"BUILT AND SOCIAL ENVIRONMENT FACTORS ASSOCIATED WITH STAGES OF CHANGE OF CYCLING FOR TRANSPORT"

CASE STUDIES FROM THE PASTA PROJECT.

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ABSTRACT

Cycling for transport provides health and other benefits to participating individuals, wider society and the environment. In a European context, where the uptake of cycling is very varied, this thesis explores how built and social environment factors affect people's cycling behaviour. Using survey data from the European project Physical Activity through Sustainable Transport Approaches (PASTA), 7,684 participants from seven European cities were assigned to three behavioural stages of change based on the Transtheoretical Model and specifically defined for cycling for transport (Pre-contemplation = "Not thinking about cycling", Contemplation-Preparation = "Thinking about cycling" and Action-Maintenance = "Cycling"). A statistical model estimated the associations of built and social environment with the stages of change, controlling for socioeconomic status and city.

Elements in both the built and social environment have strong associations with the cycling stages of change. For built environment variables, effect sizes are greatest for comfort and for the perceptions of cycling facilities (cycle parking and changing facilities). For social environment variables, social support is the most important effect, and particularly for those not thinking about cycling. The model fits the data well and sensitivity analyses confirm the selection of variables and the generality of the findings across cities.

Policy recommendations are tailored to different groups: those who do not even think about cycling need to internalise the message that cycling can be safe and comfortable. For those considering cycling, comfort is important, but having access to parking and changing facilities would also help. Providing opportunities for both of these non-cycling groups to exchange views on cycling with people close to them who are already cycling will help them act. Policies should focus on making cycling for transport accessible for everyone by tailoring interventions targeting these different behavioural change groups.

DEDICATION

To my family.

In memory of my beloved grandmother Magdalena García Bermejo,
who died of Covid-19 in April 2020:
You rest in peace; we rest in your love.

The curves of the land were familiar somehow.
Yes: the ground was becoming level, as it should, and now, of course,
it was beginning to rise again.
A great green shadow came between him and the sun.
Niggle looked up, and fell off his bicycle.
Before him stood the Tree, his Tree, finished.

"Leaf by Niggle" (Tolkien, J.R.R., 1945)

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Thanks for the generosity of my dear sister Ana and her flatmates at the time, Marta and Almu, for hosting me in Barcelona during months while I was re-doing all my calculations, you have been amazing, and this was absolutely crucial for me.

Thanks to my dear friends: "el consejo de sabias" Mireya Riego, Mónica Lomeña and Ona Riera for being there for me, especially in the hard times. And to the Catalans in London, Anna Font, Jorgina Cuixart and Mònica Mayolas; it felt like a safety net.

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I credit part of my PhD wellbeing to the bicycles I have ridden during this time: Eudora (stolen), Epona (sold), Nera (my sister's bicycle that I borrowed while in Barcelona), and Ostara "Tari" (brought from London to Barcelona). They keep the secret of all my stress-release silly songs ;).

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This thesis is dedicated to my family, always supporting and encouraging me in every possible way. I will be the first PhD in the family. I love you, this is also yours.

In memory of Thierry Chessum, who gained his PhD in his sixties. My housemate and friend in Tufnell Park. I really miss our conversations. I am sorry I couldn't finish on time for you to read this.

This also goes to my dear friend Jing Li, who was in hospital for months, after being seriously injured in a cycling collision in London two years ago. I have learned so much from you, it is admirable how it is always pure joy to be around you.

My deepest wish is that my work in cycling mobility contributes to make our cities healthier, safer and more equitable for everyone.

STATEMENT OF AUTHORSHIP

I confirm that the thesis I am submitting is primarily my own work.

I confirm that:

1. This work was done wholly while in candidature for a research degree at this University;

2. Where I have consulted the published work of others, this is always clearly attributed;

3. Where I have quoted from the work of others, the source is always given. With the exception of such quotations, this thesis is entirely my own work;

4. Where the thesis is based on work done by myself jointly with others, I have made clear exactly what was done by others and what I have contributed myself;

5. None of this work has been published before submission.

Ester Anaya-Boig, January 2021

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0 GLOSSARY AND ABBREVIATIONS

Active Mobility Measure: An active mobility measure is an action undertaken in order to increase the level of active mobility (in a specified population). This ranges from changing urban infrastructure or introducing new policies to campaigns to change people's transport behaviour.

AIC (Akaike Information Criterion): is a technique based on in-sample fit to estimate the likelihood of a model to predict/estimate the future values. AIC provides a means for model selection; a good model is the one that has minimum AIC among all the other models (Akaike, 1974).

AM (Active mobility): Regular physical activity undertaken as a means of transport. It includes travel by foot, bicycle and other vehicles which require physical effort to get moving. Use of public transport is also included in the definition as it often involves some walking or cycling to pick-up and from drop-off points. It does not include walking, cycling or other physical activity that is undertaken for recreation purposes.

BE (Built Environment)

BSS (Bicycle Sharing Scheme)

CSC (Case-Study Cities): the PASTA research project was developed in seven cities, which are treated as case-studies. See section 1.2 for the relevant background characteristics for Active Mobility in these cities.

Cycle *n* : "cycle" has been used instead of bicycle when appropriate, in order to highlight that a bicycle is only one type of cycle. Diverse and inclusive cycling has shown that bicycles are not the only cycles used for mobility.

Cycling for Transport: Cycling undertaken as a means of transport from a place to another. (Can be dual purpose but MAIN purpose is means of transport). Travel individuals do to engage in activities in other places—work, recreation, shopping, health services.

Cyclist (see section 3.2.3.2)

MNL (Multinomial logistic): Multinomial logistic regression is used to model nominal outcome variables, in which the log odds of the outcomes are modelled as a linear combination of the predictor variables (UCLA: Statistical Consulting Group, 2020).

Mobility: The PASTA project partners decided to use Mobility in Active Mobility to show commitment to a broader concept of transport. The term mobility is defined as a contemporary paradigm in the social sciences that explores the movement of people, ideas and things, as well as the broader social implications of those movements (Urry, 2007).

OBE (Observed Built Environment)

PA (Physical activity): Any bodily movement produced by skeletal muscles that results in an increase of energy expenditure.

PASTA (Physical Activity through Sustainable Transport Approaches): European project, funded by the funding scheme Horizon 2020. The project started in November 2013 and finished in October 2017. The project featured an online survey the results of which have been analysed in this thesis. Information about the project can be found in Section 1.1.

PBC (Perceived Behavioural Control)

PBE (Perceived Built Environment)

RRR (Relative Risk Ratio)

SE (Social Environment)

SES (Socio-Economic Status)

SoC (Stages of Change): The use of capital letters in this phrase indicates that its meaning comes from a specific framework (the Transtheoretical Model of Behaviour Change) found in the literature.

TPB (Theory of Planned Behaviour)

TRA (Theory of Reasoned Action)

TTM (Transtheoretical Model of Behaviour Change)

1 INTRODUCTION

Cycling for transport is a form of mobility that can contribute to making our planet a healthier place. It has been proven that cycling for transport can increase the levels of physical activity (PA) (Foley *et al.*, 2015; Goodman, Sahlqvist & Ogilvie, 2014; Sahlqvist *et al.*, 2013), and the benefits are remarkable for human health (Humphreys, Goodman & Ogilvie, 2013). Cycling for transport is well suited to provide the levels of PA that the World Health Organisation recommends for adults, at least 150 minutes per week (de Nazelle *et al.*, 2011; World Health Organization, 2020). The benefits from PA are just one kind of the many benefits that cycling is known to provide for people's health and wellbeing (Mueller *et al.*, 2015; Avila-Palencia *et al.*, 2018), society (including the economy) (Gössling *et al.*, 2019), and the environment (Ayres, 2014).

