

Wen, M., Hawkley, L.C., Cacioppo, J.T., 2006. Objective and perceived neighborhood environment, individual SES and psychosocial factors , and self-rated health: An analysis of older adults in Cook County, Illinois. Soc. Sci. Med. 63, 2575–2590. doi:10.1016/j.socscimed.2006.06.025

Wendel-vos, W., Schuit, J., De Niet, R., Boshuizen, H.C., Saris, W.H.M., Kromhout, D., 2004. Factors of the Physical Environment Associated with Walking and Bicycling. Med. Sci. Sport. Exerc. 36, 725–730. doi:10.1249/01.MSS.0000121955.03461.0A

Winters, M., Davidson, G., Kao, D., Teschke, K., 2010. Motivators and deterrents of bicycling: comparing influences on decisions to ride. Transportation (Amst). 38, 153–168. doi:10.1007/s11116-010-9284-y

World Health Organization, 2015. Physical activity strategy for the WHO European Region 14–17.

World Health Organization, 2010. Global Recommendations on Physical Activity for Health. 1–60.

Yang, L., Sahlqvist, S., 2010. Interventions to promote cycling : systematic review. BMJ 341, 1–10. doi:10.1136/bmj.c5293

Chapter 2. Experimental studies to investigate the association between the physical environment and the street's appeal to cycle for transport (photograph experiments)

Chapter 2.1 – A mix-method pilot study with manipulated photographs

Mertens, L., Van Holle, V., De Bourdeaudhuij, I., Deforche, B., Salmon, J., Nasar, J., Van de Weghe, N., Van Dyck, D., & Van Cauwenberg, J. (2014). The effect of changing micro-scale physical environmental factors on an environment's invitingness for transportation cycling in adults: an exploratory study using manipulated photographs. International Journal of Behavioral Nutrition and Physical Activity, 11(88), 1–12. http://doi.org/10.1186/s12966-014-0088-x

Mertens et al. International Journal of Behavioral Nutrition and Physical Activity 2014, 11:88
http://www.ijbnpa.org/content/11/1/88

International Journal of Behavioral Nutrition and Physical Activity

RESEARCH Open Access

The effect of changing micro-scale physical environmental factors on an environment's invitingness for transportation cycling in adults: an exploratory study using manipulated photographs

Lieze Mertens[1,2,3*], Veerle Van Holle[1,3], Ilse De Bourdeaudhuij[1], Benedicte Deforche[1,2], Jo Salmon[4], Jack Nasar[5], Nico Van de Weghe[6], Delfien Van Dyck[1,3] and Jelle Van Cauwenberg[1,2,3]

Abstract

Previous studies have shown convincing evidence for positive relationships between transportation cycling in adults and macro-scale physical environmental factors. In contrast, relationships are less consistent for more changeable, micro-scale environmental factors. The majority of existing studies used observational study designs, which cannot determine causality. The present mixed-methods study used manipulated photographs to determine causal relationships between micro-scale environmental factors and the environment's invitingness for transportation cycling. Further, interactions among environmental factors and moderating effects of gender, age and educational level were investigated. For this study, panoramic photograph of a street was manipulated on eight environmental factors: traffic, speed bump, general upkeep, evenness of the cycle path, vegetation, separation of motorized traffic, separation with sidewalk and cycle path width. Sixty-six middle-aged adults participated in the study and sorted the manipulated panoramic photographs from least to most inviting to cycle for transportation. Participants also provided qualitative data on how they sorted the streets. Multilevel cross-classified modelling was used to analyse the relationships between the environmental manipulations and the invitingness-scores. The qualitative data were deductively categorized according to the environmental factors. All environmental factors, except for separation with sidewalk, proved to have a significant main effect on the invitingness-score for transportation cycling. Cycle path evenness appeared to have the strongest effect on the invitingness. This effect was even stronger in an environment with good compared to poorly overall upkeep. Another significant interaction effect showed that the invitingness decreased when both separations along the cycle path were present compared to only a separation with traffic. No moderating effects of the demographic factors on these relationships were found. Qualitative data confirmed the observed quantitative relationships and added depth and understanding. Current study shows that
(Continued on next page)

* Correspondence: lieze.mertens@ugent.be
[1]Department of Movement and Sport Sciences, Faculty of Medicine and Health Sciences, Ghent University, Watersportlaan 2, B-9000 Ghent, Belgium
[2]Department of Human Biometry and Biomechanics, Faculty of Physical Education and Physical Therapy, Vrije Universiteit Brussel, Pleinlaan 2, B-1050 Brussels, Belgium
Full list of author information is available at the end of the article

(Continued from previous page)
the use of manipulated photographs can be an effective way to examine environment-physical activity relationships. Our findings indicate that evenness of the cycle path may be a crucial environmental factor when aiming to increase a street's invitingness for transportation cycling among middle-aged adults. The findings of our exploratory study could be used to develop an environmental intervention to determine if our findings are applicable to real changes in cycling behavior.

Keywords: Built environment, Biking, Adulthood, Experiment, Pictures, Transport, Physical activity

Background

Although the benefits of physical activity (PA) are well-known in many countries around the world, approximately 31% of adults (15 years and over) do not reach the public health guideline of 150 min/week of moderate-to-vigorous PA [1]. Interventions that focus on the incorporation of PA into daily routines are required. One possible solution is to incorporate the habitual use of active transport into daily routines. Cycling for transportation has many health benefits, and is also an important behavior from economic, social, environmental and traffic management perspectives [2-11]. Moreover, cycling for transportation has the potential to increase PA levels in European adults. Despite the many benefits, more than 30% of all trips made by car in Europe cover distances of less than 3 km and 50% are shorter than 5 km [12]. It is therefore important to identify reasons why people do and do not cycle for transport. Socio-ecological models state that the physical environment, together with social and individual attributes, provide a useful framework for explaining active transportation [13].

In previous cross-sectional studies, positive relationships between environmental factors such as walkability, access to shops/services/work, and urbanization and transportation cycling in European [14] and non-European [15] adults have been reported. These macro-scale environmental factors may be difficult to change in existing neighborhoods. In contrast, relationships are less consistent for more changeable, micro-scale environmental factors, such as vegetation, upkeep, evenness of the cycle path or traffic-related safety [14,16-18]. A possible explanation for these inconsistencies may be that environmental perceptions are generally assessed using questionnaires. Although usually valid and reliable tools are used, there are disadvantages of using questionnaires to assess features of the physical environment. Firstly, participants need to recall features of the physical environment and often, important environmental attributes are overlooked, neglected or forgotten due to recall bias [19]. Secondly, there is no standard definition of "the neighborhood", which can cause a mismatch between the target environment of the researcher and that of the participant. To accommodate these disadvantages, the use of photographs may serve as an appropriate alternative for investigating the physical environment. Furthermore, these inconsistencies may be addressed by collecting qualitative data, which enables a more in-depth understanding of what people are thinking about when they rate their neighborhood environment. Very little built environment research has utilized a mix of qualitative and quantitative methodologies [13,20].

A major limitation of previous research of the physical environment is that most studies have used observational study designs, which are not suitable for determining causality [21-23]. Because it is often not feasible to change the real environment within a research context, an experimental design using photographs and manipulating environmental factors depicted in these photographs can offer a suitable solution to identify causal relationships with the invitingness for transportation cycling. Manipulating photographs instead of real-life environments allows changing of factors or combinations of environmental factors such as evenness of the cycle path, vegetation, upkeep and traffic level while other factors are standardized. In contrast, questionnaires only have the possibility of asking one item at a time, while the real environment consists of a combination of several environmental factors simultaneously. Therefore, it is also important to investigate the moderating effects of environmental factors on the relationship between another environmental factor and the invitingness for transportation cycling. For example, the presence of a separation between cycle path and motorized traffic might only enhance the invitingness for transportation cycling if much traffic is present compared to no traffic. Conversely, the presence of vegetation might be stronger in a well-maintained compared to a poorly maintained environment. Findings obtained from research using photographs could inform environmental interventions in real life settings about which micro-scale environmental factors to modify.

A further aspect that has been infrequently studied is the moderating role of demographic factors on the relationships between micro-scale environmental factors and the likelihood of cycling for transportation. Previous research has shown that cycling for transport differs between men and women, age and socioeconomic status [24-26]. These sub-group differences in cycling for transport may be explained in part by differences in perceptions and engagement with the built environment [27-29]. Experimental research using mixed methods approaches may be useful for examining whether these demographic factors moderate associations between the built environment and cycling for transport.

The first aim of the current study was to examine the effect of manipulating photographs of micro-scale physical environmental features on adults' perceptions of the environmental invitingness for transportation cycling. Secondly, interactions among environmental factors on the invitingness were investigated to identify if certain micro-scale environmental factors moderate the relationships between other environmental factors and the invitingness for transportation cycling. Finally, moderating effects of gender, age and educational level were investigated. Both quantitative and qualitative information was collected to answer these questions.

Methods

By purposeful convenience sampling, 66 Flemish middle-aged adults (45–64 years), stratified by gender, were recruited. Only middle-aged adults living in an urban (>600 inhabitants/km^2) or semi-urban (300–600 inhabitants/km^2) municipality [30] in the region of Flanders or the Brussels Capital Region were eligible. These recruitment areas were chosen because average trip distance corresponds with a 10-minutes cycle trip and participants were required to imagine such trips in the measurement protocol (see below). Furthermore, the participants had to be physically able to cycle for 30 minutes and only one person per household could participate.

Protocol and measures

Participants were visited at home by a researcher between March and April 2013 and completed a two-step research protocol. Before starting the measurement, informed consent was obtained from the participants. The home visit consisted of a structured interview and a sorting task with panoramic photographs which lasted approximately one hour. This study protocol was approved by The Ethics Committee of the University Hospital. The detailed protocol is described below.

Photograph development

Prior to data collection, two sets (set A and set B) of 32 panoramic color photographs were developed with Adobe Photoshop© software. Previous research has established the validity of responses to color photos in comparison to on-site responses [31-33]. The use of programs such as Adobe Photoshop© to create controlled and realistic manipulations of the physical environment has been proposed by Nasar [32]. To enhance standardization, each photograph depicted the same street taken from an adult cyclist's eye-level viewpoint under dry weather conditions and without people visible in the environment. Each panoramic photograph differed from the others in at least one environmental manipulation. Five possible manipulated environmental factors were present in each photograph and were depicted in two categories: presence (score 1) or absence (score 0) of the positive environmental characteristic. The presence or absence of manipulations of five environmental factors led to a total of 32 ($2^5 = 32$) images per set. As adding an additional environmental factor would double the number of pictures and would overload the participants, two separate sets of photographs were made (set A and set B), so that a total of eight different environmental factors could be examined, including two factors that were used in both sorting tasks. Each photograph was 10.63 inches (27 cm) wide and 2.36 inches (6 cm) high.

Based on previous research with non-manipulated panoramic photographs [34] and existing literature on environment-transportation cycling relationships [14,35], the key factors for adults' cycling for transportation could be determined. The following five factors were selected to be manipulated in set A: 'traffic level', 'traffic calming', 'the evenness of the cycle path', 'general upkeep' and 'vegetation' (Figure 1). 'Traffic level' was manipulated by the presence or absence of driving cars on the road. 'Traffic calming' was manipulated by the presence or absence of a speed bump. The 'evenness of the cycling path' was manipulated by depicting a cycle path in good condition or in poor condition. 'General upkeep' represented the overall maintenance degree of the depicted environment and was manipulated by putting graffiti on the wall, depicting broken windows, garbage on the street and a hole in the road surface. Finally, the presence or absence of trees along the road and greenery on houses were the manipulations done for 'vegetation'.

Besides the first set of photographs including the key factors determined from previous research and literature, set B was developed to determine the effect of traffic safety elements on the invitingness for transportation cycling, which has been already reported in previous studies as important to obtain higher levels of cycling [14,35,36]. Therefore, two environmental factors were manipulated in set A as well as in set B, namely 'traffic level' and 'evenness of the cycle path'. The other three environmental factors manipulated in set B were: 'separation between cycle path and motorized traffic', 'separation between cycle path and sidewalk' and 'width of the cycle path' (Figure 2). The 'separation between cycle path and motorized traffic' was manipulated by whether or not a hedge was present between these two. In contrast, the manipulation of the 'separation between cycle path and sidewalk' was done by the presence or absence of bollards between the two. Finally, the width of the cycle

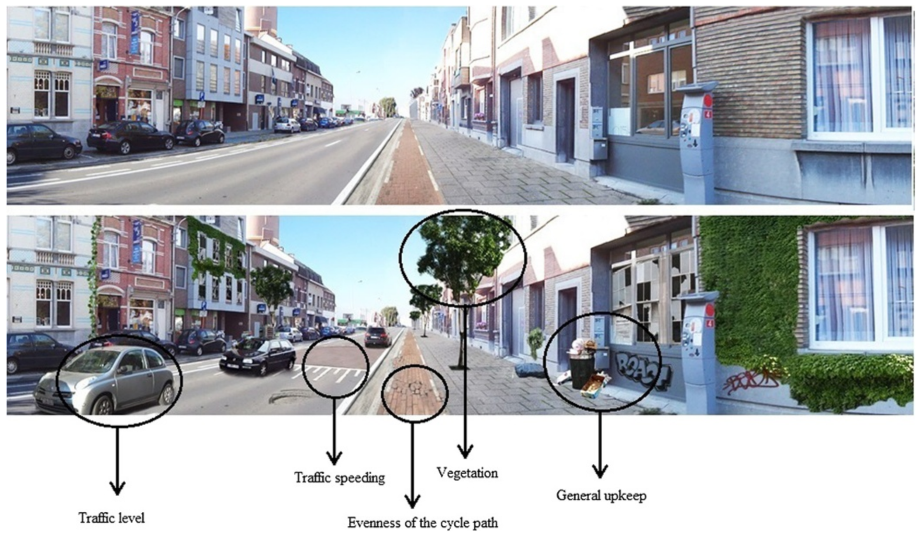

Figure 1 Examples of manipulated photographs from set A with 5 environmental factors manipulated.

path was manipulated by depicting a narrow or wide cycle path.

Interview

The home visit started with a short face-to-face interview, assessing sociodemographic information (gender, age, country of birth, highest degree of education, occupational status, marital civil status, number of vehicles in the household) and PA level. PA level was measured with the International Physical Activity Questionnaire (IPAQ, long, last 7 days interview version) [37]. Self-reported PA assessed by IPAQ showed good reliability (Spearman's correlation coefficients clustered around 0.80) and acceptable criterion validity (median ρ = 0.30) for middle-aged adults in a 12-country study [38]. Only the domains of PA that are potentially affected by the neighborhood environment (i.e., active transportation and recreational PA) were surveyed.

Sorting task

During the home visit, the participants were asked to do two similar sorting tasks (one for each set of 32 colored photographs). Before starting the sorting task, the researcher randomly scattered all 32 photographs on a table and read the following standardized instructions out loud: *'Imagine yourself cycling to a friend's home located at*

Figure 2 Examples of manipulated photographs from set B with 5 environmental factors manipulated.

Mertens et al. International Journal of Behavioral Nutrition and Physical Activity 2014, 11:88
http://www.ijbnpa.org/content/11/1/88

10 minutes cycling from your home during daytime with perfect weather. First, it is intended that you pick the worst and the best street(s) to cycle along to the house of your friend. There is no good or wrong solution, we are only interested in what matters to you the most while cycling to your friend'. When the participant had chosen the most and least inviting environments, the researcher spread 11 cards depicting scores ranging from zero to ten on the table. The following standardized instructions were given to sort the environments on their invitingness for transportation cycling on an 11-point Likert scale ranging from 0 (not inviting at all), through 5 (neutral), to 10 (very inviting): *"The photograph(s) that you indicated as least inviting were placed under score 0 and the most inviting photograph(s) under score 10. Now you have to sort the remaining pictures from lowest to highest invitingness by assigning them a score from zero to ten. You can place several pictures under the same score and you can switch them every moment. You can still move the pictures that have already received a score of 0 or 10 or add other photographs to these scores".* To identify the reasons for sorting the photographs in that way, qualitative information was collected. The next part of the study was recorded by a voice-recorder and the participants were asked to describe the reasons why they had sorted the pictures in that way. If necessary, the researcher prompted for further explanation. For the other set of 32 photographs, the same protocol was followed. To prevent order effects, the protocol alternately started with set A or B between participants.

Analyses

Quantitative analyses

Descriptive statistics were performed using SPSS 20.0 software. Multilevel cross-classified linear regression models in MLwiN 2.28 [39] were used to analyze the quantitative data to account for clustering of the invitingness-scores within participants and streets (participants and streets were treated as cross-classified) [40]. Markov Chain Monte Carlo (MCMC) procedures were used for model parameter estimation [41].

A final model was constructed in five phases. In a first step the main effects of age, gender and education on the assigned invitingness scores were analyzed in three separate models. Secondly, a basic model was developed that included the five environmental factors and the individual factors that were significantly related to the invitingness scores in step 1. Thirdly, interaction effects between environmental factors and individual factors and between environmental factors mutually were added to the basic model. In the last step, all significant main and interaction effects obtained from previous phases were combined into one model. The final model was constructed by allowing random slopes and by deleting non-significant effects that did not improve the model fit. Models were compared using the Deviance Information Criterion (DIC) [42]. This procedure was performed separately for photograph sets A and B. Level of significance was defined at $\alpha = 0.05$.

Qualitative analyses

The first step in the analysis of the qualitative data involved reading the transcripts in detail. Nvivo 9 Software (QRS International) was used to categorize qualitative data into five categories corresponding to the five manipulated environmental factors [43]. This categorization was based on the framework approach as presented by Pope and colleagues [44]. Finally, the data were summarized by environmental factor. This procedure was accomplished separately for photograph sets A and B. Because the environmental factors 'traffic level' and 'evenness of the cycle path' were manipulated in both sorting tasks, the qualitative data collected from sorting task A and B for these factors were analyzed together. Quotes from participants were used to clarify the findings.

Results

Descriptive statistics

In total, 66 adults ranged in age from 45 to 65 years participated in the study. Just over half of the sample were women and more than half attended university. Just one in four participants met PA recommendations and only one in five reported cycling for transport in the last seven days. Other descriptive characteristics of the sample are shown in Table 1.

Quantitative analyses

For sorting task A, the final model showed that all five environmental factors were significantly related to the invitingness for transportation cycling (Table 2). No traffic, the presence of a speed bump, an even cycle path, a well-maintained environment and the presence of vegetation increased perceived invitingness for transportation cycling. The largest change of the invitingness-score of transportation cycling was found between an environment with an uneven compared to an even cycle path, with an increase of 2.52 ± 0.35 points on a 11-point Likert-scale (range 0–10). Furthermore, one significant interaction effect was found, namely between 'evenness of the cycle path' and 'general upkeep' ($p < 0.001$). The positive effect of evenness is greater if the environment is well-maintained, compared to when it is poorly maintained (Figure 3). No moderating effects of gender, age and degree of education were found.

For sorting task B, four of the five environmental factors showed a significant positive main effect on invitingness (Table 2). No traffic, the presence of a separation with motorized traffic, an even cycle path, and a wide cycle path significantly increased the invitingness for

Table 1 Descriptive characteristics of the participants (n = 66)

Age (M ± SD)	53.6 ± 5.0
Women (%)	53.0
Born in Belgium (%)	95.5
Marital status (%)	
-Married	77.3
-Widowed	4.5
-Single	12.1
-Cohabiting	6.1
Education (%)	
-Primary	6.1
-Lower secondary	39.4
-Higher secondary	54.5
-Tertiary	31.7
Occupational status (%)	
-Household	9.1
-Blue collar	19.7
-White collar	71.2
Physical activity	
-Moderate-to-vigorous PA min/wk (M ± SD)	114.1 ± 167.6
-Meeting PA recommendations (%)	25.8
Current cycling for transportation level	
-Cycling for transportation min/wk (M ± SD)	32.8 ± 76.1
-No cycling for transportation (%)	80.3

M = mean; SD = standard deviation.

transportation cycling. An even cycle path increased the invitingness-score the most with an increase of 3.29 ± 0.25 points on a 11-point Likert-scale (range 0–10). 'Separation between cycle path and sidewalk' had no significant main effect (p = 0.062). A significant interaction effect was found between 'separation between cycle path and motorized traffic' and 'separation between cycle path and sidewalk' (p = 0.001) (Figure 4). A separation between cycle path and sidewalk has a negative effect on the invitingness-score, when there is already a separation between cycle path and motorized traffic present and furthermore, had no effect when a separation between cycle path and motorized traffic was absent. No moderating effects of gender, age and degree of education were found.

Qualitative analyses

The qualitative information for each environmental factor is described below.

Traffic level (sorting task A and B)

Participants preferred streets without traffic compared to streets with traffic; however, it was not reported as the most important factor and was often regarded as a temporary situation. The next quote illustrates this clearly: *"First of all, the most important factor is the condition of the cycle path. The traffic that is present, is taken into account, but not so much because it is actually a snapshot, the picture may be completely different five minutes later because those cars can be gone by then, on the other hand it can also be a lot busier by then." (man, 48 years)*

Other participants considered the presence of traffic from a more realistic perspective: *"The best picture is traffic free, no cars are driving there at the moment, so that gives a safe impression. However, it is not realistic that all streets are free from traffic." (man, 57 years)*

Evenness of the cycle path (sorting task A and B)

The participants had a clear and consistent opinion concerning the 'evenness of the cycle path': the condition of

Table 2 Main and interaction effects of the environmental and demographic factors

Sorting task A	**β (S.E.)**	*Sorting task B*	**β (S.E.)**
Intercept	1.12 (0.25)	Intercept	0.60 (0.51)
Main effects[1]		**Main effects[1]**	
Traffic level	1.43 (0.21)***	Traffic level	1.26 (0.20)***
Traffic calming	0.35 (0.12)**	Separation MT	1.92 (0.26)***
Evenness of the cycle path	2.52 (0.35)***	Separation sidewalk	−0.45 (0.24)
General upkeep	1.97 (0.24)***	Evenness of the cycle path	3.29 (0.25)***
Vegetation	0.81 (0.16)***	Width of the cycle path	0.78 (0.11)***
Interaction effects		**Interaction effects**	
Evenness*general upkeep	1.07 (0.17)***	Separation MT* separation sidewalk	−0.42 (0.13)***

SE = standard error; MT = motorized traffic.
*p < 0.05, **p < 0.01, ***p < 0.001.
[1]The reference categories for the environmental factors were the negative environmental characteristic of the factors (i.e. high traffic level, no speed bump, uneven cycle path, poorly upkeep, no vegetation, no separation MT, no separation sidewalk, narrow cycle path).
Note: The outcome variable of both sorting tasks was the environment's invitingness-score for transportation cycling on a Likert scale ranging from 0–10. The final model of sorting task A was adjusted for gender and education, since these were found to be related to the invitingness-scores. Similarly, the final model for sorting task B was adjusted for education.

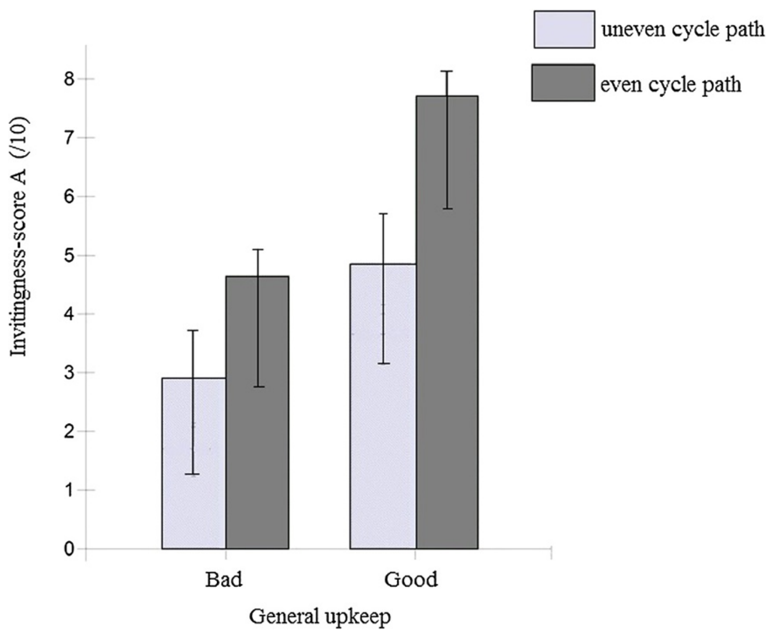

Figure 3 **Interaction effect of 'cycle path evenness' and 'general upkeep' on the invitingness-score (sorting task A).**

the cycle path was considered a priority. Fear of falling and other safety components related to the condition of the cycle path, appear to have a great impact on the invitingness: *"The least inviting streets depend on the condition of the cycle path. Cycling becomes more difficult because of the age, resulting in a higher importance of stability and balance. A good cycle path is therefore the most important factor."* (Woman, 54 years)

> *"The most important issue is the pavement and the condition of the cycle path. Safety comes first."* *(man, 48 years)*

Also in combination with other environmental factors, evenness of the cycle path was regarded as the most important attribute. This is illustrated by the following quotes: *"I still prefer a good cycle path with a lot of*

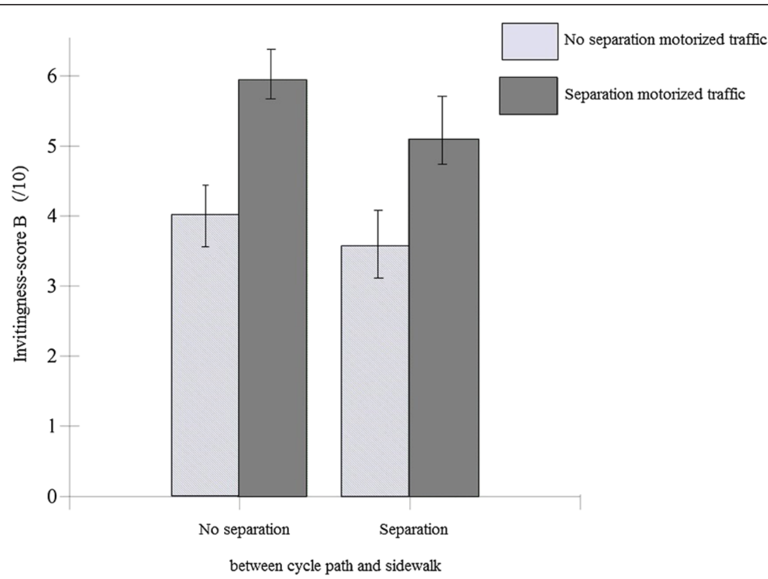

Figure 4 **Interaction effect of 'separation motorized traffic' and 'separation sidewalk' on the invitingness-score (sorting task B).**

traffic on the road, compared to a bad cycle path without any cars on the road." (Man, 60 years)

> *"The least inviting pictures are the pictures with a poor cycle path condition. Then I do not distinguish whether there is a speed bump or not because I argue that if the cycle path is not even, cyclists may fall. For me, that was the most important criterion." (woman, 54 years)*

Traffic calming (sorting task A)

The negative relationship between the presence of a speed bump and the speed of cars was mentioned by a few participants but was not considered as very important because the presence of a speed bump indirectly shows that many cars drive in the street. This is illustrated by the following quotes: *"A speed bump in the street, is less important for cyclists, because cars still drive there anyway. The fact that there is a speed bump is a mitigating factor but is less important." (Man, 53 years)*

Furthermore, some participants also mentioned a disadvantage of a speed bump, as cited in the following quote: *"The speed bump, either it bothers a little because of the annoying noise when cars driving over, or it is good when it slows down the speed of cars." (Woman, 64 years)*

General upkeep (sorting task A)

Many participants considered a poorly maintained environment as uninviting to cycle because it is not attractive or they feel unsafe. The following quotes illustrate this: *"So the pictures that I did not find attractive are the streets that are very sloppy. The establishments are also untidy and I feel unsafe. I am most attracted to the pictures where everything is clean. Both the cycle path, the street and the establishments are well-maintained. These are actually the criteria that are important for me." (woman, 53 years)*

The garbage was often mentioned as a possible obstacle while cycling, or for pedestrians who would move to the cycle path and hinder cyclists while they avoid the garbage. The quote below illustrates the attention that participants paid to the hole in the road: "*The criteria used to choose the least inviting street includes the poor condition of the road (hole in the road surface), because of the risk that cars will swing out to the cycle path to avoid the hole. That was a very important thing." (Woman, 50 years)*

Vegetation (sorting task A)

'Vegetation' was not considered to be a priority for the participants, but rather an additional component. The next quote illustrates this: *"What I really do not like is the broken cycle path. The green on the side, the bushes and the trees, I find enjoyable but that is not really a priority. Safety is more important." (Woman, 58 years)*

The presence of trees was not always reported as increasing invitingness to cycle. Participants often saw it as an obstacle while cycling, or as an obstacle for pedestrians who would move to the cycle path, as mentioned in the following quote: *"This is the least inviting picture because the cycle path is uneven, there is quite a lot of traffic on the road and there are trees on the sidewalk. I think pedestrians can switch to the cycle path and disturb cyclists." (Woman, 51 years)*

Separation between cycle path and motorized traffic (sorting task B)

Regarding the presence of a 'separation between cycle path and motorized traffic', many participants agreed that it provides an important protection for cyclists and that it increases rider safety. Separation from motorized traffic was generally preferred compared to no traffic protection: *"This picture is more inviting to cycle because effort is made to draw a border between cyclists and cars." (woman, 50 years)*

However, some adults did not like the presence of a separation on both sides of the cycle path because this gives a frightening feeling, especially in combination with a narrow bike path. This is illustrated by the following quote: "*What appears to be negative for me is having a separation on both sides of the cycle path. This is just a little too generous and moreover gives me a feeling of tightness. The most frightening separation is the separation to the sidewalk, the positive one is the separation to the street because it protects you from cars." (woman, 49 years)*

Separation between cycle path and sidewalk (sorting task B)

Most participants did not like the separation between cycle path and sidewalk because of the bollards that were used to distinguish footpath and cycle path. They were seen as uninviting, as an obstacle giving limited evasive options or giving the feeling that you were pushed to the street. This is described in the next quote: *"For the least inviting environments, I have taken the pictures with the bollards. I really do not like the bollards because I would automatically go driving on the road instead of the cycle path, just to avoid the bollards." (Woman, 53 years)*

Width of the cycle path (sorting task B)

People preferred a wide bike path compared to a narrow one, but this was not considered as a priority. This is mentioned in the following quote: "*In the first place, I have watched the condition of the cycle path. Secondly, I made a distinction in whether or not there was a separation between cycle path and traffic. Afterwards, I looked whether or not the bike path is wide." (Man, 53 years)*

Mertens et al. International Journal of Behavioral Nutrition and Physical Activity 2014, 11:88
http://www.ijbnpa.org/content/11/1/88

Discussion

This study examined the effect of manipulating micro-scale physical environmental factors on an environment's perceived invitingness for transportation cycling in adults. This is the first study investigating the effect of changing micro-scale environmental factors by using manipulated panoramic photographs. Based upon our quantitative and qualitative data, 'evenness of the cycle path' appeared to be the most important perceived environmental factor associated with invitingness to cycle for transportation. Limited research has examined this factor as a potential barrier to cycling. One Canadian study using questionnaire data found that when a route had potholes or uneven paving, the likelihood of cycling declined [45]. Because most European research used the NEWS Questionnaire to assess environmental perceptions [14], where walking/cycling facilities were incorporated together, it was not possible to draw conclusions about the isolating effect of the evenness of the cycle path in these previous studies.

'General upkeep' together with 'separation between cycle path and motorized traffic' appeared to be the second most important factors to increase the invitingness for transportation cycling. Moreover, both environmental factors interacted with another environmental factor. A well-maintained environment without graffiti on the wall, broken windows, garbage and holes in the road was perceived as more inviting to cycle for transportation compared to a poorly maintained environment. Based on the qualitative data, a large part of the effect of general upkeep is probably explained by the hole in the road surface because it was considered dangerous when a car would avoid it and come closer to the cycle path. The same results were found in a non-European study [46], indicating the importance of good road pavement for cars: the higher the defects scores were of the road surface for motorized traffic, the lower the proportion of adults who cycled to work. 'General upkeep' seems to be especially relevant when it causes dangerous situations for cyclists. Furthermore, the positive effect of an even cycle path was stronger in a well-maintained compared to a poorly maintained environment. A combination of these factors could achieve a larger effect on the invitingness of transportation cycling, than to change them separately. Furthermore, the positive effect of having a separation between cycle path and motorized traffic on transportation cycling, was confirmed by previous studies [45,47]. A recent observational study by Sallis and colleagues [29] found that implementing measures to improve cyclists' safety from cars would increase cycling.

The second interaction effect reported in this study suggest that the positive effect of a separation with traffic could be reduced if there was a separation from the sidewalk as well. A possible reason, provided in the qualitative data, was the frightening feeling for cyclists that would be created when two separations are present on both sides of the cycle path. Another reason may be the choice of using bollards in the photographs to separate cyclists from pedestrians because participants are afraid to cycle against these bollards or see this as a disturbing factor that limited evasive options. This may also explain the non-significant main effect of a 'separation between cycle path and sidewalk' on the invitingness for transportation cycling. These results should be approached with caution because the provision of separate cycling facilities was the cornerstone of Dutch, Danish and German policies to make cycling safe and attractive [35]. In these countries, city planners did not use bollards to separate cyclists and pedestrians, but grade separation, pavement coloring or surfacing and mentioned that it is important to present visual and physical, to indicate where cyclists and pedestrians are allowed to travel [48]. It is possible that only pavement coloration, as was present on the pictures too, is enough to make a distinction between cyclists and pedestrians.

In both sorting tasks, the absence of traffic was also an important issue, although many participants are realistic about the necessity of cars and make no claim to get all roads traffic free. The impact of traffic danger has also been mentioned in the literature. Perceived and objective traffic danger have been negatively associated with transportation cycling, both the 'volume' (e.g., the street has a lot of motorized traffic) as well as the 'safety' aspect (e.g., the risk of collision with automobilists) [45,47]. Nevertheless, a study of Foster and colleagues [18] found no effect of traffic volumes on transportation cycling and appeared to be more strongly related to leisure cycling than to transportation cycling.

The above mentioned significant positive associations of micro-scale modifications like an even cycle path, no obstacles, a separation from motorized traffic and low traffic level with the invitingness for transportation cycling, may have an important effect on safety. Because, safety is shown to be an important determinant regarding whether or not people will cycle [49], those small and easy changes are important to increase cycling, especially in countries where prevalence rates are still low due to lack of safety [35]. These findings may have important policy implications as they suggest that safety measures may be more effective to promote cycling for transportation than measures to improve the aesthetic appeal of a street. However, further research in real-life settings is warranted to find out whether such modifications could change actual cycling behavior.

A wide cycle path, the presence of vegetation and the presence of a speed bump were important for the invitingness, but to a lesser extent compared to the other environmental factors. The qualitative data confirmed that these environmental factors were not considered as a priority for the participants. Previous research shows [48] that the minimum width of cycle tracks should be 78 inches (1.98 m) clear to provide safe passing for cyclists while overtaking another cyclist. Another issue is the various opinions of the participants concerning the presence of trees. The trees were mostly seen as an obstacle for cyclists as well as for pedestrians, that could hinder cyclists while avoiding the trees. Other results might be obtained if the trees would be placed somewhere else. Furthermore, it is difficult to draw conclusions about the aesthetics of vegetation because different types of vegetation were manipulated together in this study. These findings, compared to existing literature, indicate the complexity of the environment. The weak relationship between the presence of a speed bump and the increasing invitingness of transportation cycling could be explained with the help of the qualitative data. Many participants could not make the link between the presence of a speed bump and the advantage for cyclists. In the literature, evidence shows that speed bumps improve safety for cyclists [35]. It might be less important for the increasing invitingness for cyclists, but it still remains an important component regarding the traffic safety.

Finally, no moderating effects of the demographic factors on the relationships between the environmental factors and the invitingness for transportation cycling were found. This finding may be encouraging for planning, because improvements of the micro-environment may have the potential to increase the invitingness of transportation cycling in both genders, the age group (45–65 years) and all educational levels. However, before drawing definite conclusions, these findings need to be replicated in a larger group of middle-aged adults recruited from different geographic areas.

The main strength of the present study was the experimental design, because causal conclusions on the effects of modifications in the environment on the invitingness can be drawn. Furthermore, these findings could be used to develop environmental interventions to determine if these findings will actually change the cycling behavior. A second strength was the collection of both quantitative and qualitative data. The qualitative data could help to figure out the underlying reasons why participants sort the pictures in a certain way. Third, there was the use of the manipulated panoramic photographs that have been validated to on-site responses. This allowed the possibility to ask for more items that were combined together at the same time.

This study also has some limitations that should be acknowledged. First, in this study the relationships with invitingness for transportation cycling was assessed and not with actual cycling behavior. Therefore, the present results can only give suggestions towards developing environmental interventions to determine if these findings will actually change the cycling behavior of adults. Environmental interventions in real life settings are needed to find out whether changing the micro-scale environmental factors, identified in this study, will affect actual cycling behavior. Second, in each sorting task, only five environmental variables could be manipulated. Adding an additional environmental factor would exponentially increase the number of photographs and the burden for the participant. Third, 'general upkeep' and 'vegetation' are environmental factors, consisting of many subcomponents that were manipulated simultaneously. Consequently, it is impossible to say which of the manipulated elements is crucial for changing the invitingness. Fourth, a limitation of using color photographs is the lack of movement [50]. In real life, people notice different things in the environment depending on their speed of travel. The use of computer-generated virtual walk-through environments could be a suitable solution [51]. Fifth, the study sample was relatively small, which might make the results less generalizable. Therefore, the findings need to be confirmed in larger samples. A last limitation of this study is that only one streetscape was used for this experiment. Consequently, it is not possible to generalize these findings to other streetscapes. In further studies it should be investigated whether the effect of micro-scale environmental factors on the invitingness for transportation cycling depends on macro-scale environmental factors. If micro and macro-environmental factors are interacting, future studies should also include different environmental macro settings, e.g., environments with high versus low land use mix diversity.

Conclusions

In conclusion, this study has contributed to the research about neighborhood built environment changes to increase the overall PA levels of adults. Our findings indicate that evenness of the cycle path may be a crucial environmental factor when aiming to increase a street's invitingness for transportation cycling among middle-aged adults. Moreover, the effects might be stronger in a good compared to a poorly maintained environment. In addition, cycling invitingness of the physical environment can be enhanced if there is a 'separation between cycle path and motorized traffic', without the presence of a 'separation between cycle path and sidewalk' by means of bollards. Also a low traffic level, a wide cycle path, the presence of a speed bump and vegetation appear to have a positive impact on the invitingness-score for transportation cycling. Furthermore, it is not inviting for transportation cycling to separate cycle path and sidewalk by using bollards. No moderating effects of demographic factors were found. To know whether these results are generalizable to the entire middle-aged adult population, our findings should be confirmed in a larger sample recruited from different geographic areas. On-site research is needed to confirm these current findings.

Competing interests
The authors declare that they have no competing interest.

Authors' contribution
VVH and JVC developed the photograph material and research protocol, in correspondence with NVdW, JN, JS, BD and IDB. VVH and JVC conducted the data collection. LM performed the data analysis and drafted the manuscript, supervised by DVD. All other co-authors critically reviewed and revised versions of the manuscript and each of them read and approved the final manuscript.

Acknowledgements
LM, JVC, VVH and DVD are supported by a grant from the Fund for Scientific Research Flanders (FWO). JS is supported by a National Health and Medical Research Council of Australia Principal Research Fellowship (APP1026216).

Author details
[1]Department of Movement and Sport Sciences, Faculty of Medicine and Health Sciences, Ghent University, Watersportlaan 2, B-9000 Ghent, Belgium. [2]Department of Human Biometry and Biomechanics, Faculty of Physical Education and Physical Therapy, Vrije Universiteit Brussel, Pleinlaan 2, B-1050 Brussels, Belgium. [3]Research Foundation Flanders (FWO), Egmontstraat 5, 1000 Brussels, Belgium. [4]Centre for Physical Activity and Nutrition Research, School of Exercise and Nutrition Science, Deakin University, Burwood Highway 221, Burwood VIC 3125, Australia. [5]Ohio State University, City and Regional Planning, 292 Knowlton Hall, West Woodruff Avenue 275, Columbus, OH 43210, USA. [6]Department of Geography, Faculty of Sciences, Ghent University, Krijgslaan 281, S8, B-9000 Ghent, Belgium.

Received: 19 December 2013 Accepted: 27 June 2014
Published: 19 August 2014

References
1. World Health Organization: *Insufficient physical activity.* World Health Organization; 2008. http://www.who.int/gho/ncd/risk_factors/physical_activity/en/.
2. World Health Organization: *Global Recommendations on Physical Activity for Health.* World Health Organization; 2010. http://www.who.int/dietphysicalactivity/factsheet_recommendations/en/.
3. Rojas-Rueda D, de Nazelle A, Tainio M, Nieuwenhuijsen MJ: **The health risks and benefits of cycling in urban environments compared with car use: health impact assessment study.** *BMJ* 2011, **343:**d4521–d4521.
4. De Hartog JJ, Boogaard H, Nijland H, Hoek G: **Do the health benefits of cycling outweigh the risks?** *Environ Health Perspect* 2010, **118:**1109–16.
5. Oja P, Titze S, Bauman A, de Geus B, Krenn P, Reger-Nash B, Kohlberger T: **Health benefits of cycling: a systematic review.** *Scand J Med Sci Sports* 2011, **21:**496–509.
6. Rissel CE: **Active travel: a climate change mitigation strategy with co-benefits for health.** *N S W Public Health Bull* 2009, **20:**10–3.
7. Woodcock J, Edwards P, Tonne C, Armstrong BG, Ashiru O, Banister D, Beevers S, Chalabi Z, Chowdhury Z, Cohen A, Franco OH, Haines A, Hickman R, Lindsay G, Mittal I, Mohan D, Tiwari G, Woodward A, Roberts I: **Public health benefits of strategies to reduce greenhouse-gas emissions: urban land transport.** *Lancet* 2009, **374:**1930–43.
8. Woodcock J, Banister D, Edwards P, Prentice A, Roberts I: **Energy and health 3 - Energy and transport.** *Lancet* 2007, **370:**1078–1088.
9. Departement of Health- Physical activity- Health improvement and prevention: *At least five a week.* Department of Health, Physical Activity, Health Improvement and Prevention; 2004. http://image.guardian.co.uk/sys-files/Society/documents/2004/04/29/At_least5aweek.pdf.
10. Pucher J, Buehler R, Bassett DR, Dannenberg AL: **Walking and cycling to health: a comparative analysis of city, state, and international data.** *Am J Public Health* 2010, **100:**1986–92.
11. Rabl A, de Nazelle A: **Benefits of shift from car to active transport.** *Transp Policy* 2012, **19:**121–131.
12. Dekoster J, Schollaert U: *Cycling: The Way Ahead for Towns and Cities.* 1999.
13. Sallis JF, Cervero RB, Ascher W, Henderson KA, Kraft MK, Kerr J: **An ecological approach to creating active living communities.** *Annu Rev Public Health* 2006, **27:**297–322.
14. Van Holle V, Deforche B, Van Cauwenberg J, Goubert L, Maes L, Van de Weghe N, De Bourdeaudhuij I: **Relationship between the physical environment and different domains of physical activity in European adults: a systematic review.** *BMC Public Health* 2012, **12:**807.
15. Saelens BE, Sallis JF, Frank LD: **Environmental correlates of walking and cycling: findings from the transportation, urban design, and planning literatures.** *Ann Behav Med* 2003, **25:**80–91.
16. McCormack G, Giles-Corti B, Lange A, Smith T, Martin K, Pikora TJ: **An update of recent evidence of the relationship between objective and self-report measures of the physical environment and physical activity behaviours.** *J Sci Med Sport* 2004, **7**(1 Suppl):81–92.
17. Wendel-Vos W, Droomers M, Kremers S, Brug J, van Lenthe F: **Potential environmental determinants of physical activity in adults: a systematic review.** *Obes Rev* 2007, **8:**425–40.
18. Foster CE, Panter JR, Wareham NJ: **Assessing the impact of road traffic on cycling for leisure and cycling to work.** *Int J Behav Nutr Phys Act* 2011, **8:**61.
19. Carpiano RM: **Come take a walk with me: the "go-along" interview as a novel method for studying the implications of place for health and well-being.** *Health Place* 2009, **15:**263–72.
20. Amaratunga D, Baldry D, Sarshar M, Newton R: **Quantitative and qualitative research in the built environment: application of "mixed" research approach.** *Work Study* 2002, **51:**17–31.
21. Ferdinand AO, Sen B, Rahurkar S, Engler S, Menachemi N: **The Relationship Between Built Environments and Physical Activity : A Systematic Review.** 2012, **102:**7–13.
22. McCormack GR, Shiell A: **In search of causality: a systematic review of the relationship between the built environment and physical activity among adults.** *Int J Behav Nutr Phys Act* 2011, **8:**125.
23. Sallis JF, Bowles HR, Bauman A, Ainsworth BE, Bull FC, Craig CL, Sjöström M, De Bourdeaudhuij I, Lefevre J, Matsudo V, Matsudo S, Macfarlane DJ, Gomez LF, Inoue S, Murase N, Volbekiene V, McLean G, Carr H, Heggebo LK, Tomten H, Bergman P: **Neighborhood environments and physical activity among adults in 11 countries.** *Am J Prev Med* 2009, **36:**484–90.
24. Heesch KC, Sahlqvist S, Garrard J: **Gender differences in recreational and transport cycling: a cross-sectional mixed-methods comparison of cycling patterns, motivators, and constraints.** *Int J Behav Nutr Phys Act* 2012, **9:**106.
25. Eurobarometer F: *Attitudes on issues related to EU Transport Policy Analytical report related to.* THE GALLUP ORGANIZATION, Flash EB No206b; 2007:1–71. http://ec.europa.eu/public_opinion/flash/fl_206b_en.pdf.
26. Eurobarometer F: **Future of transport Analytical report.** *PLoS One* 2011, 1–67. doi:10.1371/journal.pone.0062525.
27. Jongeneel-Grimen B, Busschers W, Droomers M, van Oers HAM, Stronks K, Kunst AE: **Change in neighborhood traffic safety: does it matter in terms of physical activity?** *PLoS One* 2013, **8:**e62525.
28. Duncan MJ, Spence JC, Mummery WK: **Perceived environment and physical activity: a meta-analysis of selected environmental characteristics.** *Int J Behav Nutr Phys Act* 2005, **2:**11.
29. Sallis JF, Conway TL, Dillon LI, Frank LD, Adams MA, Cain KL, Saelens BE: **Environmental and demographic correlates of bicycling.** *Prev Med* 2013, **57:**456–460.
30. Lenders S, Lauwers L, Vervloet D, Kerselaers E: *Afbakening van het Vlaamse platteland, een statistische analyse.* Vlaamse overheid; 2006. http://www2.vlaanderen.be/landbouw/downloads/volt/38.pdf.
31. Stamps: **Simulation effects on environmental preference 1993.pdf.** *J Environ Manag* 1993, **38**(2):115–132.
32. Nasar JL: **Assessing perceptions of environments for active living.** *Am J Prev Med* 2008, **34:**357–63.
33. Wells NM, Ashdown SP, Davies EHS, Cowett FD, Yang Y: **Environment, Design, and Obesity: Opportunities for Interdisciplinary Collaborative Research.** *Environ Behav* 2007, **39:**6–33.
34. Van Holle V, Van Cauwenberg J, Deforche B, Goubert L, Maes L, Nasar J, Van de Weghe N, Salmon J, De Bourdeaudhuij I: **Environmental invitingness for transport-related cycling in middle-aged adults: a proof of concept study using photographs.** In second revision to Transportation Research Part A: Policy and Practice.
35. Pucher J, Buehler R: **Making Cycling Irresistible: Lessons from The Netherlands, Denmark and Germany.** *Transp Rev* 2008, **28:**495–528.

36. Active Living Research: **How to Increase Bicycling for Daily Travel.** 2013, 1–9. http://activelivingresearch.org/how-increase-bicycling-daily-travel.
37. IPAQ: *International physical activity questionnaire (October 2002). Long last 7 days self-administered format*; 2002. http://www.ipaq.ki.se/questionnaires/IPAQ_LS_rev021114.pdf.
38. Craig CL, Marshall AL, Sjöström M, Bauman AE, Booth ML, Ainsworth BE, Pratt M, Ekelund U, Yngve A, Sallis JF, Oja P: **International physical activity questionnaire: 12-country reliability and validity.** *Med Sci Sports Exerc* 2003, **35**:1381–95.
39. Rasbash J, Charlton C, Browne WJ, Healy M, Cameron B: *(MLwiN Version 2.02)*. Centre for Multilevel Modelling, University of Bristol; 2005.
40. Beretvas SN: *Cross-classified and multiple membership models. Edited by Hox JJ, Roberts JK.* New York: Routledge Academic; 2010.
41. Browne WJ: *MCMC Estimation in MLwiN v2.1*. Centre for Multilevel Modelling University of Bristol and (*also School of Veterinary Sciences University of Bristol); 2009.
42. Browne WJ, Rasbash J, Charlton C, Kelly M, Pillinger R: *MCMC Estimation in MLwiN*. Centre for Multilevel Modelling University of Bristol and (*also School of Veterinary Sciences University of Bristol); 2012.
43. Bazeley P, Jackson K: *Qualitative Data Analysis with NVivo*. London: SAGE Publications Ltd; 2013:328.
44. Pope C, Ziebland S, Mays N: **Qaulitative research in health care. Analysing qualitative data.** *British Med J* 2000, **320**:114–6.
45. Winters M, Davidson G, Kao D, Teschke K: **Motivators and deterrents of bicycling: comparing influences on decisions to ride.** *Transportation* 2010, **38**:153–168.
46. Parkin J, Wardman M, Page M: **Estimation of the determinants of bicycle mode share for the journey to work using census data.** *Transportation* 2007, **35**:93–109.
47. Fraser SDS, Lock K: **Cycling for transport and public health: a systematic review of the effect of the environment on cycling.** *Eur J Public Health* 2011, **21**:738–43.
48. Alta Planning + Design: *CYCLE TRACKS : Lessons Learned*; 2009. http://www.cts.pdx.edu/pdf/Birk%20cycle%20track%20lessons%20learned.pdf.
49. Pucher J, Dijkstra L: **Promoting safe walking and cycling to improve public health: lessons from The Netherlands and Germany.** *Am J Public Health* 2003, **93**:1509–16.
50. Heft H, Nasar JL: **Evaluating Environmental Scenes Using Dynamic Versus Static Displays.** *Environ Behav* 2000, **32**:301–322.
51. Cubukcu E, Nasar JL: **Influence of physical characteristics of routes on distance cognition in virtual environments.** *Environ Plann B Plann Des* 2005, **32**:777–785.

doi:10.1186/s12966-014-0088-x
Cite this article as: Mertens *et al.*: The effect of changing micro-scale physical environmental factors on an environment's invitingness for transportation cycling in adults: an exploratory study using manipulated photographs. *International Journal of Behavioral Nutrition and Physical Activity* 2014 **11**:88.

Chapter 2.2 – Investigating the interaction between micro- and macro-environmental factors

Mertens, L., Van Cauwenberg, J., Ghekiere, A., Van Holle, V., De Bourdeaudhuij, I., Deforche, B., Nasar, J., Van De Weghe, N., & Van Dyck, D. (2015). Does the effect of micro-environmental factors on a street's appeal for adults' bicycle transport vary across different macro-environments? An experimental study. PLoS One, 10(8): e0136715. doi:10.1371/journal.pone.0136715

PLOS | ONE

RESEARCH ARTICLE

Does the Effect of Micro-Environmental Factors on a Street's Appeal for Adults' Bicycle Transport Vary across Different Macro-Environments? An Experimental Study

Lieze Mertens[1], Jelle Van Cauwenberg[2,3,4], Ariane Ghekiere[2,3,4], Veerle Van Holle[1,4], Ilse De Bourdeaudhuij[1]*, Benedicte Deforche[2,3], Jack Nasar[5], Nico Van de Weghe[6], Delfien Van Dyck[1,4]

1 Department of Movement and Sport Sciences, Faculty of Medicine and Health Sciences, Ghent University, Watersportlaan 2, B-9000, Ghent, Belgium, **2** Department of Public Health, Faculty of Medicine and Health Sciences, Ghent University, De Pintelaan 185, 4k3, B-9000, Ghent, Belgium, **3** Department of Human Biometry and Biomechanics, Faculty of Physical Education and Physical Therapy, Vrije Universiteit Brussel, Pleinlaan 2, B-1050, Brussels, Belgium, **4** Research Foundation Flanders (FWO), Egmontstraat 5, 1000, Brussels, Belgium, **5** Ohio State University, City and Regional Planning, 292 Knowlton Hall, West Woodruff Avenue 275, Columbus, OH, 43210, United States of America, **6** Department of Geography, Faculty of Sciences, Ghent University, Krijgslaan 281, S8, B-9000, Ghent, Belgium

* Ilse.Debourdeaudhuij@Ugent.be

CrossMark
click for updates

OPEN ACCESS

Citation: Mertens L, Van Cauwenberg J, Ghekiere A, Van Holle V, De Bourdeaudhuij I, Deforche B, et al. (2015) Does the Effect of Micro-Environmental Factors on a Street's Appeal for Adults' Bicycle Transport Vary across Different Macro-Environments? An Experimental Study. PLoS ONE 10(8): e0136715. doi:10.1371/journal.pone.0136715

Editor: Timothy C. Matisziw, University of Missouri, UNITED STATES

Received: October 1, 2014

Accepted: July 23, 2015

Published: August 28, 2015

Data Availability Statement: All relevant data are within the paper.

Funding: AG, JVC, VVH and DVD are supported by a grant from the Fund for Scientific Research Flanders (FWO) (grant numbers: JVC: 11N0313N AG: GA11111N VVH: 11O3115N DVD: FWO12/PDO/158; www.fwo.be). The funders had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript.

Abstract

Background

Characteristics of the physical environment can be classified into two broad categories: macro- ("raw" urban planning features influenced on a regional level) and micro- (features specifically within a streetscape influenced on a neighborhood level) environmental factors. In urban planning applications, it is more feasible to modify conditions at the neighborhood level than at the regional level. Yet for the promotion of bicycle transport we need to know whether relationships between micro-environmental factors and bicycle transport depend on different types of macro-environments. This study aimed to identify whether the effect of three micro-environmental factors (i.e., evenness of the cycle path surface, speed limits and type of separation between cycle path and motorized traffic) on the street's appeal for adults' bicycle transport varied across three different macro-environments (i.e., low, medium and high residential density street).

Methods

In total, 389 middle-aged adults completed a web-based questionnaire consisting of socio-demographic characteristics and a series of choice tasks with manipulated photographs, depicting two possible routes to cycle along. Conjoint analysis was used to analyze the data.

Results

Although the magnitude of the overall effects differed, in each macro-environment (i.e., low, medium and high residential density), middle-aged adults preferred a speed limit of 30 km/h,

Competing Interests: The authors have declared that no competing interests exist.

an even cycle path surface and a hedge as separation between motorized traffic and the cycle path compared to a speed limit of 50 or 70 km/h, a slightly uneven or uneven cycle path surface and a curb as separation or no separation between motorized traffic and the cycle path.

Conclusions

Our results suggest that irrespective of the macro-environment, the same micro-environmental factors are preferred in middle-aged adults concerning the street's appeal for bicycle transport. The controlled environment simulations in the experimental choice task have the potential to inform real life environmental interventions and suggest that micro-environmental changes can have similar results in different macro-environments.

Background

Globally, 31% of adults aged 15 years or older are insufficiently physically active, [1,2], which is reflected in the rapidly increasing prevalence of inactivity-related health problems [2]. In the European Union, there is a significant unfulfilled potential to increase bicycling behavior of the population, since 50% of all trips are shorter than 3 kilometers, a distance which can be cycled in 10 minutes [3]. In Flanders (Belgium), more than 70% of these trips ($\leq$ 3 km) are currently done using passive transport [4]. Bicycle transport is an accessible, economic, social, and environmentally sustainable form of physical activity, easy to integrate into adults' daily routines and moreover has the potential to increase physical activity levels in European adults. Cross-sectional studies indicated that bicycle transport is associated with higher general physical activity levels and lower body weight in adults [5]. Prospective observational studies demonstrated a strong inverse relationship between bicycle transport and all-cause mortality, cancer mortality, and cancer morbidity among middle-aged participants [6]. In addition, active transport has many other positive economic, social, environmental and traffic management effects [6–15]. Because of these benefits, communities should encourage people to cycle on a regular or daily basis [16–19]. One long-term approach to do this involves changes to the physical environment to make it more supportive of bicycling [20]. Environmental interventions and policies targeting the physical environment, can reach large populations over long periods of time and encourage more bicycling and less reliance on the car [7,21,22]. The physical environment can be defined as "the objective and perceived characteristics of the physical context in which people spend their time (e.g. home, neighborhood), including aspects of urban design, traffic density and speed, distance to and design of venues for physical activity (e.g., parks), crime and safety" [23]. Previous studies already indicated that the physical environment appears to be an important contributor to encourage bicycle transport among middle-aged adults [22,24].

Characteristics of the physical environment can be classified into two broad categories: macro- and micro-environmental factors [25,26]. Macro-environmental factors can be defined as the more "raw" urban planning features; such as street network density, residential density and land use diversity. These factors may be difficult to change in existing neighborhoods, because of their size and complexity and moreover because this would require a strong collaboration between regional authorities. Macro-environmental factors are essentially beyond the influence of individuals and even for governments and nongovernmental organizations it is usually difficult to modify large existing structural features [25,26]. Micro-environmental factors, however, can be defined as specific characteristics of environmental features within a streetscape; such as evenness cycle path surface, vegetation and speed limits. In urban planning applications, it is more feasible to modify conditions at the neighborhood level than at the regional level because these micro-environmental factors are relatively small-scaled environmental factors and potentially influenced by individuals or local actors [25,26]. Therefore, the reconfiguration of micro-environmental factors in existing neighborhoods involves a lower cost and a shorter time-frame compared to the reconfiguration of the macro-scale structural design [25,26], making micro-environmental factors more practical and promising to target in physical environmental interventions of existing neighborhoods. Studies around the world have found consistent positive relationships between macro-environmental factors (including walkability, access to shops/services/work, and urbanization) and transport-related bicycling in adults [25,26]. Unfortunately, the relationships between bicycle transport and more amenable, micro-environmental factors are less consistent [27–29]. These inconsistencies in the literature are potentially attributed to the used methodology.

Although various studies have investigated the relationships between the physical environment and physical activity, they are often cross-sectional and thus not able to establish causality [30–32]. In these studies, environmental perceptions were generally assessed with questionnaires, which involves some difficulties. First, participants have to recall features of the physical environment, which leads to recall bias [33], and second the lack of standardization in neighborhood definitions increases the inconsistency as well [34]. Moreover, because many physical environmental factors are interrelated in real life conditions, these studies cannot clearly identify the critical environmental correlates of bicycle transport. Experimental studies are required to decrease these inconsistencies and to make causal statements [22,30–32,35]. Since experiments are complex, time- and cost-consuming to conduct in real environments, an innovative experimental and cost-effective methodology is required.

Therefore, the present study opts for a controlled experiment: it uses controlled manipulations of environmental characteristics in photographs to experimentally find out whether these characteristics affect the street's appeal for bicycle transport. As research shows that responses to photos generalize well to on-site response [36,37], the findings can provide guidelines for interventions that modify micro-environmental factors to increase the street's appeal for bicycle transport. This methodology was used in two recent mixed-methods studies to determine possible causal relationships between a limited number of key micro-environmental factors and the street's appeal walking transport among older adults [38] and bicycle transport among adults [39]. This latter pilot study provided a first indication of the effects of changing micro-environmental factors on the street's appeal for bicycle transport in adults. However, this pilot study had an important limitation: it used only one macro-environment, a typical street environment in a semi-urban (300–600 inhabitants/km^2) Belgian municipality [40]. For interventions, it is essential to know how well the findings can be generalized to other macro-environments. If micro- and macro- environmental factors are interacting, interventions focusing on micro-environmental factors may have to differ depending on the macro-environment.

Therefore, the current study aims to find out if the effect of manipulated micro-environmental factors (evenness of the cycle path surface, speed limit and type of separation between cycle path and motorized traffic) on the street's appeal for middle-aged adults' bicycle transport depends on macro-environmental factors or is generalizable to different macro-environments (i.e. low, medium and high residential density street).

Methods

Protocol and measures

Flemish middle-aged adults between 45 and 65 years were recruited by purposeful convenience sampling [41] using email, social media, family, friends, clubs and organizations. By snowball sampling [41], additional participants were recruited. This age group was chosen as adults in this age range do assess the environment according to themselves, rather than in the viewpoint of their children. Participants completed a two-part web-based questionnaire, which was developed using Sawtooth Software (SSIWebversion 8.2.4.). It first assessed socio-demographic characteristics, and second the participant had to perform a series of choice tasks with manipulated photographs (a detailed description of these choice tasks appears later in this paper). Informed consent was automatically obtained from the participants when they voluntarily completed the questionnaire. The online questionnaire was available from the beginning of February until the end of March 2014 and 389 middle-aged adults participated in the study. The study was approved by the Ethics Committee of the Ghent University Hospital.

Photograph development. The manipulated photographs, depicting a possible route to cycle along, used in the choice task were developed with Adobe Photoshop software [42]. Previous research has established the validity of responses to color photos in comparison to on-site responses [36,37]. In each photograph, four environmental factors (one macro- and three micro-environmental factors) were manipulated and each environmental factor consisted of three possible levels (see Fig 1), yielding a total of 81 (= 3^4) photographs. One of the four manipulated environmental factors was considered as a macro-environmental factor and was defined in this study according to residential building density and land-use mix depicting the general street setting. Three levels were distinguished: (1) environment with low building density (open environment) and single land use, (2) environment with medium building density and single land use, (3) environment with high building density and mixed land use. See S1 File for an example of all three different street settings or macro-environments used in this study. Additionally, three micro-environmental factors (evenness cycle path surface, speed limit and type of separation between cycle path and motorized traffic) were manipulated in each photograph and consisted of an anticipated attractive, intermediate and unattractive level (e.g. even cycle path surface, slightly uneven cycle path surface and a very uneven cycle path surface). These three micro-environmental factors were chosen based on previous research [27,39,43,44] and existing literature on the relationship between the environment and bicycle transport [27,45]. Each photograph was developed from an adult cyclist's eye level viewpoint, under dry weather conditions and without people visible in the environment. Fig 1 and S1 File provides an overview and illustration of the four manipulated environmental factors with their respective levels (the terms presented in Fig 1 are used throughout the article).

The web-based questionnaire. The web-based questionnaire had two parts. The first part assessed socio-demographic characteristics: gender, age, country of birth, education, occupational status, marital status and place of residence (see Table 1 for the response categories). Next, the long form of the International Physical Activity Questionnaire (IPAQ: 'usual week') [46] was used to establish the amount of usual amount of bicycle transport in a week. The second part of the questionnaire consisted of a series of choice tasks, based on a choice based conjoint (CBC) method. This CBC method is mainly used in marketing research and enables examination of preferences for various components of a product in the decision process to pursuit the product [47]. In this study the various components are the different manipulated environmental factors and the product is a street's appeal for bicycle transport along the depicted environments. Despite conjoint analysis is more than forty years old, it continues to evolve by new technology and methodologies [47]. Furthermore, besides marketing research an ongoing stream of research is making use of this technique [48]. Conjoint analysis has been proved to be one of the best tools available for determining relative importance of factors of complex environments from the user point of view [49,50]. Using photographs to display alternatives of complex environments rather than written descriptions, immediately gives a clear view or understanding of what should be assessed (i.e. reduce recall bias). The following scenario was

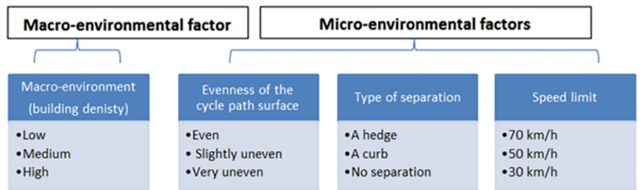

Fig 1. An overview of the environmental factors and their respective levels used in the choice tasks (ref. S1 File).

doi:10.1371/journal.pone.0136715.g001

presented to the respondents: "*Imagine yourself bicycling to a friend's home, located at 10 minutes bicycling from your home, during daytime with perfect weather circumstances. For every task you will see two streets, we ask you to choose the street that you find most appeal to cycle along to a friend. Whichever route you choose the distance to your friend is the same and all cycle paths are one-way. There is no right or wrong solution, we are only interested in which street you would prefer to cycle along.*" First, participants could see three examples and afterwards they received a set of 14 randomly assigned choice tasks. More than 20 choice tasks may make respondents less likely to complete the task [51]. The computer program randomly determined the picture pairs that appeared in the choice tasks, allowing each level within each attribute to appear an equal number of times in the choice task and consequently allowing that not all possible combinations need to be presented to each participant.

An a priori power analysis (power 0.80 and $\alpha = 0.05$) calculated by the following formula: *nta /c > 500 (n = number of participants; t = 14: number of choice tasks; a = 2: number of alternatives per task; c = 9: the largest product of levels of any two factors*) [47] showed that a minimum of 161 subjects was needed when manipulating four environmental factors in one photograph (with three levels each) and presenting 14 choice tasks to each participant.

To assess test-retest reliability, we conducted a pilot study (n = 27) in which four fixed tasks were deliberately added to the set of choice tasks. In this pilot study, participants had to complete 16 choice tasks. The same two choice tasks were presented at the beginning and at the end of the questionnaire. These choice based conjoint tasks were identical for all participants

Table 1. Descriptive characteristics of the participants (n = 389).

Age (M ± SD) (year)	53.8 ± 5.2	**Occupational status (%)**	
Women (%)	55.3	- Household	4.4
Born in Belgium (%)	96.4	- Blue collar	6.7
Marital status (%)		- White collar	68.9
- Married	75.3	- Unemployed	3.9
- Widowed	2.3	- Retired	15.2
- Divorced	10	- Career interruption	1
- Single	4.4	**BMI (M ± SD)**	24.8 ± 4.0
- Cohabiting	8	**Current bicycle transport level**	
Education (%)		- Bicycle transport min/wk (M ± SD)	37.3 ± 33.1
- Primary	1.8	- No bicycling for transport (%)	24.69
- Lower secondary	19		
- Higher secondary	13.4		
- Tertiary	65.8		

M = mean; SD = standard deviation; BMI = body mass index

doi:10.1371/journal.pone.0136715.t001

(= fixed tasks). Subsequently, it was examined whether participants chose the same street both times. The percentage of agreement for the first task was 81% and 93% for the second fixed task (n = 27). An adequate level of agreement is generally considered to be 70% [52]. These results indicated that our choice tasks are reliable.

Analyses

Choice-based conjoint analysis (CBC). Choice-based conjoint analysis (CBC) was used to analyze the data [47]. First, average part-worth utilities were calculated from the individual utilities gained from hierarchical Bayes (HB) estimation to determine the main effects of each environmental factor on the street's appeal for bicycle transport along the depicted environments. This has been suggested as the most appropriate method to analyze data gained from choice based conjoint [53]. Utilities represent the degree of preference given to a particular level of an environmental factor and are similar to a β obtained from linear regression analyses [47].

Second, the average relative importance of each environmental factor was calculated from the individual utility data gained from hierarchical Bayes (HB) estimation. Utility values cannot be compared across components, because they have different metrics, but each component has a unique scale determined through the hierarchical Bayes estimation procedure. Therefore, the difference in individual utilities between the most and least preferred levels of a component can be used to represent the importance of each component for each respondent [47]. This individual importance represents the relative importance of each environmental factor when judging a street on the street's appeal for adults' bicycle transport. An individual importance is calculated by subtracting the lowest from the highest utility for the given factor and dividing this by the sum of differences across all components for that participant. The individual relative importance can in turn be used to calculate the average relative importance of each component for the total sample [47]. Furthermore, also the relative importance of the micro-environmental factors within each macro-environment was calculated.

Third, interaction effects were also derived from part-worth utilities gained from the hierarchical Bayes (HB) estimation using dummy coding (burn in: 100,000; total iterations: 1,100,000). Three separate models were constructed to analyze the interaction effects of micro-environmental factors with the macro-environment: 'macro-environment by evenness of the cycle path surface', 'macro-environment by speed limit' and 'macro-environment by type of separation between cycle path and motorized traffic'. The interaction effects were illustrated by graphs and tables in which the total utilities of the different streets were shown. Total utilities were calculated by the sum of the part-worth utilities, representing the degree of preference given to a particular level of an environmental factor. The size of the interaction effect was determined by calculating the difference in total utilities for each participant separately. The average of these values over all subjects, is the average interaction effect. A 95% confidence interval was calculated to define significance.

Results

Descriptive statistics

In total, 389 adults (214 women and 175 men) between 45 and 65 years participated in the study. Most participants (65.8%) reported a tertiary education degree (higher, university or postgraduate). Approximately one quarter of the participants said they did not cycle for transport in a usual week. See Table 1 for other descriptive characteristics of the sample.

Main effects of the environmental factors

For the macro-environmental factor, participants preferred a low (average part-worth utility = 1.93±3.45; 95% CI: 1.59, 2.27) residential density street above a medium (0.76±1.89; 95% CI: 0.58, 0.95) or high (reference level) residential street. Moreover, they preferred a medium residential density street to a high residential street. For the micro-environmental factors, participants preferred an even cycle path surface (3.61±5.01; 95% CI: 3.11, 4.11) to a slightly uneven (2.25±2.49; 95% CI: 2.00, 2.50) or very uneven (reference level) cycle path; and they preferred a slightly uneven cycle path surface to a very uneven cycle path surface. They also preferred a traffic limitation of 30 km/h (4.43±2.90; 95% CI: 4.14, 4.72) to one of 50 km/h (2.51 ±1.62; 95% CI: 2.35, 2.67) or 70 km/h (reference level) and they preferred a traffic limitation of 50 km/h to one of 70 km/h. Finally, the participants preferred a cycle path separated from traffic with a hedge (4.91±3.13; 95% CI: 4.60, 5.22) to one separated from traffic with a curb (2.04 ±1.90; 95% CI: 1.86, 2.23) or one located on the street (reference level), and they preferred a cycle path separated from traffic with a curb to one located on the street. See S1 File for an illustration of the different manipulations (e.g. the different types of separations between cycle path and motorized traffic).

Relative importance of the environmental factors

The average importance of the four factors, based on individual utility calculations, shows that the macro-environment was the least important factor in making choices among the different street alternatives. Given that there is no overlap between the confidence intervals of the micro-environmental factors, it appears that the average importance of the macro-environment (18.15±14.66%; 95% CI: 16.69, 19.61) was significantly lower compared to the three micro-environmental factors. The three micro-environmental factors, however, did not significantly differ from each other in relative importance with 26.71±22.36% (95% CI: 24.48, 28.93) for evenness of the cycle path surface, 26.68±16.50% (95% CI: 27.04, 30.32) for type of separation between cycle path and motorized traffic and 26.47±15.62% (95% CI: 24.92, 28.02) for speed limit.

Relative importance of the micro-environmental factors within each macro-environment

Greater importance was found for type of separation between cycle path and motorized traffic than for evenness of the cycle path surface in each macro-environment (see Fig 2). The results showed that in a low residential density environment a separation (37.20±16.98%; 95% CI: 35.51, 38.89) was also more important than the presence of speed limit (33.10±15.47%; 95% CI: 31.56, 34.63). In a medium residential density environment, the presence of a speed limit (36.05±17.56%; 95% CI: 34.31, 37.80) was more important than the evenness of the cycle path surface (29.57±23.13%; 95% CI: 27.27, 31.87). The remaining importance of the micro-environmental factors did not significantly differ from each other in each macro-environment.

Interaction effects

Interaction between macro-environment and evenness of the cycle path surface. Fig 3 shows the overall utilities for streets differing in macro-environment and evenness of the cycle path surface. The characters on Fig 3 illustrate the distance between the total utilities. In each macro-environment, an even cycle path surface was preferred for bicycling to a slightly or very uneven cycle path surface, and a slightly uneven was preferred to a very uneven cycle path surface. Only the strength of this positive effect of evenness of the cycle path surface differed

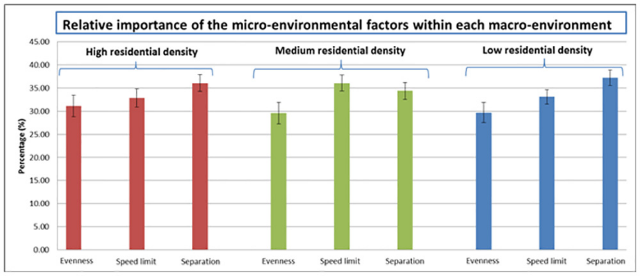

Fig 2. The average relative importance of the three micro-environmental factors in each macro-environment.

doi:10.1371/journal.pone.0136715.g002

between the three macro-environments. The effect of an even cycle path surface compared to a very uneven cycle path surface or a slightly uneven cycle path surface was lower in a medium residential density environment compared to a high or low residential building density (see Table 2 and Fig 3). No significant difference in effect of evenness of the cycle path surface emerged for comparisons of a low to a high residential density environment.

Interaction between macro-environment and speed limit. Fig 4 shows the overall utilities for streets differing in macro-environment and speed limit. In each macro-environment the most strict speed limit (30 km/h) was preferred first and secondly 50 km/h above 70 km/h. Only in a medium residential density environment the participants preferred a speed limit of 70 km/h above 50 km/h. The positive effect of a speed limit of 30 km/h compared to 70 km/h or 50 km/h was largest in a low residential density environment, except for the effect of a speed limit of 30 km/h compared to 50 km/h which was stronger in a medium residential density environment (see Table 2 and Fig 4).

Interaction between macro-environment and type of separation between cycle path and motorized traffic. Fig 5 shows the overall utilities for streets differing in macro-environment and type of separation between cycle path and motorized traffic. In each macro-environment, participants preferred first a hedge as separation between cycle path and motorized traffic and secondly a curb above a cycle path located on the street. However, the strength of the effect of the type of separation differed between the different macro-environments. The effect of a hedge instead of no separation was larger in a high compared to a medium residential density environment. There was no significant difference of this effect between a high compared to low and a low compared to medium residential density environment. Moreover the effect of a curb

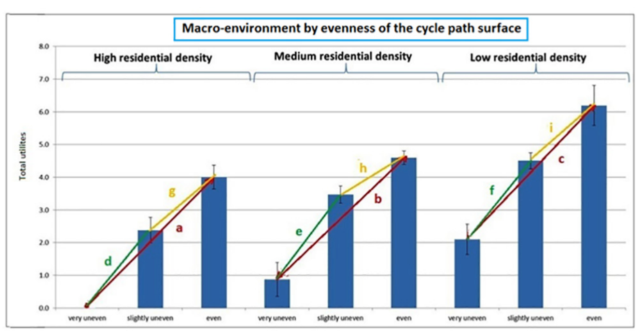

Fig 3. Interaction effect between the macro-environment and the evenness of the cycle path surface. Note: a, b, c, d, e, f, g, h, i = the distance between the total utilities; * = $p<0.05$; a > b*, a < c, b < c*, d < e*, d < f, e > f*, g < h*, g < i, h < i*.

doi:10.1371/journal.pone.0136715.g003

Table 2. Interaction effect between the macro-environment and evenness of the cycle path surface, speed limit and type of separation between cycle path and motorized traffic.

Macro-environment and evenness of the cycle path surface									
Evenness	***Very uneven—even***			***Very uneven—slightly uneven***			***Even—slightly uneven***		
Macro	***High—Med***	***High—Low***	***Med—Low***	***High—Med***	***High—Low***	***Med—Low***	***High—Med***	***High—Low***	***Med—Low***
MEAN	-0.28	0.09	0.37	0.21	0.02	-0.19	-0,49	0,07	0,57
SD	0.93	1.53	1.10	1.06	1.08	1.44	0,95	1,15	1,03
-95% CI	-0.37	-0.06	0.27	0.11	-0.09	-0.33	-0,59	-0,04	0,46
+95% CI	-0.19	0.25	0.48	0.32	0.13	-0.05	-0,40	0,19	0,67
Fig 3	a > b*	a < c	b < c*	d < e*	d < f	e > f*	g < h*	g < i	h < i*
Macro-environment and speed limit									
Speed limit	***70 km/h—30 km/h***			***70 km/h—50 km/h***			***30 km/h—50 km/h***		
Macro	***High—Med***	***High—Low***	***Med—Low***	***High—Med***	***High—Low***	***Med—Low***	***High—Med***	***High—Low***	***Med—Low***
MEAN	-0,62	0,19	0,81	-4,19	0,11	4,30	3,57	0,08	-3,49
SD	0,96	0,91	1,21	1,94	1,24	1,80	1,96	0,58	2,03
-95% CI	-0,72	0,10	0,69	-4,38	-0,02	4,12	3,37	0,02	-3,69
+95% CI	-0,53	0,28	0,93	-4,00	0,23	4,47	3,76	0,14	-3,28
Fig 4	j > k*	j < l*	k < l*	m > n*	m < o	n < o*	p > q*	p < r*	q > r*
Macro-environment and type of separation between cycle path and motorized traffic									
Type of separation	***No separation—hedge***			***No separation—curbe***			***Hedge—curb***		
Macro	***High—Med***	***High—Low***	***Med—Low***	***High—Med***	***High—Low***	***Med—Low***	***High—Med***	***High—Low***	***Med—Low***
MEAN	-0.25	-0.10	0.15	0.85	0.46	-0.38	-1.09	-0.56	0.54
SD	1.43	2.11	1.59	1.41	1.71	2.55	0.99	1.66	1.63
-95% CI	-0.39	-0.30	-0.01	0.71	0.29	-0.64	-1.19	-0.72	0.37
+95% CI	-0.10	0.11	0.31	0.99	0.63	-0.13	-0.99	-0.39	0.70
Fig 5	s > t*	s > u	t < u	v < w*	v < x*	w > x*	y > z_1*	y < z_2*	z_1 < z_2*

RSD = residential building density, SD = standard deviation, CI = confidence interval,

* = p<0.05

Note: a, b, c, d, e, f, g, h, i, j, k, l, m, n, o, p, q, r, s, t, u, v, w, x, y, z^1, z^2 = the distance between the total utilities, which are marked on Figs 3, 4 and 5.

doi:10.1371/journal.pone.0136715.t002

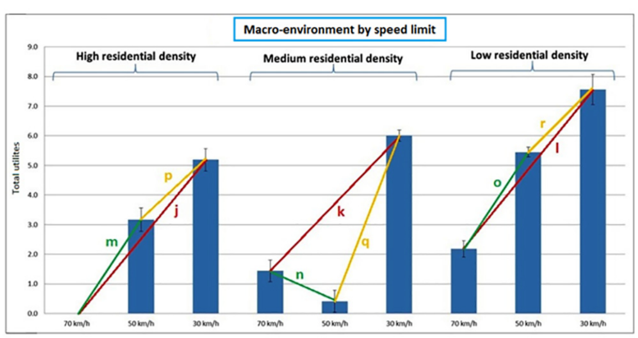

Fig 4. Interaction effect between the macro-environment and speed limit. Note: j, k, l, m, n, o, p, q, r = the distance between the total utilities; * = p<0.05; j > k*, j < l*, k < l*, m > n*, m < o, n < o*, p > q*, p < r*, q > r*.

doi:10.1371/journal.pone.0136715.g004

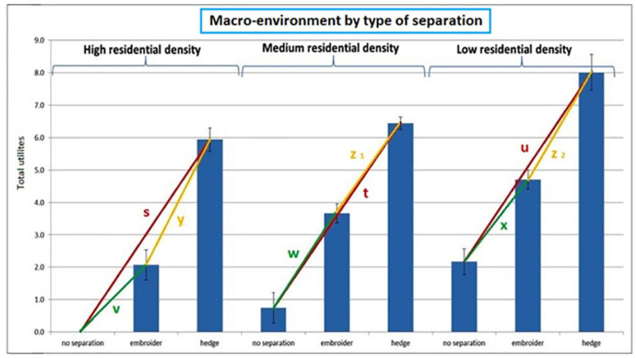

Fig 5. Interaction effect between the macro-environment and type of separation between cycle path and motorized traffic. Note: s, t, u, v, w, x, y, z^1, z^2 = the distance between the total utilities; * = p<0.05; s > t*, s > u, t < u, v < w*, v < x*, w > x*, y > z1*, y < z2*, z1 < z2*.

doi:10.1371/journal.pone.0136715.g005

instead of no separation was largest in a medium and also greater in a low compared to high residential density environment (see Table 2 and Fig 5).