Cycling is not available for everyone, which means all these benefits are not available either. Access to cycling has a material dimension – mainly built environment factors – but there are also behavioural factors that determine this access. Both psychosocial factors and the environment seem to influence peoples' behaviour towards cycling (Panter & Jones, 2010; Sallis *et al.*, 2006), the focus is on the two, the individual and the environment. To better understand how individuals make their choices, behavioural theories such as the Theory of Planned Behaviour (TPB) (Ajzen, 1991), and the Transtheoretical Model of behaviour change (TTM) (Prochaska & Diclemente, 1986) have been applied to cycling for transport in recent years (e.g. Forward, 2014; Muñoz, Monzon & Lois, 2013; Bird *et al.*, 2013). According to the TTM, behaviour change occurs over time in a gradual and continuous process, involving progress through a series of stages, the Stages of Change. This approach allows to match interventions to the different needs of the individuals in the different Stages. The Social Ecological Model of human development (Bronfenbrenner, 1977) was developed to widen the scope of behavioural theories and include the interrelations between individuals and the environment, adding the external environmental factors to the psychological approaches to behaviour. This thesis combines these theories and models and applies them to measure the effect of built and social environment on the Stages of Change as defined in the TTM.

This study was developed in Europe, where current urban mobility patterns provide ample potential to increase cycling for transport, although the situations at city level are highly diverse (European Commission, 2013). The variability of cycling uptake in different cities highlights the importance of contextual information such as the wider transport and transport policy backgrounds for a better understanding of research outcomes (Heinen, van Wee & Maat, 2010; Oosterhuis, 2016).

The built environment has a significant association with cycling. There is evidence to support that changes in the built environment have the potential to influence cycling behaviour (Song, Preston

& Brand, 2013). Well-designed and safe infrastructure is needed to facilitate a change towards cycling (Mertens *et al.*, 2016; Pucher, Dill & Handy, 2010) and thus make cycling accessible for as many people as possible.

The social environment can also be observed or perceived and it relates to the attitudes and behaviour of people surrounding the individual, in different levels of closeness and types of social interactions or engagements (family, friends, neighbours, workmates…). The cycling literature has highlights two types of social environment factors especially relevant for cycling behaviour, social norms or what an individual believes to be normal in their group (Ogilvie *et al.*, 2011; Muñoz, Monzon & Lois, 2013; Forward, 2014) and social support or the interpersonal exchange of aid and assistance (Titze *et al.*, 2008; Ma & Dill, 2015).

This research is developed at the intersection of transport, health and psychology on a quest to understand how the environment makes people more or less available for cycling for transport.

1.1 Background: the PASTA project

The project "Physical Activity Through Sustainable Transport Approaches", with the acronym "PASTA", was funded by the European Union's Seventh Framework Program. The PASTA project proposal was put together by 14 partners for the call FP7-HEALTH-2013-INNOVATION-1. Within this call, the proposal was framed in area 3, Optimising the delivery of healthcare to European citizens, sub-area 3.3 Health promotion and prevention and Topic 3.3.1 Social innovation for health promotion. This frame is important because, correspondingly, the project belongs to these areas and topics. The project started in November 2013 and finished at the end of October 2017. I started my collaboration with the project in February 2014 and supported the Centre for Environmental Policy - Imperial College London in its responsibilities as a partner of the project.

The PASTA project focused on the promotion and factors enabling active mobility (i.e. walking and cycling including in combination with public transport use) in cities as an innovative approach to integrate physical activity into our everyday lives.

The concept of PASTA was developed with thorough consideration of the broader state of promotion of active mobility in current European practice and the research thereof. The project addresses a range of challenges, which come to the fore, and evolve around the central questions of: "What are the determinants (correlates) of active mobility", "What are successful interventions to increase active mobility?", "How can active mobility be promoted effectively?", "What are the health gains of the promotion of active mobility?", "How can the evidence of the health gains from active mobility serve as an argument to advocate and justify investments in active mobility?" and "How to get all the relevant stakeholders' support?"

As such, the project identifies key challenges in three areas of research - a) the effectiveness of measures to promote active mobility and related framework conditions, b) improved understanding of correlates of active mobility and its effects on general physical activity and injury risk, c) Health impact assessments of active mobility as a crucial component to its success as an innovative approach to health promotion.

The consortium brought together a broad variety of disciplines and stakeholders aimed at linking cutting edge research with maximum impact on policies to enable and promote healthy physically active lifestyles. Within the project team and in the Advisory Board scientists and leading experts from a range of disciplines, including epidemiology, physiology, physical activity, public health, environmental sciences, climate change and energy, transport and urban planning, health impact assessment, and health and transport economics work together on the goals to generate knowledge on the effects of active mobility and their optimal promotion and implementation and to spread these findings among stakeholders and decision makers.

The main activities carried out by the project were:

- The core module of the study: an online longitudinal survey, tracking data from over 10,000 people in seven European cities, to assess the link between active mobility and the effect on physical activity, injury risk and exposure to air pollution. The survey consisted of a baseline questionnaire and follow-up questionnaires to be sent every two weeks. The survey was open for 27 months and participants could enter it anytime, on a rolling basis.
- The add-on module gathered a smaller sample of 122 people who took part in a study to track their commuting routes with GPS and measure their physical activity and the health effects of their exposure to air pollution with non-invasive methods.
- A series of workshops and interviews were carried out in the 7 case study cities, with practitioners form the transport and health sector. The idea behind these workshop and interviews was to look more closely at the link between promoting active mobility - like walking and cycling - and health in towns and cities and explore examples of cooperation among diverse sectors and city departments in charge for health, urban planning and transport.

The PASTA project also contributed to a new version of the Health economic assessment tool (HEAT) for walking and for cycling – a tool developed in 2008 by the World Health Organisation Regional Office for Europe (a partner of the PASTA project).

Amongst the outcomes of the project there are Best Practice Compilations, a glossary of terms and an indicator set to provide a common method to evaluate active mobility initiatives, several infographics and other guidance and dissemination materials.

Within the PASTA project, the Centre for Environmental Policy (CEP) – Imperial College London was one of the partners. The main involvement of CEP was in Work Package 3 of the project, also called Core Module, in which the survey and the health add-on were designed, implemented and analysed. But CEP also collaborated in other Work Packages dealing with Literature review, Case Studies and Good Practices, Stakeholder engagement, Policy and Dissemination.

I was involved mainly in the Core module, which is the main source of my data (see Methods chapter for more details), supporting the survey and the health add-on. But I also collaborated in the workshops and interviews and in the data collection and drafting for various project outcomes and deliverables.

Within the PASTA project, all partners were able to participate in publications. The publications in which I have collaborated can be found in the Appendix: Publications.

1.2 Study area: the seven Case-Study Cities

The PASTA project survey was released in seven Case-Study Cities (hereafter CSC): Antwerp in Belgium, Barcelona in Spain, London in the United Kingdom, Örebro in Sweden, Rome in Italy, Vienna in Austria and Zurich in Switzerland. These cities were selected based on the location of some of the study's partners.

In order to apply an in-depth evaluation framework (Gerike *et al.*, 2016), the relevant background information about the seven CSC was collected in the project by each of the local partners in charge. Imperial College London was responsible for the data collection in London. One of the aims of the evaluation was to capture the impact of built and social environment on people's Active Mobility behaviour.

I contributed to the collection of contextual information for London. The collection of the information for the remaining six cities was undertaken by the respective local partner and coordinated by the corresponding Work Package leaders: BOKU in Austria and ICLEI in Germany. Some of the information collected was used internally in the project Deliverables, of which the author of this thesis is a contributor; as this information was not published, from now on it will be simply referenced as "PASTA consortium". Factsheets for each of the cities were produced by the PASTA consortium and are available on the PASTA website: Antwerp (PASTA Consortium, 2018a), Barcelona (PASTA Consortium, 2018b), London (PASTA Consortium, 2018c), Örebro

(PASTA Consortium, 2018d), Rome (PASTA Consortium, 2018e), Vienna (PASTA Consortium, 2018f), Zurich (PASTA Consortium, 2018g).

A selection of the background information pertaining to the CSC collected by the PASTA consortium is presented in the following sections. Most of the figures presented in this section were collected at the beginning of the PASTA project, which is why dates from the sources range from 2011 to 2014 (these were the most up-to-date sources found by each partner in 2014). This contextual information has not been updated to ensure that it is representative of the landscape in each city in the year in which the survey was launched.

1.2.1 Population

The PASTA project CSC featured big and medium-sized cities (in European terms).

Table 1. Basic population statistics for each Case Study City.

Indicator	Antwerp (2014)	Barcelona (2014)	London (2014)	Örebro (2014)	Rome (2014)	Vienna (2014)	Zurich (2014)
Population [Thousands of inhabitants]	514	1,602	8,630	117	2,863	1,767	381
Area [km^2]	204	101	1,569	1,380	1,285	415	88
Density [inhabitants per km^2]	2,519	15,861	5,500	85	2,228	4,258	4,329

Sources: (Belgian statistical office, 2014; Institut d'Estadística de Catalunya, 2014; Italian Institute of Statistics, 2014; Lukacsy & Fendt, 2015; Office for National Statistics, 2014; Zurich Statistical Office, 2014; Swedish Government Statistics Office, 2014)

Most of the cities had similar population densities, whereas Barcelona's is higher and Örebro's lower. These figures are calculated over the total area of the municipality. It would have been more accurate to calculate the population density only of the urban area, but these figures were not available in all cases. Nevertheless, given the noticeable inconsistency of the Örebro value, further research was undertaken and the alternative value of 2,286 inhabitants per km^2 was found, which takes into account only Örebro's urban area (Statistics Sweden, 2020).

1.2.2 Transport provision and policies

The concept of "transport provision" gathers indicators about the provision of infrastructure and services for each mobility mode. Policy categories add information on restrictions or conditions of use for these services or infrastructures.

Table 2. Transport systems and services indicators collected by the PASTA project.

Indicator	Antwerp	Barcelona	London	Örebro	Rome	Vienna	Zurich
Road network [km]	1,649	1,362	n.s.	3,604	8,770	2,763	n.s.
Road pricing [y = yes/ n = no]	n	n	y	n	y	y	n
Parking fees [in € per hour]	0.5 – 1.6	1.8 – 3.0	n.s.	0.5 – 3.0	1.0 – 1.5	0.0 – 2.0	14 per day
PT network [km]	n.s.	1,747	n.s.	n.s.	2,323	794	280
PT annual ticket [price in €]	249	n.s.	1,820	800	250	365	665
Cycling network* [km]	n.s.	187	n.s.	215	254	1,223	340
Bike-sharing schemes [y = yes/ n = no]	Y	y	y	N	n	y	y

n.s., not specified - lack of comparable data; * Figures might include different types of cycling infrastructure, in the case of Vienna cycling routes and cycling against one-way traffic is included.

Sources: PASTA project consortium (Ajuntament de Barcelona, 2014; Carreno *et al.*, 2013; Gerència d'Hàbitat Urbà & Martí, 2014; Lukacsy & Fendt, 2015; Zürich & Amt, 2013; Office for National Statistics, 2013)

1.2.3 Transport demand

On the demand side of mobility, the modal split (the share of trips by mode) of the seven CSC is also very varied (Figure 1).

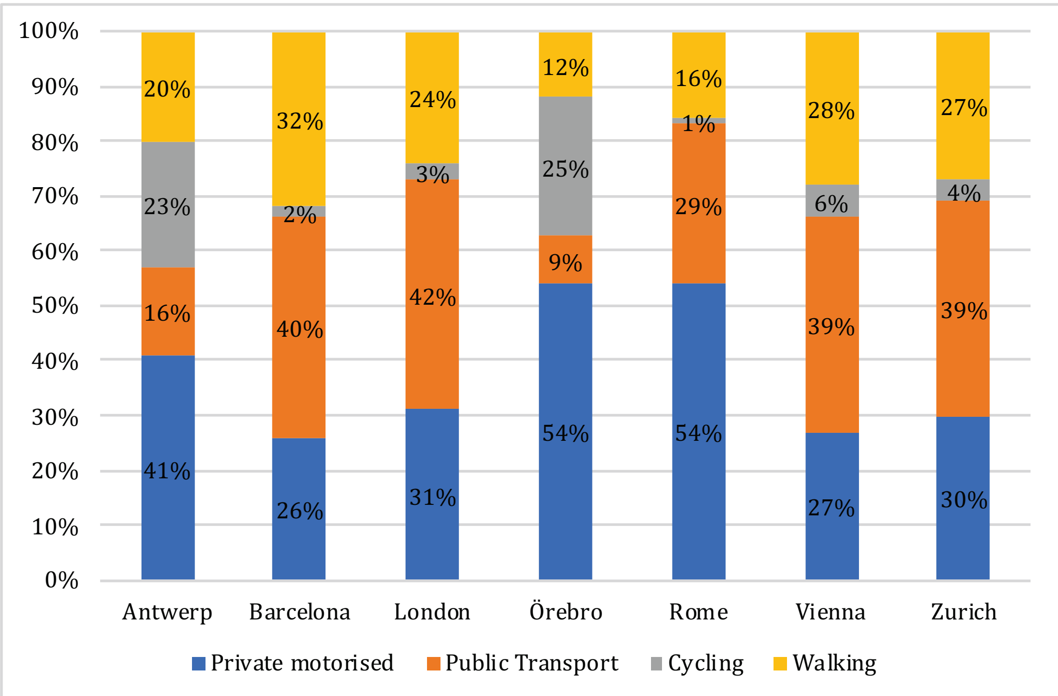


Figure 1. Modal split of the case study cities. Source: ibid. Table 2

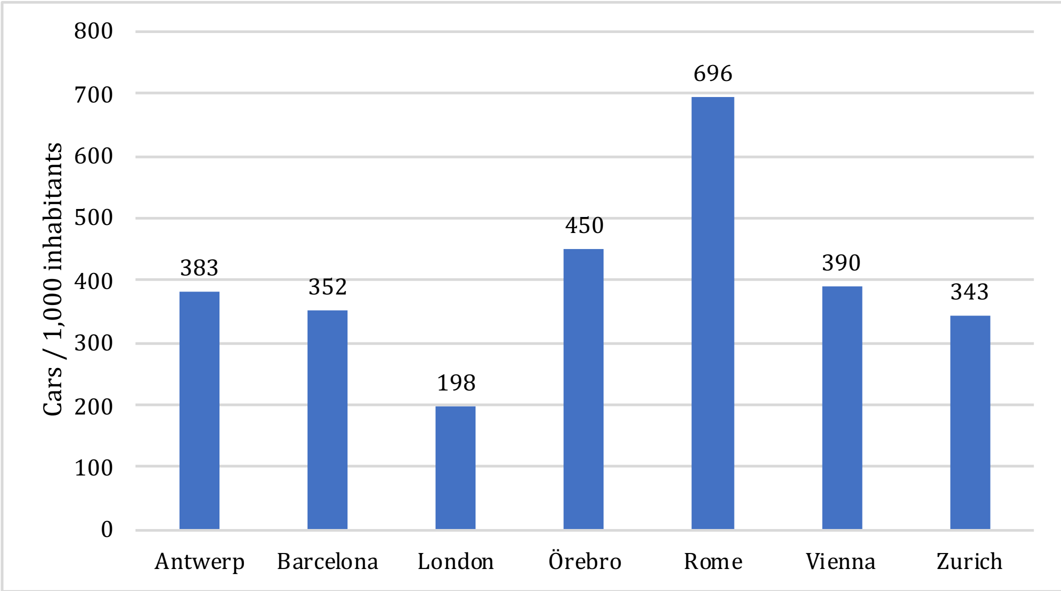


Figure 2. Car ownership in the case study cities. Sources: Ibid. Table 2

Antwerp and Örebro have the highest share of cyclists with around a quarter of trips made by bicycle, but at the same time they also have a high share of car traffic (Figure 1), high rates of car ownership (Figure 2), and low public transport modal share (Figure 1). No other city has a cycle share of more than 6%. Rome has the highest rate of car ownership and the lowest cycle modal split; London has the lowest car ownership rate. Public transport rates are high in Barcelona, London, Zurich and Vienna and are combined with low car ownership rates. Barcelona is the only CSC with more than a 30% share of walking trips, followed by Vienna, Zurich, London and Antwerp.