Discussion

This is the first controlled experiment to examine the effect of manipulating micro-environmental factors on the environment's perceived street's appeal for adults' bicycle transport in different street settings or macro-environments. The analyses indicate that the effect of micro-environmental modifications may well generalize to physical environmental interventions in different macro-environments. Although we found several statistically significant interactions between the micro-environmental factors and the macro-environmental factor, the direction of the effects across the different macro-environments did not differ, only the magnitude of the effect did.

There was no significant difference in relative importance between the three micro-environmental factors, independent of the macro-environment. Thus, all three micro-environmental factors were equally important for the street's appeal for bicycle transport. However, within each macro-environment, small differences in relative importance of the micro-environmental factors were detected. The presence of a separation was more important than evenness of the cycle path surface in all three macro-environments. In a low residential density environment, a separation was also more important than a speed limit and in a medium residential density environment, the presence of a speed limit was more important than evenness of the cycle path surface. Otherwise, the relative importance of the three micro-environmental factors was similar in each macro-environment. Since the real environment consists of a large number of micro-environmental factors, it is essential for future research to include all possible environmental factors in photograph experiments in order to make the best simulation of the real environment. However, this research step was necessary because it would be unmanageable to manipulate all possible micro-environmental factors, together with different macro-environmental factors in the photographs.

The current study also showed that the macro-environment was less important for the street's appeal for bicycle transport than the three micro-environmental factors. This suggests that each improvement in a micro-environmental factor is a promising practical direction for interventions. However, our finding that participants preferred a low to either a medium or high residential density environment for bicycle transport differs from previous cross-sectional studies. Those studies indicated that certain macro-environment factors, including walkability, access to shops/services/work and degree of urbanization with bicycle transport, are associated with more bicycle transport [27]. People living in more urbanized areas or in a highly walkable environment tend to do more bicycle transport than people living in less walkable environments [27,54,55]. Although a more walkable environment probably encourages bicycling through the short access to shops/services/work, the current study shows that the view of a less walkable environment is more appealing for bicycling. It is possible that these contrasting findings result from the standardized 10 minute travel time in the present study. Concerning walkability, the distance to a destination is a crucial aspect for transportation behavior and in low dense areas, travel distances are usually larger than 10 minutes. Adding the effect of distance as an additional factor to the choice tasks, could be a good research question for future research. The discrepancy between our finding and previous findings may also result from differences between the perception of the street's appeal for bicycle transport, the intention to cycle and the actual bicycling behavior [56,57].

Examination of the importance of the levels within each environmental factor (main effects) revealed that an even cycle path surface, a speed limit of 30 km/h, and a hedge between cycle path and motorized traffic were most preferred to middle-aged adults for the street's appeal for bicycle transport along the depicted environments. A previous study using manipulated photographs yielded similar results [39]. The present study confirmed these results but for different macro-environments, which was the ultimate goal in this research. In addition, previous cross-sectional studies found evenness of the cycle path surface [58,59], speed limit [45,60] and type of separation between cycle path and motorized traffic [59,61,62] to be related to bicycle transport. Our results indicated that small changes in the micro-environmental factors can help to increase the street's appeal for bicycle transport in various macro-environments. Since in this study only a selection of three micro-environmental factors and not all potentially relevant micro-environmental factors (e.g., general upkeep of the environment, presence of vegetation, traffic volume) were used in these experiments, further research is needed to determine the effect of all those factors.

The main strength of this study is the used innovative methodology that enables to establish causal relationships between environmental manipulations and the street's appeal for bicycle transport. Because it is very difficult and expensive to investigate the effects of changing real environments on actual bicycling behavior, this study used a cost-effective approach by manipulating photographs of environments. However, further research in real-life settings is warranted to find out whether current findings can be replicated when studying the effects of real environmental modifications on actual bicycling behavior. Furthermore, these causal relationships cannot be recorded by more recent methodologies like photo-elicitation [63] (requiring participants to take photo images of their journey and revealing actual preferences) or GPS [64] (indicates where an individual is active). These methodologies could help to record changes in behavior as a result of natural experiments, but could not give information about the importance of micro- and macro-environmental factors. The current study adds to the literature, as it is still unclear what type of infrastructure is required to encourage bicycle transport. This might be due to the fact that environmental factors have not been specified enough to elicit associations between bicycle transport and built environment in previous studies [65]. In contrast, our study focuses on small, amenable micro-environmental factors, which are feasible to modify during interventions. Furthermore, it remains important to keep in mind that interventions should not focus on only one particular determinant of active transport, such as the built environment. Evidence shows that multi-layered interventions are most successful to initiate and sustain behavior change effectively [7,65].

Future research can benefit from some of the strengths of the present approach: the use of different macro-environments to examine the effect of manipulating micro-environmental factors, testing responses to photographs rather than verbal descriptions of places, the use of manipulated simulations to create a controlled experiment, and the use of a choice-based conjoint method (CBC), which allow testing for effects without presenting all of the possible combinations. The study also allowed to test more items that were combined at the same time. Such methodology can answer questions about effects of environmental changes on the street's appeal for adults' bicycle transport. The same method can also be used for different subgroups like children and senior citizens, and perhaps can also be used for other behaviors such as walking or general physical activity. Consequently, these controlled simulations can provide ready-made advice for natural experiments, which can be considered a logical next step in this study project. Findings obtained from research using manipulated photographs could inform physical environmental interventions in real life settings about which environmental factors to modify in different macro-environments.

There are, however, some limitations that have to be acknowledged. First, the present study assessed effects on the street's appeal for bicycle transport and, not actual bicycling behavior. Consequently, studies are needed to examine the effects of changing real environments on bicycling behavior in various contexts. Second, the present study focused on three micro-environmental factors. Although previous research had indicated them as important factors, perhaps other factors would have effects alone or in interaction with other factors. Future research should identify and include all potentially relevant micro-environmental factors and investigate their interactions. Third, a limitation of using color photographs is the two-dimensional character or the lack of movement in the environment. In real life, people notice different things in the environment depending on their speed of travel. Manipulating computer-generated virtual walkthrough environments (three-dimensional) could offer a solution for this problem [66]. Fourth, our sampling yielded a sample of well-educated adults with 65.8% having a tertiary education degree. This is much more than the statistics for the Flemish population indicate with 28.1% having a tertiary degree [67]. Future research needs to establish how well the findings apply to other less educated groups. A study from Scheepers et al. (2013) [68] indicated a higher use of active transport modes by persons with an university or college degree. Because there are differences in bicycling behaviors between individuals with a different individual educational level, future research should also investigate the moderating effects of other personal determinants (such as gender, age and employment) on the relationships between manipulating the environment and the street's appeal for bicycle transport as well [22].

Conclusions

The present study used different macro-environments to examine the effect of manipulating micro-environmental factors. Our findings indicate that in each different macro-environment (i.e. low, medium and high residential density), middle-aged adults preferred a speed limit of 30 km/h, an even cycle path and a hedge as separation between motorized traffic and the cycle path compared to a speed limit of 50 or 70 km/h, a slightly uneven or uneven cycle path surface and a curb as separation or no separation between motorized traffic and the cycle path. The direction of these effects were all the same in each macro-environment, only the magnitude of the effects differed between the different macro-environments. Our results suggest that irrespective of the macro-environment, the same micro-environmental factors are preferred in middle-aged adults concerning the street's appeal for bicycle transport. Consequently, no other physical environmental factors might be modified in different street settings. Any small changes to the micro-environmental factors (e.g. changing the speed limits from 50 km/h to 30 km/h) can effectively help to increase the street's appeal for bicycle transport among adults.

These controlled simulations could inform environmental interventions in real life settings to modify similar micro-environmental factors in different macro-environments. However, these findings need to be confirmed by on-site research.

Supporting Information

S1 File.
(PDF)

Acknowledgments

AG, JVC, VVH and DVD are supported by a grant from the Fund for Scientific Research Flanders (FWO). The authors would like to thank Daphne Reinehr for developing the photographs.

Author Contributions

Conceived and designed the experiments: LM AG JVC VVH DVD NVdW JN BD IDB. Performed the experiments: LM AG. Analyzed the data: LM JVC. Wrote the paper: LM. Critically reviewed and revised versions of the manuscript: LM AG JVC VVH DVD NVdW JN BD IDB. Read and approved the final manuscript: LM AG JVC VVH DVD NVdW JN BD IDB.

References

1. World Health Organization (2010) Global Recommendations on Physical Activity for Health. Available: http://whqlibdoc.who.int/publications/2010/9789241599979_eng.pdf.
2. World Health Organization (2008) Insufficient physical activity. Available: http://www.who.int/gho/ncd/risk_factors/physical_activity/en/.
3. Rudinger G, Donaghy K, Poppelreuter S (2006) Societal trends, mobility behaviour and sustainable transport in Europe and North America. Available: http://www.ejtir.tudelft.nl/issues/2006_01/pdf/2006_01_04.pdf.
4. Janssens D, Declercq K, Wets G (2014) Onderzoek Verplaatsingsgedrag Vlaanderen 4.5 (2012–2013). Instituur voor Mobiliteit: 116. Available: http://www.mobielvlaanderen.be/pdf/ovg45/ovg45-analyse-globaal.pdf.
5. Wanner M, Götschi T, Martin-Diener E, Kahlmeier S, Martin BW (2012) Active transport, physical activity, and body weight in adults: a systematic review. American journal of preventive medicine 42: 493–502. Available: http://www.ncbi.nlm.nih.gov/pubmed/22516490. Accessed 6 May 2014. doi: 10.1016/j.amepre.2012.01.030 PMID: 22516490
6. Oja P, Titze S, Bauman a, de Geus B, Krenn P, Reger-Nash B, et al. (2011) Health benefits of cycling: a systematic review. Scandinavian journal of medicine & science in sports 21: 496–509. Available: http://www.ncbi.nlm.nih.gov/pubmed/21496106. Accessed 24 May 2013.
7. World health organization (2009) Interventions on diet and physical activity: what works (summary report). Available: http://www.who.int/dietphysicalactivity/summary-report-09.pdf.
8. Rojas-Rueda D, de Nazelle a., Tainio M, Nieuwenhuijsen MJ (2011) The health risks and benefits of cycling in urban environments compared with car use: health impact assessment study. Bmj 343: d4521–d4521. Available: http://www.bmj.com/cgi/doi/10.1136/bmj.d4521. Accessed 24 May 2013. doi: 10.1136/bmj.d4521 PMID: 21816732
9. De Hartog JJ, Boogaard H, Nijland H, Hoek G (2010) Do the health benefits of cycling outweigh the risks? Environmental health perspectives 118: 1109–1116. Available: http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=2920084&tool = pmcentrez&rendertype = abstract. Accessed 11 June 2013. doi: 10.1289/ehp.0901747 PMID: 20587380
10. Rissel CE (2009) Active travel: a climate change mitigation strategy with co-benefits for health. New South Wales public health bulletin 20: 10–13. Available: http://www.ncbi.nlm.nih.gov/pubmed/19261210. PMID: 19261210
11. Woodcock J, Edwards P, Tonne C, Armstrong BG, Ashiru O, Banister D, et al. (2009) Public health benefits of strategies to reduce greenhouse-gas emissions: urban land transport. Lancet 374: 1930–1943. Available: http://www.ncbi.nlm.nih.gov/pubmed/19942277. Accessed 16 August 2013. doi: 10.1016/S0140-6736(09)61714-1 PMID: 19942277

12. Woodcock J, Banister D, Edwards P, Prentice A, Roberts I (2007) Energy and health 3—Energy and transport. Lancet 370: 1078–1088.
13. Departement of Health- Physical activity- Health improvement and prevention (2004) At least five a week. Available: http://www.bhfactive.org.uk/sites/Exercise-Referral-Toolkit/downloads/resources/cmos-report-at-least-five-a-week.pdf.
14. Pucher J, Buehler R, Bassett DR, Dannenberg AL (2010) Walking and cycling to health: a comparative analysis of city, state, and international data. American journal of public health 100: 1986–1992. Available: http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=2937005&tool = pmcentrez&rendertype = abstract. Accessed 31 May 2013. doi: 10.2105/AJPH.2009.189324 PMID: 20724675
15. Rabl A, de Nazelle A (2012) Benefits of shift from car to active transport. Transport Policy 19: 121–131. Available: http://linkinghub.elsevier.com/retrieve/pii/S0967070X11001119. Accessed 24 May 2013.
16. Gaffron P (2003) The implementation of walking and cycling policies in British local authorities. Transport Policy 10: 235–244. Available: http://linkinghub.elsevier.com/retrieve/pii/S0967070X03000246. Accessed 21 November 2014.
17. Pucher J, Dill J, Handy S (2010) Infrastructure, programs, and policies to increase bicycling: an international review. Preventive medicine 50 Suppl 1: S106–S125. Available: http://www.ncbi.nlm.nih.gov/pubmed/19765610. Accessed 10 July 2014. doi: 10.1016/j.ypmed.2009.07.028 PMID: 19765610
18. Buehler R, Pucher J (2012) Walking and Cycling in Western Europe and the United States. TR NEWS 280. Available: http://policy.rutgers.edu/faculty/pucher/TRNWesternEurope.pdf.
19. Commission of the European Communities (2007) GREEN PAPER Towards a new culture for urban mobility. Available: http://ec.europa.eu/transport/clean/green_paper_urban_transport/doc/2007_09_25_gp_urban_mobility_en.pdf.
20. Sallis JF, Cervero RB, Ascher W, Henderson K a, Kraft MK, Kerr J, et al. (2006) An ecological approach to creating active living communities. Annual review of public health 27: 297–322. Available: http://www.ncbi.nlm.nih.gov/pubmed/16533119. Accessed 4 June 2013. PMID: 16533119
21. Vandenbulcke G, Thomas I, de Geus B, Degraeuwe B, Torfs R, Meeusen R, et al. (2009) Mapping bicycle use and the risk of accidents for commuters who cycle to work in Belgium. Transport Policy 16: 77–87. Available: http://linkinghub.elsevier.com/retrieve/pii/S0967070X09000407. Accessed 13 September 2013.
22. Jongeneel-Grimen B, Busschers W, Droomers M, van Oers H a M, Stronks K, Kunst AE, et al. (2013) Change in neighborhood traffic safety: does it matter in terms of physical activity? PloS one 8: e62525. Available: http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=3642189&tool = pmcentrez&rendertype = abstract. Accessed 10 December 2013. doi: 10.1371/journal.pone.0062525 PMID: 23658741
23. Davison KK, Lawson CT (2006) Do attributes in the physical environment influence children's physical activity? A review of the literature. International Journal of Behavioral Nutrition & Physical Activity 3: 19.
24. Van Dyck D, Cerin E, Conway TL, De Bourdeaudhuij I, Owen N, Kerr J, et al. (2012) Perceived neighborhood environmental attributes associated with adults' transport-related walking and cycling: Findings from the USA, Australia and Belgium. The international journal of behavioral nutrition and physical activity 9: 70. Available: http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=3489620&tool = pmcentrez&rendertype = abstract. Accessed 2 May 2014. doi: 10.1186/1479-5868-9-70 PMID: 22691723
25. Swinburn B, Egger G, Ph D, Raza F (1999) Dissecting Obesogenic Environments : The Development and Application of a Framework for Identifying and Prioritizing Environmental Interventions for Obesity 1. 570: 563–570.
26. Cain KL, Millstein R a, Sallis JF, Conway TL, Gavand K a, Frank LD, et al. (2014) Contribution of streetscape audits to explanation of physical activity in four age groups based on the Microscale Audit of Pedestrian Streetscapes (MAPS). Social science & medicine (1982) 116: 82–92. Available: http://www.ncbi.nlm.nih.gov/pubmed/24983701. Accessed 27 March 2015.
27. Van Holle V, Deforche B, Van Cauwenberg J, Goubert L, Maes L, Van de Weghe N, et al. (2012) Relationship between the physical environment and different domains of physical activity in European adults: a systematic review. BMC public health 12: 807. Available: http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=3507898&tool = pmcentrez&rendertype = abstract. Accessed 5 June 2013. doi: 10.1186/1471-2458-12-807 PMID: 22992438
28. McCormack G, Giles-Corti B, Lange a, Smith T, Martin K, Pikora TJ (2004) An update of recent evidence of the relationship between objective and self-report measures of the physical environment and physical activity behaviours. Journal of science and medicine in sport / Sports Medicine Australia 7: 81–92. Available: http://www.ncbi.nlm.nih.gov/pubmed/15214606. PMID: 15214606

29. Foster CE, Panter JR, Wareham NJ (2011) Assessing the impact of road traffic on cycling for leisure and cycling to work. The international journal of behavioral nutrition and physical activity 8: 61. Available: http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=3127970&tool = pmcentrez&rendertype = abstract. Accessed 29 October 2013. doi: 10.1186/1479-5868-8-61 PMID: 21663654

30. Ferdinand AO, Sen B, Rahurkar S, Engler S, Menachemi N (2012) The Relationship Between Built Environments and Physical Activity : A Systematic Review. 102: 7–13. doi: 10.2105/AJPH.2012.300740

31. McCormack GR, Shiell A (2011) In search of causality: a systematic review of the relationship between the built environment and physical activity among adults. The international journal of behavioral nutrition and physical activity 8: 125. Available: http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=3306205&tool = pmcentrez&rendertype = abstract. Accessed 4 June 2013. doi: 10.1186/1479-5868-8-125 PMID: 22077952

32. Sallis JF, Bowles HR, Bauman A, Ainsworth BE, Bull FC, Craig CL, et al. (2009) Neighborhood environments and physical activity among adults in 11 countries. American journal of preventive medicine 36: 484–490. Available: http://www.ncbi.nlm.nih.gov/pubmed/19460656. Accessed 5 June 2013. doi: 10.1016/j.amepre.2009.01.031 PMID: 19460656

33. Carpiano RM (2009) Come take a walk with me: the "go-along" interview as a novel method for studying the implications of place for health and well-being. Health & place 15: 263–272. Available: http://www.ncbi.nlm.nih.gov/pubmed/18606557. Accessed 24 May 2013.

34. Spittaels H, Foster C, Oppert J-M, Rutter H, Oja P, Sjöström M, et al. (2009) Assessment of environmental correlates of physical activity: development of a European questionnaire. The international journal of behavioral nutrition and physical activity 6: 39. Available: http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=2713198&tool = pmcentrez&rendertype = abstract. Accessed 20 November 2014. doi: 10.1186/1479-5868-6-39 PMID: 19580645

35. Bauman AE, Reis RS, Sallis JF, Wells JC, Loos RJF, Martin BW (2012) Correlates of physical activity: why are some people physically active and others not? Lancet 380: 258–271. Available: http://www.ncbi.nlm.nih.gov/pubmed/22818938. Accessed 11 July 2014. doi: 10.1016/S0140-6736(12)60735-1 PMID: 22818938

36. Nasar JL (2008) Assessing perceptions of environments for active living. American journal of preventive medicine 34: 357–363. Available: http://www.ncbi.nlm.nih.gov/pubmed/18374252. Accessed 24 May 2013. doi: 10.1016/j.amepre.2008.01.013 PMID: 18374252

37. Wells NM, Ashdown SP, Davies EHS, Cowett FD, Yang Y (2007) Environment, Design, and Obesity: Opportunities for Interdisciplinary Collaborative Research. Environment and Behavior 39: 6–33. Available: http://eab.sagepub.com/cgi/doi/10.1177/0013916506295570. Accessed 13 June 2013.

38. Van Cauwenberg J, Van Holle V, De Bourdeaudhuij I, Clarys P, Nasar J, Salmon J, et al. (2014) Using manipulated photographs to identify features of streetscapes that may encourage older adults to walk for transport. PloS one 9: e112107. Available: http://www.ncbi.nlm.nih.gov/pubmed/25396732. Accessed 20 November 2014. doi: 10.1371/journal.pone.0112107 PMID: 25396732

39. Mertens L, Van Holle V, De Bourdeaudhuij I, Deforche B, Salmon J, Nasar J, et al. (2014) The effect of changing micro-scale physical environmental factors on an environment's invitingness for transportation cycling in adults: an exploratory study using manipulated photographs. The international journal of behavioral nutrition and physical activity 11: 88. Available: http://www.ncbi.nlm.nih.gov/pubmed/25135666. Accessed 21 November 2014. doi: 10.1186/s12966-014-0088-x PMID: 25135666

40. Lenders S, Lauwers L, Vervloet D, Kerselaers E (2006) Afbakening van het Vlaamse platteland, een statistische analyse. Available: http://www2.vlaanderen.be/landbouw/downloads/volt/38.pdf.

41. Portney LG, Watkins MP (2009) Foundations of Clinical Research—Applications to practice. Third. United States of America: Pearson Education.

42. Adobe Systems Incorporated (2013) ADOBE PHOTOSHOP CC. Available: http://wwwimages.adobe.com/content/dam/Adobe/en/devnet/photoshop/pdfs/photoshop-cc-scripting-guide.pdf.

43. Van Holle V, Van Cauwenberg J, Deforche B, Goubert L, Maes L, Nasar J, et al. (2014) Environmental invitingness for transport-related cycling in middle-aged adults: A proof of concept study using photographs. Transportation Research Part A: Policy and Practice 69: 432–446. Available: http://linkinghub.elsevier.com/retrieve/pii/S0965856414002201. Accessed 5 December 2014.

44. Ghekiere A, Van Cauwenberg J, de Geus B, Clarys P, Cardon G, Salmon J, et al. (2014) Critical environmental factors for transportation cycling in children: a qualitative study using bike-along interviews. PloS one 9: e106696. Available: http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=4175075&tool = pmcentrez&rendertype = abstract. Accessed 20 November 2014. doi: 10.1371/journal.pone.0106696 PMID: 25250738

45. Pucher J, Buehler R (2008) Making Cycling Irresistible: Lessons from The Netherlands, Denmark and Germany. Transport Reviews 28: 495–528. Available: http://www.tandfonline.com/doi/abs/10.1080/01441640701806612. Accessed 24 May 2013.
46. Craig CL, Marshall AL, Sjöström M, Bauman AE, Booth ML, Ainsworth BE, et al. (2003) International physical activity questionnaire: 12-country reliability and validity. Medicine and science in sports and exercise 35: 1381–1395. Available: http://www.ncbi.nlm.nih.gov/pubmed/12900694. Accessed 29 May 2013. PMID: 12900694
47. Orme BK (2009) Getting Started with Conjoint Analysis: Strategies for Product Design and Pricing Research. Resarch publishers, Madison, WI.
48. Massiani J, Rosato P (2008) Using conjoint analysis to investigate preferences of inhabitants for the future of a greyfield area : an application to the Old Port in Trieste. 39: 59–80.
49. Alves S, Aspinall P a., Thompson CW, Sugiyama T, Brice R, Vickers A (2008) Preferences of older people for environmental attributes of local parks: The use of choice-based conjoint analysis. Facilities 26: 433–453. Available: http://www.emeraldinsight.com/10.1108/02632770810895705. Accessed 15 August 2013.
50. Nordh H, Alalouch C, Hartig T (2011) Assessing restorative components of small urban parks using conjoint methodology. Urban Forestry & Urban Greening 10: 95–103. Available: http://linkinghub.elsevier.com/retrieve/pii/S1618866711000021. Accessed 27 May 2014.
51. Sawtooth Software Inc. (2013) The CBC System for Choice-Based Conjoint Analysis: 1–27. Available: https://sawtoothsoftware.com/download/techpap/cbctech.pdf.
52. Multon KD (2012) Interrater Reliability. Encylopedia of Research Design: 627–629. Available: http://www.bibb.k12.ga.us/cms/lib01/GA01000598/Centricity/Domain/105/Interrater/ReliabilityArticle_1.pdf.
53. Allenby GM, Arora N, Ginter JL (2014) On the of Demand Heterogeneity. 35: 384–389. Available: http://www.jstor.org/stable/3152035?origin=JSTOR-pdf&seq=1#page_scan_tab_contents.
54. Grasser G, Van Dyck D, Titze S, Stronegger W (2013) Objectively measured walkability and active transport and weight-related outcomes in adults: a systematic review. International journal of public health 58: 615–625. Available: http://www.ncbi.nlm.nih.gov/pubmed/23224518. Accessed 27 May 2014. doi: 10.1007/s00038-012-0435-0 PMID: 23224518
55. Owen N, De De Bourdeaudhuij I, Sugiyama T, Leslie E, Cerin E, Van Dyck D et al. (2010) Bicycle use for transport in an Australian and a Belgian city: associations with built-environment attributes. Journal of urban health : bulletin of the New York Academy of Medicine 87: 189–198. Available: http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=2845830&tool = pmcentrez&rendertype = abstract. Accessed 27 May 2014.
56. Danner UN, Aarts H, de Vries NK (2008) Habit vs. intention in the prediction of future behaviour: the role of frequency, context stability and mental accessibility of past behaviour. The British journal of social psychology / the British Psychological Society 47: 245–265. Available: http://www.ncbi.nlm.nih.gov/pubmed/17678574. Accessed 23 May 2014. PMID: 17678574
57. Moudon AV, Lee C, Cheadle AD, Collier CW, Johnson D, Schmid TL, et al. (2005) Cycling and the built environment, a US perspective. Transportation Research Part D: Transport and Environment 10: 245–261. Available: http://linkinghub.elsevier.com/retrieve/pii/S1361920905000167. Accessed 25 May 2014.
58. Bidordinova A, Member S (2010) MOTIVATORS AND BARRIERS TO UTILITARIAN CYCLING IN DOWNTOWN: 1–15.
59. Winters M, Davidson G, Kao D, Teschke K (2010) Motivators and deterrents of bicycling: comparing influences on decisions to ride. Transportation 38: 153–168. Available: http://link.springer.com/10.1007/s11116-010-9284-y. Accessed 16 August 2013.
60. Titze S, Giles-Corti B, Knuiman MW, Pikora TJ, Timperio a, Bull FC, et al. (2010) Associations Between Intrapersonal and Neighborhood Environmental Characteristics and Cycling for Transport and Recreation in Adults: Baseline Results From the RESIDE Study. J Phys Act Health 7: 423–431. PMID: 20683083
61. Fraser SDS, Lock K (2010) Cycling for transport and public health: a systematic review of the effect of the environment on cycling. European journal of public health 21: 738–743. Available: http://www.ncbi.nlm.nih.gov/pubmed/20929903. Accessed 7 August 2013. doi: 10.1093/eurpub/ckq145 PMID: 20929903
62. Sallis JF, Conway TL, Dillon LI, Frank LD, Adams MA, Cain KL, et al. (2013) Environmental and demographic correlates of bicycling. Preventive medicine 57: 456–460. doi: 10.1016/j.ypmed.2013.06.014 PMID: 23791865
63. Ogilvie D, Griffin S, Jones A, Mackett R, Guell C, Panter J, et al. (2010) Commuting and health in Cambridge: a study of a “natural experiment” in the provision of new transport infrastructure. BMC public health 10: 703. Available: http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=2999608&tool =

pmcentrez&rendertype = abstract. Accessed 16 December 2014. doi: 10.1186/1471-2458-10-703 PMID: 21080928

64. Krenn PJ, Titze S, Oja P, Jones A, Ogilvie D (2013) Use of Global Positioning Systems to Study Physical Activity and the Environment : American Journal of Preventive Medicine 41: 1–20. Available: http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3821057/pdf/emss-53972.pdf.

65. Badland H, Knuiman M, Hooper P, Giles-Corti B (2013) Socio-ecological predictors of the uptake of cycling for recreation and transport in adults: results from the RESIDE study. Preventive medicine 57: 396–399. Available: http://www.ncbi.nlm.nih.gov/pubmed/23792583. Accessed 20 November 2014. doi: 10.1016/j.ypmed.2013.06.015 PMID: 23792583

66. Cubukcu E, Nasar JL (2005) Influence of physical characteristics of routes on distance cognition in virtual environments. Environment and Planning B: Planning and Design 32: 777–785. Available: http://www.envplan.com/abstract.cgi?id = b31191. Accessed 6 September 2013.

67. Belgian Federal Government (2013) Statistics Belgium. Available: http://statbel.fgov.be/.

68. Scheepers E, Wendel-Vos W, van Kempen E, Panis LI, Maas J, Stipdonk H, et al. (2013) Personal and environmental characteristics associated with choice of active transport modes versus car use for different trip purposes of trips up to 7.5 kilometers in The Netherlands. PloS one 8: e73105. Available: http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=3764150&tool = pmcentrez&rendertype = abstract. Accessed 18 November 2014. doi: 10.1371/journal.pone.0073105 PMID: 24039866

S1 File

Chapter 2.3 – Creating an order of importance of the micro-environmental factors and investigating the interaction between micro-environmental factors

Mertens, L., Van Dyck, D., Ghekiere, A., De Bourdeaudhuij, I., Deforche, B., Van de Weghe, N., & Van Cauwenberg, J. (2016). Which environmental factors most strongly influence a street's appeal for bicycle transport among adults? International journal of health geographics 2016, 15(1):31, 1-14. DOI 10.1186/s12942-016-0058-4.

Mertens *et al. Int J Health Geogr (2016) 15:31*
DOI 10.1186/s12942-016-0058-4

International Journal of Health Geographics

RESEARCH Open Access

Which environmental factors most strongly influence a street's appeal for bicycle transport among adults? A conjoint study using manipulated photographs

Lieze Mertens[1], Delfien Van Dyck[1,2], Ariane Ghekiere[2,3,4], Ilse De Bourdeaudhuij[1*], Benedicte Deforche[3,4], Nico Van de Weghe[5] and Jelle Van Cauwenberg[2,3,4]

Abstract

Background: Micro-environmental factors (specific features within a streetscape), instead of macro-environmental factors (urban planning features), are more feasible to modify in existing neighborhoods and thus more practical to target for environmental interventions. Because it is often not possible to change the whole micro-environment at once, the current study aims to determine which micro-environmental factors should get the priority to target in physical environmental interventions increasing bicycle transport. Additionally, interaction effects among micro-environmental factors on the street's appeal for bicycle transport will be determined.

Methods: In total, 1950 middle-aged adults completed a web-based questionnaire consisting of a set of 12 randomly assigned choice tasks with manipulated photographs. Seven micro-environmental factors (type of cycle path, speed limit, speed bump, vegetation, evenness of the cycle path surface, general upkeep and traffic density) were manipulated in each photograph. Conjoint analysis was used to analyze the data.

Results: Providing streets with a cycle path separated from motorized traffic seems to be the best strategy to increase the street's appeal for adults' bicycle transport. If this adjustment is not practically feasible, micro-environmental factors related to safety (i.e. speed limit, traffic density) may be more effective in promoting bicycle transport than micro-environmental factors related to comfort (i.e. evenness of the cycle path surface) or aesthetic (i.e. vegetation, general upkeep). On the other hand, when a more separated cycle path is already provided, micro-environmental factors related to comfort or aesthetic appeared to become more prominent.

Conclusions: Findings obtained from this research could provide advice to physical environmental interventions about which environmental factors should get priority to modify in different environmental situations.

Trial registration: The study was approved by the Ethics Committee of the Ghent University Hospital. Trial registration: B670201318588. Registered at 04/10/2013. http://www.ugent.be/ge/nl/faculteit/raden/ec

Keywords: Active transport, Micro-environment, Built environment, Biking, Adulthood, Experiment, Photographs

Background

Although cycling is known as a sustainable form of human transport, it is not yet sufficiently integrated into daily life routines in the global population. In Europe, 50 % of all trips are shorter than 3 km, which is a feasible distance for cycling. However, a large part of these trips is still done by motorized modes of transport [1]. For example in Flanders (Belgium), only 25 % of all trips shorter than 3 km and only 14 % of all trips shorter than 5 km are done actively (i.e. by foot or by bike) among adults between 18 and 65 years old [2]. Several cross-sectional

*Correspondence: Ilse.Debourdeaudhuij@Ugent.be
[1] Department of Movement and Sport Sciences, Faculty of Medicine and Health Sciences, Ghent University, Watersportlaan 2, 9000 Ghent, Belgium
Full list of author information is available at the end of the article

studies among adults indicated that bicycle transport is associated with higher general physical activity levels and lower body weight [3–6]. In addition, bicycle transport also has many other benefits on social (social cohesion), environmental (reduced carbon footprint) and economic (infrastructure costs) level [7–14]. It is therefore in favor of both the individual and the community to create supportive environments that make it easier to engage in bicycle transport [15–18]. Policy development together with relevant sectors such as urban planning, active transport policies, built environment strategies and crime prevention polices should be encouraged at national and subnational level to promote regular bicycle transport by adapting the environment or community [19–24]. By modifying the environment, large populations over long periods of time can be reached. It is therefore important to know which environmental determinants affect bicycle transport among adults.

Built environmental variables can be classified into two broad categories: macro- and micro-scale environmental factors [25, 26]. Macro-environmental factors can be regarded as 'raw' urban planning features; such as walkability, connectivity of the street network, residential density and land use mix diversity. These factors are difficult to change in existing environments because of their large size and complexity, and because they are influenced by different levels of authorities [25, 26]. On the other hand, micro-environmental factors can be defined as relatively small environmental factors such as evenness of the cycle path surface, vegetation and speed limits. These factors are influenced by individuals or local actors and are less complex which makes them more feasible to modify in existing neighborhoods (i.e. lower cost and shorter timeframe) compared to the reconfiguration of the macro-scale structural design [25, 26].

In the literature, most research has been conducted on macro-scale environmental factors. Worldwide, consistent strong positive relationships have been found between macro-scale environmental factors and transport-related cycling in adults. Higher levels of walkability, improved access to shops/services/work and higher degree of urbanization were positively related to bicycle transport in adults [27–30]. Unfortunately, research on the micro-environmental factors affecting bicycle transport is scarce and results are inconsistent [31–35]. Previous studies showed inconsistent associations between modifiable micro-environmental factors and bicycle transport [35–38]. For example, some studies found associations of lower road motorized traffic volumes [31] and the presence of traffic calming elements with more cycling for transport [39], while other studies found that higher volumes of motorized traffic were associated with more bicycle transport [36, 38], or found no associations at all [37, 40, 41]. Mixed evidence was also found for aesthetics. Several studies found a positive association between vegetation and bicycle transport [29, 42–44], while other studies did not find significant associations [5, 40, 45]. Furthermore, although the importance of well separated cycle paths for bicycle transport have already been identified [21, 46], not all research could confirm this positive association [37, 47]. Furthermore, it is still unclear which micro-environmental factors relate most strongly to cycling for transport. Because it is often not possible to change the whole micro-environment at once, it is necessary to explore the individual impact of each parameter and to know which environmental factors should get priority in environmental interventions increasing bicycle transport. Furthermore, since the real environment consists of a combination of several environmental factors simultaneously, it is also crucial to investigate the interaction effects of different micro-environmental factors. For example, a previous pilot study (conducted in a small sample) [48] with manipulated photographs showed that the positive effect of cycle path evenness appeared to increase in an environment with good compared to poorly overall upkeep. Conversely, the street's appeal for bicycle transport decreased when both separations along the cycle path were present (i.e. separation from motorized traffic as well as pedestrians) compared to only a separation with traffic [48]. Furthermore, investigating the relative importance of environmental factors within a particular micro-environmental factor could be interesting for a detailed analysis of these interactions effects. For example, it would be interesting to find out which environmental factors subsequently are important in situations where an even cycle path surface is provided. Unfortunately, this has not frequently been studied in large populations. Therefore, future studies investigating the effect of micro-environmental factors and their interaction effects on the street's appeal for bicycle transport are important.

The main issue with previous studies investigating the effect of micro-environmental factors on bicycle transport is related to the cross-sectional observational study designs [34, 49]. Although usually valid and reliable tools are used (e.g. questionnaires), there are some methodological concerns: participants have to recall features of the physical environment, which involves recall bias [50] and the lack of standardization in neighborhood definitions increases the inconsistency as well [51]. To accommodate these shortcomings, stronger designs are required with improved causal inference [17, 30, 34, 52, 53]. Since natural experiments are complex, time- and cost-consuming to conduct in real environments, an innovative experimental and cost-effective methodology is required.

Therefore, the present study opts for a controlled experiment: it uses experimental manipulations of environmental factors in photographs to examine whether these factors affect the street's appeal for bicycle transport. The validity of color photos in comparison to on-site responses has already been proven in previous studies [54, 55]. Furthermore, respondents who judge photographs do not have to recall features of the physical environment (as is the case when using questionnaires), which improves the reliability of the results. In addition, defining the 'neighborhood' is no longer necessary with this methodology because the assessment of the physical environment happens consistently between participants. Since these photograph experiments control for co-variation (i.e. environmental factors that co-occur), this approach overpowers previous studies by allowing the researcher to differentiate the separate influence of each environmental factor under controlled conditions [55]. This methodology using manipulated photographs results from previous research with non-manipulated photographs [35] and was tested in a recent mixed-method pilot study investigating the effect of a limited number of key micro-environmental factors and the street's appeal for adults' bicycle transport [48]. In this study only five micro-environmental factors were simultaneously manipulated and each factor only had a maximum of two levels. This exploratory study, conducted in a small sample, provided a proof-of-concept to use manipulated photographs to assess a street's appeal for adults in a controlled experiment. From this previous research step, there is a need to carry out a large-scale study in which the effects of all relevant micro-environmental factors are studied. Findings obtained from these controlled experiments might provide guidelines for interventions that use micro-environmental modifications to create more supportive environments for bicycle transport. Only adults in the age range between 45 and 65 years old where included in this study because they assess the physical environment according to their own needs, rather than in perspective of their parental vision (considering their child).

In summary, this study adds to the literature as it is still unclear what type of infrastructure regarding the micro-environment is required to specifically encourage bicycle transport. Furthermore, the experimental design of our study overpowers previously used cross-sectional observational study designs and moreover is a cost-effective methodology compared to natural experiments. Additionally, one of the main novelties compared to existing literature is that the current study creates an order of importance or hierarchy of the different micro-environmental factors and also investigates interaction effects between different micro-environmental factors.

The main aim of the current study was to determine the relative importance of micro-environmental factors for a street's appeal for bicycle transport among middle-aged adults (45–65 years). Second, interaction effects among micro-environmental factors on the street's appeal for bicycle transport were determined to investigate the effect of combinations of micro-environmental factors.

Methods

Protocol and measures

By purposeful convenience sampling, Flemish middle-aged adults between 45 and 65 years were recruited using email, social media, family, friends, clubs, organizations and companies. Additional participants were recruited by snowball sampling. Participants completed a two-part web-based questionnaire, which was developed using Sawtooth Software (SSI Web version 8.3.8.). The online questionnaire was available from the beginning of November 2014 until the end of January 2015 and 1969 middle-aged adults completed the study. Eighteen participants who did not have the proper age (45–65 years old) were excluded from the analysis. Informed consent was automatically obtained from the participants when they voluntarily completed the questionnaire. The study was approved by the Ethics Committee of the Ghent University Hospital.