1.2.4 Road safety

The PASTA consortium published a health impact assessment of cycling network expansions in the seven CSC in which mortality impacts for changes in physical activity, air pollution and traffic incidents were quantified (Table 2; Mueller *et al.*, 2018). Building on this work, further data collection was undertaken in order to include two extra indicators of cycling safety: the number of injured cyclists (any severity) for the year 2014 (the launch of the survey) or the closest year that was found; and the number of injured cyclists per 10 billion kilometres cycled.

Note that the indicator of injured cyclists has certain limitations: there typically are unreported cases and its comparability might be compromised depending on whether it includes all kinds of crashes (including those involving other vehicles and pedestrians, and also cyclist falls, i.e. single vehicle collisions).

Table 3. Cycling safety in the seven PASTA Case-Study Cities

City	Antwerp[a]	Barcelona[b]	London[c]	Örebro[d]	Rome[e]	Vienna[f]	Zürich[g]
Cycling km/ year*	313,625,445	89,663,002	463,174,636	59,361,390	98,362,110	219,430,669	45,048,048
Fatalities/ year	4	3	13	1	4	3	1
Fatalities/ 10 bn km	13	33	28	17	41	14	22
Injured cyclists	193	672	5,132	212	271	913	242
Injured cyclists/ 10 bn km	615	7,495	11,080	3,571	2,755	4,161	5,372

*Estimated by Mueller et al. (2018)
Fatality data compiled for Mueller et al (2018 Table S.14):
[a]mean annual traffic fatalities by mode of transport 2011-2014 (Politie Antwerpen, 2014).
[b]mean annual traffic fatalities by mode of transport 2011-2015 (Agència de Salut Pública, 2016),
[c]annual traffic fatalities by mode of transport 2014 (Transport for London, 2015).
[d]annual traffic fatalities by mode of transport 2012 (Swedish Transport Board, 2012).
[e]annual traffic fatalities by mode of transport 2015 (Istituto nazionale di statistica, 2016).
[f]mean annual traffic fatalities by mode of transport 2010-2015 (Statistik Austria, 2015; Kuratorium für Verkehrssicherheit, 2014).
[g]annual traffic fatalities by mode of transport 2011 (Stadt Zürich Dienstabteilung Verkehr, 2011)

Cyclists injured (excluding fatalities and including any severity injury) compiled specifically for this thesis:
[a]Injured cyclists 2014 (Politie Antwerpen, 2015).
[b]Injured cyclists 2014 (Ajuntament de Barcelona, 2016).
[c]Injured cyclists 2014 (Transport for London, 2015).
[d]Injured cyclists 2014 (Swedish Transport Agency, 2020).
[e]Injured cyclists 2015 (Istituto nazionale di statistica, 2016).
[f] Injured cyclists 2013 (Stadt Wien, 2020).
[g] Injured cyclists 2014 (Stadt Zürich Dienstabteilung Verkehr, 2016).

Using the estimations that Mueller *et al.* (2018) proposed for kilometre cycled, London and Barcelona seemed to have the highest injury risks of the CSC. The lowest cycling injury risk, by far, was found in Antwerp, although Rome was the second lowest. Rome's injury risk might be surprising given the low cycling modal share (Figure 1) and the high fatality risk, so it could be due to under-reporting of non-fatal crashes.

1.3 Research aims and objectives

1.3.1 Aim

This thesis applies the Transtheoretical Model of Behaviour Change to cycling for transport. In this model, the individual finds themself in one of the five Stages of Change towards adopting and maintaining the behaviour of cycling for transport. The PASTA project provided built and social environment data for seven European cities, allowing a multi-centred, international study on the influence of the environment in cycling behaviour.

The aim of this research is to explore the built and social environment factors influencing people's Stages of Change for cycling for transport.

1.3.2 Objectives

- To assign participants to their Stage of Change and describe their socio-demographic and environmental characteristics.
- To analyse associations between built and social environment factors and the Stages of Change for cycling for transport.
- To provide policy recommendations based on the results of this study.

In order to deliver these objectives, the remainder of the document features a Literature Review chapter that will report on the conceptual approaches and environmental factors explored in previous studies, followed by Materials and Methods, and Results chapter. All of these chapters contribute mainly to the two first objectives, whereas the Discussion chapter also contributes to the third. Finally, a Conclusion chapter summarises the contribution of this thesis to all objectives and to scientific knowledge.

2 LITERATURE REVIEW

In line with the aim and objectives stated above, the exploration of the existing academic literature focuses on two areas: behavioural theories relevant to cycling to establish the conceptual framework, and factors associated with cycling for transport. This chapter establishes the state of knowledge in these research areas and supports an appropriate selection of the PASTA data relevant for this study.

Behavioural theories (Section 2.1) most frequently applied to cycling behaviour have been found to be the Theory of Planned Behaviour, the Social Ecological Model and the Transtheoretical Model of Behaviour. Researchers have applied and explored these theories in specific case studies, producing knowledge that will be evaluated and finally put in connection with the objectives in this thesis.

Factors associated with cycling for transport (Section 2.2) will be reviewed in three groups: first, and most basic, the socio-demographic factors included in published studies. Secondly, environmental factors are divided into built environment and social environment, and within each of these groups, the review will focus on the factors that the literature has found most relevant for cycling for transport.

2.1 Behavioural theories

As summarised in the paper reviewing conceptual frameworks of active mobility behaviour published by the PASTA consortium (Götschi *et al.*, 2017), there has recently been an exponential growth in active mobility research. A growing number of conceptual frameworks have been published since the early 2000s. Earlier frameworks were simpler and emphasized the distinction between environmental vs. individual factors, while more recent studies have proposed more complex travel behaviour theories. This section provides the grounds of a conceptual framework for this study, in line with the objectives of this thesis and the availability of data from the PASTA survey. It explores three health behaviour theories most frequently applied to cycling for transport in the literature: the Theory of Planned Behaviour (Section 2.1.1), the Socio-Ecological Model (Section 2.1.2) and the Transtheoretical Model of Behaviour Change (Section 2.1.3); and their application to cycling for transport, with mentions of physical activity, active mobility, or other mobility-relevant behaviours when appropriate.

2.1.1 The Theory of Planned Behaviour

The Theory of Planned Behaviour (TPB) details how the influences on an individual determine that individual's decision to follow a particular behaviour (Ajzen, 1991). This theory is an extension of the widely applied Theory of Reasoned Action (TRA; Ajzen & Fishbein, 1975). The

TPB suggests that the determinants of behaviour are intentions to engage in that behaviour and perceived behavioural control (PBC) over that behaviour.

Intentions represent a person's motivation in the sense of their conscious plan or decision to exert effort to perform the behaviour.

PBC is a person's expectancy that performance of the behaviour is within their control. The concept is similar to Bandura's (1982) concept of self-efficacy. PBC has an influence on which behaviour an individual chooses to pursue, how much effort they will put into that chosen behaviour and how they prepare for the activity (Ajzen, 1991).

For the TPB, this review will first summarise its theoretical basis, a model featuring a number of inter-related elements (Section 2.1.1.1); second, it will explore the literature applying the TPB to cycling for transport (Section 2.1.1.2), and third, some limitations and adjustments of this model that may be relevant in this case (Section 2.1.2.2).

2.1.1.1 Theoretical basis

According to the theory of planned behaviour (TPB), human action is guided by three kinds of belief:

- Beliefs about the likely consequences of the behaviour (behavioural beliefs): these produce a favourable or unfavourable attitude toward the behaviour
- Beliefs about the normative expectations of others (normative beliefs): these result in perceived social pressure or subjective norm
- Beliefs about the presence of factors that may further or hinder performance of the behaviour (control beliefs): which give rise to perceived behavioural control defined as the perceived ease or difficulty of performing the behaviour

In combination, attitude toward the behaviour, subjective norm, and perception of behavioural control lead to the formation of a behavioural intention. As a general rule, the more favourable the attitude and subjective norm, and the greater the perceived control, the stronger should be the person's intention to perform the behaviour in question. Intention is thus assumed to be the immediate antecedent of behaviour.

In other words, according to TPB, individuals are likely to intend to follow a particular health action if they believe that the behaviour will lead to particular outcomes which they value, if they believe that people whose views they value think they should carry out the behaviour, and if they feel that they have the necessary resources and opportunities to perform the behaviour. The three belief systems are linked to the extent that in people who are realistic about a behaviour's difficulty, a measure of PBC can serve as a proxy for actual control and can contribute to the prediction of the behaviour in question (see Ajzen, 1991). To this end, TPB is depicted as a multi-linear model, as can be seen in Figure 3:

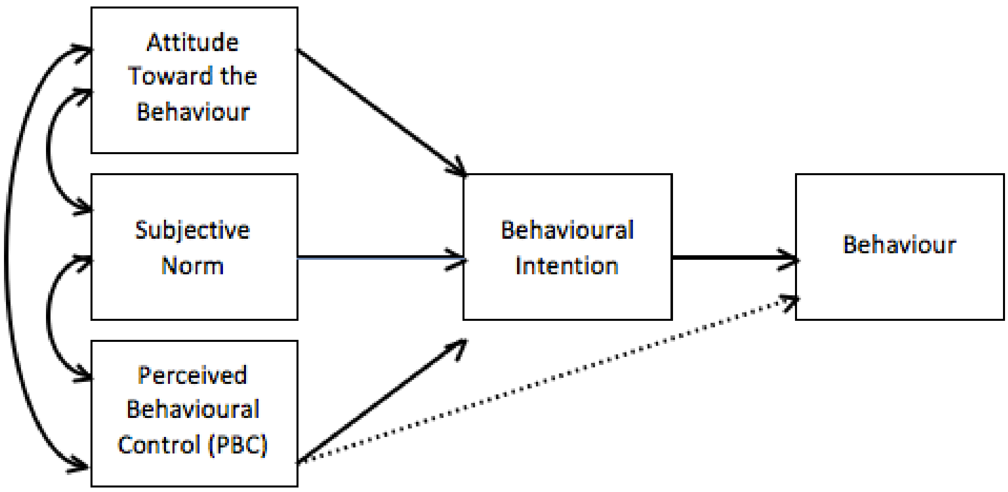


Figure 3. Theory of Planned Behaviour (TPB) Model. Adapted from Ajzen (1991)

Ajzen (1991) outlines the underlying causes for each of the influencing factors listed above, as being salient (accessible) beliefs. It would be too cognitively demanding for an individual to take account of each belief they hold about a behaviour and so beliefs that hold most influence are those that are most salient at the time (Ajzen, 1991).

According to TPB, it should be possible to influence intentions and behaviour by designing an intervention that has significant effects on one or more of the antecedent factors, that is, on attitudes toward the behaviour, subjective norms, and perceptions of behavioural control. The results of studies by Bamberg *et al.* (see below) demonstrate the utility of TPB as a conceptual framework for predicting travel mode choice and for understanding the effects of an intervention on this behaviour.

The work of Bamberg *et al.* (2011; 2003) supports the inclusion of all three psychological variables as factors affecting behavioural intention. Research carried out on the bus use of students travelling to university found that attitude, subjective norms and PBC all influenced students' intention to use buses (Bamberg, Ajzen & Schmidt, 2003). The introduction of a semester ticket was found to have an impact on all three psychological variables and subsequently strengthen the student's intention to use buses as their primary mode of transport.

2.1.1.2 TPB and cycling-related literature

The theory is frequently cited and has been used in numerous studies that aim to understand the root causes of pro-environmental or sustainable behaviour and also to assess the relative effect of each independent variable on behavioural intention. Scholars such as; Bamberg (Bamberg, 2013a; Bamberg *et al.*, 2011; Bamberg, Hunecke & Blöbaum, 2007; Bamberg, Ajzen & Schmidt, 2003), Gatersleben (2012) and Darnton (2008) have used the TPB to explain transport mode choice.

- Attitude towards behaviour: Heinen *et al.* (2011) assessed Dutch cycling commuters attitudes within the TPB framework. Results showed variance in attitude toward cycling over different distances commuted and this resulted from a difference in importance of behavioural beliefs for cyclists that commute over different distances.
- Subjective Norm: After Ajzen's publication of the TPB in 1991, other studies complemented his views and the TPB evolved, for example, adding Descriptive norm to the Subjective norm. In some of the later studies, Injunctive norm was understood as related or equivalent to Subjective norm. See Section 0 for a complete explanation and cycling-related literature for Subjective, Descriptive and Injunctive norms.
- Perceived Behavioural Control (PBC): PBC is governed by a set of control beliefs that can be based on past behavioural experiences and also information received from other individuals about the behaviour or action (Ajzen, 1991). PBC is therefore a complementary component of the TPB to subjective norms, whereby if an individual experiences another individual or group of individuals carrying out a given behaviour and they are able to identify the group or individual as being 'like themselves' then PBC will increase and the individual is more likely to carry out a given behaviour (Gatersleben & Appleton, 2007). Work by Goodman *et al.* (2014) on cycling behaviour shows that after the introduction of the London Cycle-Hire Scheme, individuals observed that others, like themselves, were cycling. This increased the number of recreational cyclists within the city as when individuals observed others like themselves cycling this meant that their PBC increased and so they themselves were more likely to cycle.

2.1.1.3 Limitations and adjustments to TPB

The TPB provides a simple framework for understanding individual behaviour, however, it has been accused of overlooking essential determinants of everyday behaviours and in such cases, modifications have been made to the model. There have been limitations noted and academics such as Ouellette & Wood (1998) have highlighted that TPB does not fully explain all variables that actually determine an individual's behaviour. For example, some authors Kahneman (2012), Thaler & Sunstein (2009), Jackson (2005), Klöckner & Matthies (2004) and Ouellette & Wood (1998) highlight how the TPB only takes into account behaviours that undergo cognitive reasoning; the theory assumes that all behaviours can be accounted for by an individual making a conscious decision. However, as Kahneman (2012) states, everyday human behaviours can be irrational and automatic. The TPB does not account for these types of processes.

Klöckner & Matthies (2004) researched individual car choice and it was noted how habit played a significant role in mode of transport choice – an automatic psychological variable that TPB does not account for. This is supported by work carried out by Donald *et al.* (2014) whereby habit is seen as a main contributory factor in determining commuter's transportation method.

Researchers have aimed to minimise the limitations of TPB by modifying the theory in order to explain the behaviours on which this thesis focuses. Authors have extended the theory in order to incorporate determinants of behaviour that are an essential addition to TPB in order for it to be representative of the target behaviour. Heath & Gifford (2002) included descriptive norms in TPB and found that the extended model was a better predictor of public transport usage and Heinen *et al.* (2011) included habit to help explain cycling behaviour. In a study by Anable (2005), whose research was focussed on individual travel mode choice, TPB was also extended to include habitual behaviour.

Further additions to TPB were moral norm, environmental attitudes, worldview and knowledge. As well as the additions of determinants of behaviour, Anable (2005) also modified the theory to develop the pre-existing determinants of behaviour to have definitions that are more specific for travel mode choice. These were: an identity norm that is a more precise definition of the subjective norm and self-efficacy as a development of PBC.