Photograph development

Prior to data collection, a set of 1945 manipulated panoramic color photographs were developed with Adobe Photoshop© software [56]. The developed photographs were all modified versions of one 'basic' panoramic photograph representing a typical semi-urban (300–600 inhabitants/km^2) street in Flanders (Belgium) [57]. The 'basic' photograph was taken from an adult cyclist's eye-level viewpoint under dry weather conditions and depicts a hypothetical cycling route where adults could cycle along. The newly developed photographs differed from each other in at least one micro-environmental manipulation. Seven micro-environmental factors (type of cycle path, speed limit, speed bump, vegetation, evenness of the cycle path surface, general upkeep and traffic density) were manipulated in each photograph and consisted of at least two possible levels. The levels of the environmental factors are presented in Table 1 and the corresponding abbreviations are used throughout the article. These micro-environmental factors and their levels were selected based on existing literature [27, 58] and previous qualitative and quantitative research with (non-)manipulated panoramic photographs [35, 48, 59] studying relationships between the environment and bicycle transport. For example, a previous mixed-methods pilot study with manipulated photographs indicated that it is not inviting for bicycle transport

Table 1 Overview of the manipulated micro-environmental factors and their specific levels

Type of cycle path	C1. No cycle path
	C2. Cycle path, separated from traffic by marked white lines
	C3. Cycle path, separated from traffic with a curb, not separated from walking path by color
	C4. Cycle path separated from traffic with a hedge, not separated from walking path by color
	C5. Cycle path separated from traffic with a curb, separated from walking path by color
	C6. Cycle path separated from traffic with a hedge, separated from walking path by color
Speed limit	S1. 50 km/h
	S2. 30 km/h
Speed bump	B1. Absent
	B2. Present
Vegetation	V1. No trees
	V2. Two trees
	V3. Four trees
Evenness of the cycle path surface	E1. Very uneven surface
	E2. Moderately uneven surface
	E3. Even surface
General upkeep	M1. Bad upkeep (much graffiti and litter)
	M2. Moderate upkeep (a bit of graffiti and litter)
	M3. Good upkeep (no graffiti or litter)
Traffic density	D1. Four cars + truck
	D2. Three cars
	D3. One car

to separate the cycle path and the sidewalk by using bollards [48]. Qualitative data from that study reported that cyclists see these bollards as a disturbing factor that limited their evasive options and also showed that some were afraid to cycle against those bollards. However, from previous research from the Netherlands, Denmark and Germany, we know that it is important to provide a visual and/or physical separation between cyclists and pedestrians for example by grade separation, pavement coloring or surfacing [58]. From this reasoning, we wanted to investigate if a separation by pavement coloration has a more positive effect to separate cyclists from pedestrians instead of bollards as separation. To determine each micro-environmental factor and their levels, a thoughtful reasoning using the literature and previous results was made [27, 35, 48, 58, 59]. An example of the anticipated best and worst street to cycle along are shown in Fig. 1.

The web-based questionnaire

The web-based questionnaire consisted of two parts. First, socio-demographic characteristics were assessed: age, gender, country of birth, marital status, education, and occupational status (see Table 2 for the response categories). Self-reported weight and height were assessed to calculate body mass index (BMI). Additionally, the amount of usual bicycle transport in a week was assessed by using the long form of the International Physical Activity Questionnaire (IPAQ: 'usual week') [60].

In the second part of the questionnaire, a choice based conjoint (CBC) method was used to implement a series

Fig. 1 The anticipated best and worst street to cycle along by manipulating the micro-environmental factors (Table 1). Anticipated best street to cycle along (first photograph): C6, S2, B2, V3, E3, M3, D3. Anticipated worst street to cycle along (second photograph): C1, S1, B1, V1, E1, M1, D1

of choice tasks with manipulated photographs, depicting two possible routes to cycle along. This CBC method is often used in marketing research and aims to identify the relative importance of various components of a product (micro-environmental factors in a street) in the decision process to pursuit the product (cycling for transport in that street) [61]. In this part, the following scenario was presented to the respondents: "Imagine yourself cycling to a friend's home, located at 10 min cycling from your home, during daytime with perfect weather circumstances. For every task you will see two streets, we ask you to choose the street that you find most appealing to cycle along to that friend. Whichever route you choose, the distance to your friend is the same and all cycle paths are one-way. There is no right or wrong solution, we are only interested in which street you would prefer to cycle along." Participants were first shown three examples and afterwards they received a set of 12 randomly assigned and two fixed choice tasks, which is a recommended quantity for such tasks [61, 62]. Figure 2 shows an example of a choice task. Since a full-profile design was used in the choice task, the two photographs in each randomly assigned choice task could differ in one to seven environmental factors [61]. The two fixed choice tasks were identical for all participants and were used to check if participants answered the choice tasks consistently. One respondent was deleted from the analysis as the response to both fixed tasks was not accurate in comparison with the other 1949 participants. We therefore believe that the respondent probably completed the questionnaire without attention.

Table 2 Descriptive characteristics of the participants (n = 1950)

Age (M ± SD) (years)	54.3 ± 5.6	Occupational status (%)	
Women (%)	56.8	Household	5.1
Born in Belgium (%)	96.3	Blue collar	5.3
Marital status (%)		White collar	67.9
Married	68.4	Unemployed	3.2
Widowed	1.6	Retired	17.5
Divorced	13.7	Career interruption	1.0
Single	7.6	Current bicycle transport level	
Cohabiting	8.6	No bicycle transport (%)	21.7
Education (%)		Bicycle transport min/wk (M ± SD)	147 ± 170
Primary	2.2	Living area	
Lower secondary	19.4	Urban (%)	15.4
Higher secondary	13.9	Suburban (%)	74.0
Tertiary	64.6	Rural (%)	10.6
BMI (M ± SD) (kg/m^2)	25.2 ± 4.0		

M mean, *SD* standard deviation, *BMI* body mass index

A priori power analysis (power 0.80 and α = 0.05) was calculated by the following formula: *nta/c > 500* (*n = number of participants; t = 14: number of choice tasks; a = 2: number of alternatives per task; c = 18: the largest product of levels of any two factors*) [61]. This showed that a minimum of 322 subjects was needed when manipulating seven environmental factors in one photograph (with a maximum of six levels) and presenting 14 choice tasks to each participant. It was intended to reach at least three times more this number to allow possibly subgroup analysis.

To assess test–retest reliability of the choice tasks, we conducted a pilot study (n = 28) in which 14 fixed choice tasks were added to the questionnaire. These fixed choice tasks were identical for all participants. The same choice tasks were presented to the participants twice with a 1-week interval. Subsequently, it was examined whether participants chose the same street at both time points. The percentage of agreement for the 14 choice tasks ranged from 72 to 100 % (n = 28). These results indicated that our choice tasks are reliable, since an adequate level of agreement is generally considered to be 70 % [63].

Analyses

Choice-based conjoint analysis (CBC) was used to analyze the data. First, the average relative importance of each environmental factor was calculated from the individual utility data gained from Hierarchical Bayes (HB) estimation using dummy coding. This analysis method has been suggested as the most appropriate method to analyze data gained from choice based conjoint [64]. Average relative importances indicate the influence of an environmental factor on the choice relating to the photograph choice task. These average importances are calculated by the difference in average part-worth utilities between the most and least preferred levels of a factor [61]. Average part-worth utilities represent the degree of preference given to a particular level of an environmental factor and are similar to a beta-value (β) obtained from linear regression analyses [61]. The greater the importance of an environmental factor, the greater the factor has an impact on the choice.

Second, the main effect of each level of each environmental factor on the street's appeal for bicycle transport along the depicted environments was determined using the individual part-worth utilities gained from HB estimation. Average part-worth utilities were calculated and 95 % confidence intervals were determined to compare these part-worth utilities representing the degree of preference for the environmental factor level [61].

Third, interaction effects were also derived from part-worth utilities gained from the HB estimation and were selected using 'CBC interaction search tool'

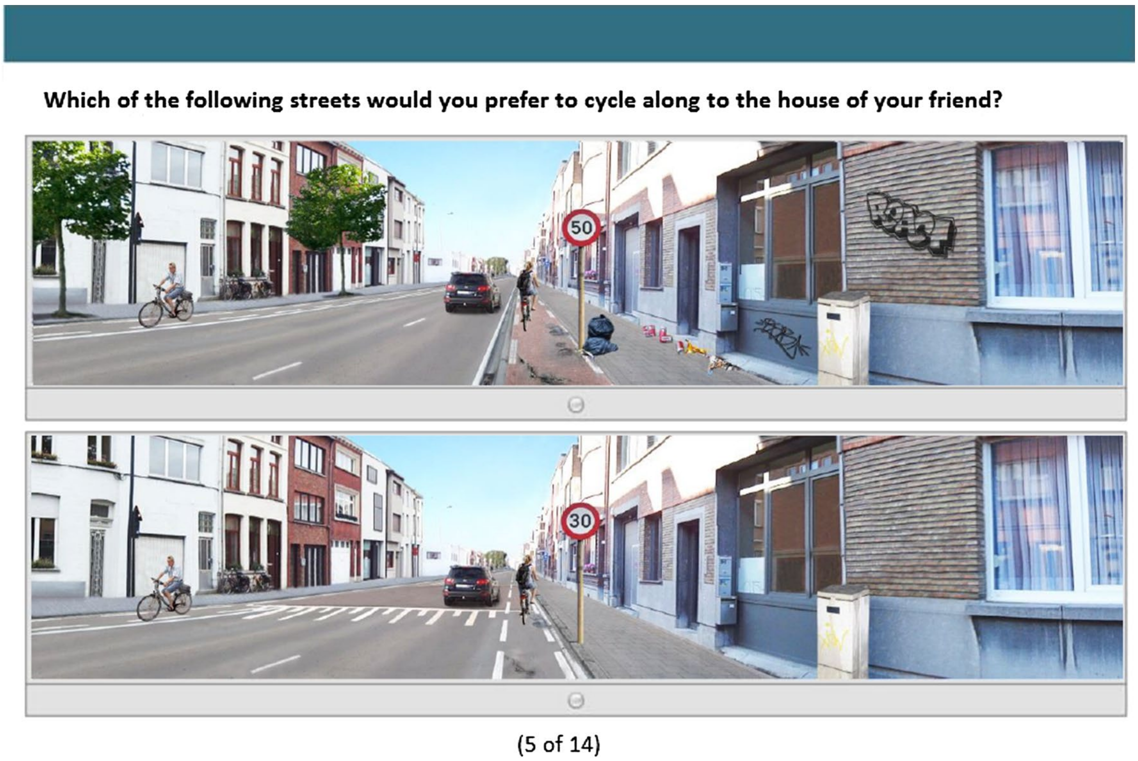

Fig. 2 An example of a randomly assigned choice task used in the questionnaire

of the Sawtooth Software [65]. Separate models were constructed to analyze the interaction effects between different micro-environmental factors. These results were illustrated by graphs and tables in which the total utilities of the different streets were shown. Total utilities were calculated by the sum of the part-worth utilities and representing the degree of preference given to a photograph or for the environmental factors depicted in a street. A 95 % confidence interval was calculated to examine significance.

Last, given that different interaction effects were found with type of cycle path and that this factor is obvious most prominent, the relative importance of all other micro-environmental factors was calculated within each type of cycle path.

Results

Descriptive statistics

The sample consisted of 1950 participants ranging in age from 45 to 65 years: 56.8 % were women, 77.0 % were married or cohabiting, 64.6 % had followed tertiary education (college, university or postgraduate) and 17.5 % was retired (see Table 2). Mean age of the total sample was 54.3 years (SD = 5.6) and mean BMI was 25.2 kg/m^2 (SD = 4.0). Approximately one fifth (21.7 %) of the adults did not cycle for transport in a usual week and the mean of the entire sample was 147 ± 170 min per week bicycle transport in a usual week.

Relative importance of the micro-environmental factors

'Type of cycle path' (average importance = 60.14 ± 14.04 %; 95 % CI 59.48, 60.81) was by far the most important micro-environmental factor when choosing one out of two streets for bicycle transport (see Fig. 3). The second most important environmental factor was 'speed limit' (average importance = 8.50 ± 5.65 %; 95 % CI 8.25, 8.75) followed by 'evenness of the cycle path surface' (average importance = 7.76 ± 5.47 %; 95 % CI 7.52, 8.00). These factors were chosen over 'traffic density' (average importance = 7.14 ± 6.55 %; 95 % CI 6.85, 7.43), 'general upkeep' (average importance = 7.11 ± 5.53 %; 95 % CI 6.87, 7.36) and 'vegetation' (average importance = 6.96 ± 5.17 %; 95 % CI 6.73, 7.19) which did not significantly differ from each other. The presence of a 'speed bump' (average importance = 2.38 ± 1.86 %; 95 % CI 2.30, 2.47) was significantly less important than any other micro-environmental factor.

Main effects of the environmental factors

Within each micro-environmental factor, all part-worth utilities from the different levels of each environmental factor significantly differed from each other ($p < 0.05$), with

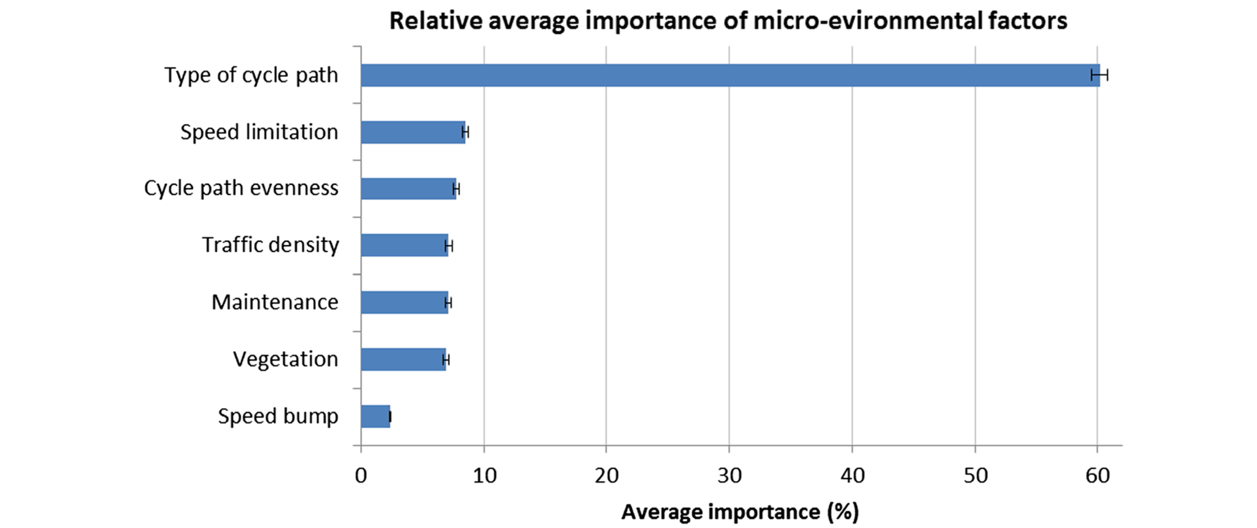

Fig. 3 Relative importance of the micro-environmental factors

obvious preferences for the anticipated most attractive level over the intermediate and the anticipated unattractive level (see Fig. 4). For example, participants preferred an even cycle path surface (average part-worth utility = 1.90 ± 1.40; 95 % CI 1.84, 1.96) over a slightly uneven (average part-worth utility = 0.47 ± 1.04; 95 % CI 0.43, 0.52) and a very uneven cycle path surface (reference level); and they preferred a slightly uneven cycle path over a very uneven cycle path surface. One notable result was found for 'type of cycle path'. A cycle path separated from traffic with a hedge and not separated from walking path by color was significantly more preferred (C4: average part-worth utility = 16.75 ± 3.64; 95 % CI 16.59, 16.91) than a cycle path separated from traffic with a curb and separated from walking path by color (C5: average part-worth utility = 13.18 ± 5.22; 95 % CI 12.95, 13.42). See Fig. 5 for an illustration of the different types of cycle paths manipulated in this study.

Interaction effects

The combination of all possible interaction effects gave 21 possible interaction effects of which six were significant, namely 'type of cycle path × speed limit', 'type of cycle path × vegetation', 'type of cycle path × evenness of the cycle path surface', 'type of cycle path × traffic density', 'speed bump × traffic density', 'vegetation × general upkeep'. The results of these interaction effects were illustrated by graphs and tables in which the total utilities of the different streets were shown. Total utilities represent the degree of preference and can be found in Additional files 1, 2, 3, 4, 5, 6.

The significant interaction effect between 'type of cycle path' and 'speed limit' (Chi square = 16.87; p = 0.005) shows that the effect of speed limit has the greatest impact on the street's appeal for bicycle transport when there was no cycle path (C1) (see Fig. 6; Table A.1 in Additional file 1). Adjusting the speed limit from 50 to 30 km/h along all different cycle paths had a significant effect, except for the most preferred cycle path. The effect of speed limit did not provide a significant increase on the street's appeal for bicycle transport when the cycle path was separated from traffic with a hedge and separated from walking path by color (C6).

The significant interaction effect between 'type of cycle path' and 'vegetation' (Chi square = 27.78; p = 0.002) shows that the effect of vegetation was significant in all different types of cycle paths (see Additional file 2). The direction of the effects did not differ, only the magnitude of the effect did. For instance, the greatest effect of vegetation (from zero to four trees) was found when there was no cycle path provided on the street, compared to all types of cycle path.

Similar results were found for the interaction effect between 'type of cycle path' and 'traffic density' (Chi square = 19.01; p < 0.001). The effect of traffic density was significant for all different types of cycle paths in the expected direction, only the strength of the effect differed across the different cycle paths (see Additional file 3). The greatest effect of traffic density on the street's appeal for bicycle transport was found when there was no cycle path.

The significant interaction effect between 'type of cycle path' and 'evenness of the cycle path surface' (Chi square = 44.94; p = 0.040) showed that the greatest effect of evenness of the cycle path surface (from very uneven or moderately uneven to an even cycle path surface) was

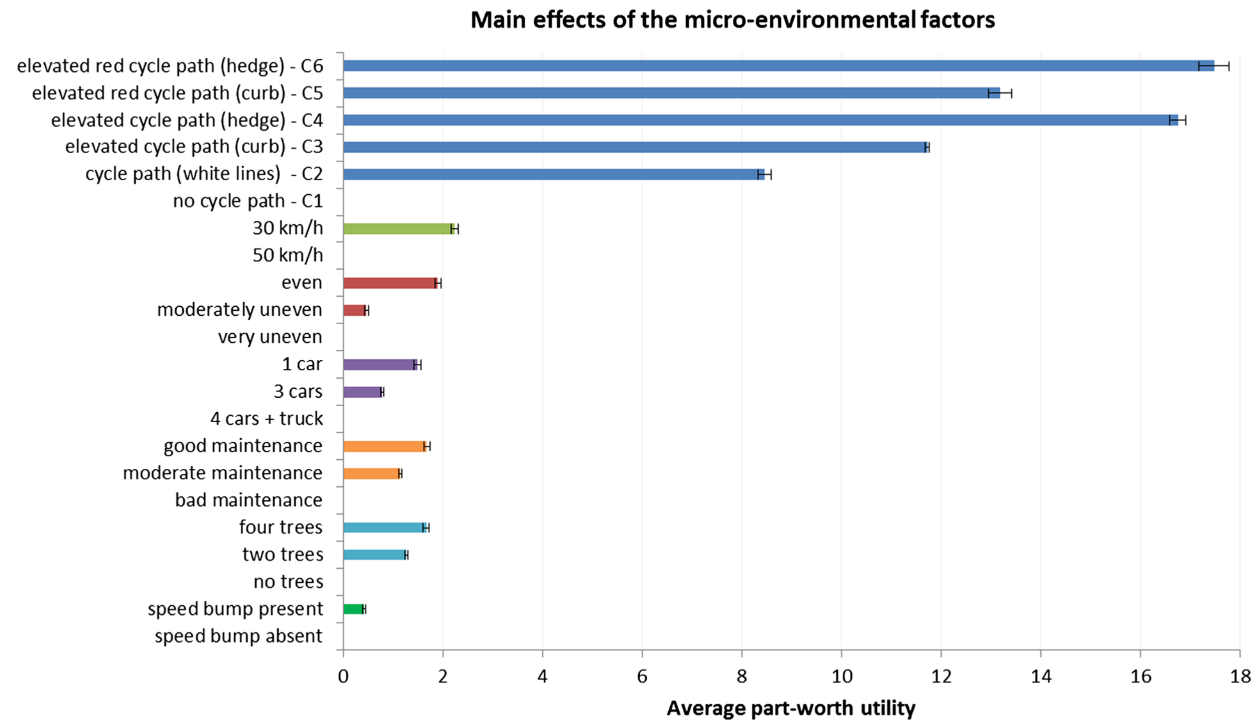

Fig. 4 Main effects of the micro-environmental factors

Fig. 5 Different types of cycle paths manipulated in this study

found with cycle paths where a separation with motorized traffic by a curb is provided (see Additional file 4). The greatest effects from a very uneven to an even cycle path surface on the street's appeal for bicycle transport was found with a cycle path separated from traffic with a curb and separated from walking path by color (C5). Additionally, the greatest effect of evenness from a moderately uneven to an even cycle path surface on the street's appeal was found with a cycle path separated from traffic with a curb and not separated from walking path by color (C3).

There was also a significant interaction effect between 'speed bump' and 'traffic density' (Chi square = 9.71; $p = 0.008$). The effect of a speed bump (installing a speed bump on the street) on the street's appeal for bicycle transport, was greater when the traffic density was lower (reducing the number of cars to the intermediate or lowest level) (see Additional file 5).

Finally, the significant interaction effect between 'vegetation' and 'general upkeep' (Chi square = 10.19; $p = 0.040$) showed that depending on the number of trees another effect of general upkeep was found (see Additional file 6). The effect of general upkeep from moderate to good upkeep was greater if there were no trees present in the environment. The effect of general upkeep from bad to good upkeep was greater in an environment

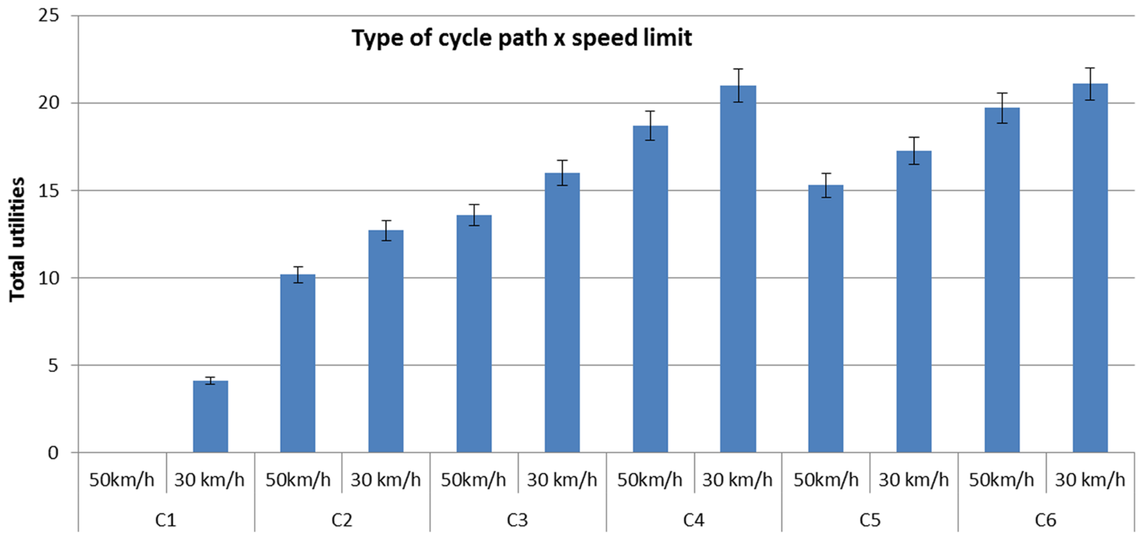

Fig. 6 Interaction effect between cycle path type and speed limit. *C1* no cycle path; *C2* cycle path separated from traffic by marked white lines; *C3* cycle path separated from traffic with a curb, not separated from walking path by color; *C4* cycle path separated from traffic with a hedge, not separated from walking path by color; *C5* cycle path separated from traffic with a curb, separated from walking path by color; *C6* cycle path separated from traffic with a hedge, separated from walking path by color

with two trees and the effect between bad and moderate upkeep was greater in an environment with four trees.

Relative importance of the micro-environmental factors within different cycle paths

Given that several interaction effects were found with 'cycle path type' and it appeared to be by far the most important micro-environmental factor in making choices among different street alternatives, the relative importance of all other environmental factors within each type of cycle path was defined. It is useful to determine which priority must be given in adapting the environment if a community does not have the ability to build a desired cycle path.

In Fig. 7, the relative importance of the remaining six environmental factors is presented for each type of cycle path. The results showed that modifying the speed limit was the most important environmental factor in situations where there was no cycle path (C1), no elevated cycle path (C2) or no cycle path with separations at both sides (C3 and C4). When there was no cycle path present in the environment (C1), the effect of speed limit (average part-worth utility = 23.97 ± 10.96 %; 95 % CI 23.48, 24.45) and traffic density (average part-worth utility = 21.46 ± 9.75 %; 95 % CI 21.03, 21.89) created the largest impact on the street's appeal for bicycle transport. Furthermore, with increasing separation (going from C1 to C6), speed limit appeared to become less important. In situations where the most preferred type of cycle path was already present (C6: elevated cycle path, separated from motorized traffic with a hedge and separated from the walking path by color), the first three micro-environmental factors did not significantly differ from each other: traffic density (average part-worth utility = 20.87 ± 9.93 %; 95 % CI 20.43, 21.31), evenness of the cycle path surface (average part-worth utility = 20.61 ± 9.98 %; 95 % CI 20.17, 21.05) and general upkeep (average part-worth utility = 20.01 ± 9.77 %; 95 % CI 19.58, 20.44). Moreover, the effect of speed limit was significantly lower when the most preferred cycle path was present (C6) compared to situations when less preferred cycle paths were present.

Discussion

We identified the micro-environmental factors that should get priority when adapting the micro-environment to increase the street's appeal for middle-aged adults' bicycle transport. In addition, we investigated the interaction effects between different micro-environmental factors. The current study proved that the 'type of the cycle path' appeared to be the most important micro-environmental factor affecting the street's appeal for adults' bicycle transport under optimal conditions in terms of trip length and trip objective. A cycle path separated from traffic with a hedge was significantly more preferred than a cycle path separated from traffic with a curb, regardless of the separation from walking path by color. Previous research already showed a positive outcome of having a good separation between cyclists and motorized traffic on bicycle transport but did not focus

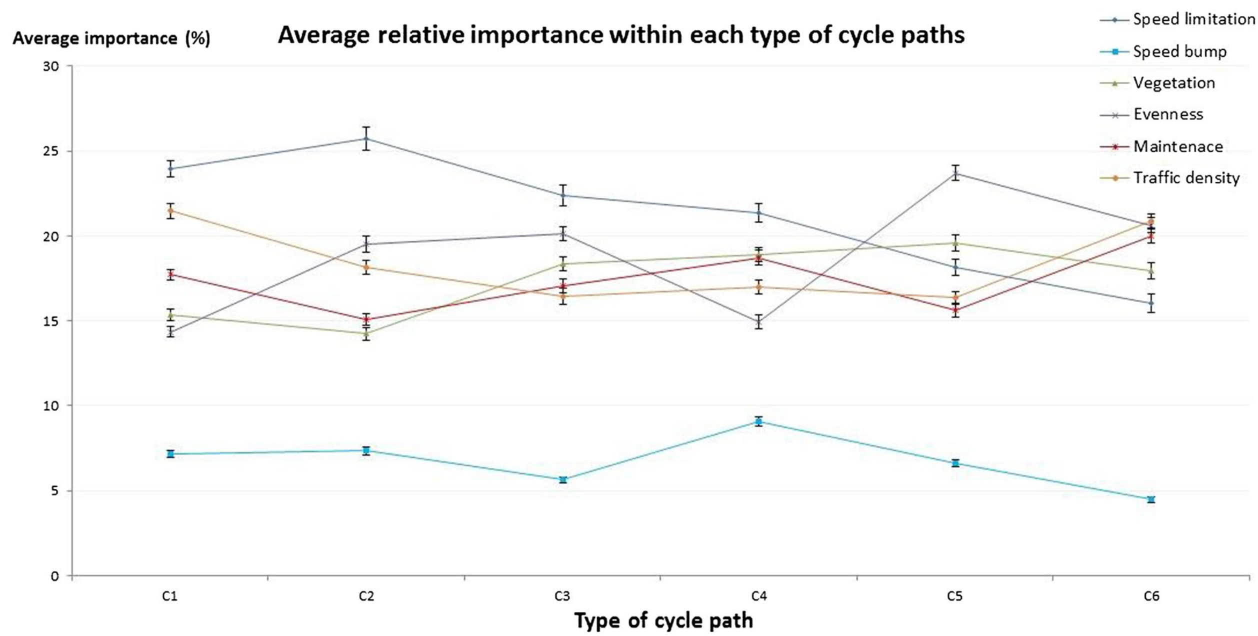

Fig. 7 Average relative importance of the six environmental factors within the different cycle path types. *C1* no cycle path; *C2* cycle path separated from traffic by marked white lines; *C3* cycle path separated from traffic with a curb, not separated from walking path by color; *C4* cycle path separated from traffic with a hedge, not separated from walking path by color; *C5* cycle path separated from traffic with a curb, separated from walking path by color; *C6* cycle path separated from traffic with a hedge, separated from walking path by color

on the relative importance of different types of 'separations' [49, 66, 67]. One of these studies indicated that research should also focus on the different designs to separate cyclists from cars [67]. The present study presented an initial possibility to investigate different gradation levels for possible separation between motorized traffic and cycle path (i.e. marked white lines—curb—hedge). A remarkable result in the present study was the large effect on the street's appeal of the most preferred type of separation, a small hedge. As a small hedge will not provide complete protection for cyclists from cars, it will merely be the perception of a separation that apparently makes them feel safer. Increased traffic safety or only the perception of it will be of great importance. This corresponds to recent findings, indicating that implementing measures to improve cyclists' safety from cars could increase cycling [66]. The current study showed that adapting the cycle path should get priority over other micro-environmental factors, such as speed limit, speed bump, vegetation, evenness of the cycle path surface and general upkeep. Even when it is not possible to actually separate cyclists from motorized traffic with a hedge, the presence of a curb or an indication by marked white lines may stimulate bicycle transport. An additional separation between cycle path and walking path by color will increase the street's appeal even more, but much less pronounced in comparison with the benefit obtained by a suitable separation with motorized traffic.

Changing the type of cycle path might not be possible in all situations (e.g. financial or space constraints). Therefore, we also investigated the relative importance of the environmental factors within each type of cycle path which has not been studied previously. When there are no possibilities to provide a separation between cycle path and motorized traffic, adjusting the speed of the traffic from 50 km/h to 30 km/h may ensure an increase in the street's appeal for bicycle transport. Furthermore, traffic density was found to be the second most important environmental factor to adapt when there is no cycle path in the street. Similar results were found for the interaction effects; decreasing the traffic speed or traffic density has a larger effect on the street's appeal for bicycle transport when there is no cycle path provided in the street compared to situations where other cycle paths are present. On the other hand, modifying the speed limit from 50 to 30 km/h has no additional effect on the street's appeal when the most preferred cycle path is present. These results indicate that in situations where there is no cycle path provided, micro-environmental factors associated to traffic-related safety appear to be most prominent. These findings should be communicated to policies at national and subnational level encouraging bicycle transport. The first priority when executing environmental interventions is the provision of a cycle path. If this adjustment is not practically feasible, micro-environmental factors related to safety (i.e., speed limit, traffic density) may be more effective in promoting bicycle transport than micro-environmental factors related to comfort (i.e. evenness of the cycle path surface) or aesthetic (i.e. vegetation, general upkeep). The importance of traffic safety regarding bicycle transport has also been mentioned in the literature [10, 49, 67]. The study of Fraser and Lock [49] noticed that when we want to create safe environments, we need to improve our research on the built environment prioritizing the needs of cyclists, including the evaluation of both rates of physical activity and road injury [49].

Furthermore, when a more separated cycle path (going from C1 to C6) is provided, micro-environmental factors related to comfort (i.e. evenness of the cycle path surface) or aesthetic (i.e. vegetation, general upkeep) appeared to become more important. For example, the effect of evenness obtained from the interaction analysis showed that increasing the evenness of the cycle path surface has the greatest effect on the street's appeal when a cycle path is separated from traffic with a curb. Improving the evenness of the cycle path surface could increase the street's appeal for bicycle transport even more when there is already a separation by means of a curb present. Moreover, when the most preferred cycle path is present (separated from traffic with a hedge and separated from walking path by color), the relative importance of the other environmental factors became more similar. In this situation, it does not matter which of the three micro-environmental factors ('traffic density', 'evenness of the cycle path surface' or 'general upkeep') will be modified first. They may achieve the same effect on bicycle transport because these factors did not significantly differ in importance from each other.

The effect of vegetation (from the lowest or intermediate to the anticipated most attractive level) on the street's appeal for bicycle transport was the greatest when there was no cycle path provided in the street. But on the other hand, we also know that when there is no cycle path provided, other micro-environmental factors turn out to be more important than vegetation. Nevertheless, the presence of vegetation may contribute to the street's appeal as second important factor in situations with a cycle path separated from traffic with a hedge (C4) or a cycle path separated from traffic with a curb and separated from walking path by color (C5).

Although, speed bump is the least preferred micro-environmental factor of all seven, the effect of the presence of a speed bump can be enhanced by reducing traffic density. Providing the street of a speed bump should not get priority over the other environmental factors, but a recommendation to the transport policies could be that adapting both factors together (speed bump and traffic density) is better than just focusing on installing a speed bump. A possible explanation for this effect could be found with the help of qualitative data from a recent mixed-method study [48], in which participants argued that the presence of a speed bump indirectly shows that many cars drive in the street.

The main strength of the current study was the used methodology (i.e. the choice based conjoint method using manipulated photographs) to answer the research questions. In real life, when people choose a route to cycle along to go to a place, they have to choose between combinations of factors. For example, people could make a decision by considering multiple factors such as limited speed of the cars, an even cycle path, some green along the route. Therefore, it is important to identify which factors are more important than others in such complex decisional contexts in order to understand how to create more encouraging cycling environments. The CBC method using manipulated photographs could identify the relative importance of micro-environmental factors in a street's appeal to cycle for transport [61]. This methodology allows studying the effects of environmental changes (manipulations) under controlled conditions, i.e. controlling the variation within and between the manipulated micro-environmental factors. The controlled manipulations of micro-environmental factors in the photographs are a cost-effective approach and could be used to experimentally find out which factors affect a street's appeal for bicycle transport under optimal conditions in terms of trip length and trip objective. Findings obtained from this study could provide practical guidelines for environmental interventions focusing on adapting micro-environmental factors to create more supportive environments for bicycle transport. From a previous study we know that these findings are not only valid for the street context depicted in the photographs of current study (i.e. a typical street environment in a semi-urban (300–600 inhabitants/km^2) Belgian municipality [57]), but most likely also for other street contexts (i.e. an environment with low building density and single land use or an environment with high building density and mixed land use) [59]. To our knowledge, this is the first study that creates an order of importance or hierarchy of the different micro-environmental factors. Furthermore, also interaction effects between different environmental factors were examined. Finally, by disseminating the research through the web, a very large sample was reached. However, this method also involved some disadvantages. Participants with a tertiary education (64.6 %) and a white collar occupation status (67.9 %) were over-represented in our study compared with the statistics of the Flemish population [68]; where 28.1 %

has a tertiary degree and the majority of the adults has a blue collar occupation. With our research, we have reached mainly highly educated people. Future research needs to establish whether these findings can be generalized to the entire Flemish population of mid-aged adults. Another limitation of current study is the two-dimensional character or the lack of movement/noise in the photograph environments. This can be overcome by using three-dimensional methods like manipulating computer-generated virtual walkthrough environments [69]. Nevertheless, using such methods is very expensive and only small samples can be reached. Finally, the most important weakness is that the current study did not assess effects on actual cycling behavior, but only on the street's appeal for bicycle transport. Consequently, these findings need to be confirmed by on-site research.

Some suggestions for future research can be made. A first suggestion is to compare our findings with results of other age groups. In the current study, only middle-aged adults between 45 and 65 years old were included to assess the viewpoint of the adult population. Besides this, also the viewpoint of younger adults assessing the environment in the perspective of their child is an important contributor as well as the viewpoint of older adults. Since, interventions targeting the built environment to encourage active transport, can reach a large proportion of the population [15], it is important to determine whether the same micro-environmental factors are important for different age-groups. Secondly, the current study fixed both trip objective and trip length. It would be interesting for future research to investigate the role of these environmental factors in relation to the preferred cycling route. Thirdly, integrating the role of socio-environmental factors (e.g. neighborhood safety) might enrich future studies' inputs and results. Finally, future research should also investigate the moderating effects of socio-demographics, psychosocial correlates and bicycle use on the relationship between the micro-environment and bicycle transport.

Conclusions

To our knowledge, this is the first study that creates an order of importance or hierarchy of relevant micro-environmental factors. Furthermore, also interaction effects between different environmental factors were examined as well as the relative importance of environmental factors within a particular micro-environmental factor. Providing streets with a cycle path separated from motorized traffic seems to be the best strategy to increase the street's appeal for adults' bicycle transport. A cycle path marked by white lines can already contribute to this, but a separation between cycle path and motorized traffic by means of a curb or a hedge appeared to be preferred. An additional separation with the walking path by color would increase the street's appeal for bicycle transport even more. If this adjustment is not practically feasible, micro-environmental factors related to safety (i.e., speed limit, traffic density) may be more effective in promoting bicycle transport than micro-environmental factors related to comfort (i.e. evenness of the cycle path surface) or aesthetic (i.e. vegetation, general upkeep). Furthermore, when a more separated cycle path is provided, micro-environmental factors related to comfort (i.e. evenness of the cycle path surface) or aesthetic (i.e. vegetation, general upkeep) appeared to increase in importance. Findings obtained from this research could provide advice to physical environmental interventions about which environmental factors should get priority to modify in different environmental situations.

Additional files

Additional file 1. Interaction effect between cycle path type and speed limit.

Additional file 2. Interaction effect between cycle path type and vegetation.

Additional file 3. Interaction effect between cycle path type and traffic density.

Additional file 4. Interaction effect between cycle path type and evenness.

Additional file 5. Interaction effect between speed bump and traffic density.

Additional file 6. Interaction effect between vegetation and general upkeep.

Abbreviations

C1: no cycle path; C2: cycle path, separated from traffic by marked white lines; C3: cycle path, separated from traffic with a curb, not separated from walking path by color; C4: cycle path separated from traffic with a hedge, not separated from walking path by color; C5: cycle path separated from traffic with a curb, separated from walking path by color; C6: cycle path separated from traffic with a hedge, separated from walking path by color.

Authors' contributions

LM, AG and JVC developed the photograph material and research protocol, in correspondence with NVdW, DVD, BD and IDB. LM, AG and JVC conducted the data collection. LM performed the data analysis and drafted the manuscript, supervised by DVD and JVC. All other co-authors critically reviewed and revised versions of the manuscript. All authors read and approved the final manuscript.

Author details

[1] Department of Movement and Sport Sciences, Faculty of Medicine and Health Sciences, Ghent University, Watersportlaan 2, 9000 Ghent, Belgium. [2] Research Foundation Flanders (FWO), Egmontstraat 5, 1000 Brussels, Belgium. [3] Department of Public Health, Faculty of Medicine and Health Sciences, Ghent University, De Pintelaan 185, 4k3, 9000 Ghent, Belgium. [4] Department of Human Biometry and Biomechanics, Faculty of Physical Education and Physical Therapy, Vrije Universiteit Brussel, Pleinlaan 2, 1050 Brussels, Belgium. [5] Department of Geography, Faculty of Sciences, Ghent University, Krijgslaan 281, S8, 9000 Ghent, Belgium.

Acknowledgements

The authors would like to thank Daphne Reinehr for developing the photographs.

Competing interests
The authors declare that they have no competing interests.