2.1.2 The Social Ecological Model

Bronfenbrenner (1977) developed the Social Ecological Model (SEM) as a result of the 'restricted scope' of experimental psychology. He observed that experiments were done outside of the context in which behaviours would usually take place, and so lacked validity. This prompted the development of a model that incorporated external influences.

The focus of Bronfenbrenner's research in 1977 was child development, however the model has more recently been used to help explain health related behaviours such as physical activity promotion by Sallis *et al.* (1998), Sallis *et al.* (2006) and Owen *et al.* (2011).

For the SEM, this review will first summarise its theoretical basis, a model considering several systems that influence behaviour (Section 2.1.2.1); and second, it will explore the literature applying the SEM to cycling for transport (Section 2.1.2.2).

2.1.2.1 Theoretical basis

Bronfenbrenner (1977) argued that in order to understand human development and human behaviour, researchers must consider the entire 'ecological system' of which individuals are a part. Bronfenbrenner (1977, 1993) structured his argument around the idea that human behaviour is a function of the complex interactions between an individual's psychological characteristics and the environment. The environment can be segmented into the proximal and the more distant environment and there are 34 environment changes that influence the individual depending on their proximity. The author (Bronfenbrenner, 1977, 1993) identified a series of interacting and reinforcing 'systems' that an individual is embedded within. Bronfenbrenner (1993) describes five influencing systems that include multiple behaviour variables. However, in more recent applications and descriptions of SEM only four systems are applied, the fifth influencing system is entitled 'chronosystems'; this takes into consideration time, where consistency over time in an individual's environmental setting helps govern the individual's behaviours. The other four systems are:

- The Microsystem or the 'individual' system includes proximal influences on an individual's behaviour such as the role of an individual in society, close family relationships, peer group relationships and psychological determinants of behaviour. The influencing factors that sit within the 'microsystem' are those that have been the focus of previous theories of behaviour described such as TPB. Bronfenbrenner describes the need to consider the microsystem but also take into account wider influences on behaviour.
- The Mesosystem or the interpersonal system takes into consideration the influence of interacting factors from the microsystem on an individual's behaviour. For example, the interpersonal system considers how a family member's experiences outside of the 'family unit' have an influence on another family member's behaviour and beliefs. Bronfenbrenner considers the mesosystem to be a 'system of microsystems'; key to this idea is the strong influence of an individual's behaviour on another individual's behaviour. In other theories of behaviour, these influences are categorised as social norms (McLeroy *et al.*, 1988).
- The Exosystem is also known as 'community' influences. Community influences result from the neighbourhood or environmental setting of an individual such as geographical bounds or local authorities. McLeroy *et al.* (1988) highlight the importance of taking into consideration the overall community setting that an individual is embedded within; if an intervention fails to include community relations, the acceptability of said intervention is likely to decrease. Influences on behaviour that result from a community system are: values, social norms, attitudes and external influences such as infrastructure (McLeroy *et al.*, 1988). The internal determinants of behaviour previously listed are psychological determinants, however, their consideration within the 'exosystem' supports

Bronfenbrenner's (1977) suggestion that each subsystem is interconnected, for example, where the infrastructure in place may have an effect on social norms.

- The Macrosystem is the collection of exosystems influencing an individual's behaviour and includes public policy and cultural influences on a behaviour such as physical activity (Bronfenbrenner, 1993; McLeroy *et al.*, 1988; Stokols, 1996). The model proposed by Gatersleben & Vlek (1998) takes into consideration that macrosystems can influence behaviour.

A key strength of SEM and a reason for which it has been employed in health behaviours is that it presents multiple levels at which an intervention can be targeted, encouraging those designing interventions to consider the wider influences on behaviour (Ogilvie *et al.*, 2011). This prevents significant determinants of behaviour from being overlooked and allows the understanding of interconnectivity of determinants of behaviour to act as 'levers to change' (Golden & Earp, 2012).

Ogilvie *et al.* (2011) indicate that an underlying strength to the SEM is the inclusion of the physical environment as an influencing factor on behaviour. As well as this strength, researchers such as McLeroy *et al.* (1988) highlight the model's inclusion of the relationship between an individual's behaviour and the social environment as a key strength. The theory does not provide definitive answers as to which specific determinant(s) of behaviour are most influential for the intervention's target behaviour, but it does provide a detailed framework of influencing factors that those designing the intervention can take into account.

2.1.2.2 SEM and cycling-related literature

The SEM has been previously applied to health behaviours and physical activity promotion by a number of researchers including Sallis et al (1998; 2008; 2006), Owen *et al.* (2006) and Ogilvie *et al.* (2011). For behaviours such as walking or cycling, for which environmental provisions need to be in place for the uptake of the behaviour, the SEM highlights multiple influencing factors on behaviour (McLeroy *et al.*, 1988). Ogilvie *et al.* (2011) state that SEM outlines how factors of a target behaviour interact rather than specifying how a particular intervention might lead to a change in this behaviour.

Ogilvie *et al.* (2011) altered the model designed by Saelens *et al.* (2003) by identifying differing components to psychological influences on 37 behaviours and allocating individual influences on behaviour to groups that Bronfenbrenner (1993, 1977) would have referred to as different systems. This demonstrates another strength of SEM, the ability for those evaluating the environment to treat the model as dynamic, with the ability to be adjusted to a given behaviour.

The SEM, due to its broad and all-encompassing nature, can be merged with pre-existing models of behaviour. Ogilvie *et al.*, (2011) did this by including behavioural intention and habit into the model. The research carried out focused on cycling and walking behaviour and is part of the iConnect study, which recognises that the infrastructure in place is one of the most important influencing factors on cycling and walking behaviours. Infrastructure can be adapted and influenced the most by policy makers (Ogilvie *et al.*, 2011; Saelens, Sallis & Frank, 2003).

The afore-mentioned research of Ogilvie *et al.* for the iConnect study also considers the wider effect of changing infrastructure. They state that the change in the physical environment may result in an increase in the individual's intention to cycle (Ogilvie *et al.*, 2011). It is then recognised that as cycling increases in frequency a 'positive feedback' loop is created by which a change in infrastructure results in an increase in frequency in cycling which then causes people's perception of the social environment to change (Ogilvie *et al.*, 2011). This new social norm results in more individuals cycling, as their peers appear to be cycling more frequently.

The structure of SEM allows this flow of events to be firstly predicted and secondly understood and the example from the iConnect study indicates how 'levers' do exist in this model, whereby changing the cycling infrastructure ultimately results in the formation of a new social norm (Golden & Earp, 2012). This supports McLeroy's (1988) statement, describing how behaviour and the social environment influence each other and that interventions are more likely to be successful when they operate within multiple levels of the SEM (Sallis *et al.*, 2006). The SEM's all-inclusive nature is a great strength of the model, but is also deemed its largest weakness (Ajzen, 1991). This is because there are a vast number of variables within the model that have a series of complex relationships.

2.1.3 The Transtheoretical Model of Behaviour Change

The Transtheoretical Model of Behaviour Change (TTM) is an example of a cross-theory model that can be applied to active transport interventions. The TTM takes into consideration time and the individual's progress through different Stages of Change (Prochaska & Velicer, 1997; Velicer *et al.*, 1999). It is based on the assumptions that (1) no single theory can account for the complexity of behaviour change; (2) behaviour change is a process that unfolds over time through several stages; (3) stages are stable and open to change; and (4) specific processes and principles of change should be used at specific stages to maximize the efficacy of behaviour change (Prochaska, Redding & Evers, 2015).

Many recent stage models are variations of TTM, which has dominated other stage theories due to its wide applicability: the TTM now has a robust history of empirical application across a range of behaviours.