Availability of data and materials
The dataset(s) supporting the conclusions of this article is (are) included within the article (and its additional file(s)).

Consent for publication
Informed consent was automatically obtained from the participants when they voluntarily completed the questionnaire.

Ethics approval and consent to participate
The study was approved by the Ethics Committee of the Ghent University Hospital.

Funding
AG (Grant Number: GA11111N), JVC (Grant Number: 11NO313N), and DVD (Grant Number: FWO12/PDO/158) are supported by a Grant from the Fund for Scientific Research Flanders (FWO).

Received: 26 April 2016 Accepted: 3 August 2016
Published online: 01 September 2016

References

1. Rudinger G, Donaghy K, Poppelreuter S. Societal trends, mobility behaviour and sustainable transport in Europe and North America. Eur J Transp Infrastruct Res. 2006;6(1):61–76.
2. Vlaamse overheid Departement Mobiliteit en Openbare Werken. Onderzoek Verplaatsingsgedrag Vlaanderen 4. Brussel.
3. Wanner M, Götschi T, Martin-Diener E, Kahlmeier S, Martin BW. Active transport, physical activity, and body weight in adults: a systematic review. Am J Prev Med. 2012;42:493–502.
4. World Health Organization. Global Recommendations on Physical Activity for Health. 2010. p. 1–60. http://apps.who.int/iris/bitstream/10665/44399/1/9789241599979_eng.pdf. Accessed 25 Aug 2016.
5. Oja P, Titze S, Bauman A, de Geus B, Krenn P, Reger-Nash B, Kohlberger T. Health benefits of cycling: a systematic review. Scand J Med Sci Sports. 2011;21:496–509.
6. Kelly P, Kahlmeier S, Götschi T, Orsini N, Richards J, Roberts N, Scarborough P, Foster C. Systematic review and meta-analysis of reduction in all-cause mortality from walking and cycling and shape of dose response relationship. Int J Behav Nutr Phys Act. 2014;11:132.
7. Rissel CE. Active travel: a climate change mitigation strategy with co-benefits for health. N S W Public Health Bull. 2009;20:10–3.
8. Woodcock J, Edwards P, Tonne C, Armstrong BG, Ashiru O, Banister D, Beevers S, Chalabi Z, Chowdhury Z, Cohen A, Franco OH, Haines A, Hickman R, Lindsay G, Mittal I, Mohan D, Tiwari G, Woodward A, Roberts I. Public health benefits of strategies to reduce greenhouse-gas emissions: urban land transport. Lancet. 2009;374:1930–43.
9. Departement of Health, Physical Activity. Health improvement and prevention: at least five a week. 2004. p. 1–128. http://www.bhfactive.org.uk/sites/Exercise-Referral-Toolkit/downloads/resources/cmos-report-at-least-five-a-week.pdf. Accessed 25 Aug 2016.
10. Pucher J, Buehler R, Bassett DR, Dannenberg AL. Walking and cycling to health: a comparative analysis of city, state, and international data. Am J Public Health. 2010;100:1986–92.
11. Rabl A, de Nazelle A. Benefits of shift from car to active transport. Transp Policy. 2012;19:121–31.
12. Active Transport. https://secure.ausport.gov.au/clearinghouse/knowledge_base/organised_sport/sport_and_government_policy_objectives/active_transport.
13. de Hartog JJ, Boogaard H, Nijland H, Hoek G. Do the health benefits of cycling outweigh the risks? Environ Health Perspect. 2010;118:1109–16.
14. Rojas-Rueda D, de Nazelle A, Tainio M, Nieuwenhuijsen MJ. The health risks and benefits of cycling in urban environments compared with car use: health impact assessment study. BMJ. 2011;343:d4521.
15. World Health Organization. Interventions on diet and physical activity: what works (summary report). 2009. p. 1–48. http://www.who.int/dietphysicalactivity/summary-report-09.pdf. Accessed 25 Aug 2016.
16. Vandenbulcke G, Thomas I, de Geus B, Degraeuwe B, Torfs R, Meeusen R, Panis LI. Mapping bicycle use and the risk of accidents for commuters who cycle to work in Belgium. Transp Policy. 2009;16:77–87.
17. Jongeneel-Grimen B, Busschers W, Droomers M, van Oers HA, Stronks K, Kunst AE. Change in neighborhood traffic safety: does it matter in terms of physical activity? PLoS ONE. 2013;8:e62525.
18. Sallis JF, Cervero RB, Ascher W, Henderson KA, Kraft MK, Kerr J. An ecological approach to creating active living communities. Annu Rev Public Health. 2006;27:297–322.
19. Gaffron P. The implementation of walking and cycling policies in British local authorities. Transp Policy. 2003;10:235–44.
20. Pucher J, Dill J, Handy S. Infrastructure, programs, and policies to increase bicycling: an international review. Prev Med. 2010;50(Suppl 1):S106–25.
21. Buehler R, Pucher J. Walking and cycling in Western Europe and the United States. TR NEWS (280) 2012.
22. Commission of the European Communities. GREEN PAPER towards a new culture for urban mobility. Commission of the European Communities: Brussels; 2007.
23. World Health Organization. Global Status report on noncommunicable diseases. 2014. p. 1–302. http://apps.who.int/iris/bitstream/10665/148114/1/9789241564854_eng.pdf. Accessed 25 Aug 2016.
24. Pucher J, Buehler R. Cycling for everyone: lessons from Europe. J Transp Res Board. 2007;2074:58–65.
25. Swinburn B, Egger G, Raza F. Dissecting obesogenic environments: the development and application of a framework for identifying and prioritizing environmental interventions for obesity. Prev Med. 1999;29(6):563–70.
26. Cain KL, Millstein RA, Sallis JF, Conway TL, Gavand KA, Frank LD, Saelens BE, Geremia CM, Chapman J, Adams MA, Glanz K, King AC. Contribution of streetscape audits to explanation of physical activity in four age groups based on the Microscale Audit of Pedestrian Streetscapes (MAPS). Soc Sci Med (1982). 2014;116:82–92.
27. Van Holle V, Deforche B, Van Cauwenberg J, Goubert L, Maes L, Van de Weghe N, De Bourdeaudhuij I. Relationship between the physical environment and different domains of physical activity in European adults: a systematic review. BMC Public Health. 2012;12:807.
28. Saelens BE, Sallis JF, Frank LD. Environmental correlates of walking and cycling: findings from the transportation, urban design, and planning literatures. Ann Behav Med. 2003;25:80–91.
29. Van Dyck D, Cerin E, Conway TL, De Bourdeaudhuij I, Owen N, Kerr J, Cardon G, Frank LD, Saelens BE, Sallis JF. Perceived neighborhood environmental attributes associated with adults' transport-related walking and cycling: findings from the USA, Australia and Belgium. Int J Behav Nutr Phys Act. 2012;9:70.
30. McCormack GR, Shiell A. In search of causality: a systematic review of the relationship between the built environment and physical activity among adults. Int J Behav Nutr Phys Act. 2011;8:125.
31. Foster CE, Panter JR, Wareham NJ. Assessing the impact of road traffic on cycling for leisure and cycling to work. Int J Behav Nutr Phys Act. 2011;8:61.
32. Wendel-Vos W, Droomers M, Kremers S, Brug J, van Lenthe F. Potential environmental determinants of physical activity in adults: a systematic review. Obes Rev. 2007;8:425–40.
33. McCormack G, Giles-Corti B, Lange A, Smith T, Martin K, Pikora TJ. An update of recent evidence of the relationship between objective and self-report measures of the physical environment and physical activity behaviours. J Sci Med Sport. 2004;7(1 Suppl):81–92.
34. Bauman AE, Reis RS, Sallis JF, Wells JC, Loos RJF, Martin BW. Correlates of physical activity: why are some people physically active and others not? Lancet. 2012;380:258–71.
35. Van Holle V, Van Cauwenberg J, Deforche B, Goubert L, Maes L, Nasar J, Van de Weghe N, Salmon J, De Bourdeaudhuij I. Environmental invitingness for transport-related cycling in middle-aged adults: a proof of concept study using photographs. Transp Res Part A Policy Pract. 2014;69:432–46.
36. Vandenbulcke G, Dujardin C, Thomas I, De Geus B, Degraeuwe B, Meeusen R, Panis LI. Cycle commuting in Belgium: spatial determinants and "re-cycling" strategies. Transp Res Part A Policy Pract. 2011;45:118–37.

37. de Geus B, De Bourdeaudhuij I, Jannes C, Meeusen R. Psychosocial and environmental factors associated with cycling for transport among a working population. Health Educ Res. 2008;23:697–708.
38. Titze S, Stronegger WJ, Janschitz S, Oja P. Environmental, social, and personal correlates of cycling for transportation in a student population. J Phys Act Health. 2007;4(1):66–79.
39. Titze S, Giles-Corti B, Knuiman MW, Pikora TJ, Timperio A, Bull FC, Van Niel K. Associations between intrapersonal and neighborhood environmental characteristics and cycling for transport and recreation in adults: baseline results from the RESIDE study. J Phys Act Health. 2010;7:423–31.
40. Van Dyck D, Cardon G, Deforche B, Giles-Corti B, Sallis JF, Owen N, De Bourdeaudhuij I. Environmental and psychosocial correlates of accelerometer-assessed and self-reported physical activity in Belgian adults. Int J Behav Med. 2011;18:235–45.
41. Parkin J, Wardman M, Page M. Estimation of the determinants of bicycle mode share for the journey to work using census data. Transportation. 2008;35:93–109.
42. Lee C, Moudon AV. Neighbourhood design and physical activity. Build Res Inf. 2008;36(5):395–411.
43. Zlot AI, Schmid TL. Relationships among community characteristics and walking and bicycling for transportation or recreation. Am J Health Promot. 2005;19:314–7.
44. Wendel-vos W, Schuit J, De Niet R, Boshuizen HC, Saris WHM, Kromhout D. Factors of the physical environment associated with walking and bicycling. Med Sci Sports Exerc. 2004;36(4):725–30.
45. Kondo K, Su ÆJ, Kiyoshi LÆ, Yusuke KÆ, Takagi H, Sunagawa ÆH, Akabayashi ÆA. Association between daily physical activity and neighborhood environments. Environ Health Prev Med. 2009;14(3):196–206. doi:10.1007/s12199-009-0081-1.
46. Caulfield B, Brick E, Thérèse O. Determining bicycle infrastructure preferences—a case study of Dublin. Transp Res Part D. 2012;17:413–7.
47. Evenson KR, Herring AH, Huston SL. Evaluating change in physical activity with the building of a multi-use trail. Am J Prev Med. 2005;28:177–85.
48. Mertens L, Van Holle V, De Bourdeaudhuij I, Deforche B, Salmon J, Nasar J, Van de Weghe N, Van Dyck D, Van Cauwenberg J. The effect of changing micro-scale physical environmental factors on an environment's invitingness for transportation cycling in adults: an exploratory study using manipulated photographs. Int J Behav Nutr Phys Act. 2014;11:88.
49. Fraser SDS, Lock K. Cycling for transport and public health: a systematic review of the effect of the environment on cycling. Eur J Public Health. 2010;21:738–43.
50. Carpiano RM. Come take a walk with me: the "go-along" interview as a novel method for studying the implications of place for health and wellbeing. Health Place. 2009;15:263–72.
51. Spittaels H, Foster C, Oppert J-M, Rutter H, Oja P, Sjöström M, De Bourdeaudhuij I. Assessment of environmental correlates of physical activity: development of a European questionnaire. Int J Behav Nutr Phys Act. 2009;6:39.
52. Sallis JF, Bowles HR, Bauman A, Ainsworth BE, Bull FC, Craig CL, Sjöström M, De Bourdeaudhuij I, Lefevre J, Matsudo V, Matsudo S, Macfarlane DJ, Gomez LF, Inoue S, Murase N, Volbekiene V, McLean G, Carr H, Heggebo LK, Tomten H, Bergman P. Neighborhood environments and physical activity among adults in 11 countries. Am J Prev Med. 2009;36:484–90.
53. Ferdinand AO, Sen B, Rahurkar S, Engler S, Menachemi N. The relationship between built environments and physical activity: a systematic review. Am J Public Health. 2012;102(10):e7–13.
54. Nasar JL. Assessing perceptions of environments for active living. Am J Prev Med. 2008;34:357–63.
55. Wells NM, Ashdown SP, Davies EHS, Cowett FD, Yang Y. Environment, design, and obesity: opportunities for interdisciplinary collaborative research. Environ Behav. 2007;39:6–33.
56. Adobe Systems Incorporated: Adobe Photoshop CC. 2013. p. 1–87. http://wwwimages.adobe.com/content/dam/Adobe/en/devnet/photoshop/pdfs/photoshop-cc-scripting-guide.pdf. Accessed 25 Aug 2016.
57. Lenders S, Lauwers L, Vervloet D, Kerselaers E. Afbakening van het Vlaamse platteland, een statistische analyse. 2006. p. 1–63. http://www2.vlaanderen.be/landbouw/downloads/volt/38.pdf. Accessed 25 Aug 2016.
58. Pucher J, Buehler R. Making cycling irresistible: lessons from the Netherlands, Denmark and Germany. Transp Rev. 2008;28:495–528.
59. Mertens L, Van Cauwenberg J, Ghekiere A, Van Holle V, De Bourdeaudhuij I, Deforche B, Nasar J, Van de Weghe N, Van Dyck D. Does the effect of micro-environmental factors on a street's appeal for adults' bicycle transport vary across different macro-environments? An experimental study. PLoS One 2015;10:1–17.
60. Craig CL, Marshall AL, Sjöström M, Bauman AE, Booth ML, Ainsworth BE, Pratt M, Ekelund U, Yngve A, Sallis JF, Oja P. International physical activity questionnaire: 12-country reliability and validity. Med Sci Sports Exerc. 2003;35:1381–95.
61. Orme BK. Getting started with conjoint analysis: strategies for product design and pricing research. Madison: Resarch Publishers; 2009.
62. Sawtooth Software Inc. The CBC system for choice-based conjoint analysis. 2013. p. 1–27. https://sawtoothsoftware.com/download/techpap/cbctech.pdf. Accessed 25 Aug 2016.
63. Multon KD. Interrater reliability. In: Salkind NJ, editor. Encyclopedia research design. Thousand Oaks, CA: Sage; 2012. p. 627–629. doi:10.4135/9781412961288.n194. http://methods.sagepub.com/reference/encyc-of-research-design/n194.xml. Accessed 25 Aug 2016.
64. Allenby GM, Arora N, Ginter JL. On the heterogeneity of demand. J Mark Res. 1998;35:384–9.
65. Interaction Search Tool. https://www.sawtoothsoftware.com/help/issues/ssiweb/online_help/index.html?interaction_search_tool.htm.
66. Sallis JF, Conway TL, Dillon LI, Frank LD, Adams MA, Cain KL, Saelens BE. Environmental and demographic correlates of bicycling. Prev Med. 2013;57:456–60.
67. Winters M, Davidson G, Kao D, Teschke K. Motivators and deterrents of bicycling: comparing influences on decisions to ride. Transportation. 2010;38:153–68.
68. Statistics Belgium. http://statbel.fgov.be/.
69. Cubukcu E, Nasar JL. Influence of physical characteristics of routes on distance cognition in virtual environments. Environ Plan. 2005;32:777–85.

Additional file 1 - Interaction effect between cycle path type and speed limit

Table A.1. Interaction effect between type of cycle path and speed limit (chi-square= 16.87; p=0.005)

	C1		**C2**		**C3**	
	50km/h	*30 km/h*	*50km/h*	*30 km/h*	*50km/h*	*30 km/h*
MEAN	*0.00*	*4.11*	*10.19*	*12.71*	*13.56*	*16.00*
SD	*0.00*	*0.18*	*0.45*	*0.56*	*0.60*	*0.71*
-95% CI	*0.00*	*3.93*	*9.74*	*12.15*	*12.96*	*15.29*
+95% CI	*0.00*	*4.29*	*10.64*	*13.28*	*14.17*	*16.71*
	C4		**C5**		**C6**	
	50km/h	*30 km/h*	*50km/h*	*30 km/h*	*50km/h*	*30 km/h*
MEAN	*18.70*	*20.98*	*15.28*	*17.27*	*19.71*	*21.08*
SD	*0.83*	*0.93*	*0.68*	*0.77*	*0.87*	*0.94*
-95% CI	*17.87*	*20.05*	*14.60*	*16.50*	*18.83*	*20.15*
+95% CI	*19.53*	*21.91*	*15.96*	*18.03*	*20.58*	*22.02*

C1: no cycle path; C2: cycle path separated from traffic by marked white lines; C3: cycle path separated from traffic with a curb, not separated from walking path by color; C4: cycle path separated from traffic with a hedge, not separated from walking path by color; C5: cycle path separated from traffic with a curb, separated from walking path by color; C6: cycle path separated from traffic with a hedge, separated from walking path by color.

Additional file 2 - Interaction effect between cycle path type and vegetation

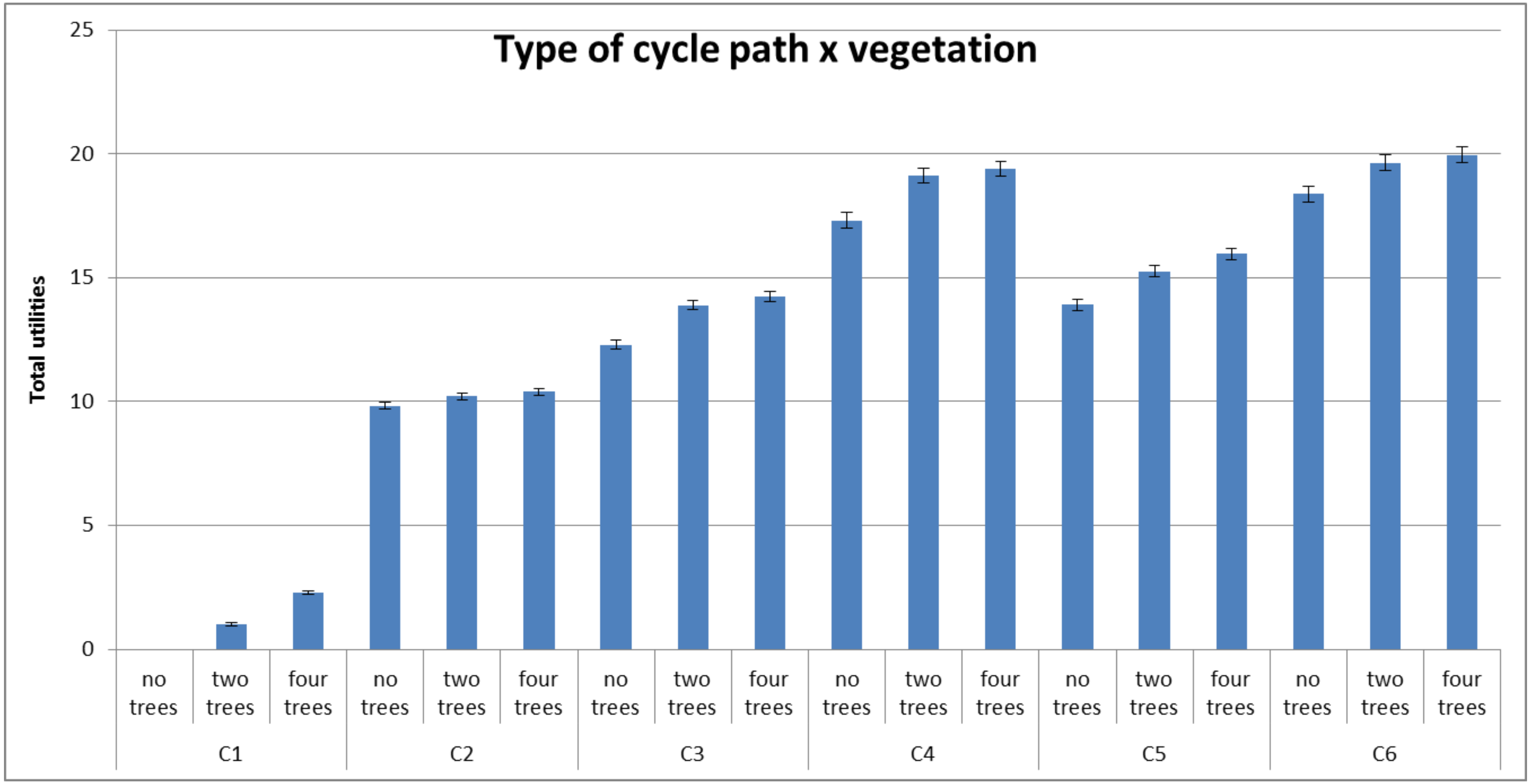

Figure B.1. Interaction effect between type of cycle path and vegetation (chi-square= 27.78; p=0.002)

Table B.1. Interaction effect between type of cycle path and vegetation (chi-square= 27.78; p=0.002)

	C1			C2			C3			C4			C5			C6		
	no trees	two trees	four trees	no trees	two trees	four trees	no trees	two trees	four trees	no trees	two trees	four trees	no trees	two trees	four trees	no trees	two trees	four trees
MEAN	0.00	1.00	2.30	9.83	10.22	10.39	12.30	13.90	14.24	17.30	19.12	19.39	13.91	15.26	15.96	18.37	19.64	19.96
SD	0.00	1.54	1.71	3.09	3.02	2.80	4.32	4.25	4.60	7.08	6.88	6.85	5.03	4.97	5.14	7.45	6.98	7.10
-95% CI	0.00	0.94	2.23	9.69	10.08	10.27	12.11	13.71	14.04	16.99	18.82	19.09	13.69	15.04	A5.73	18.04	19.33	19.64
+95% CI	0.00	1.07	2.38	9.97	10.35	10.52	12.49	14.09	14.44	17.62	19.43	19.69	14.13	15.48	16.19	18.70	19.95	20.27

C1: no cycle path; C2: cycle path separated from traffic by marked white lines; C3: cycle path separated from traffic with a curb, not separated from walking path by color; C4: cycle path separated from traffic with a hedge, not separated from walking path by color; C5: cycle path separated from traffic with a curb, separated from walking path by color; C6: cycle path separated from traffic with a hedge, separated from walking path by color.

Additional file 3 - Interaction effect between cycle path type and traffic density

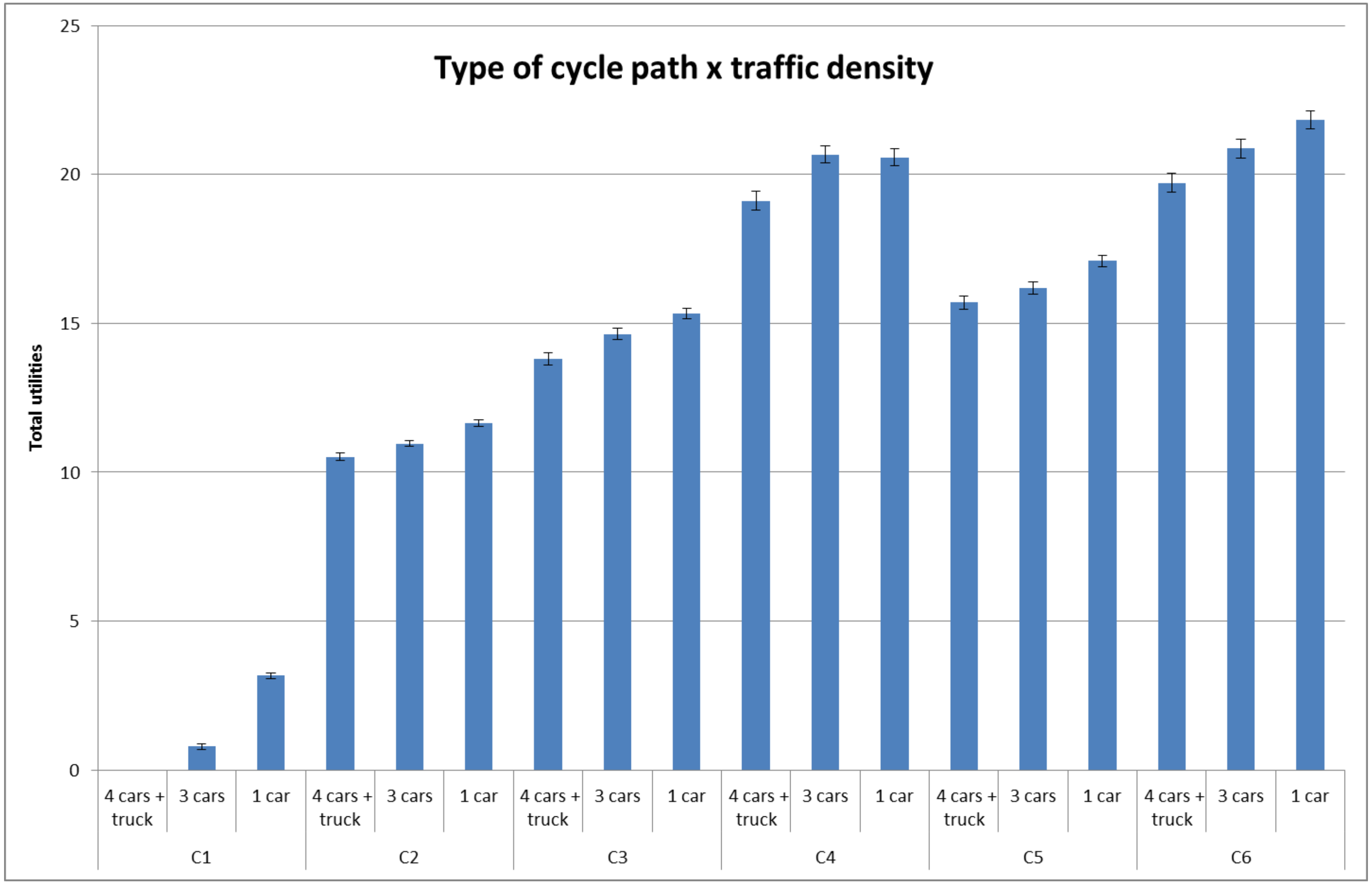

Figure C.1. Interaction effect between type of cycle path and traffic density

Table C.1. Interaction effect between type of cycle path and traffic density

	C1			C2			C3			C4			C5			C6		
	4 cars + truck	3 cars	1 car	4 cars + truck	3 cars	1 car	4 cars + truck	3 cars	1 car	4 cars + truck	3 cars	1 car	4 cars + truck	3 cars	1 car	4 cars + truck	3 cars	1 car
MEAN	0.00	0.79	3.17	10.52	10.96	11.65	13.81	14.64	15.31	19.11	20.67	20.57	15.69	16.17	17.10	19.72	20.86	21.82
SD	0.00	2.18	2.32	2.94	2.28	2.69	4.50	4.26	3.91	7.11	6.52	6.40	5.27	4.67	4.30	7.21	6.88	6.87
-95% CI	0.00	0.70	3.06	10.39	10.86	11.53	13.61	14.45	15.14	18.80	20.38	20.29	15.46	15.96	16.91	19.40	20.56	21.51
+95% CI	0.00	0.89	3.27	10.65	11.06	11.77	14.01	14.83	15.49	19.43	20.96	20.85	15.93	16.38	17.29	20.04	21.17	22.12

C1: no cycle path; C2: cycle path separated from traffic with lines, not separated from walking path; C3: cycle path separated from traffic with a curb, not separated from walking path; C4: cycle path separated from traffic with a hedge, not separated from walking path; C5: cycle path separated from traffic with a curb, separated from walking path by color; C6: cycle path separated from traffic with a hedge, separated from walking path by color.

Additional file 4 - Interaction effect between cycle path type and evenness

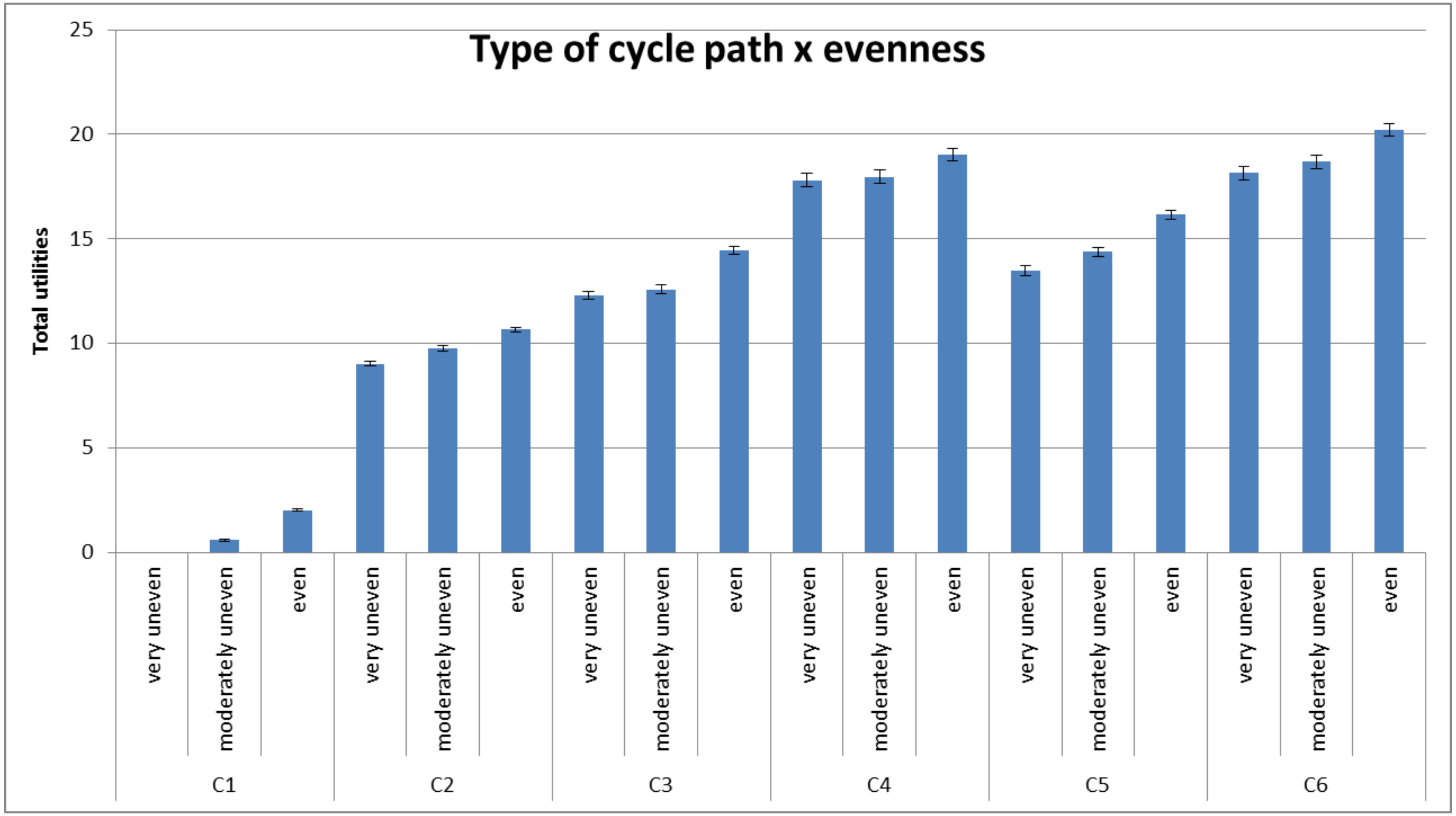

Figure D.1. Interaction effect between type of cycle path and evenness of the cycle path surface.

Table D.1. Interaction effect between type of cycle path and evenness of the cycle path surface.

	C1			C2			C3			C4			C5			C6		
	very uneven	moderately uneven	even	very uneven	moderately uneven	even	very uneven	moderately uneven	even	very uneven	moderately uneven	Even	very uneven	moderately uneven	even	very uneven	moderately uneven	even
MEAN	0.00	0.59	2.02	9.02	9.75	10.65	12.28	12.59	14.43	17.81	17.97	19.05	13.47	14.38	16.15	18.15	18.69	20.19
SD	0.00	1.33	1.56	2.68	3.26	2.98	4.12	4.49	4.19	7.28	6.83	6.63	5.15	4.83	4.70	7.22	7.35	6.69
-95% CI	0.00	0.53	1.95	8.91	9.60	10.52	12.10	12.39	14.25	17.49	17.67	18.75	13.24	14.16	15.94	17.83	18.37	19.90
+95% CI	0.00	0.64	2.09	9.14	9.89	10.78	12.46	12.79	14.62	18.13	18.28	19.34	13.70	14.59	16.36	18.47	19.02	20.49

C1: no cycle path; C2: cycle path separated from traffic by marked white lines; C3: cycle path separated from traffic with a curb, not separated from walking path by color; C4: cycle path separated from traffic with a hedge, not separated from walking path by color; C5: cycle path separated from traffic with a curb, separated from walking path by color; C6: cycle path separated from traffic with a hedge, separated from walking path by color.

Additional file 5 - Interaction effect between speed bump and traffic density

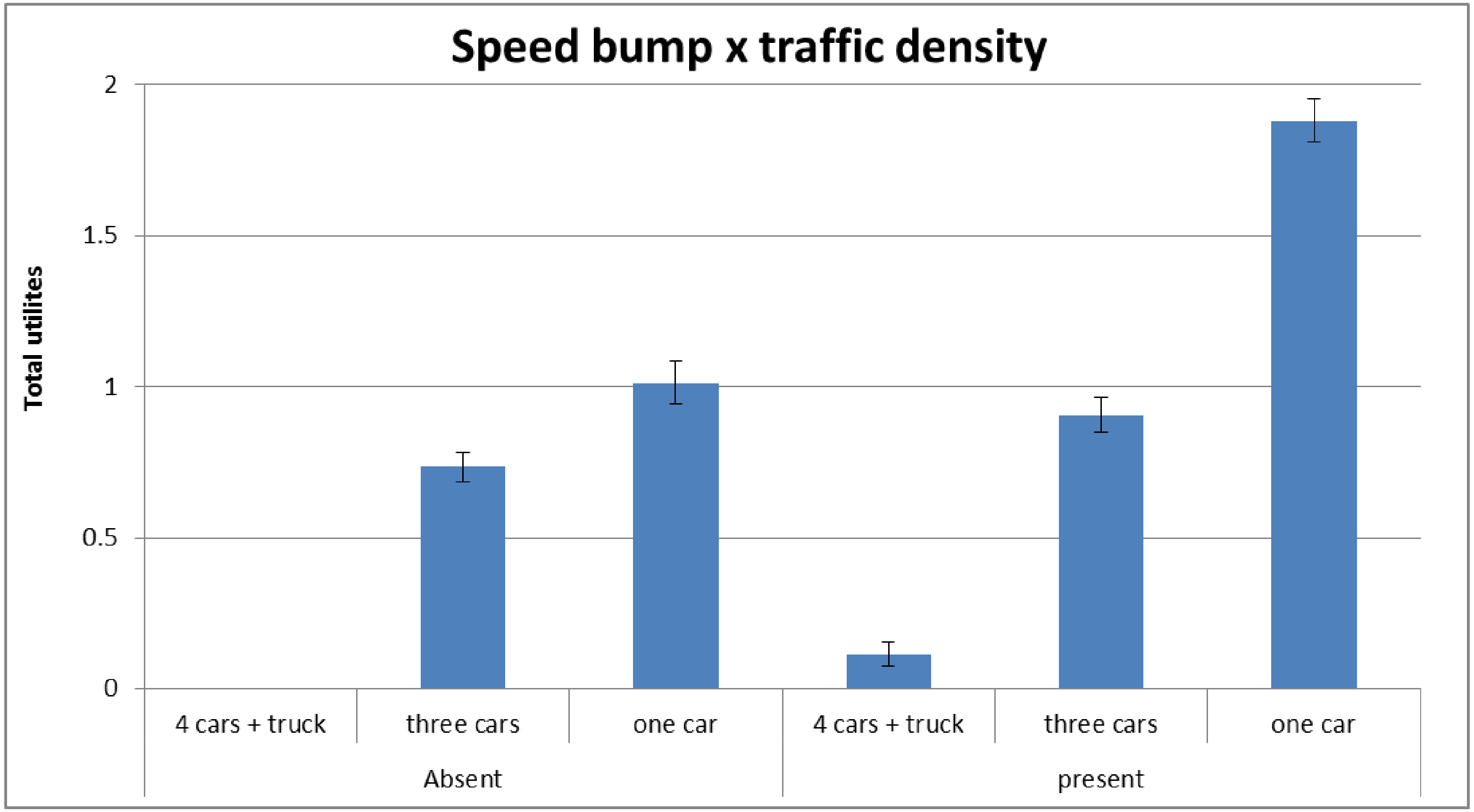

Figure E.1. Interaction effect between speed bump and traffic density

Table E.1. Interaction effect between speed bump and traffic density

	Absent			Present		
	4 cars + truck	three cars	one car	4 cars + truck	three cars	one car
MEAN	0.00	0.73	1.01	0.11	0.91	1.88
SD	0.00	1.13	1.65	0.89	1.29	1.61
-95% CI	0.00	0.68	0.94	0.08	0.85	1.81
+95% CI	0.00	0.78	1.09	0.15	0.96	1.95

Additional file 6 - Interaction effect between vegetation and general upkeep

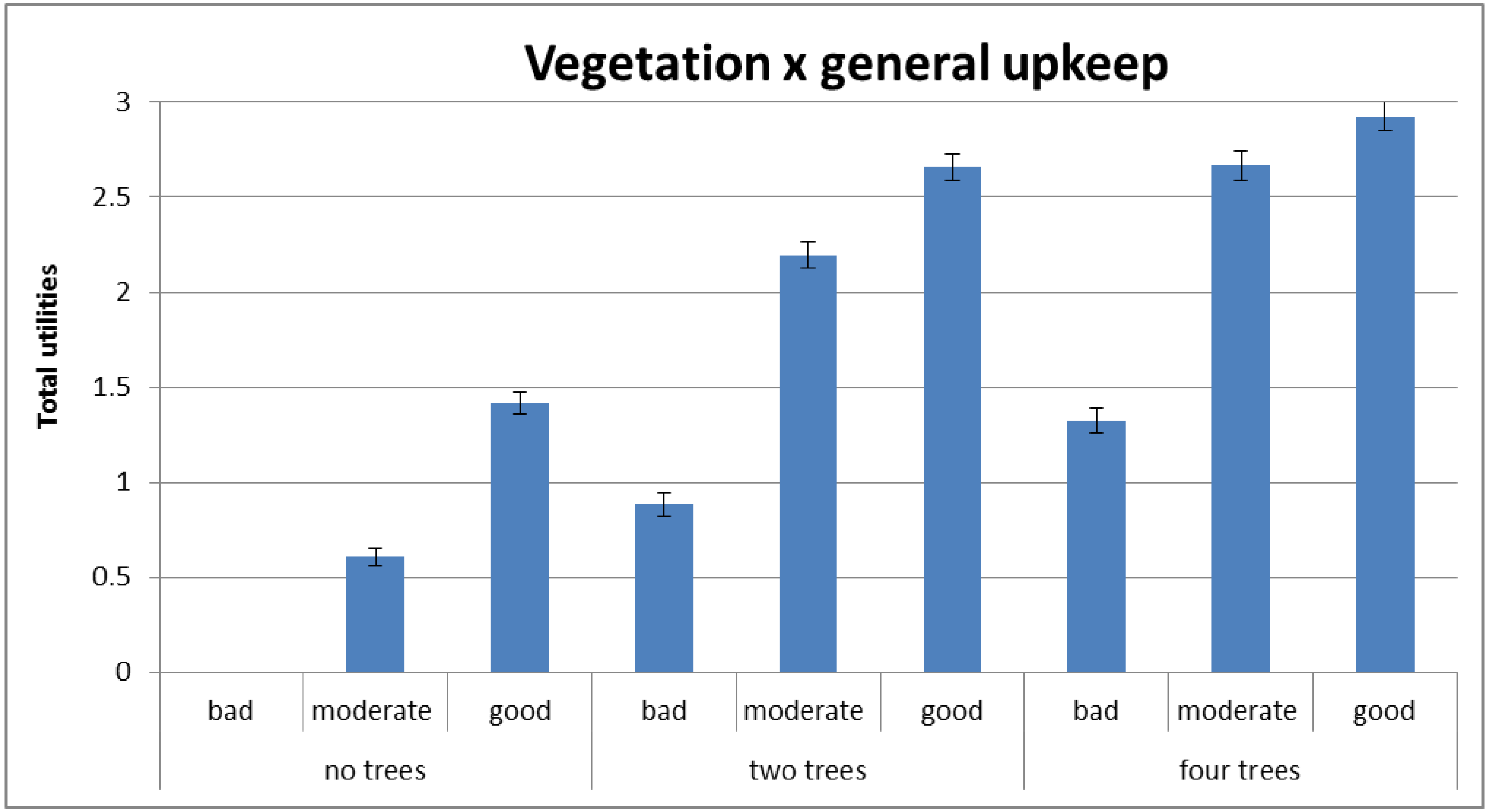

Figure F.1. Interaction effect between vegetation and general upkeep

Table F.1. Interaction effect between vegetation and general upkeep

	no trees			two trees			four trees		
	bad	moderate	good	bad	moderate	good	bad	moderate	Good
MEAN	0.00	0.60	1.42	0.88	2.20	2.66	1.32	2.67	2.93
SD	0.00	1.09	1.32	1.32	1.50	1.54	1.45	1.74	1.72
-95% CI	0.00	0.56	1.36	0.82	2.13	2.59	1.26	2.59	2.85
+95% CI	0.00	0.00	1.48	-0.29	-2.67	-3.54	-1.02	2.75	-3.87

Chapter 2.4 – Subgroup analysis: differences in environmental preferences towards cycling for transport

Mertens, L., Van Cauwenberg, J., Ghekiere, A., De Bourdeaudhuij, I., Deforche, B., Van De Weghe, N., & Van Dyck, D. (2016). Differences in environmental preferences towards cycling for transport among adults: a latent class analysis. BMC Public Health, 16(782), 1–10. http://doi.org/10.1186/s12889-016-3471-5

Mertens *et al. BMC Public Health* (2016) 16:782
DOI 10.1186/s12889-016-3471-5

BMC Public Health

RESEARCH ARTICLE
Open Access

Differences in environmental preferences towards cycling for transport among adults: a latent class analysis

Lieze Mertens[1], Jelle Van Cauwenberg[2,3,4], Ariane Ghekiere[2,3,4], Ilse De Bourdeaudhuij[1*], Benedicte Deforche[2,3], Nico Van de Weghe[5] and Delfien Van Dyck[1,4]

Abstract

Background: Increasing cycling for transport can contribute to improve public health among adults. Micro-environmental factors (i.e. small-scaled street-setting features) may play an important role in affecting the street's appeal to cycle for transport. Understanding about the interplay between individuals and their physical environment is important to establish tailored environmental interventions. Therefore, the current study aimed to examine whether specific subgroups exist based on similarities in micro-environmental preferences to cycle for transport.

Methods: Responses of 1950 middle-aged adults (45–65 years) on a series of choice tasks depicting potential cycling routes with manipulated photographs yielded three subgroups with different micro-environmental preferences using latent class analysis.

Results: Although latent class analysis revealed three different subgroups in the middle-aged adult population based on their environmental preferences, results indicated that cycle path type (i.e. a good separated cycle path) is the most important environmental factor for all participants and certainly for individuals who did not cycle for transport. Furthermore, only negligible differences were found between the importances of the other micro-environmental factors (i.e. traffic density, evenness of the cycle path, maintenance, vegetation and speed limits) regarding the two at risk subgroups and that providing a speed bump obviously has the least impact on the street's appeal to cycle for transport.

Conclusions: Results from the current study indicate that only negligible differences were found between the three subgroups. Therefore, it might be suggested that tailored environmental interventions are not required in this research context.

Keywords: Built environment, Biking, Adulthood, Subgroup, Photographs, Transport

Background

Cross-sectional evidence has shown that active transport, especially cycling for transport, could be an important contributor to general public health by increasing physical activity (PA) levels among adults, reducing the risk of all-cause mortality and helping to maintain a healthy body weight [1, 2]. Cycling for transport can be integrated into adults' daily life routines, is feasible and inexpensive, and can reduce traffic congestion and CO_2 emissions [3–11]. As 50 % of all trips in Europe are shorter than 3 km, a feasible distance to cycle, there is considerable potential for an increase in the prevalence of cycling for transport [12]. Current Belgian statistics showed that, for adults, only 25 and 14 % of all trips shorter than 3 and 5 km respectively are undertaken using active transport (i.e. walking or cycling) [13]. Consequently, there is a need for interventions to promote cycling for transport in adults. In this regard, it is important to verify the key determinants of cycling for transport in adults.

Ecological models emphasize the importance of the physical environment, together with social and individual characteristics, to explain PA [14]. Furthermore, it is

* Correspondence: Ilse.Debourdeaudhuij@Ugent.be
[1]Department of Movement and Sport Sciences, Faculty of Medicine and Health Sciences, Ghent University, Watersportlaan 2, B-9000 Ghent, Belgium
Full list of author information is available at the end of the article

known that transport-related PA is more consistently associated with the physical environment than recreational physical activity [15]. Previous studies indicated that micro-environmental factors (e.g. evenness of the cycle path, vegetation, speed limits) might be more amenable to change than macro-environmental factors (e.g. street connectivity, residential density) [16, 17]. Since micro-environmental factors are relatively small-scale street-setting features and can be influenced on a neighborhood level by local actors, they are more feasible to target in existing neighborhoods than macro-environmental factors which are large-scale urban planning features influenced on regional/national level [16, 17]. Unfortunately, knowledge about the influence of these micro-environmental factors on adults' cycling for transport is scarce and often inconsistent [18–22]. This is mainly due to the applied cross-sectional observational study designs [21, 23]; stronger designs with improved causal inference are necessary [21, 24–27]. A possible solution would be to conduct on-site experiments, but since these are usually long-term expensive projects, and since it is ethically not defensible to change real environments without being sure that these changes are effective (risk of negative effects and difficulty undoing real-life changes), another approach is required. Therefore, we developed a methodology using manipulated photographs which can simulate these experiments and identify critical environmental correlates associated with a street's appeal to cycle for transport. This methodology studies the effects of environmental changes (manipulations) under controlled conditions, i.e. controlling the variation within and between the manipulated micro-environmental factors. Comparison with on-site responses [28, 29] support the validity of responses to colored photographs.

A recent large-scale conjoint study with manipulated photographs was able to identify the relative importance of a range of relevant displayed micro-environmental factors in the decision process of choosing the most appealing of two possible cycling routes [30]. The main finding was that the provision of cycle paths separated from motorized traffic is the best strategy to increase the street's appeal to cycle for transport among middle-aged adults. Furthermore, this study showed that in streets where it is impossible to provide a well-separated cycle path (e.g. due to financial or space constraints), targeting micro-environmental factors related to safety (i.e. speed limit, traffic density) may be more effective in promoting bicycle transport than micro-environmental factors related to comfort (i.e. evenness of the cycle path surface) or aesthetics (i.e. vegetation, maintenance). On the other hand, micro-environmental factors related to comfort or aesthetics were more important in streets where a well-separated cycle path was already provided. However, we do not know whether these environmental changes are beneficial for the entire target population (i.e. middle-aged adults between 45 and 65 years old). In order to optimize environments and thus environmental interventions with the aim to encourage cycling for transport, it is important to gain insight in the associations of the physical environment (positive or negative) with cycling for transport among different subgroups [31].

Existing literature has revealed some different transportation patterns, needs, and purposes between different subgroups. For example, previous studies showed that issues of safety and comfort regarding cycling for transport are more important for women compared to men [32, 33]. Since the amount of cycling is determined by the inter-relation between individuals and their physical environment [14, 34], it is important to understand these interactions. First, it must be ascertained whether micro-environmental preferences towards cycling for transport are specific to particular subgroups, especially those who could benefit most from these interventions (i.e. at risk subgroups like those with poor attitudes towards cycling, poorer cycling skills or those living in a neighborhood with unsafe traffic conditions) [32, 33, 35, 36]. To create a mass cycling culture, it may be essential to target infrastructure and policies likely to influence groups that are currently not cycling a lot (e.g. women or older people) [37]. As it appears that regular cyclists will cycle regardless of the circumstances (e.g. lack of good cycling infrastructures, long travel distance) because they like to cycle [38], tailoring environmental interventions for at-risk subgroups should be possible without disadvantaging regular cyclists. Also, identifying the demographics and other characteristics of at-risk subgroups would enable the development of environmental interventions in environments most relevant to these populations.

Therefore, the current study aimed to examine whether there are subgroups with different micro-environmental preferences for cycling for transport among middle-aged adults (45–65 years) using latent class analysis. Furthermore, specific characteristics of these subgroups were identified based on socio-demographics, transport behavior, psychosocial determinants of cycling for transport, neighborhood environmental perceptions, cycling skills, concerns and preferences of participants.

Methods

Protocol and measures

Flemish middle-aged adults were recruited by purposeful convenience using email, social media, family, friends, clubs, organizations and companies. Furthermore, snowball sampling was used to recruit additional participants. As a wider age range might cause interference and therefore less accurate results [5], only adults between 45 and 65 years old were invited to participate in our research. This subgroup was selected as from the age of 45 years there is an increased risk of cardiovascular disease that may be partially attributed to an age-related decline in regular physical activity [1–3]. Older adults (>65 years) were not included in this research because they can be considered as a separate group due to their retirement and limited mobility in comparison to younger adults [4]. Eighteen participants who fell outside the age range of 45–65 years old, were excluded from the analysis. In total, 1950 middle-aged adults completed the two-part web-based questionnaire, developed with Sawtooth Software (SSI Web version 8.3.8.). Data collection took place between November 2014 and January 2015. Additional study details have been described elsewhere [30].

The web-based questionnaire

The web-based questionnaire consisted of two main parts. In the first part, questions gathered information about participant characteristics as described below.

Self-reported *socio-demographic variables* included age, gender, educational level (two categories: primary school, lower/higher secondary - tertiary), area of residence (two categories: village, town or rural area - city or city border), weight and height (to calculate body mass index).

Participants' *transport behavior* (i.e. walking and cycling for transport), cycling for leisure and motorized transport were assessed using the relevant sections of the validated International Physical Activity Questionnaire (IPAQ long form: 'usual week') [39, 40].

Psychosocial determinants focusing on cycling for transport were assessed based on validated questionnaires of psychosocial correlates of general physical activity [41] and psychosocial correlates of cycling-specific behaviors among adults [42, 43]. Seven psychosocial correlates of cycling for transport (5-point scale) were generated (see Table 1).

Perceptions of the physical neighborhood environment were evaluated using the validated Assessing Levels of Physical Activity (ALPHA) environmental questionnaire [44, 45]. Ten items assessed participants' perceptions of their neighborhood environment using a 5-point scale ranging from totally disagree to totally agree (see Table 1).

Lastly, participants described their perceived *cycling skills and concerns and preferences* about cycling for transport using a five-point scale (1 = totally disagree; 5 = totally agree) inspired by a previously used questionnaire assessing basic cycling skills among children [46]. The construct cycling skills was created using the following two items: 'I think I can cycle well' and 'I find cycling on a straight line or with one hand easy' ($\alpha = 0.77$). Furthermore, four separate items assessed the preferences for cycling for transport and two assessed cycling concerns (see Table 1). For the construct 'I find a fluorescent vest or bicycle helmet important', a sum was made between: 'I find wearing a fluorescent vest or bicycle helmet important' and 'I wear a fluorescent vest or bicycle helmet' ($\alpha = 0.81$).

In the second part of the web-based questionnaire, a series of twelve randomly assigned choice tasks were presented to the participants using manipulated photographs to illustrate two possible routes to cycle along. For each choice task, participants had to choose which of the two depicted streets (manipulated photographs) they would prefer to cycle along to the house of their riend. This choice based conjoint (CBC) method [47] enabled examination of the characteristics influencing a street's appeal to cycle for transport. Each manipulated photograph was different in one to seven micro-environmental factors, which varied in two to six levels (see Fig. 1): traffic density (3 levels), vegetation (3 levels), speed limit (2 levels), speed bump (2 levels), type of cycle path (6 levels), maintenance (3 levels) and evenness of the cycle path (3 levels). The selection of these micro-environmental factors was based on existing literature [15, 48] and previous research with (non-) manipulated panoramic photographs [22, 49, 50] studying relationships between the environment and bicycle transport in the same age group. A detailed description of the manipulation process of the photographs and the choice tasks (good test-retest reliability > 70 %) [51] can be found elsewhere [30].

Analyses

SPSS Statistics 22 was used to calculate the descriptive characteristics of the total sample. Conjoint analyses do not accommodate 'typical' moderation analysis, but they do allow latent class analysis to distinguish various subgroups according to their environmental preferences (i.e. importance of micro-environmental factors) for cycling for transport based on the choice-based conjoint tasks [47, 52]. Latent class analysis is a model-based approach where the cluster criterion choice is less arbitrary than the standard cluster analysis and shows a higher construct and predictive validity [53, 54]. Participants were assigned to a subgroup based on the highest probability of belonging to a class and not in a discrete manner (all-or-nothing) as with cluster analysis [55]. A latent class analysis with 15 replications was conducted in Sawtooth Software (SSI Web version 8.3.8.) [52]. The number of subgroups was selected based on the model fit, the number of participants in each subgroup and the distribution in the importance of the micro-environmental factors [52]. In Additional file 1, a detailed overview of the different models for 2, 3 and 4 subgroups is given. Finally, three subgroups emerged from our analysis of which the model had an Akaike's Information Criterion (AIC) of 18755 and with a distribution of respectively 232, 598, and 1120 participants for each subgroup.

For each subgroup separately, Hierarchical Bayes (HB) estimation using dummy coding was executed to calculate

Table 1 Differences in socio-demographics, transport behavior, perceptions, cycling skills, opinions and psychosocial determinants between the subgroups

	Total sample	Subgroup 1	Subgroup 2	Subgroup 3	*p-value*
Segment Sizes (n)	n = 1950	n = 232	n = 598	n = 1120	
	100 %	11.9 %	30.7 %	57.4 %	
Socio-demographic characteristics					
Age (yrs, M ± SD)	54.3 ± 5.6	54.7 ± 5.5	54.1 ± 5.5	54.3 ± 5.7	0.328
Gender (% women)	56.8	47.8	60.9	56.5	0.003
SES (% tertiary education)	64.6	68.1	65.2	63.5	0.376
Area of residence (% village, town or rural)	59.4	54.3	56.7	62.0	0.025
BMI (kg/m^2)	25.2 ± 3.8	25.3 ± 4.2	25.2 ± 3.8	25.1 ± 3.7	0.732
Cohabitation (%)	86.1	81.9	85.2	87.4	0.064
Transport behavior					
Motorized transport min/wk (M ± SD)	215.1 ± 252.2	210.9 ± 268.9	201.9 ± 227.6	223.0 ± 260.8	0.258
Bicycle transport min/wk (M ± SD)	147.7 ± 171.1	178.8 ± 181.3[b,c]	135.1 ± 147.6[a]	148.0 ± 179.7[a]	0.005
Walk for transport min/wk (M ± SD)	63.5 ± 109.4	81.9 ± 136.3[b,c]	63.6 ± 110.0[a]	59.7 ± 102.4[a]	0.021
Bicycle leisure time min/wk (M ± SD)	120.3 ± 170.9	132.6 ± 174.2	114.5 ± 166.5	120.8 ± 172.5	0.397
Number of motorized vehicles (M ± SD)	1.6 ± 1.0	1.3 ± 0.9[b,c]	1.6 ± 1.0[a]	1.6 ± 1.0[a]	<0.001
Psychosocial determinants (5-point scale) (M ± SD)					
Habit (1 item)	3.4 ± 1.5	3.7 ± 1.5[b,c]	3.3 ± 1.5[a]	3.3 ± 1.5[a]	0.009
Social norm (4 items, α = 0.90)	2.9 ± 1.2	3.0 ± 1.3	2.9 ± 1.2	2.8 ± 1.1	0.178
Modeling (4 items, α = 0.55)	3.2 ± 0.8	3.3 ± 0.8[c]	3.2 ± 0.8	3.1 ± 0.8[a]	0.046
Social support (4 items, α = 0.81)	2.4 ± 1.0	2.6 ± 1.0	2.4 ± 1.0	2.4 ± 0.9	0.184
Self-efficacy (11 items, α = 0.92)	3.7 ± 0.9	3.9 ± 0.9[b,c]	3.7 ± 0.9[a]	3.7 ± 0.9[a]	0.006
Perceived benefits (10 items, α = 0.84)	4.0 ± 0.6	4.1 ± 0.6[b,c]	4.0 ± 0.6[a]	4.0 ± 0.6[a]	0.008
Perceived barriers (16 items, α = 0.90)	2.4 ± 0.7	2.3 ± 0.7[b,c]	2.4 ± 0.7[a]	2.4 ± 0.7[a]	0.014
Perceived neighborhood environment (5-point scale) (M ± SD)					
Amount of single unit houses	3.0 ± 1.5	2.7 ± 1.5[b,c]	3.0 ± 1.5[a]	3.0 ± 1.4[a]	0.003
Presence of shops in the neighborhood	3.3 ± 1.4	3.4 ± 1.3	3.2 ± 1.4	3.3 ± 1.3	0.168
Presence of a stop for public transport	4.3 ± 1.0	4.4 ± 1.0	4.3 ± 1.0	4.3 ± 1.0	0.464
Presence of recreational opportunities (park, pool)	3.3 ± 1.4	3.5 ± 1.4	3.3 ± 1.4	3.3 ± 1.4	0.134
Neighborhood traffic safety	3.2 ± 1.1	3.3 ± 1.1	3.1 ± 1.1	3.2 ± 1.1	0.168
Neighborhood safety of crime	2.2 ± 1.0	2.1 ± 1.0	2.1 ± 1.0	2.2 ± 1.0	0.391
Sufficient cycling infrastructure	3.1 ± 1.1	3.0 ± 1.1	3.1 ± 1.1	3.1 ± 1.1	0.551
Neighborhood social environment	3.4 ± 1.0	3.4 ± 1.0	3.4 ± 1.0	3.4 ± 1.0	0.559
Good maintenance of cycling infrastructure	2.9 ± 1.1	2.8 ± 1.1	2.9 ± 1.1	2.9 ± 1.1	0.415
Presence of vegetation	3.1 ± 1.1	3.1 ± 1.1	3.1 ± 1.1	3.1 ± 1.1	0.939
Cycling skills (5-point scale) (M ± SD)	4.1 ± 0.7	4.1 ± 0.8	4.1 ± 0.7	4.1 ± 0.7	0.963
Cycling concerns (5-point scale) (M ± SD)					
As a cyclist I feel vulnerable in the traffic	3.7 ± 0.9	3.9 ± 0.9[b]	3.7 ± 1.0[a,c]	3.7 ± 0.9[b]	0.007
Importance of a fluorescent vest or bicycle helmet	4.9 ± 1.8	4.9 ± 1.8	4.7 ± 1.8[c]	5.0 ± 1.8[b]	0.001
Cycling preferences (5-point scale) (M ± SD)					
I prefer the safest cycling route	3.8 ± 0.9	3.9 ± 1.0[b]	3.7 ± 0.9[a,c]	3.9 ± 0.9[b]	0.002
I prefer the shortest cycling route	3.2 ± 1.0	3.2 ± 1.0	3.2 ± 1.0	3.2 ± 0.9	0.670
I prefer the most beautiful cycling route	3.6 ± 0.9	3.6 ± 0.9	3.6 ± 0.9	3.6 ± 0.9	0.215
I prefer to cycle alone	3.6 ± 1.0	3.7 ± 1.0[c]	3.7 ± 1.0[c]	3.5 ± 1.1[a,b]	0.003

[a]signficiant difference with subgroup 1
[b]significant difference with subgroup 2
[c]significant difference with subgroup 3

Fig. 1 Examples of manipulated photographs, differing in seven micro-environmental factors with a maximum of 6 level. These examples ranging from the least separated cycle path (first photograph) to the most separated cycle path (last photograph) and randomly differed in the other micro-environmental factors

part-worth utilities and importances [56]. The average relative importance represents the importance of each environmental factor on the preference for a street. These average importances are calculated by the difference in average part-worth utilities between the most and least preferred levels of a factor [47]. The average part-worth utilities symbolize the degree of preference given to a particular level of an environmental factor and can be interpreted similarly to a regression coefficient [47]. The greater the importance of an environmental factor, the greater the impact of that factor has on the choice. Furthermore, chi-square analyses (categorical variables) and MANOVAs (continuous variables) were performed in SPSS Statistics 22 to examine the significant differences in characteristics between the various subgroups. For all analyses, statistical significance was set at $p < 0.05$.

Ethics, consent and permissions

The participants automatically gave their informed consent by filling in the online questionnaire. The study was approved by the Ethics Committee of Ghent University Hospital (B670201318588).

Results

Descriptive statistics of the total sample

The total sample consisted of 1950 participants aged between 45 and 65 years, 56.8 % were women, 64.6 % had undertaken tertiary education (college, university or postgraduate) and 21.7 % did not cycle for transport in a usual week. A detailed description of the total sample can be found in Table 1.

Subgroup analysis – Differences in relative importance and part-worth utilities

Latent class analysis revealed three subgroups with homogenous preferences for the micro-environmental factors affecting the street's appeal to cycle for transport. Table 2 presents the relative importance of each environmental factor within the total sample and the three subgroups. The corresponding part-worth utilities can be found in Additional file 2. Results indicated cycle path type was the most important micro-environmental factor for all participants. However, the importance of the other micro-environmental factors influencing the street's appeal to cycle for transport varied across individuals, resulting in three subgroups.

Subgroup 1 consisted of 232 individuals. Following type of cycle path (42.7 %), this group attached most importance to stricter speed limits with an importance of 25.7 %. Next, the following three micro-environmental factors were less important than speed limit but did not significantly differ from each other: evenness of the cycle path (7.5 %), traffic density (7.5 %) and vegetation (7.3 %). Maintenance (5.1 %) and speedbumps (4.2 %) were the least important factors.

Subgroup 2 included 598 respondents and had a similar relative importance for type of cycle path (39.4 %) to subgroup 1. Following type of cycle path, traffic density (14.9 %), evenness of the cycle path (14.1 %) and maintenance (13.7 %) were the most important environmental factors. The importance of these environmental factors did not differ significantly. Vegetation (10.7 %) and speed limits (4.1 %) were significantly less important. Finally, speed bump had the lowest importance (3.1 %).

Subgroup 3 represented the largest group with 1120 participants and attached relatively more importance to type of cycle path (71.9 %) compared to both other subgroups. The other micro-environmental factors were significantly less important: speed limits (6.9 %), vegetation (5.7 %), evenness of the cycle path (5.3 %), maintenance (4.5 %), traffic density (3.4 %) and speed bump (2.4 %).

Subgroup analysis – Differences in characteristics between the three subgroups

Descriptive characteristics and significant differences in socio-demographics, transport behavior, psychosocial determinants of cycling for transport, neighborhood environmental perceptions, cycling skills, concerns and preferences between the three subgroups can be found in Table 1. A significant difference was found for gender with subgroup 2 having a larger proportion of women. Area of residence also differed significantly between the three subgroups: 54.3 % of the participants of subgroup 1 lived in a village, town or rural area, compared to 56.7 % of subgroup 2 and 62.0 % of subgroup 3. No significant differences for age, SES, BMI and cohabitation were found between the three subgroups.

Results from the MANOVAs showed that minutes of cycling for transport per week, minutes of walking for transport per week and number of motorized vehicles were significantly different between subgroup 1 and the two other subgroups. Participants of subgroup 1 cycled and walked significantly more for transport and owned significantly less motorized vehicles compared to subgroup 2 or subgroup 3 (no significant difference between subgroup 2 and 3). No significant differences between the three subgroups were found for minutes of motorized transport and bicycle leisure time per week.

Differences in psychosocial determinants between the three subgroups were found for habit, modeling, self-efficacy, perceived benefits and perceived barriers.

Table 2 The relative importances of each environmental factor for the total sample and within each subgroup

	Total sample (*n* = 1950)[a]	Group 1 (*n* = 232)[a]	Group 2 (*n* = 598)[a]	Group 3 (*n* = 1120)[a]
Type of cycle path	58.47 ± 16.96	42.67 ± 5.12	39.44 ± 9.94	71.90 ± 4.10
Speed limit	8.29 ± 7.11	25.73 ± 3.95	4.10 ± 2.91	6.91 ± 2.45
Evenness of the cycle path	8.23 ± 5.96	7.50 ± 3.47	14.05 ± 7.22	5.27 ± 2.11
Traffic density	7.41 ± 7.45	7.47 ± 4.24	14.93 ± 9.01	3.38 ± 1.75
Vegetation	7.44 ± 5.31	7.33 ± 2.63	10.70 ± 7.72	5.72 ± 2.69
Maintenance	7.37 ± 6.20	5.12 ± 2.92	13.69 ± 7.30	4.46 ± 2.44
Speedbump	2.79 ± 2.23	4.17 ± 3.05	3.09 ± 2.41	2.35 ± 1.73

[a]Average relative importances % (M + SD)

Subgroup 1 showed significantly higher scores on habit, self-efficacy, perceived benefits and a lower score on perceived barriers compared to subgroup 2 and subgroup 3. Additionally, subgroup 1 perceived significantly more modeling compared to subgroup 3. No significant differences were found for social norm and social support between the three subgroups.

There was only one significant difference in neighborhood environmental perceptions between the subgroups. Subgroup 1 perceived significantly less single unit houses in the neighborhood compared to subgroup 2 and subgroup 3.

Significant differences in cycling concerns and preferences were found for "as a cyclist I feel vulnerable in the traffic" and for "I prefer the safest cycling route". Subgroup 2 reported lower preference for the safest route and felt less vulnerable in traffic compared to both other subgroups. Furthermore, subgroup 3 reported a higher preference for cycling alone in comparison to subgroup 1 and 2. Finally, subgroup 3 assigned more importance to wearing a fluorescent vest or bicycle helmet than subgroup 2. No significant differences were found between the three subgroups for cycling skills and the other cycling preferences (preferring the shortest or most beautiful cycling route).

Discussion

To target at risk subgroups regarding cycling for transport, the different needs of particular subpopulations need to be identified. With latent class analysis, three subgroups of the middle-aged adult population could be distinguished. These subgroups had similar preferences for micro-environmental characteristics based on the responses given to a series of choice tasks depicting potential cycling routes. Previously, we showed that the provision of cycle paths separated from motorized traffic was the best strategy to increase a street's appeal to cycle for transport in a population sample [30]. Results from the present study indicated that type of cycle path remained the most important environmental factor for all three subgroups, but significant differences in preferences for the other micro-environmental factors were observed.

The first subgroup distinguished itself from the other subgroups by awarding relatively more importance to restrictions in speed limits and being the most physically active group compared to both other subgroups. It had significantly higher rates of walking and cycling for transport, owned significantly less motorized vehicles and perceived less single unit houses in their neighborhood environment. Additionally, subgroup 1 was characterized by a higher proportion of men and those living in urban places. Furthermore, this group reported more favorable values on psychosocial determinants of cycling for transport compared to both other subgroups, and perceived more modeling from partner, child (ren), friends or colleagues compared to subgroup 3. A possible explanation for the great importance regular cyclists attended to stricter speed limits, might be that they are more often confronted with the negative consequences of fast moving traffic (e.g. dangerous situations, noise, odor pollution) compared to someone who does not cycle regularly. Consequently, the presence of aesthetic and comfort-related environmental factors may be much less important for this subgroup, since traffic-related environmental factors predominate. Additionally, previous studies have found cycling for transport can be increased by increasing traffic safety through reducing the speed of motorized traffic [57, 58] and by increasing the speed of cyclists compared to the speed of cars [48, 59].

The second subgroup attached relatively more importance to traffic density, evenness of the cycle path, maintenance and vegetation. This subgroup consisted of the highest percentage of women, felt significantly less vulnerable in traffic and did not prefer the safest cycling route compared to both other subgroups. Since this subgroup cycled less than subgroup 1, it is important to know which environmental changes might increase the street's appeal to encourage cycling for transport. A study of Twaddle et al. (2010) observed that women were more likely to be occasional cyclists, while men were more likely to be regular cyclists, and suggested if women's cycling needs were tackled the number of cyclists could be increased [36]. Along with the finding that cycle path type also was most important in this subgroup, it seems that they mainly attached importance to traffic density, evenness of the cycle path, vegetation and maintenance, rather than speed limit or the presence of a speed bump. Consequently, interventions focusing on these factors, might offer a solution to increase the number or female cyclists. A possible explanation for these findings is that women attach more importance to the enjoyable aspect of cycling for transport than men [32, 36, 60].

Subgroup 3, representing the majority of all respondents, paid relatively more importance to cycle path type compared to both other subgroups and attached less importance to all other micro-environmental factors. This subgroup distinguished itself from subgroup 2 in that it attached more importance to wearing a fluorescent vest or a helmet. Furthermore, this group showed the least preference to cycle alone and contained the highest percentage of inhabitants living in a rural environment, village or town of all groups. The higher importance score for cycle path type in subgroup 3 might be explained by their lower preference for cycling alone than both other subgroups, and therefore might give more attention to features enabling cycling with other people side by side. Furthermore, in less-urbanized environments speed limits are often less strict compared to urban environments [61], and consequently it might be that people living in a rural environment attach more importance to being well separated from the fast-moving traffic.

In conclusion, it can be assumed that subgroup 2 and subgroup 3 could be seen as at risk populations (e.g. together 88.1 % of the sample) since they cycled significantly less in comparison to subgroup 1. Cycle path type appeared to be by far the most important environmental factor in comparison to the other micro-environmental factors, and certainly for subgroup 3, representing the majority of the respondents. The most preferred cycle path type was a cycle path separated from motorized traffic by a hedge (hedge > curb > white lines) and might be further improved by a separation from the sidewalk by color [30]. However, the effect of separation from the sidewalk was much less pronounced than separation from motorized traffic. This is in line with the results from Winters et al. (2010) who found consistent results supporting the importance of separated cycle paths from traffic independent of the type of cyclist (regular, frequent, occasional and potential cyclists) [62]. In addition, a stated preference study indicated that cycling facilities separated from motorized traffic were the most preferred form of cycling infrastructure, regardless of cycling confidence [63]. Therefore, we can conclude that no tailoring is required for an intervention that focuses on better separated cycle paths, since it is by far the most important factor for all subgroups. Apart from this result, in situations when a good separated cycle path is already provided or cannot be provided, no clear difference was found between the relative importance of the other micro-environmental factors for subgroup 2 and 3. Broadly speaking, all other factors (i.e. traffic density, evenness of the cycle path, maintenance, vegetation and speed limits) seem similarly important (i.e. there was no consistent pattern of difference in importances) and that providing a speed bump will have the least impact on the street's appeal to cycle for transport. Consequently, results from our study can advise developers of environmental interventions with the purpose of encouraging cycling for transport that tailored interventions in this context are not needed. Nevertheless, future research in real life settings is warranted to investigate if changes to micro-environmental factors are associated with changes in actual cycling behavior among particular subgroups.

A strength of the current study is the use of latent class analysis to investigate whether specific subgroups exist based on similarities in micro-environmental preferences to cycle for transport. Latent class analysis is a model-based clustering approach which means that the cluster criterion choice is less arbitrary than the standard cluster analysis and shows a higher construct and predictive validity [53, 54, 64]. Furthermore, a large sample of 1950 middle-aged adults could be reached by distributing the research through the web which allowed comparable numbers in each subgroup. Nevertheless, this web-based sampling method has also some limitations such as the overrepresentation of certain individuals (e.g. 64.6 % had a tertiary education and 78.3 % did cycle for transport in a usual week) in comparison to the statistics of the Flemish population where 28.1 % has a tertiary education [65] and around 45 % indicate using their bicycle weekly [66]. Therefore, caution is needed when generalizing the present results to the entire middle-aged Flemish population. Furthermore, the most important limitation is that the current study did not assess effects on actual cycling behavior, but only the street's appeal to cycle for transport. Consequently, these findings need to be confirmed by on-site research.

Conclusions

Although latent class analysis revealed three different subgroups in the middle-aged adult population based on their environmental preferences, results indicated that cycle path type (i.e. a good separated cycle path) is the most important environmental factor for all participants and certainly for individuals who did not cycle for transport. Furthermore, only negligible differences were found between the relative importance of the other micro-environmental factors (i.e. traffic density, evenness of the cycle path, maintenance, vegetation and speed limits) and that providing a speed bump has the least impact on a street's appeal to cycle for transport. This suggests that tailored environmental interventions are not needed in this research context.

Additional files

Additional file 1: A detailed overview of the different models for 2, 3 and 4 subgroups. (PDF 128 kb)

Additional file 2: The part worth utilities of the environmental levels of each factor separately for each subgroup. (PDF 53 kb)

Abbreviation

PA, physical activity

Acknowledgements

The authors would like to thank Daphne Reinehr for developing the photographs.

Funding

AG (grant number: GA11111N), JVC (grant number: 11NO313N), and DVD (grant number: FWO12/PDO/158) are supported by a grant from the Fund for Scientific Research Flanders (FWO).

Availability of data and materials

Additional data are available upon request.

Authors' contribution

LM, AG and JVC developed the photograph material and research protocol, in correspondence with NVdW, DVD, BD and IDB. LM, AG and JVC conducted the data collection. LM performed the data analysis and drafted the manuscript, supervised by DVD. All other co-authors critically reviewed and revised versions of the manuscript and each of them read and approved the final manuscript.

Competing interests
The authors declare that they have no competing interests.

Consent for publication
This study contains only aggregated data and there are no details on individuals reported within the manuscript.

Ethics approval and consent to participate
The participants automatically gave their informed consent by filling in the online questionnaire. The study was approved by the Ethics Committee of Ghent University Hospital (B670201318588).

Author details
[1]Department of Movement and Sport Sciences, Faculty of Medicine and Health Sciences, Ghent University, Watersportlaan 2, B-9000 Ghent, Belgium. [2]Department of Public Health, Faculty of Medicine and Health Sciences, Ghent University, De Pintelaan 185, 4k3, B-9000 Ghent, Belgium. [3]Department of Human Biometry and Biomechanics, Faculty of Physical Education and Physical Therapy, Vrije Universiteit Brussel, Pleinlaan 2, B-1050 Brussels, Belgium. [4]Research Foundation Flanders (FWO), Egmontstraat 5, 1000 Brussels, Belgium. [5]Department of Geography, Faculty of Sciences, Ghent University, Krijgslaan 281, S8, B-9000 Ghent, Belgium.

Received: 10 February 2016 Accepted: 6 August 2016
Published online: 12 August 2016

References

1. Wanner M, Götschi T, Martin–Diener E, Kahlmeier S, Martin BW. Active transport, physical activity, and body weight in adults: a systematic review. Am J Prev Med. 2012;42:493–502.
2. Kelly P, Kahlmeier S, Götschi T, Orsini N, Richards J, Roberts N, Scarborough P, Foster C. Systematic review and meta-analysis of reduction in all-cause mortality from walking and cycling and shape of dose response relationship. Int J Behav Nutr Physical Activity. 2014;11:132.
3. World health organization: Interventions on diet and physical activity: what works (summary report). 2009. http://www.who.int/dietphysicalactivity/summary-report-09.pdf.
4. Rojas Rueda D, De Nazelle A, Tainio M, Nieuwenhuijsen MJ. The health risks and benefits of cycling in urban environments compared with car use: health impact assessment study. BMJ. 2011;343:d4521.
5. de Hartog JJ, Boogaard H, Nijland H, Hoek G. Do the health benefits of cycling outweigh the risks? Environ Health Perspect. 2010;118:1109–16.
6. Oja P, Titze S, Bauman A, De Geus B, Krenn P, Reger-Nash B, Kohlberger T. Health benefits of cycling: a systematic review. Scand J M & Sci Sports. 2011;21(4):496-509.
7. Rissel CE. Active travel: a climate change mitigation strategy with co-benefits for health. New South Wales public Health Bull. 2009;20:10–3.
8. Woodcock J, Edwards P, Tonne C, Armstrong BG, Ashiru O, Banister D, Beevers S, Chalabi Z, Chowdhury Z, Cohen A, Franco OH, Haines A, Hickman R, Lindsay G, Mittal I, Mohan D, Tiwari G, Woodward A, Roberts I. Public health benefits of strategies to reduce greenhouse-gas emissions: urban land transport. Lancet. 2009;374:1930–43.
9. Pucher J, Buehler R, Bassett DR, Dannenberg AL. Walking and cycling to health: a comparative analysis of city, state, and international data. Am J Public Health. 2010;100:1986–92.
10. Rabl A, de Nazelle A. Benefits of shift from car to active transport. Transp Policy. 2012;19:121–31.
11. Götschi T, Garrard J, Giles-Corti B. Cycling as a Part of Daily Life: A Review of Health Perspectives. Transp Rev. 2015;1647(October):1–27.
12. Rudinger G, Donaghy K, Poppelreuter S. Societal trends, mobility behaviour and sustainable transport in Europe and North America. Eur J Transport and Infrastructure Res. 2006;6(1):61-76.
13. Vlaamse overheid Departement Mobiliteit en Openbare Werken.: Onderzoek Verplaatsingsgedrag Vlaanderen 4. Brussel; Mobiel Vlaanderen.
14. Sallis JF, Cervero RB, Ascher W, Henderson KA, Kraft MK, Kerr J. An ecological approach to creating active living communities. Annu Rev Public Health. 2006;27:297–322.
15. Van Holle V, Deforche B, Van Cauwenberg J, Goubert L, Maes L, Van de Weghe N, De Bourdeaudhuij I. Relationship between the physical environment and different domains of physical activity in European adults: a systematic review. BMC Public Health. 2012;12:807.
16. Swinburn B, Egger G, Raza F: Dissecting Obesogenic Environments: The Development and Application of a Framework for Identifying and Prioritizing Environmental Interventions for Obesity. Preventive Med. 1999;29(6):563-570.
17. Cain KL, Millstein RA, Sallis JF, Conway TL, Gavand KA, Frank LD, Saelens BE, Geremia CM, Chapman J, Adams MA, Glanz K, King AC. Contribution of streetscape audits to explanation of physical activity in four age groups based on the Microscale Audit of Pedestrian Streetscapes (MAPS). Soc Sci Med (1982). 2014;116:82–92.
18. Foster CE, Panter JR, Wareham NJ. Assessing the impact of road traffic on cycling for leisure and cycling to work. Int J Behav Nutr Physical Activity. 2011;8:61.
19. Wendel-Vos W, Droomers M, Kremers S, Brug J, van Lenthe F. Potential environmental determinants of physical activity in adults: a systematic review. Obesity Rev Off J Int Assoc Study Obesity. 2007;8:425–40.
20. McCormack G, Giles-Corti B, Lange A, Smith T, Martin K, Pikora TJ. An update of recent evidence of the relationship between objective and self-report measures of the physical environment and physical activity behaviours. J Sci Med Sport/Sports Med Aust. 2004;7(1 Suppl):81–92.
21. Bauman AE, Reis RS, Sallis JF, Wells JC, Loos RJF, Martin BW. Correlates of physical activity: why are some people physically active and others not? Lancet. 2012;380:258–71.
22. Van Holle V, Van Cauwenberg J, Deforche B, Goubert L, Maes L, Nasar J, Van de Weghe N, Salmon J, De Bourdeaudhuij I. Environmental invitingness for transport-related cycling in middle-aged adults: A proof of concept study using photographs. Transp Res A Policy Pract. 2014;69:432–46.
23. Fraser SDS, Lock K. Cycling for transport and public health: a systematic review of the effect of the environment on cycling. Eur J Pub Health. 2010;21:738–43.
24. Sallis JF, Bowles HR, Bauman A, Ainsworth BE, Bull FC, Craig CL, Sjöström M, De Bourdeaudhuij I, Lefevre J, Matsudo V, Matsudo S, Macfarlane DJ, Gomez LF, Inoue S, Murase N, Volbekiene V, McLean G, Carr H, Heggebo LK, Tomten H, Bergman P. Neighborhood environments and physical activity among adults in 11 countries. Am J Prev Med. 2009;36:484–90.
25. McCormack GR, Shiell A. In search of causality: a systematic review of the relationship between the built environment and physical activity among adults. Int J Behav Nutr Physical Activity. 2011;8:125.
26. Ferdinand AO, Sen B, Rahurkar S, Engler S, Menachemi N. The Relationship Between Built Environments and Physical Activity: a systematic review. Am J Public Health. 2012;102(10):e7–e13.
27. Jongeneel-Grimen B, Busschers W, Droomers M, van Oers HAM, Stronks K, Kunst AE. Change in neighborhood traffic safety: does it matter in terms of physical activity? PLoS One. 2013;8:e62525.
28. Nasar JL. Assessing perceptions of environments for active living. Am J Prev Med. 2008;34:357–63.
29. Wells NM, Ashdown SP, Davies EHS, Cowett FD, Yang Y. Environment, Design, and Obesity: Opportunities for Interdisciplinary Collaborative Research. Environ Behav. 2007;39:6–33.
30. Mertens L, Van Dyck D, Ghekiere A, De Bourdeaudhuij I, Deforche B, Van de Weghe N, Van Cauwenberg J. Which environmental factors most strongly influence street's appeal for bicycle transport among adults? A conjoint study using manipulated photographs. J Health Geographics. 2016 (in press).
31. Giles-Corti B, King AC. Creating active environments across the life course : "thinking outside the square". Br J Sports Med. 2009;43:109–14.
32. Heesch KC, Sahlqvist S, Garrard J. Gender differences in recreational and transport cycling: a cross-sectional mixed-methods comparison of cycling patterns, motivators, and constraints. Int Jo Behav Nutr Physical Activity. 2012;9:106.
33. Garrard J, Rose G, Lo SK. Promoting transportation cycling for women: the role of bicycle infrastructure. Prev Med. 2008;46:55–9.
34. Sallis JF, Owen N, Fisher EB: Ecological models of health behavior. In In health behavior and health education: theory, research and practice. Edited by Glanz K, Rimer B, Viswanath K. San Fransico; Jossey-Bass. 2008:465–486
35. Sallis JF, Conway TL, Dillon LI, Frank LD, Adams MA, Cain KL, Saelens BE. Environmental and demographic correlates of bicycling. Prev Med. 2013;57:456–60.
36. Twaddle H, Hall F, Bracic B. Latent Bicycle Commuting Demand and Effects of Gender on Commuter Cycling and Accident Rates. Transport Res Record J Transport Res Board. 2010;2190(October 2015):28–36.