This review will first summarise the theoretical basis of the TTM, a stage-based model in which different processes operate at the levels of the experiential and the behavioural constructs (Section 2.1.3.1). Limitations and criticisms of this model will be included in the theoretical section. Second, it will explore the literature applying the TTM to cycling for transport (Section 2.1.3.2),

2.1.3.1 Theoretical basis

The theoretical basis for the Stages approach to behaviour change mainly stems from DiClemente and Prochaska's work (1982), which was first to feature a model with only three stages. It evolved into a model with four stages (1986; Prochaska & DiClemente, 1982), and subsequently reached the most stable and commonly used conceptualisation of behavioural change as a transition through five stages in Prochaska's later work (Prochaska, Redding & Evers, 1997; Prochaska, DiClemente & Norcross, 1992; Prochaska & Velicer, 1997):

1) **Pre-contemplation** (Not ready): This stage is strongly defined by the lack of intention. People in this stage have no intention of taking any action in the foreseeable future. This might be due to several reasons, amongst them: having a lack of information or being mis-informed about the consequences of the Action; or having experienced unsuccessful attempts at changing than could have left them demoralized. Individuals in this situation can be referred to as resistant, unmotivated or unready.

2) **Contemplation** (Getting ready): People express their intention to change, and/or have realised that a change may be necessary. They have developed awareness about the advantages of changing but they are still too concerned about perceived or real disadvantages. They are coming to terms with the possibility of change but are still not ready to act. Individuals in this stage can get stuck in the ambivalence of the pros and cons and not be prepared to act immediately.

3) **Preparation** (Ready): The intention is formed to undertake the specific action in the near future. These individuals have a plan of action that has helped them remove barriers and get ready for action.

4) **Action**: People in this stage have made modifications to their lifestyle over the previous few months and there has been an actual behaviour change whereby the action is now

observable. The TTM is generally applied to study individual actions that have been widely proved to be beneficial to health, wider well-being or the environment.

5) **Maintenance**: in this stage, people have been sustaining a specific behaviour for some time. The change was made some time ago and they have grown increasingly more confident that they will maintain the change they made and continue with the acquired behaviour. The observed behaviour happens automatically. There is still the potential for relapse, if people become overconfident or they are influenced by an external event.

Some approaches also include a 'termination' stage, at which point it is assumed there will be no further stage changes. However, most applications omit this sixth step, considering that although maintenance implies long term behavioural stability, stage changes are still possible.

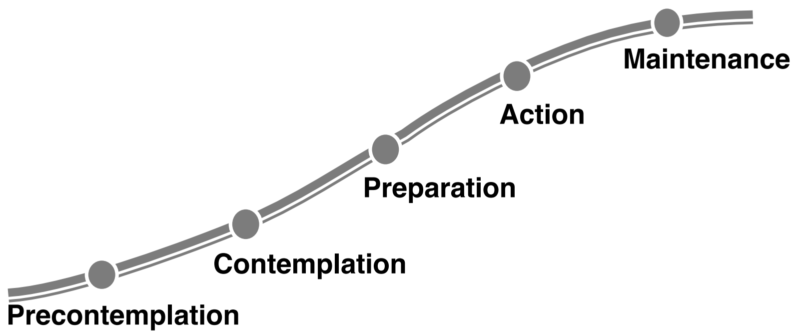


Figure 4. Stages of Change. Based on (Prochaska and Diclemente, 1986).

The transtheoretical approach also introduces a number of processes that influence the transitions between stages (Figure 5) and fall into two higher level constructs: experiential and behavioural. Processes in the experiential construct include:

- Consciousness Raising (Get the Facts)
- Dramatic Relief (Pay Attention to Feelings)
- Environmental re-evaluation (Notice Your Effect on Others)
- Social Liberation (Notice Public Support) Processes
- Self-re-evaluation (Create a New Self-Image)

Processes in the behavioural construct include:

- Self-Liberation (Make a Commitment)
- Helping Relationships (Get Support)
- Counter Conditioning (Use Substitutes)

- Reinforcement Management (Use Rewards)
- Stimulus Control (Manage Your Environment)

In addition, the theory describes two further constructs: self-efficacy (confidence that barriers can be overcome) and decision balance (weighing up pros and cons), each of which function as indicators of progress within the behaviour change process, as opposed to explanatory variables of stage transition. These two constructs influence behavioural change throughout the stages.

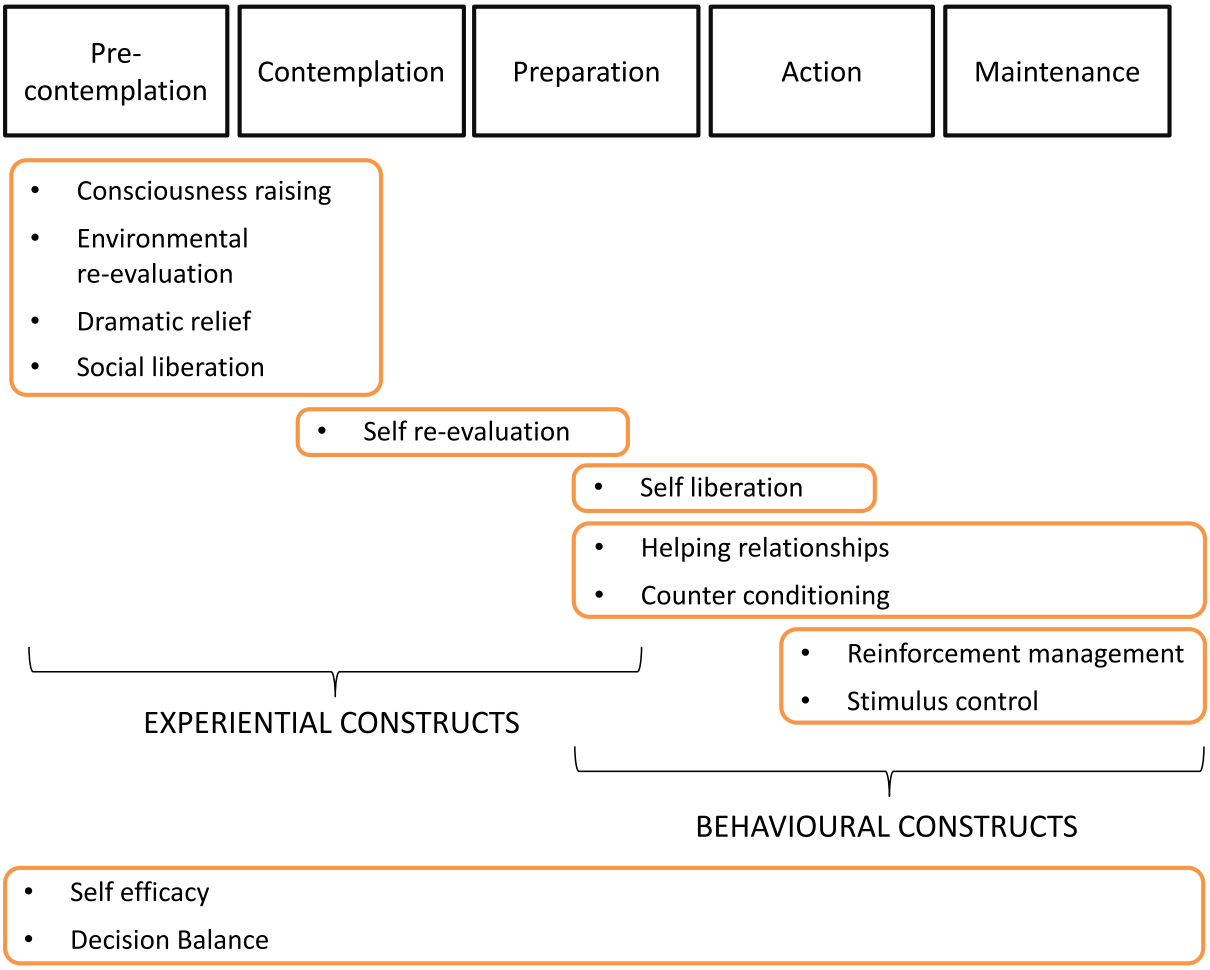


Figure 5. Constructs and processes that influence the transitions between Stages of Change. Source: adapted from ProChange (2019).