37. Aldred R, Woodcock J, Goodman A. Does More Cycling Mean More Diversity in Cycling? Transp Rev. 2015;1647(October):1–17.
38. Gatersleben B, Appleton K. Contemplating cycling to work : attitudes and perceptions in different stages of change. Transp Res A Policy Pract. 2007;41(May):302–12.
39. IPAQ: International physical activity questionnaire (October 2002). Long last 7 days self-administered format. 2002, 71(October). http://www.sdp.univ.fvg.it/sites/default/files/IPAQ_English_self-admin_long.pdf.
40. Craig CL, Marshall AL, Sjostrom M, Bauman AE, Booth ML, Ainsworth BE, Pratt M, Ekelund U, Yngve A, Sallis JF, Oja P. International physical activity questionnaire: 12-country reliability and validity. Med Sci Sports Exerc. 2003;35:1381–95.
41. De Bourdeaudhuij I, Sallis J. Relative Contribution of Psychosocial Variables to the Explanation of Physical Activity in Three Population-Based Adult Samples. Prev Med. 2002;34:279–88.
42. De Geus B, De Bourdeaudhuij I, Jannes C, Meeusen R. Psychosocial and environmental factors associated with cycling for transport among a working population. Health Educ Res. 2008;23:697–708.
43. Verhoeven H, Van Cauwenberg J, Clarys P, De Bourdeaudhuij I, De Geus B, Vandelanotte C, Van Dyck D, Deforche B. Psychosocial and environmental correlates of walking, cycling, public transport and passive transport to various destinations in Flemish older adolescents. PLoS One. 2016;11(1):e0147128. http://dx.doi.org/10.1371/journal.pone.0147128
44. Spittaels H, Foster C, Oppert J-M, Rutter H, Oja P, Sjöström M, De Bourdeaudhuij I. Assessment of environmental correlates of physical activity: development of a European questionnaire. Int J Behav Nutr Physical Activity. 2009;6:39.
45. Spittaels H, Verloigne M, Gidlow C, Gloanec J, Titze S, Foster C, Oppert M, Rutter H, Oja P, Sjöström M, De Bourdeaudhuij I. Measuring physical activity-related environmental factors: reliability and predictive validity of the European environmental questionnaire ALPHA. Int J Behavioral Nutr Phys Act. 2010;7(48).
46. Ducheyne F, De BI, Lenoir M, Cardon G. Test-Retest Reliability and Validity of a Child and Parental Questionnaire on Specific Determinants of Cycling to School. Pediatr Exerc Sci. 2012;24(2):289–311.
47. Orme BK. Getting Started with Conjoint Analysis: Strategies for Product Design and Pricing Research. Madison, WI: Resarch publishers; 2009.
48. Pucher J, Buehler R. Making Cycling Irresistible: Lessons from The Netherlands, Denmark and Germany. Transp Rev. 2008;28:495–528.
49. Mertens L, Van Holle V, De Bourdeaudhuij I, Deforche B, Salmon J, Nasar J, Van de Weghe N, Van Dyck D, Van Cauwenberg J. The effect of changing micro-scale physical environmental factors on an environment's invitingness for transportation cycling in adults: an exploratory study using manipulated photographs. Int J Behav Nutr Physical Activity. 2014;11:88.
50. Mertens L, Van Cauwenberg J, Ghekiere A, Van Holle V, De Bourdeaudhuij I, Deforche B, Nasar J, Van de Weghe N, Van Dyck D. Does the Effect of Micro-Environmental Factors on a Street's Appeal for Adults' Bicycle Transport Vary across Different Macro-Environments? An Experimental Study. PloS one. 2015;10:e0136715.
51. Multon KD: Interrater Reliability. Encylopedia Res Design 2012:627–629. Edited by: Neil J. Salkind. doi: http://dx.doi.org/10.4135/9781412961288.n194 Print ISBN: 9781412961271 | Online ISBN: 9781412961288. http://methods.sagepub.com/reference/encyc-of-research-design/n194.xml.
52. Orme BK: Latent Class v4.5. Software for Latent Class Estimation for CBC Data. 2012. https://www.sawtoothsoftware.com/download/techpap/lclass_manual.pdf.
53. Magidson J, Vermunt JK: Latent class models for clustering: A comparison with K-means. Can J Marketing Res. 2002;20:37-44.
54. Notelaers G, Einarsen S, De Witte H, Vermunt JK. Measuring exposure to bullying at work: The validity and advantages of the latent class cluster approach. Work Stress. 2006;20:289–302.
55. Software S: The CBC Latent Class Technical Paper. Technical Paper Series. 2004;98382(Version 3): 1-21
56. Allenby GM, Arora N, Ginter JL: On the Heterogeneity of Demand. J Marketing Res. 1998;35:384–389.
57. Bauman A, Rissel C, Garrard J, Ker I, Speidel R, Fishman E. Cycling : getting Australia moving–barriers, facilitators and interventions to get more Australians physically active through cycling. Cycling Promotion Fund, Melbourne. 2008;593–601.
58. Owen N, De De Bourdeaudhuij I, Sugiyama T, Leslie E, Cerin E, Van Dyck D, Bauman A. Bicycle use for transport in an Australian and a Belgian city: associations with built-environment attributes. J Urban Health Bull New York Acad Med. 2010;87:189–98.
59. Pucher J, Dill J, Handy S. Infrastructure, programs, and policies to increase bicycling: an international review. Prev Med. 2010;50 Suppl 1:S106–25.
60. Schintler L, Root A, Button K. Women's Travel Patterns and the Environment: An Agenda for Research. Trans Res Record J Trans Res Board. 2000;1726(1): 33-40.
61. Vandenbulcke G, Thomas I, de Geus B, Degraeuwe B, Torfs R, Meeusen R, Int Panis L. Mapping bicycle use and the risk of accidents for commuters who cycle to work in Belgium. Transp Policy. 2009;16:77–87.
62. Winters M, Davidson G, Kao D, Teschke K. Motivators and deterrents of bicycling: comparing influences on decisions to ride. Transportation. 2010;38:153–68.
63. Caulfield B, Brick E, Thérèse O. Determining bicycle infrastructure preferences – A case study of Dublin. Transportation Res Part D. 2012;17:413–7.
64. Vermunt JK, Magidson J. Latent class cluster analysis. 2000:1–21. http://members.home.nl/jeroenvermunt/hagenaars2002b.pdf.
65. Statistics Belgium [http://statbel.fgov.be/]
66. Janssens D, Declercq K, Wets G. Onderzoek Verplaatsingsgedrag Vlaanderen 4.5 (2012-2013). Instituur voor Mobiliteit. 2014:1-116.

Additional file 1

Table 1.1. Summary of best replications

Groups	Log-likelihood	Pct Cert	AIC	CAIC	BIC	ABIC	Chi-Square	Relative Chi-Square
2	-9459	41,68	18980	19260	19229	19131	13522	436
3	-9331	42,47	18755	19181	19134	18985	13778	293
4	-9245	43,00	18617	19187	19124	18924	13949	221

Table 1.2. Tabulation with the comparison between different groups

Tabulation of 2 group vs. 3 group solutions

	1	2	3	Total
1	179	593	38	810
2	53	5	1082	1140
Total	232	598	1120	1950

Tabulation of 3 group vs. 4 group solutions

	1	2	3	4	Total
1	40	2	2	188	232
2	362	0	222	14	598
3	239	868	0	13	1120
Total	641	870	224	215	1950

Table 1.3. The distribution in attribute importances for 2, 3 and 4 groups

Attribute Importances (%) 2 groups		
Type of cycle path	42,5	73,8
Speed limits	8,8	8,4
Speed bump	1,4	2,0
Vegetation	9,6	5,2
Evenness of cycle path	12,5	4,8
Maintenance	11,9	4,1
Traffic density	13,2	1,9

The average maximum membership probability is 0.89072.

Attribute Importances (%) 3 groups			
Type of cycle path	47,8	41,41	74,3
Speed limits	24,5	2,9	6,9
Speed bump	3,6	0,7	1,9
Vegetation	7,5	10,7	5,5
Evenness of cycle path	5,7	15,1	5,1
Maintenance	4,0	14,4	4,3
Traffic density	6,8	14,8	2,0

The average maximum membership probability is 0.84138.

Attribute Importances (%) 4 groups				
Type of cycle path	60,8	75,81102	24,45952	48,10116
Speed limits	3,8	8,26820	3,75293	25,73029
Speed bump	1,0	2,0	0,6	3,8
Vegetation	8,8	4,6	11,7	7,2
Evenness of cycle path	10,9	4,2	17,7	3,9
Maintenance	8,1	3,7	19,5	4,4
Traffic density	6,5	1,5	22,3	6,9

The average maximum membership probability is 0.77612.

Additional file 2

Table 2.1: The part worth utilities of the environmental levels of each factor separately for each subgroup.

	Subgroup 1			Subgroup 2			Subgroup 3		
	MEAN	95% CI-	95% CI+	MEAN	95% CI-	95% CI+	MEAN	95% CI-	95% CI+
Type of cycle path									
C1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
C2	6.05	5.88	6.22	7.44	7.32	7.56	10.98	10.89	11.06
C3	9.10	8.93	9.26	8.34	8.25	8.43	16.09	16.04	16.15
C4	13.27	13.01	13.53	8.83	8.71	8.95	24.72	24.64	24.80
C5	10.51	10.37	10.65	8.68	8.58	8.79	18.50	18.46	18.55
C6	12.83	12.62	13.03	9.25	9.02	9.48	25.73	25.68	25.78
Speed limits									
50 km/h	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
30 km/h	8.18	8.05	8.32	0.64	0.56	0.73	2.50	2.44	2.55
Speedbump									
absent	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
present	1.17	1.01	1.32	0.15	0.08	0.22	0.60	0.55	0.65
Vegetation									
no trees	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
two trees	2.10	1.98	2.23	1.63	1.55	1.72	1.23	1.19	1.27
four trees	1.35	1.17	1.52	2.18	2.01	2.34	1.94	1.87	2.01
Evenness of the cycle path									
very uneven	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
moderately uneven	-0.74	-0.94	-0.54	0.96	0.83	1.09	0.62	0.57	0.66
even	0.90	0.62	1.18	3.37	3.21	3.52	1.76	1.71	1.82
Maintenance									
bad maintenance	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
moderate maintenance	0.57	0.39	0.74	2.24	2.16	2.33	0.90	0.87	0.94
good maintenance	0.73	0.57	0.88	3.20	3.03	3.38	1.41	1.35	1.48
Traffic density									
4 cars + truck	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3 cars	1.15	0.93	1.37	2.23	2.12	2.33	0.12	0.08	0.16
1 car	1.69	1.44	1.95	3.45	3.25	3.65	0.78	0.72	0.84

C1: no cycle path; C2: cycle path separated from traffic by marked white lines; C3: cycle path separated from traffic with a curb, not separated from walking path by color; C4: cycle path separated from traffic with a hedge, not separated from walking path by color; C5: cycle path separated from traffic with a curb, separated from walking path by color; C6: cycle path separated from traffic with a hedge, separated from walking path by color.

Part 3. General discussion

The overall aim of this PhD thesis was to get a better insight in how the physical environment, especially the micro-environment, influences cycling for transport among the adult population, and to verify the interplay between socio-demographics, psychosocial and physical environmental factors to explain cycling for transport.

In this general discussion, an overview of the main findings of the different research studies will first be given, subdivided in the two main chapters. Furthermore, an overall reflection of our study findings in relation to the existing literature is provided in an 'overall discussion and conclusions' section. Next, the strengths and limitations of this PhD research are discussed, as well as some recommendations for future research. Finally, the practical implications of this research and a concise overall conclusion of this PhD are provided.

1 Summary of the main research findings

Chapter 1 – Cross-sectional studies: the SPOTLIGHT project

The *first aim* of this thesis was to describe cross-sectional associations between the physical environment and adult's cycling for transport across five European urban regions, along with the analysis of the moderating role of sociodemographic variables such as age, gender, socio-economic status (SES) and country on this association (*chapter 1*).

A first study (*chapter 1.1*) determined t**he perceived environmental correlates of cycling for transport across five European urban regions** using a questionnaire within the SPOTLIGHT-project. Results showed that respondents living in neighborhoods with more air pollution, a larger amount of choices between different routes to walk or cycle, lower traffic speed, or neighborhoods perceived as less pleasant to walk or cycle in, cycled more for transport.

A second study (*chapter 1.2*) examined the **objective environmental correlates of cycling for transport across five European urban regions** using the SPOTLIGHT virtual audit tool. Results of this study indicated that participants who live in a neighborhood with more streets where the speed limit is ≤ 30 km/h, more parked cars that form an obstacle on the road, or more bicycle lanes cycled more for transport.

Both for the perceived environment (chapter 1.1) and the objective physical environment (chapter 1.2), only few significant moderating effects of sociodemographic factors were found. These results suggest that despite the significant differences in cycling levels according to gender, age, education and region, generic environmental interventions could benefit most population subgroups, even across urban regions in the five different investigated countries (Belgium, the Netherlands, Hungary, France, and UK).

Chapter 2 – Experimental studies: photograph experiments

The second chapter of this thesis examined the associations between the physical environment and the adults' street's appeal to cycle for transport using manipulated photographs.

The *second aim* was intended to determine the **critical micro-environmental correlates** of cycling for transport and to identify **the relative importance** of these micro-environmental factors. Results from the pilot study (*chapter 2.1*) indicated that all included micro-environmental factors (i.e. evenness of the cycle path, vegetation, separation with motorized traffic, cycle path width, motorized traffic, speed bump, and general upkeep) except for separation with sidewalk by means of bollards, were associated with the street's appeal to cycle for transport. Based on this proof of concept, a 'large-scale' conjoint-study (*chapter 2.3*) was performed to create an **order of importance** within the micro-environmental factors. Results indicated that all manipulated micro-environmental factors were significantly associated with the street's appeal to cycle for transport, but significant differences in relative importance were found. Type of cycle path was by far the most important micro-environmental factor (average importance= 60.4%) related to the street's appeal to cycle for transport among middle-aged adults. The second and third most important micro-environmental factors were speed limit and evenness of the cycle path, with respectively 8.5% and 7.8% average importance. Furthermore, the following micro-environmental factors did not differ significantly from each other: traffic density (7.1%), general upkeep (7.1%) and vegetation (7.0%) but they were significantly chosen above the presence of a speed bump (2.4%).

As a *third aim*, the interaction effects between different environmental factors were examined: the interaction between **macro- and micro-environmental factors**, as well as the interaction **between different micro-environmental factors**. Overall results showed that although the magnitude of the overall effects differed slightly in each macro-environment (i.e. low, medium, and high residential density); the same micro-environmental factors are preferred regarding the street's appeal to cycle for transport independent of the macro-environment (*chapter 2.2*). Regardless of the macro-environment, participants preferred a speed limit of 30 km/h, an even cycle path surface and a hedge as separation between the motorized traffic and the cycle path compared to a speed limit of 50 or 70 km/h, a slightly uneven or uneven cycle path, and a curb as separation or no separation between the motorized traffic and the cycle path. These controlled experimental simulations suggested that micro-environmental changes could have similar results in different macro-environments.

A first indication of possible interaction effects between different micro-environmental factors was found in *chapter 2.1*. For example, a separation between cycle path and sidewalk had a negative effect on the street's appeal to cycle for transport when there was already a separation between the cycle path and the motorized traffic. From the qualitative data, it could be derived that cyclists experienced a frightening feeling when cycling in between two separations on both sides of the cycle path. Furthermore, the 'large-scale' conjoint-study verified the interaction effects between an extensive selection of micro-environmental factors and their levels (*chapter 2.3*). Results indicated that the small effect of a speed bump on the street's appeal to cycle for transport could be enhanced by reducing traffic density. Since cycle path type was predominantly the most important micro-environmental factor, the relative importance of all other micro-environmental factors was calculated within each type of cycle path. Results indicate that in street settings where no cycle path is provided, micro-environmental factors associated to traffic-related safety (i.e. speed limit, traffic density) prevail. In contrast, when a more separated cycle path is provided, micro-environmental factors related to comfort (i.e. evenness of the cycle path) or aesthetics (i.e. vegetation, general upkeep) appeared to become more important.

The last aim (*fourth aim*) of this thesis was to explore whether **subgroups exist** with different physical environmental preferences regarding the street's appeal to cycle for transport using latent class analysis. In *chapter 2.1*, no moderating effects of gender, age and degree of education were found on the associations between a selective amount of micro-environmental factors and the street's appeal to cycle for transport. Although results indicated that the most important environmental factor for all participants remains a good separated cycle path, three subgroups were revealed within the middle-aged adult population (*chapter 2.4*). Broadly speaking, cycle path type was almost the only important environmental factor for those who live in less-urbanized environments, and for those who preferred to cycle accompanied. Speed limit seems to be an additional second most important environmental factor, next to cycle path type, for the subgroup consisting of the most male participants, living in urban areas, having more favorable psychosocial determinants towards cycling, or cycling more in comparison with both other subgroups. Traffic density, evenness of the cycle path and general upkeep are more important for the subgroup consisting of the most female participants, those who felt less vulnerable in traffic or those who did not prefer the safest cycling route.

2 Overall discussion and conclusions

2.1 Most important micro-environmental correlates of cycling for transport

Policy-makers and urban planners might benefit from advice on which micro-environmental factors should be targeted to encourage cycling for transport. Evidence-based interventions are more likely to succeed and might prevent failures or waste of limited resources. Therefore, it is important to outline which micro-environmental factors are important to provide an encouraging environment to cycle.

2.1.1 Cycle path type

Both in our experimental studies and in our objective cross-sectional European study, the presence of a cycle path appeared to be a dominant correlate to encourage cycling for transport. Previous cross-sectional studies showed similar results [1–9]. For example, a previous study determined the cycling route-selection criteria and identified that the presence of cycle paths were the most important criterion, mentioned by 78% of the participants, out of a list of 35 cycling related criteria [3]. Other cross-sectional studies also have indicated that cycle paths separated from motorized traffic were determining factors related to the decisions process to travel by bike [1,2]. Countries with a strong bicycle culture as the Netherlands, Denmark and Germany showed us that the dominant environmental factor to achieve high levels of cycling seems to be the provision of separate cycling facilities combined with traffic calming strategies along heavily travelled roads of residential neighborhoods [10]. These findings could now be confirmed with our stronger experimental design studies. Furthermore, an important added value of our photograph experiments in comparison with previously conducted cross-sectional studies is that the importance of different types of cycle paths regarding the street's appeal to cycle for transport could be verified. Based on these findings, advice could be given for the development of environmental interventions suggesting that providing cycle paths well separated from motorized traffic (i.e. hedge > curb > white lines) seems to be the best strategy to increase the street's appeal to cycle for transport among adults. Furthermore, an additional separation with the walking path by color would increase the street's appeal to cycle for transport even more, but this does not apply for a separation by means of bollards.

Although our studies cannot prove that cycle path type influences the actual cycling behavior, previous studies showed some indications that this environmental factor is related to cycling. A longitudinal study of Sallis et al. (2013) showed that cycling could be increased if cycling was safe from cars [11].

Additionally, a previous study indicated that a concern with safety in traffic is a constraint to cycle and that cyclists prefer cycle paths separated from motorized traffic [7]. From a review of the literature regarding cycling injuries and crashes it is shown that the presence of cycling facilities (e.g. on-road marked cycle paths, and off-road cycle paths) was associated with the lowest risk of crashes and injuries among cyclists [12]. Furthermore, another recent study regarding the risk of injuries to cyclists indicated that the risk of cycling injuries was lower on major streets with bike lanes and without parked cars [13]. Consequently, these results suggest that safety reasons may be very important to determine the preferred bike-specific infrastructure of cyclists. Furthermore, improvements to the cycle paths regarding a separation from motorized traffic can cause an increase to safety both objectively and subjectively [12,13], which may result in an increase of the cycling levels [11].

However, in the cross-sectional European study investigating environmental perceptions related to cycling for transport, no association was found for the presence of cycle paths in the neighborhood but only for more polluted neighborhoods, better connected neighborhoods, less pleasant neighborhoods to walk or cycle in, and neighborhoods with lower traffic speed levels. A possible explanation for these results is the reverse causality which means that regular cyclists are more exposed and consequently are more aware of the negative environmental factors in the environment (e.g. more aware of air pollution or the less pleasant attributes to cycle). Another possible explanation suggests that car use as well as bicycle use is higher in denser environments [14,15]. It has already been demonstrated in previous literature that the macro-environment, i.e. walkability, translating in higher density, easier accessibility of destinations, and more mixed land use, is positively related to cycling for transport in Europe [14,16] and outside Europe [17,18]. From these results investigating the perceptions, it can be deduced that some environmental factors probably derived from a higher walkability index (e.g. more choice between different routes to walk/cycle, more air pollution, less pleasant environment to walk or cycle) are simply more present in high walkable neighborhoods despite of the preference of the cyclists. Consequently, people will cycle in those high walkable neighborhoods despite of the air pollution or the less pleasantness of the neighborhood. The same reasoning can be made for the positive association between objectively determined parked cars that form an obstacle and cycling for transport among European adults. Previous qualitative research indicated that parked cars bother cyclists because they do not allow a good overview of the traffic situation or could be dangerous when suddenly opening doors [19] or quantitative research indicated that the risk of injuries to cyclists is lower with less parked cars on the streets [13]. Nevertheless, cyclists will cycle in such high walkable neighborhoods even if those parked cars or other environmental factors (i.e. more air pollution) bother them.

From this reasoning, we should make policy makers aware that in high walkable neighborhoods it is also important to take into account environmental factors which are often overlooked such as air pollution or parked cars. Considering these factors will ensure that neighborhoods become safer, healthier and more enjoyable to cycle for transport [13,20]. The provision of separated cycle paths might also help to deal with those environmental factors.

2.1.2 Speed limit

Stricter speed limits for the motorized traffic appeared to be significantly related to cycling for transport in each study of this doctoral research. Both the perceptions and the objectively determined data regarding lower traffic speed (i.e. speed limit ≤ 30 km/h) were associated with higher odds to cycle for transport among adults in five urban regions across Europe. Furthermore, also our experimental data using the manipulated photographs found a significant association between stricter speed limits and the street's appeal to cycle for transport. Reducing the authorized speed of the motorized traffic might help to improve safety for cyclists, which has been proved to be effective to increase cycling [11]. Moreover, zones where the maximum speed is limited to 30 km/h are proved to reduce the number and severity of bicycle crashes [21]. Additionally, stricter speed limits for motorized traffic might also help to improve environmental quality (e.g. reduce emission and noise) [22]. Consequently, lower overall speed limits for the motorized traffic might reduce the overall convenience and attractiveness of car use [10]. Furthermore, it might increase cycling both by increasing the speed of cycling relative to the speed of cars, and by increasing safety of cycling [22].

Since the relative importance of the other micro-environmental factors was considerably lower compared to the above described correlates (i.e. of which cycle path type was the most important factor followed by speed limit), they are discussed in the chapter below (2.2 Interactions between different environmental factors). These results correspond to the theory applied in the model "Hierarchy of walking needs", of which the micro-environmental factors concerning 'safety' turn out to be more important than environmental factors belonging to the more upper urban form layers like 'comfort' and 'pleasurability' [23].

Take home message

In conclusion, when considering micro-environmental factors, the most important strategy to create supportive environments and to stimulate cycling for transport is to improve the traffic safety for cyclists. This can be done by providing cycle paths well separated from motorized traffic or by reducing the authorized speed of the motorized traffic. Furthermore, policy makers must be informed that in high walkable neighborhoods it is important to pay attention to the overlooked environmental factors such as air pollution or parked cars that form an obstacle on the road. The provision of separated cycle paths might help to deal with those environmental factors and consequently can ensure that neighborhoods become safer, healthier and more enjoyable to cycle for transport.

2.2 Interactions between different environmental factors

According to the “Hierarchy of walking needs” [23], we know that although a hierarchical structure could be designated, interactions between different urban layers (i.e. physical environmental factors) are acknowledged as well. Returning to the definition of the macro- and micro-environment, the macro-environment could be seen as the basic urban form layer (i.e. accessibility), while the other urban form layers (i.e. safety, comfort, and pleasurability) could be regarded as the micro-environment. Interactions between the different layers, thus interactions between macro- and micro-environmental factors as interactions between micro-environmental may occur [23].

Our experimental results suggested that micro-environmental changes have similar outcomes in different macro-environments. These results should be treated with caution because only a selection of three micro-environmental factors was manipulated in three different macro-environments. Nevertheless, this proof of concept gives a first indication about the generalization of the adjustment of micro-environmental factors in different macro-environments.

According to the street’s appeal to cycle for transport we found that participants preferred a low residential density street with single land use compared to a medium or high residential street with mixed land use. Although they prefer to cycle in a low density street, previous literature showed that high walkable neighborhoods were positively associated with actual cycling for transport behavior [14,24,25]. This is not illogical, since everything is nearer in those high walkable neighborhoods and often more efficient to get around by bike. The “Hierarchy of walking needs” communicated similar results. This model highlighted the importance of the lower (non-)urban form needs before the more upper urban form needs could be satisfied [23].

Besides the interaction between micro- and macro-environmental factors, interactions between micro-environmental factors are also important. Since real environments consist of a combination of different micro-environmental factors, it is important to investigate which different combinations can improve or reduce the street's appeal to cycle for transport. For example, our studies were able to find out which micro-environmental factors should get priority to modify in different environmental situations. This advice might help policy makers and urban planners to develop more effective interventions. Our results indicate that a physical separation on both sides of the cycle path has a negative effect on the street's appeal to cycle for transport. However, when modifying the separation between the cycle path and the sidewalk, it is important to take into account the preferences of the pedestrians as well. An experimental photograph study focusing on the street's appeal to walk for transport among older adults (>65 years) showed that pedestrians preferred a hedge to be separated from cyclists and motorized traffic in comparison to no separation [26]. However, the need to be separated from the motorized traffic appears to be much more pronounced for adult cyclists compared to older adult pedestrians [26]. A cross-sectional study with non-manipulated photographs indicated that older adults with two or more functional limitations preferred environments with clear markings or colors as separation between the sidewalk and cycle path compared to no separation [27]. Furthermore, a cross-sectional study of Svensson et al. (2007) indicated that this shared space constraint between pedestrians and cyclists leads to a mobility problem for cyclists (e.g. feeling of tightness, limiting their evasive options) and a security and safety problem for pedestrians (e.g. they feel insecure when cyclists pass close to them) among the total population [28]. Consequently, it has been suggested to design the separation between the cycle path and the sidewalk in such a way that both road users stay on their own pathway without affecting their mobility [29]. Therefore, it is not recommended to provide a physical separation (e.g. bollards) between the cyclists and the pedestrians but rather a visual separation (e.g. coloring) if the cycle path is already physically separated from the motorized traffic.

Next, adjusting the speed limit from 50 km/h to 30 km/h had a significant effect along all different cycle paths, except for the best separated cycle path (separated by motorized traffic with a hedge, and separated with the sidewalk by color). Therefore, it is not needed to adjust the speed limit when a safe cycle path is already provided. In addition, restricting the speed limit to 30 km/h might have the greatest effect on the street's appeal to cycle for transport when no cycle path is present. However, since it is not always realistic to restrict the speed of the motorized traffic to 30 km/h, it could also help to reduce the speed to 50 km/h. Furthermore, decreasing the traffic density may increase the street's appeal to cycle for transport, and obtained the largest effect if no cycle path was present. Related to these findings, advice could be given to communities with limited financial resources or space constraints in the street to give priority to safety related micro-environmental factors (i.e. speed limit, traffic density) in situations where no cycle path is provided or cannot be improved. Furthermore, in situations where improved cycle paths already exist, micro-environmental factors related to comfort (i.e. evenness of the cycle path) or aesthetics (i.e. vegetation, general upkeep) appeared to become more important. These results overpower previous cross-sectional studies as they were unable to control both the variation within environmental factors (i.e. investigating the influence of an environmental factor) as the co-variation between environmental factors (i.e. investigate the combinations between environmental factors).

It is not always possible to adapt the speed limit in every situation. Therefore, it is also interesting to observe the effect of other strategies which may decrease the speed of the motorized traffic. In the literature, there is consistency about the fact that traffic calming devices (e.g. speed bumps, road narrowing, traffic circles, zigzag routes) enhances overall traffic safety and report large increases in overall levels of walking and cycling [10]. However, our study results showed that the effect of a speed bump on the street's appeal to cycle for transport is very small but indicated that when adapting both environmental factors, providing a speed bump and reducing the traffic density, it is more favorable for the street's appeal to cycle for transport. Consequently, it is important to verify whether the positive effect of a micro-environmental factor is attributable to itself, or rather to the presence of other micro-environmental factors. Since there are many different kinds of traffic calming devices, it is plausible that there is a difference in the street's appeal to cycle for transport between the various forms of traffic calming devices.

Take home message

From the previous section in this PhD-thesis, it became clear that cycle path type is the key player regarding encouraging environments to cycle for transport. On the one hand, when it is practically not feasible to provide a separated cycle path, micro-environmental factors related to safety (i.e. speed limit, traffic density) are more prominent in comparison to micro-environmental factors related to comfort (i.e. evenness of the cycle path) or aesthetic (i.e. vegetation, general upkeep). On the other hand, when a more separated cycle path is already provided, micro-environmental factors related to comfort or aesthetics appeared to become more important. Furthermore, it is recommended to provide a visual separation instead of a physical separation between the cycle path and the sidewalk if there is already a physical separation provided between the cycle path and the motorized traffic. Finally, providing a speed bump might have a more beneficial effect in combination with a reduction of the traffic density. In addition, our experimental results suggested that micro-environmental changes have similar outcomes in different macro-environments and therefore gives a first indication about the generalization of the adjustment of micro-environmental factors in different macro-environments.

2.3 One size fits all?

Only very few significant moderating effects were found in our studies, suggesting that generic environmental interventions could benefit most population subgroups, even across five different urban regions in Europe. Although previous studies reported obvious differences between countries or rather continents [14,30], we might assume that within the same part of a continent similar environmental factors will be important. It can be concluded that the large variety in prevalence of cycling for transport or the cultural differences in the five different countries across Europe did not really have a major effect on the physical environmental determinants of cycling for transport. Since the largest part of participants lived in Western Europe (i.e. France, the Netherlands, UK, and Belgium), it might be assumed that interventions could focus on the same environmental factors in Western Europe. Generalizing these outcomes to other geographical areas or to Eastern Europe (of which only a small part of the participants belonged, i.e. Hungary) is not really possible.

Cycle path type remains the most important environmental factor for all participants. Only a few differences in characteristics were found between the three subgroups revealed from similarities in micro-environmental preferences regarding the street's appeal to cycle for transport. In the literature, there is also some evidence about the different environmental preferences in relation to cycling for transport among different population subgroups. For example, there is some evidence that less-experienced cyclists and women do not prefer high traffic volumes and speeds and prefer more separated facilities [31]. However, lower traffic volumes or speeds will also be beneficial for experienced cyclists or men. Therefore, these findings suggest that potential environmental adaptations could be more favorable for some subgroups in comparison to others, without disadvantaging those others.

Our experimental study is an important study outcome as we can inform environmental interventions to modify the cycle path type since this environmental factor favors the whole middle-aged adult population, and especially those who cycled less. Furthermore, it can be assumed that environmental interventions focus best on at risk subgroups (i.e. people who cycled less) to increase the number of cyclists. However, no clear suggestions can be made since only negligible differences were found between the importances of the other micro-environmental factors (i.e. traffic density, evenness of the cycle path, maintenance, vegetation and speed limit). In addition, a previous study indicated that regular cyclists will cycle regardless of the circumstances (e.g. lack of good cycling infrastructures, long travel distance), because they like to cycle [32] or because it is more convenient to cycle instead of using the car [23]. Therefore, we might assume that tailored environmental interventions for at-risk subgroups will not disadvantage regular cyclists. Consequently, it is possible to target a particular subgroup with an environmental intervention because it will have no adverse effect on anyone.

Besides considering the preferences of subgroups within the adult population, it is also important to take into account the environmental preferences of the other age groups (i.e. children, adolescents, elderly (>65 years)). It has already been confirmed that safer and less stressful cycling routes are preferable to streets with fast-moving traffic for children and older people [33]. Similar photograph experiments were conducted among children and their parents to investigate the relative importance of micro-environmental factors for children's cycling for transport. Comparable results have been found for both the children (10-12 years) and their parents, as for the middle-aged adults: the cycle path type was by far the most important environmental factor [34]. This was followed by traffic density, maintenance and evenness of the cycle path for the children's street appeal to cycle for transport and by speed limit and maintenance for the parents' street appeal to cycle for transport. These results are promising for interventions since the conclusion for these subgroups is similar to the results found for the adult population; the most effective environmental interventions to increase the street's appeal to cycle for transport are clearly designed separated cycle paths from motorized traffic [34,35]. With regard to the elderly (>65 years) population, there is only very limited research about the association between the physical environment and cycling for transport. Furthermore, the prevalence of cycling for transport is significantly lower for this subgroup [36], partially due to their limited mobility [37].

Take home message

The moderating effects found in this PhD-thesis regarding the association between the physical environment and cycling for transport were scarce and only negligible differences were found, which is promising for interventions. Therefore, it might be suggested that tailored environmental interventions are not really needed in this research context. Similar environmental adaptations are likely to have a stronger effect in some subgroups compared to others but will not harm (i.e. have a negative effect on) other subgroups.

3 Strengths and limitations

A brief overview of the main strengths and limitations of the original research studies conducted within this PhD-thesis will be acknowledged and discussed below.

To start with the ***strengths***, all different conducted studies belonging to this PhD-thesis focused on cycling for transport. Since cycling for transport is a very accessible and inexpensive form of physical activity which can be done on a regular basis, it can be an important contributor to reach the daily physical activity guidelines and consequently facilitate global public health. In addition, cycling for transport has many other benefits like environmental benefits, economic advantages and traffic management profits [38–41].

Second, different types of data have been integrated in this research. Both quantitative (*chapter 1, chapter 2.1, chapter 2.2, chapter 2.3, chapter 2.4*) and qualitative (*chapter 2.1*) research methodologies were used to collect and analyze the data. The qualitative data gives added depth and understanding to the observed quantitative relationships. Furthermore, two different methodologies to measure the physical environment (i.e. perceived vs. objective) were integrated in this PhD-thesis as well. Finally, different research designs were used. Cross-sectional data of the SPOTLIGHT study were used in *chapter 1* and an experimental design using manipulated photographs was used in *chapter 2* of this PhD-thesis.

A third strength is the relatively large study samples which could be reached in our studies. Our cross-sectional data included about 4000 European adults distributed across five different urban regions in Europe (*chapter 1*) and we reached 1950 Flemish middle-aged adults by disseminating the photographs experiments through the web (*chapter 2.3*).

Finally, not only data from Belgium was integrated in this PhD-thesis, but also data from urban regions in four other European countries (i.e. the Netherlands, France, UK, and Hungary) which enables us to contribute to the European perspective regarding the association between the physical environment and cycling for transport.

Besides the strengths, there are also some ***limitations*** of the original research studies that have to be acknowledged. First, since we focused on the adult population, it is not possible to generalize the results of this PhD-thesis to the entire population. More specifically for *chapter 1*, the largest part of participants lived in Western Europe (i.e. France, the Netherlands, UK, and Belgium), and consequently generalization of these outcomes to other geographical areas or even to Eastern Europe (to which only a small part of the participants belonged, i.e. Hungary) is not possible. In addition, results for chapter 1 only apply to urban regions because the studies were conducted in large cities. Furthermore, the response rate of the SPOTLIGHT-study was low (around 10.8%), leading to possible response bias because probably only highly motivated people participated. This makes the generalization of these results less representative for the population as a whole [42]. In *chapter 2*, an over-representation of highly educated participants (around 65%) or participants with a white-collar occupation status (around 68%) was caused by disseminating the questionnaire through the web. This is much higher than the statistics of the Flemish population indicate; around 28% of the adults is highly educated (tertiary education) and the majority of the adults has a blue collar occupation [43]. Therefore, we should be careful when generalizing the results of *chapter 2* to the entire Flemish middle-aged population.

Second, the cross-sectional design used in *chapter 1* prohibited determination of causality. Stronger designs such as experimental or longitudinal designs are recommended to close this research gap and to enable causal interference with regard to the impact of physical environmental factors on cycling for transport [44,45]. The same problem applies for the photographs experiments (*chapter 2*). These studies only investigated the associations with the street's appeal to cycle for transport and not with actual cycling behavior. Therefore, outcomes from these experimental studies can only give advice to the development of environmental interventions which has to determine if changing the studied micro-environmental factors in real life settings actually affect the cycling behavior. Furthermore, the cross-sectional study design in chapter 2 does not address the problem of self-selection which may have biased the research results; 'Do people cycle more because they live in a cycling-friendly environment, or do they choose to live in a cycling-friendly environment because they like to cycle?' [46,47]. However, several studies have adjusted their analyses for residential self-selection and could conclude that the residential environment has an impact on people's amount of physical activity regardless of choosing a specific neighbourhood [48,49]. Nevertheless, it is recommended for future studies to take the residential self-selection into account when studying association between the physical micro-environment and cycling for transport among adults.

Third, using photographs has a lot of advantages, but also some limitations such as the time consuming task and expertise needed to manipulate the photographs, the two-dimensional character or the lack of movement [50]. It is possible that depending on the speed of travel, people notice different things in the environment. Furthermore, photographs are also constrained by the lack of noise which makes it together with the lack of movement difficult to simulate several micro-environmental factors such as speed limit, or traffic density.

Fourth, the SPOTLIGHT project (chapter 1.2) groups the data into geographical neighborhoods units [51]. Neighbourhoods were defined according to their local administrative boundaries, but this does not necessarily correspond to the activity space (or residential neighborhood) of an individual [52]. Although residents may live in the same predefined neighborhoods, their activity space or perception of their neighborhood may completely differ (cfr. the modifiable Areal Unit Problem (MAUP)) [53].

Finally, the sample of our pilot study (chapter 2.1) consists of 80% non-cyclists and was used as a basis for the subsequent studies (chapter 2.2 and chapter 2.3). However, the sample of those studies consists of 25% and 22% non-cyclists respectively. It is plausible that micro-environmental factors which should encourage people to start cycling are different from environmental factors that need to persuade cyclists to cycle longer distances. Since the proportion of non-cyclists is relatively low in our later photograph studies (chapter 2.2, 2.3 and 2.4), future studies should particular pay attention on this target group to verify if those results are valid for non-cyclists as well.

4 Directions for future research

In addition to the acknowledged limitations, recommendations for future research are addressed below.

First, since the use of manipulated photographs has the inability to study the association with actual cycling behavior, environmental interventions in real life settings are still needed to identify if changing micro-environmental factors will actually affect cycling behavior. However, our experimental findings determined with the manipulated photographs do form the base for indicating which environmental factors might be prioritized in which situation/context to modify in environmental interventions. Environmental interventions also have to make clear whether changes in cycling behavior can occur when adapting just one micro-environmental factor in the neighborhood or whether adjusting a combination of different micro-environmental factors is needed to ensure behavior change. In addition, cost benefit or cost-effectiveness analyses are required to identify the effect of changing environmental factors on the benefits for health care or cycling crashes. It is assumed that the inclusion of the health benefits obtained by more physical activity favors the cost effectiveness from a transport sector perspective [54]. However, more and better quality evaluations of implemented environmental interventions are needed to enrich this knowledge [54]. Furthermore, the effect of other strategies (e.g.

awareness campaigns or targeting psychosocial factors of individuals) in combination with the environmental changes should also be investigated.

Second, another approach or intermediate research step in this context is the use of computer-generated virtual bike-through environments (three-dimensional) [55] to accommodate the limitations of the manipulated photographs (i.e. the lack of motion and noise). Moreover, the integration of studying the cycling facilities at dangerous intersections is also possible with this methodology. It is important to study safety aspects for cyclists at intersections since a larger number of crashes as well as more serious crashes occur at intersections [56]. However, there are also some disadvantages associated with the use of this methodology such as the higher costs, the needed expertise or the difficulty to reach a larger sample.

Third, with our experimental design using manipulated photographs, there are also some expanded possibilities for future research. It is possible to include other micro-environmental factors or to extend the number of gradations (i.e. levels) of one micro-environmental factor. For example, integrating the role of social environmental factors (e.g. related to safety or violence) might enrich the study's inputs and results. In addition, it would be interesting for future research to investigate the role of trip objective and trip length in relation to the preferred cycling route, since these were currently both fixed in our photograph experiments. Varying in different gradations of traffic calming devices (e.g. road narrowing, traffic islands, on-street parking) for the motorized traffic could be further explored since providing a speed bump appears not to be the most preferred approach. Another possibility is to internationalize these photograph experiments in order to investigate if the current outcomes are internationally valid. This can be gradually built up, starting with the two neighboring countries of Belgium, expanding to North-East-South of Europe, and finally reaching out throughout Europe. International differences regarding effects of micro-environmental changes on the street's appeal to cycle for transport in adults could be identified.

Fourth, our results showed that the air polluted environments will not prevent cyclists to cycle. Therefore, knowledge about the consequences of air pollution on cycling for transport has to be clarified. Governments and transport planners have to be aware of this problem and have to take their responsibility to protect cyclists from poor air quality. For example, guidelines are required about how far the cycle path should be located from the motorized traffic without harming cyclists' health. Since cyclists breath faster and heavier than other commuters (e.g. pedestrians, car and bus passengers), the estimated inhaled exposure is considerably higher and consequently the health risks for cyclists are much worse [57]. A previous study suggested to encourage cyclists to take alternative routes instead of the busiest road with the aim to reducing the air pollution exposure. However, as the cycling duration increased because of the alternative route, the exposure increased as well. Consequently, this study suggested to further separate the infrastructure of cyclists form cars to reduce cyclist's exposure [20]. A study conducted in Aukland, New Zeeland suggested some guidelines about how far the cycle path should be located from the motorized traffic to reduce the pollutant exposure of CO (carbon monoxide) which was 5.8 to 14.2 meters away from the centre of the road, depending on activity and dispersion conditions [58]. Space constraints may occur, nonetheless this study concluded that even small increases in separation length between the active commuters and passive commuters might results in significant reductions in pollutant exposure [58]. Still, the concentration of air pollution in the cycling environment is also dependent on several other factors such as the vehicle mix, the traffic volume, the traffic flow, weather or wind conditions [56]. Furthermore, the exposure to air pollution (ultrafine particles) during transport has been estimated [59] to count for considerably less (only 5%) in comparison to the home environment, which accounts for 50% of the daily personal exposure. Nevertheless, it is suggested that the benefits of the increased physical activity (i.e. increased cycling for transport) are likely to outweigh the risks of the increased uptake of polluted air while cycling [56].

Fifth, when investigating the objective physical environmental correlates of cycling for transport, we suggested to also look at the environmental factors of neighborhoods adjacent to the residential neighborhood or other neighborhoods which may be relevant (e.g. work environment of individuals) as cyclists often travel longer distances than only their residential neighborhood. According to the modifiable Areal Unit Problem (MAUP), results could be affected when the data was grouped into units for analysis. Therefore, we advocated that the activity space (or residential neighborhood) of an individual is rather created by the individual itself, and does not necessarily correspond to the administrative boundaries [52]. Although residents may live in the same delimited neighborhoods, their activity space or perception of their neighborhood may completely differ [53]. Since the cycling environment of an individual is often more extensive than the determined residential neighborhood, there is a need to determine which neighborhood definition is most relevant to map the activity space regarding cycling for transport of an individual. Furthermore, the solution could be to objectively determine the activity space of an individual, for example with the use of GPS devices. In addition, these devices enable us to investigate which cycling routes participants' actual take (e.g. the shortest route, the safest route, the prettiest route) and compare the objectively environmental factors along these routes. However, registering individual GPS-based neighbourhoods will not be realistic to conduct in large-scale studies. Therefore a recent study of Madsen et al. (2014) investigated cycling tracks and suggested that in the case of cycling for transport, ellipse-shaped buffers from home to a cluster of daily destinations (e.g. city center) could better capture the transport cycling behavior instead of administrative units [60].

Sixth, in future research an additional effort should be made in order to reach adults with a lower socio-economic status as well. In order to reach this subgroup, other data collection strategies are needed, such as visiting specific workplaces and low-wage industries in which people with a lower socio-economic status are concentrated [61]. Furthermore, the influence of the socio-economic status of a neighbourhood has to be taken into account when investigating physical micro-environment – cycling for transport relationships. For the relationship between walkability (i.e. the macro-environment) and cycling for transport, no interactions of neighbourhood SES were found which indicates that walkability seems to be favorable for all economic strata [16]. However, evidence about the role of neighbourhood SES on the relation between the micro-environment and cycling for transport is still lacking.

Seventh, since cycling requires a certain basic fitness, balance and agility level, it could be an added value to investigate the potential moderating effects of physical fitness on the relationship between the physical environment and cycling for transport. Such information may specify which micro-environmental factors will be more important to encourage unfit individuals to cycle for transport.

Lastly, by the tremendous growth of electric bicycle users, and especially ‘speed pedelecs’, it is important to investigate whether these ‘new’ road users need other environmental requirements. Research is needed to investigate the environmental and safety impact of the emerging electric bicycle users and to compare those to alternative modes of transport (e.g. traditional bicycles, or motorized traffic). Electric bicycles are promising to displace car trips, however, because of their size, speed characteristics and the need to charge their batteries, different environmental adjustments in comparison to traditional bicycles are potentially required.

5 Practical implications

The promotion of cycling could be encouraged from a public health perspective but also from an environmental, economic or traffic management perspective. The current results of this PhD-thesis can provide some practical implications to policy-makers and urban planners in order to advice environmental interventions in real-life settings.

When building up new residential areas, environmental policies have to pay attention to the macro-environment, such as providing a good street connectivity or easy access to destinations. According to the "Hierarchy of walking needs" we know that macro-environmental factors (i.e. the basic urban form layer) will be more fundamental in the decision-making process to cycle in comparison to the more upper micro-environmental levels [23]. The most appropriate situation would be to create a cycling- and pedestrian friendly supporting macro-environment (e.g. providing only a good street connectivity for the vulnerable road users) which only offers additional benefits for the pedestrians or the cyclists, and not for the motorized traffic. However, since the macro-environment might be difficult to change in existing neighborhoods, it will be more recommended to modify micro-environmental factors or street characteristics since these are more feasible to reconstruct. Nevertheless, a satisfied macro-environment (e.g. close destinations, good connectivity) could only strengthen the advantage of the preferred micro-environment. The most important strategy to create supportive micro-environments and to stimulate cycling for transport is to improve the traffic safety for cyclists. This can be done by providing separated cycle paths (even if they are only marked with white lines on the road) or by reducing the authorized speed of the motorized traffic. The most preferred cycle path is a cycle path that is well separated from the motorized traffic (i.e. hedge > curb > white lines). Furthermore, policy makers must be informed that in high walkable neighborhoods it is important to pay attention to the overlooked environmental factors such as air pollution or parked cars that form an obstacle on the road. The provision of separated cycle paths might help to deal with those environmental factors and consequently can ensure that neighborhoods become safer, healthier and more enjoyable to cycle for transport.

Furthermore, since it might not be possible (i.e. financial or space constraints) to change the cycle path in all situations, safety related micro-environmental factors (i.e. speed limit, traffic density) should be prioritized above comfort (i.e. evenness of the cycle path) or aesthetics (i.e. vegetation, general upkeep) related environmental factors. Furthermore, when a more preferable environmental situation is already provided, comfort or aesthetics related micro-environmental factors such as the evenness of the cycle path, general upkeep or the presence of vegetation, become more prominent.

Environmental adaptations (e.g. improving cycle path type) appear to have a favorable effect for the whole adult population; consequently tailored environmental interventions are not essential to conduct. Nevertheless, it is plausible that potential environmental adaptations could be more favorable for some subgroups in comparison to others, but these environmental changes will not disadvantage anyone. After the adjustments of the physical environment (i.e. making more supportive cycling environment) targeting the entire population, it would be recommended to implement community-wide promotional activities at the same time [62]. The community might play an important role for example to inform the population about the newly constructed cycling infrastructure or to give indications to show where the safest cycle paths are located. Other stakeholders may be city services, companies or workplaces. For example, an intervention called ‘Bike to Work: cyclists are rewarded’ has been proven to be a feasible workplace intervention in Flanders; an increased amount of cyclists was found among the employees who were aware of the program [63]. Another possibility is to implement educational and motivational programs to promote cycling for certain at risk subgroups. After creating supportive environments to cycle, the focus can be shifted from the total population to individual perspectives or to specific at-risk subgroups with the use of specific interventions to cycle. For example, an intervention targeting obese women demonstrated that they could change their commuting habits and achieve treatment success for cycling by providing a standard care in combination with a more intensive behavioral counseling package [64]. A next step could be the application of mass media purposing to change the social norms regarding cycling for transport [62]. For example, changing the public acceptance and legislate to wear a bicycle helmet might influence the whole bike culture of a country [65]. However, these above mentioned strategies should only be executed after a supportive cycling environment is created because good intentions are unrealizable when there is a lack of opportunity to cycle (i.e. bad cycle paths).

6 Conclusion

This PhD-thesis investigated the association between the physical micro-environment and cycling for transport. The most important strategy to create supportive micro-environments and to stimulate cycling for transport is to improve the traffic safety for cyclists. This can be done by providing separated cycle paths (even if they are only marked with white lines on the road) or by reducing the authorized speed of the motorized traffic. The most preferred cycle path is a cycle path that is well separated from the motorized traffic (i.e. hedge > curb > white lines). Furthermore, policy makers must be informed that in high walkable neighborhoods it is important to pay attention to the overlooked environmental factors such as air pollution or parked cars that form an obstacle on the road. The provision of separated cycle paths might help to deal with those environmental factors and consequently can ensure that neighborhoods become safer, healthier and more enjoyable to cycle for transport.

Since it might not be possible (i.e. financial or space constraints) to change the cycle path in all situations, safety related micro-environmental factors (i.e. speed limit, traffic density) must be prioritized above comfort (i.e. evenness of the cycle path) or aesthetics (i.e. vegetation, general upkeep) related environmental factors. Furthermore, when a more preferable (i.e. separated) cycle path is already provided, comfort or aesthetics related micro-environmental factors such as the evenness of the cycle path, the presence of vegetation, become more prominent. Next, it is recommended to provide a visual separation instead of a physical separation between the cycle path and the sidewalk if there is already a physical separation provided between the cycle path and the motorized traffic. Finally, a speed bump has a more beneficial effect when reducing the traffic density at the same time. In addition, our experimental results suggested that micro-environmental changes have similar outcomes in different macro-environments and therefore gives a first indication about the generalization of the adjustment of micro-environmental factors in different macro-environments.

From our results we can carefully conclude that tailored environmental interventions may not be required in this research context since environmental adaptations (e.g. improving cycle path type) appear to have a favorable effect for the whole adult population. Nevertheless, it is plausible that potential environmental adaptations could be more favorable for some subgroups in comparison to others, but these environmental changes will not disadvantage (i.e. have a negative effect on) anyone. Finally, no clear suggestions can be made about other micro-environmental factors (i.e. traffic density, evenness of the cycle path, maintenance, vegetation and speed limit) since only negligible differences were found between the importance of these factors.

7 References

1. Winters M, Davidson G, Kao D, Teschke K. Motivators and deterrents of bicycling: comparing influences on decisions to ride. Transportation (Amst). 2010;38: 153–168. doi:10.1007/s11116-010-9284-y

2. Fraser SDS, Lock K. Cycling for transport and public health: a systematic review of the effect of the environment on cycling. Eur J Public Health. 2010;21: 738–43. doi:10.1093/eurpub/ckq145

3. Hochmair H. Towards a Classification of Route Selection Criteria for Route Planning Tools. Developments in Spatial Data Handling. 2005. pp. 481–492.

4. Buehler R, Pucher J. Cycling to work in 90 large American cities: new evidence on the role of bike paths and lanes. Transportation (Amst). 2011;39: 409–432. doi:10.1007/s11116-011-9355-8

5. Dill J, Carr T. Bicycle Commuting and Facilities in Major U . S . Cities : If You Build Them , Commuters Will Use Them – Another Look. 2003; 1–9.

6. Handy S, Wee B Van, Kroesen M. Promoting Cycling for Transport : Research Needs and Challenges. Transp Rev A Transnatl Transdiscipl J. 2014;34: 37–41. doi:10.1080/01441647.2013.860204

7. Heesch KC, Sahlqvist S, Garrard J. Gender differences in recreational and transport cycling: a cross-sectional mixed-methods comparison of cycling patterns, motivators, and constraints. Int J Behav Nutr Phys Act. International Journal of Behavioral Nutrition and Physical Activity; 2012;9: 106. doi:10.1186/1479-5868-9-106

8. Heinen E, Van Wee B, Maat K. Commuting by Bicycle : An Overview of the Literature. 2010;30: 59–96. doi:10.1080/01441640903187001

9. Pucher J, Buehler R, Seinen M. Bicycling renaissance in North America ? An update and re-appraisal of cycling trends and policies. Transp Res Part A. Elsevier Ltd; 2011;45: 451–475. doi:10.1016/j.tra.2011.03.001

10. Pucher J, Buehler R. Making Cycling Irresistible: Lessons from The Netherlands, Denmark and Germany. Transp Rev. 2008;28: 495–528. doi:10.1080/01441640701806612

11. Sallis JF, Conway TL, Dillon LI, Frank LD, Adams MA, Cain KL, et al. Environmental and demographic correlates of bicycling. Prev Med (Baltim). 2013;57: 456–460.

12. Reynolds CCO, Harris MA, Teschke K, Cripton PA, Winters M. The impact of transportation infrastructure on bicycling injuries and crashes : a review of the literature. Environ Heal. 2009;19. doi:10.1186/1476-069X-8-47

13. Teschke K, Harris MA, Reynolds CCO, Winters M, Babul S, Chipman M. Route Infrastructure and the Risk of Injuries to Bicyclists : A Case-Crossover Study. Res Pract. 2012;102: 2336–2343. doi:10.2105/AJPH.2012.300762

14. Van Holle V, Deforche B, Van Cauwenberg J, Goubert L, Maes L, Van de Weghe N, et al. Relationship between the physical environment and different domains of physical activity in European adults: a systematic review. BMC Public Health. 2012;12: 807. doi:10.1186/1471-2458-12-807

15. Douglas MJ, Watkins SJ, Gorman DR, Higgins M. Are cars the new tobacco ? J Public Health (Bangkok). 2011;33: 160–169. doi:10.1093/pubmed/fdr032

16. Van Dyck D, Cardon G, Deforche B, Sallis JF, Owen N, De Bourdeaudhuij I. Neighborhood SES and walkability are related to physical activity behavior in Belgian adults. Prev Med (Baltim). 2010;50 Suppl 1: S74–9. doi:10.1016/j.ypmed.2009.07.027

17. Saelens BE, Sallis JF, Frank LD. Environmental correlates of walking and cycling: findings from the transportation, urban design, and planning literatures. Ann Behav Med. 2003;25: 80–91. Available: http://www.ncbi.nlm.nih.gov/pubmed/12704009

18. Panter JR, Jones A. Attitudes and the environment as determinants of active travel in adults: what do and don’t we know? J Phys Act Heal. 2010;7: 551–561. Available: http://www.ncbi.nlm.nih.gov/pubmed/20683098

19. Ghekiere A, Van Cauwenberg J, de Geus B, Clarys P, Cardon G, Salmon J, et al. Critical environmental factors for transportation cycling in children: a qualitative study using bike-along interviews. PLoS One. 2014;9: e106696. doi:10.1371/journal.pone.0106696

20. Good N, Mölter A, Ackerson C, Bachand A, Carpenter T, Clark ML, et al. The Fort Collins Commuter Study : Impact of route type and transport mode on personal exposure to multiple air pollutants. 2016; 397–404. doi:10.1038/jes.2015.68

21. Grundy C, Steinbach R, Edwards P, Green J, Armstrong B, Wilkinson P. Effect of 20 mph traffic speed zones on road injuries in London, 1986-2006: controlled interrupted time series analysis. BMJ. 2009;339: b4469. doi:10.1136/bmj.b4469

22. Pucher J, Dill J, Handy S. Infrastructure, programs, and policies to increase bicycling: an international review. Prev Med (Baltim). 2010;50 Suppl 1: S106–25. doi:10.1016/j.ypmed.2009.07.028

23. Alfonzo M a. To Walk or Not to Walk? The Hierarchy of Walking Needs. Environ Behav. 2005;37: 808–836. doi:10.1177/0013916504274016

24. Van Dyck D, Cerin E, Conway TL, De Bourdeaudhuij I, Owen N, Kerr J, et al. Perceived neighborhood environmental attributes associated with adults' transport-related walking and cicyling: Findings from USA, Australia and Belgium. Int J Behav Nutr Phys Act. 2012;9: 59–68. doi:10.1186/1479-5868-9-70

25. Van Dyck D, De Meester F, Cardon G, Deforche B, De Bourdeaudhuij I. Physical environmental attributes and active transportation in Belgium: What about adult and adolescents living in the same neighborhoods. Am J Heal Promot. 2013;27: 330–8. doi:10.4278/ajhp.120316-QUAN-146

26. Van Cauwenberg J, De Bourdeaudhuij I, Clarys P, Nasar J, Salmon J, Goubert L, et al. Street characteristics preferred for transportation walking among older adults: A choice-based conjoint analysis with manipulated photographs. Int J Behav Nutr Phys Act (under Rev. International Journal of Behavioral Nutrition and Physical Activity; 2016; 1–17. doi:10.1186/s12966-016-0331-8

27. Van Cauwenberg J, Van Holle V, De Bourdeaudhuij I, Clarys P, Nasar J, Salmon J, et al. Physical Environmental Factors that Invite Older Adults to Walk for Transportation. J Environ Psychol. 2014;38: 94–103.

28. Svensson A, Hydén C, Jonsson L. Separation between pedestrians and bicyclists. 3rd Urban Street Symposium. Seattle, Washington; 2007. pp. 1–10.

29. Alta Planning + Design. CYCLE TRACKS : Lessons Learned. 2009;

30. Bassett DR, Pucher J, Buehler R, Thompson DL, Crouter SE. Walking , Cycling , and Obesity Rates in Europe , North America , and Australia. J Phys Act Health. 2008;5: 795–814.

31. Broach J, Dill J, Gliebe J. Where do cyclists ride? A route choice model developed with revealed preference GPS data. Transp Res Part A Policy Pract. Elsevier Ltd; 2012;46: 1730–1740. doi:10.1016/j.tra.2012.07.005

32. Gatersleben B, Appleton K. Contemplating cycling to work : attitudes and perceptions in different stages of change. Transp Res Part A Policy Pract. 2007;41: 302–312.

doi:10.1016/j.tra.2006.09.002

33. Pucher J, Buehler R. Cycling for Everyone : Lessons from Europe. Transp Res Rec J Transp Res Board. 2007;2074: 58–65.

34. Ghekiere A, Deforche B, Mertens L, De Bourdeaudhuij I, Clarys P, de Geus B, et al. Creating Cycling-Friendly Environments for Children: Which Micro-Scale Factors Are Most Important? An Experimental Study Using Manipulated Photographs. PLoS One. 2015;

35. Ghekiere A, Van Cauwenberg J, Mertens L, Clarys P, de Geus B, Cardon G, et al. Assessing cycling-friendly environments for children: are micro-environmental factors equally important across different street settings? Int J Behav Nutr Phys Act. ???; 2015;12: 54. doi:10.1186/s12966-015-0216-2

36. SafetyNet. Pedestrians & Cyclists [Internet]. 2009. Available: http://ec.europa.eu/transport/road_safety/specialist/knowledge/pdf/pedestrians.pdf

37. Rojas-Rueda D, de Nazelle A, Tainio M, Nieuwenhuijsen MJ. The health risks and benefits of cycling in urban environments compared with car use: health impact assessment study. BMJ. 2011;343: 1–8. doi:10.1136/bmj.d4521

38. Woodcock J, Edwards P, Tonne C, Armstrong BG, Ashiru O, Banister D, et al. Public health benefits of strategies to reduce greenhouse-gas emissions: urban land transport. Lancet. Elsevier Ltd; 2009;374: 1930–43. doi:10.1016/S0140-6736(09)61714-1

39. Rabl A, de Nazelle A. Benefits of shift from car to active transport. Transp Policy. Elsevier; 2012;19: 121–131. doi:10.1016/j.tranpol.2011.09.008

40. Rissel CE. Active travel: a climate change mitigation strategy with co-benefits for health. N S W Public Health Bull. 2009;20: 10–3. Available: http://www.ncbi.nlm.nih.gov/pubmed/19261210

41. Bauman A, Rissel C, Garrard J, Ker I, Speidel R, Fishman E. Cycling : getting Australia moving – barriers , facilitators and interventions to get more Australians physically active through cycling. 31st Australas Transp Res forum. 2008; 593–601. Available: http://atrf.info/papers/2008/2008_bauman_rissel_garrard_ker_spiedel_fishman.pdf

42. Boundless. Biases in Experimental Design: Validity, Reliability, and Other Issues. [Internet]. 2016. Available: https://www.boundless.com/psychology/textbooks/boundless-psychology-textbook/researching-psychology-2/bias-in-psychological-research-407/biases-in-experimental-design-validity-reliability-and-other-issues-132-12667/

43. Belgian Federal Government. Statistics Belgium [Internet]. 2013. Available: http://statbel.fgov.be/

44. Bauman AE, Reis RS, Sallis JF, Wells JC, Loos RJF, Martin BW. Correlates of physical activity: why are some people physically active and others not? Lancet. 2012;380: 258–71. doi:10.1016/S0140-6736(12)60735-1

45. Ferdinand AO, Sen B, Rahurkar S, Engler S, Menachemi N. The Relationship Between Built Environments and Physical Activity : A Systematic Review. Am J Public Health. 2012;102: 7–13. doi:10.2105/AJPH.2012.300740

46. McCormack GR, Shiell A. In search of causality: a systematic review of the relationship between the built environment and physical activity among adults. Int J Behav Nutr Phys Act. BioMed Central Ltd; 2011;8: 125. doi:10.1186/1479-5868-8-125

47. Transportation Research Board. Does the Built Environment Influence Physical Activity ? [Internet]. 2005. Available: http://onlinepubs.trb.org/onlinepubs/sr/sr282.pdf

48. Baar J, Romppel M, Igel U, Brähler E, Grande G. The independent relations of both residential self-selection and the environment to physical activity. Int J Environ Health Res. 2015;25: 288–98.

49. Van Dyck D, Cardon G, Deforche B, Owen N, De Bourdeaudhuij I. Relationships between neighborhood walkability and adults' physical activity: How important is residential selfselection? Health Place. 2011;17: 1011–1014.

50. Heft H, Nasar JL. Evaluating Environmental Scenes Using Dynamic Versus Static Displays. Environ Behav. 2000;32: 301–322. doi:10.1177/0013916500323001

51. Flowerdew R, Manley DJ, Sabel CE. Neighbourhood effects on health: does it matter where you draw the boundaries? Soc Sci Med. 2008;66: 1241–55. doi:10.1016/j.socscimed.2007.11.042

52. Sherman JE, Spencer J, Preisser JS, Gesler WM, Arcury T a. A suite of methods for representing activity space in a healthcare accessibility study. Int J Health Geogr. 2005;4: 24. doi:10.1186/1476-072X-4-24

53. Coulton C. Defining Neighborhoods for Research and Policy. Cityscape A J Policy Dev Res. 2012;14: 231–236.

54. Brown V, Zapata B, Moodie M, Veerman JL, Carter R. A systematic review of economic analyses

of active transport interventions that include physical activity bene fi ts. Transp Policy. Elsevier; 2016;45: 190–208. doi:10.1016/j.tranpol.2015.10.003

55. Cubukcu E, Nasar JL. Influence of physical characteristics of routes on distance cognition in virtual environments. Environ Plan B Plan Des. 2005;32: 777–785. doi:10.1068/b31191

56. Götschi T, Garrard J, Giles-Corti B. Cycling as a Part of Daily Life: A Review of Health Perspectives. Transp Rev. 2015;1647: 1–27. doi:10.1080/01441647.2015.1057877

57. Zuurbier M, Hoek G, Hazel P Van Den, Brunekreef B. Minute ventilation of cyclists, car and bus passangers: an experimental study. Environ Heal. 2009;10: 1–10. doi:10.1186/1476-069X-8-48

58. Grange SK, Dirks KN, Costello SB, Salmond JA. Cycleways and footpaths: What separation is needed for equivalent air pollution dose between travel modes? Transp Res Part D Transp Environ. Elsevier Ltd; 2014;32: 111–119. doi:10.1016/j.trd.2014.07.014

59. Bekö G, Kjeldsen BU, Olsen Y, Schipperijn J, Wierzbicka A, Karottki DG, et al. Contribution of various microenvironments to the daily personal exposure to ultrafine particles: Personal monitoring coupled with GPS tracking. Atmos Environ. 2015;110: 122–129. doi:10.1016/j.atmosenv.2015.03.053

60. Madsen T, Schipperijn J, Christiansen LB, Nielsen TS, Troelsen J. Developing suitable buffers to capture transport cycling behavior. Front public Heal public Heal. 2014;2: 61. doi:10.3389/fpubh.2014.00061

61. Harris JR, Huang Y, Hannon PA, Williams B. Low–Socioeconomic Status Workers: Their Health Risks and How to Reach Them. J Occup Environ Med. 2011;53: 132–138.

62. Sallis JF, Cervero RB, Ascher W, Henderson K a, Kraft MK, Kerr J. An ecological approach to creating active living communities. Annu Rev Public Health. 2006;27: 297–322. doi:10.1146/annurev.publhealth.27.021405.102100

63. Dubuy V, Cocker K De, Bourdeaudhuij I De, Maes L, Seghers J, Lefevre J. Evaluation of a workplace intervention to promote commuter cycling : A RE-AIM analysis. BMC Public Health. 2013;13: 1–11.

64. Hemmingsson E, Uddén J, Neovius M, Ekelund U, Ro S. Increased physical activity in abdominally obese women through support for changed commuting habits : a randomized clinical trial. Int J Obes. 2009;33: 645–652. doi:10.1038/ijo.2009.77

65. Happer C, Philo G. Special Thematic Section on " Societal Change " The Role of the Media in the Construction of Public Belief and Social Change Methods : Content Analysis. J Soc Polit Psychol. 2013; doi:10.5964/jspp.v1i1.96

Dankwoord - Acknowledgements

"Less is more", op basis van dit citaat heb ik de cover voor mijn doctoraat ontwikkeld. Maar dit statement zal ik echter niet kunnen gebruiken in mijn dankwoord. Want hoe meer steun en vertrouwen je tijdens het traject tegemoet komt, hoe sterker je in jezelf gelooft, expertise opbouwt en jezelf ziet ontplooien. Net daarom is het meest dankbare citaat dat ik kan gebruiken om elke betrokkene te bedanken, "More is more".

Hoe het allemaal begon….

Na vijf jaar studeren had ik drie diploma's op zak (Master Lichamelijke Opvoeding en Bewegingswetenschappen, Master Gezondheidsvoorlichting –en bevordering en mijn Specifieke Lerarenopleiding). Maar ondanks deze grote basis wist ik nog niet welke kant ik uit wilde. Om deze keuze nog even uit te stellen en verder na te denken over wat ik met mijn toekomst wilde doen, ben ik met studiegenoten Clarisse, Silke en Eline de wereld gaan verkennen (Australië, Nieuw-Zeeland en Thailand). Deze prachtige reis heeft me ontzettend veel bijgebracht en zorgde voor het ultieme 'pauze moment' in mijn carrière. Met frisse moed en kracht had ik toegestemd om een doctoraat te maken. Geen idee of dit echt iets voor mij zou zijn, maar ik vond dat ik deze kans niet mocht laten liggen. En ook al waren de eerste dagen als 'werkmens' (onderzoeksdag) toch wel even aanpassen, ik ben altijd met plezier komen werken en ben mezelf nog altijd enorm dankbaar dat ik toen die keuze heb gemaakt. Het is zelfs zo dat ik uitkijk om een vervolg te maken op dit doctoraat.

In de eerste plaats wil ik mijn promotor en copromotor bedanken, Prof. dr. Ilse De Bourdeaudhuij en Prof. dr. Benedicte Deforche. Ilse en Benedicte, bedankt om me deze kans te geven, me te overtuigen deze stap te zetten en het vertrouwen te hebben in mij dat ik dit tot een goed einde kon brengen. Ook al was het af en toe wat bang afwachten op jullie feedback, jullie hebben er beide voor gezorgd dat het altijd nog een beetje beter kan. Jullie hebben me communicatief sterker gemaakt, me vertrouwen gegeven om meer Engels te praten en me gevormd tot een kritisch persoon. Naar mijn gevoel zaten we op dezelfde golflengte qua zelfstandig werken en het vragen van feedback waardoor de samenwerking goed aanvoelde. Bedankt om me te begeleiden in dit volledige doctoraatsproces.

Daarnaast zou ik graag Prof. Nico Van de Weghe, alle co-auteurs en alle leden van mijn examencommissie bedanken voor hun kritische feedback die me de mogelijkheid gaf om mijn onderzoek en mijn doctoraat te verbeteren. Jullie invalshoeken en expertises hebben mijn kennis op andere vlakken verruimd.

Delfien, jij werd bestempeld als mijn 'begeleider' en een betere kon in me echt niet inbeelden! Bedankt voor de vlugge en goed onderbouwde feedback, de verbetering van mijn soms rare zinsconstructies maar ook voor de oppeppende woorden wanneer ik die nodig had. Ik hoop dat jij je carrière op de Universiteit nog verder mag en kan uitbouwen zodat je naast mij ook nog vele andere (doctoraat)studenten kan onderwijzen en begeleiden.

Freja, jij nam de taken van Delfien over als ze op zwangerschapsverlof was (wat toch wel twee keer in die 3,5 jaar is voorgekomen), je las dingen na die volledig buiten jouw eigen expertise lag, maar kon me toch telkens goede feedback verschaffen. Zelfs bij de eindspurt om mijn antwoorden op de vragen van de jury op tijd in te dienen, heb je me nog geholpen enkele dingen na te lezen ondanks je mijn doctoraat niet gelezen had. Ik was zo blij dat ik toen op jou kon rekenen, bedankt!

Jelle, ondanks je nooit de stempel van ‘begeleider’ hebt gekregen, was jij voor mijn onderzoek zelfs meer dan dat. Gezien onze gelijkaardige onderzoeken en jouw expertise, kon ik altijd bij je terecht voor een kleine of een grote vraag. Je was dan ook altijd bereid om me te helpen. Bedankt dat ik bij je terecht kon als het nodig was.

Ariane, ook jij was een collega die heel dicht bij mijn onderzoek stond, maar naast die collega werd je al snel een goed maateke van mij waardoor we zowel op professioneel vlak als erbuiten heel leuke tijden hebben beleefd (Londen en Zuid-Afrika). Naast de werk gerelateerde zaken was er altijd tijd voor een babbeltje. De laatste tijd zien we elkaar wat minder, is het druk voor je nieuwe job, maar dit weerhoud ons niet om contact te blijven houden en het is leuk dat we nog steeds op elkaar kunnen rekenen.

De collega’s van het HILO, te starten bij mijn eigen onderzoeksgroep (Maïté, Katrien, Marieke, Ann, Sofie, Sara, Vicky, Julie, Nele, Louise, Celien en Laurent) en de collega’s van het UZ (Hannah, Dorien, Linde en An-Sofie). Bedankt dat ik jullie mocht leren kennen, de leuke babbels, om de onderzoeksdagen aangenamer te maken, de loopjes en de leuke babybezoekjes; ik kijk al uit naar de volgende! Hannah, merci voor de mooie Zuid-Afrika reis! Prof. dr. Greet Cardon, bedankt om me te komen verassen met de standing desk! Sara, Nele en Femke bedankt voor jullie aanwezigheid op de bureau en een luisterend oor te bieden als het even nodig was om stoom af te blazen. Enkele recente HILO-verlaters en tegelijkertijd ook super collega’s (Sara, Veerle, Jolien, Griet en Cédric), het was leuk jullie nog te mogen leren kennen. Hoewel onze wegen nu verschillend zijn, zal het altijd fijn zijn jullie nog eens terug te zien.

Ook de collega’s uit de andere onderzoeksgroepen wil ik graag bedanken. Tine, Laura en Jasmien, allen uit hetzelfde afstudeerjaar; als dan geen band schept! Leuk dat we zo goed vertegenwoordigd zijn op het HILO en ik daar deel mocht van uitmaken; merci! Eline, Nadia, An, Rudie, en ook de jongkies die er onlangs zijn bijgekomen (Rud, Kevin, Senne, Kobe, Janne,…), bedankt voor de vele babbels, aanmoedigende woorden, toffe loopjes, en spetterende afterworks! De afgelopen HILO-weekends waren al super, laat die volgende maar komen!

Naast de collega’s, kunnen natuurlijk ‘mijn vrienden van thuis’ in dit dankwoord niet ontbreken. Elien, Heleen en Ilse; mijn maatjes van de jaren 90’. Topjaar, topvrienden en topwijven! Altijd kan ik op jullie rekenen voor een goede babbel en weet ik dat mijn diepste geheimen veilig zijn. De NOL’ers (Saar, Jana, Lore, Lisa, Casje, Koen, Simon, Elise, Kokkie,…) en KSA-vrienden bedankt om het weekend voor mijn interne zo aangenaam mogelijk te maken, losstaand van de nachtmerries die ik toen had. Met jullie erbij is een feestje altijd verzekerd, dus tijdens het weekend een stapje zetten met jullie was dan ook de ideale uitlaatklep voor mij. Bij jullie kan ik dan ook één en al mezelf zijn! Jana, bedankt voor de vele uitjes en je me nog even wat jonger laat voelen.

De LO-Ladies wil ik ook graag even persoonlijk bedanken, dankjewel voor de leuke en soms marginale weekendtripjes, de vele instuiven en gewoon jullie toffe gezelschap! Ook de boys van den LO mogen hier niet ontbreken en iedereen die daarmee in relatie staat. Merci voor de zalige tijd tijdens de opleiding, de kroegentochten, de openingsfuiven, de galabals, en alle andere onverwachte zotte feestjes.

De laatste woorden van mijn dankwoord gaan uit naar de belangrijkste mensen in mijn leven.

Mama en papa, een warmere thuis kan ik me niet voorstellen. Al van kinds af aan zijn wij erg verwend geweest en nog steeds! Mama, we hebben altijd over de middag thuis kunnen komen eten en de lekkerste vieruurtjes met thee stonden klaar om 16u10. Wij hebben nooit iets te kort gekomen. Papa, jij vond studieresultaten altijd heel belangrijk en was altijd enorm goed gezind als we met een goed rapport thuis kwamen. Hoewel punten niet alles zijn, was het leuk te voelen dat we jou daar zo blij konden mee maken. Jullie hebben ons altijd gestimuleerd om zoveel mogelijk uit te proberen tijdens onze vrije tijd (vele verschillende sporten, tekenschool, muziekles en zelfs dictie), taxi mama stond altijd klaar. Waar we uiteindelijk ook terecht kwamen, jullie stonden steeds achter ons keuze. Marie, Merlijn, Lukas en Melchior; jullie zijn één voor één toppers! Zus en broers, bedankt voor de fantastische kindertijd en alle mooie herinneringen die we hebben. Het is altijd leuk om terug thuis te komen en het is telkens opnieuw uitkijken naar de warme familiemomenten op zondagavond. Laat die reis maar komen!

Simon, mijn maateke en mijn liefje voor al meer dan 9 jaar. Alles begon met jou aan de start van onze studies LO. Ik was direct verkocht en dat kon ik moeilijk verbergen. We hebben de afgelopen 9 jaar prachtige momenten beleefd, mooie herinneringen opgebouwd, zalige tripjes gemaakt en uiteindelijk de stap gezet om samen te wonen en ons eigen huisje te kopen. Ondanks dat het me niet evident leek om mijn warme thuis te verlaten, kan ik nu wel met 1000% zekerheid zeggen dat ik mijn nieuwe warme thuis samen met jou gemaakt heb. Simon, dankjewel dat we samen mochten opgroeien en dat je mij mee hebt helpen vormen van een 18 jarige 'kiddo' tot een 'volwassen' vrouw. Ik kan nog steeds veel van je leren en jij bent dan ook de perfecte persoon om me even te temperen wanneer ik te koppig ben of wanneer ik er iets te snel zeg wat ik denk. Ook jouw mama en papa, je zussen en je familie mogen in dit dankwoord niet ontbreken. Jullie staan altijd klaar om te helpen en telkens kunnen we op jullie rekenen als het nodig is. Bedankt dat ik deel mag uitmaken van jullie mooie warme familie!

Simon, dankjewel om in mij te blijven geloven, me even te laten razen als het nodig was, een knuffel te geven als ik het even moeilijk had, het huishouden voor jouw rekening te nemen en me steeds positieve woorden in te fluisteren. Ik zou mijn leven niet meer met iemand anders willen delen. Laten we nog vele jaren bijdoen en ik kan je al verzekeren; je bent voor mij geslaagd als man.

Lieze

P.S. Zoek niet maar geniet!

December 2016