Changing by stages

The understanding of behaviour change as a dynamic process with several stages is not new. In 1944 the psychologist Kurt Lewin identified a model whereby individuals are understood to first pass through a motivational stage of intention setting followed by a volitional stage of intention striving, during which skills and strategies are developed. This approach has been adopted and developed by many subsequent studies, for example, in the Health Action Process Approach (HAPA) social-cognition model of health behaviour (Schwarzer *et al.*, 2003). The HAPA subdivides the volitional stage into sub-processes of initiation, maintenance and recovery. The HAPA model notably identifies self-efficacy as the most influential motivational factor and predictor of behavioural intentions for the motivational phase, and a key determinant of success in the volitional stage.

Other stage models include: the Precaution Adoption Process Model (Weinstein & Sandman, 2008), which describes seven stages of behaviour change for precautionary health behaviours: unaware, unengaged, undecided, decided not act / decided to act, action and maintenance; and the Model of Action Phases (Gollwitzer, 1990), which describes a horizontal path between desire and action through four phases: choice of action goal, plan execution, enact execution, and evaluation of efforts. In the context of the environmental sector, Bamberg (2013b) identifies three important stages of behavioural change: awareness, intention, and implementation and applies this in a study of motor car usage. Many later models (such as Bamberg's) are derivations of or amendments to the transtheoretical model. However, the diversity and range of stage models shows that categorisation of boundaries and appropriate stages can be adjusted or developed to suit the context. Many of the variations of stage theory models have been developed for a particular application: such as for preventative behaviours (attending health screenings, installing fire alarms, etc.) or for changing risky behaviour.

Overall, there are found to be four common elements of each of the stage theories, as proposed by Weinstein *et al.* (1998). Each stage theory is seen to have a category system to define the different stages, and an ordering of the stages (although most recognise that transition between stages can be bi-directional, and rapid progression by an individual may occasionally skip a stage). In addition, stage theories state that there are common barriers to change that will affect people who are in the same stage, and conversely that people in different stages will be affected by different barriers (or to a different degree).

Constructs: the role of self-efficacy and decision balance

Of the TTM constructs, self-efficacy and decision balance are found to be particularly influential. Self-efficacy is closely related to perceived behavioural control and is consistently found to be the most important single determinant at an individual level. It appears to be highly relevant at every stage of change, with indicators of self-efficacy in the targeted behaviour increasing with stage progression.

Decision balance is also influential across the different stages, although the mode of influence changes with stage progression, with a meta-analysis by Hall and Rossi (2008) suggesting that decisional balance tends to have the strongest relationship with the earlier Stages of Change. This supports earlier findings by Marshall and Biddle (2001) that the largest influence of behavioural ‘pros’ is observed between the Pre-contemplation and Contemplation Stages, and a more recent study by Forward (2014) which observed that perceived consequences become more positive and less negative as stages progress. This fits with the application of TTM to smoking cessation interventions, in which cons are more influential than pros in the early stages, and the reverse is true in the later stages (e.g. Velicer *et al.*, 1999).

Limitations and criticisms of the TTM

Though widely used, TTM is not without its critics. The TTM recognises that behaviour change is a continuous, often cyclical process, with different characteristics associated with different stages. However, by defining the Stages of Change, the model necessarily introduces boundaries between stages. As such, the model has been criticised for its simplification of complex processes, and for boundary definitions that do not take full account of underpinning psychological processes (e.g. Adams & White, 2005). However meta-analysis of the TTM’s application to physical activity and exercise behaviours (Marshall & Biddle, 2001) shows that in this context there are observable differences in behaviour even between pre-contemplation and contemplation stages, suggesting that the characterisation of distinct stages is indeed useful.

Other criticisms include the use of temporally sequenced stages, and the TTM’s limited ability to describe conscious decision making, as it is generally used to describe the results of an intervention and generally does not allow for inclusion of other conscious factors, such as rewards or punishments (West, 2005). However, such criticisms focus primarily on the application of TTM to smoking or other health behaviours. Its use within the context of active travel is relatively recent, and application in this area of behaviour is expected to overcome some of these limitations as the motivations and barriers affecting travel mode choice are very different to those influencing smoking behaviour (Nigg *et al.*, 2011). This suggests that the use of TTM in the context of active travel can yield very useful results.

However, it is also important to take into account that the papers mentioned in this section are related to physical activity behaviour in general and consider active mobility as just one of a mixture of diverse behaviours. In this way, a better assessment is required of the TTM constructs related specifically to cycling behaviour.

2.1.3.2 TTM and cycling-related literature

The TTM was first developed to examine changes in smoking behaviour, and then expanded to consider wider alcohol and drug use behaviours (Prochaska, DiClemente & Norcross, 1992). It has since been applied to a range of health behaviours in addition to smoking, including weight control, condom use (Prochaska *et al.*, 1994) and cancer screening behaviours (Eiser & Cole, 2002). Stages of Change models are well established both in public health and travel behaviour research and more recently, TTM has shown particular promise for application in the context of active mobility and specifically in cycling (Thigpen, 2014; Driller, Thigpen & Handy, 2014; Thigpen, Driller & Handy, 2015).

Policies focused on cycling have some commonalities with health programmes - cycling can benefit individual health, public health (through reduced air pollution) and the local environment; although the motivations and barriers are often more diverse and can make studies more complex. Typically, assessments of the impact of cycling interventions or related environment attempt to explain changes in actual behaviours, such as increased walking or cycling. This is often measured through self-reported number of trips, proportion of total travel behaviour, time spent on a given travel mode or self-identification of walking or cycling habits (e.g. shift from 'occasional' to 'regular' walker or cyclist). The application of TTM shows particular promise for this context, using a stage of change analysis, which can overcome some of the limitations associated with approaches that restrict its focus to cycling behaviour. The more complex psychological approach of TTM can contribute to better intervention design and policymaking.

Mutrie *et al.* (2002) were one of the first authors to apply a transtheoretical framework to active commuting, namely implementing and evaluating a walk to work promotion intervention (which also promoted cycling) through a randomised controlled trial. The Stages of Change were defined as:

- Pre-contemplation: no intention to become more active in the next 6 months
- Contemplation: thinking about becoming more active in commuting within the next 6 months
- Preparation: having a plan of action such as buying a cycle, or having attempted some active commuting, but not enough to meet 30 minutes on most days of the week
- Action: have become a regular active commuter, but only during the previous 6 months or less
- Maintenance: have achieved regular active commuting for longer than 6 months

Only subjects who were in the Contemplation or Preparation stages for active commuting were recruited, and these were randomly assigned to the intervention or control group. A significantly larger percentage of the intervention group progressed to higher stages of active commuting (49% versus 31%) compared to the control group. Factors around distance to work, age and gender did not seem to have an effect on this progression. In this study, only walking was successfully increased and significantly different between groups; cycling was not.

Gatersleben and Appleton (2007) applied the Stages of Change model to cycling to work, using the following classification:

- Pre-contemplation: have never used a cycle to travel to work and never considered using one
- Contemplation: have never used a cycle to travel to work, but considered (rarely, sometimes, or often) using one
- Preparedeness: has rarely or sometimes used a bicycle to travel to work and have rarely, sometimes or often considered using one
- Action: have often used a bicycle to travel to work
- Maintenance: have a history of using their bicycle to travel to and from work

They then assessed perception and attitudes on each of the Stages of Change, focusing on perceptions and perceptions on personal barriers (e.g., I am not fit enough to cycle, I would feel uncomfortable on a bicycle); external barriers (e.g. not enough cycle lanes, unsafe to cycle); and attitudes about walking / cycling (e.g., cycling is healthy, cycling is good for the environment).

As people progress from Pre-contemplation to Action it is seen that their attitudes towards cycling become more positive and their perceptions of barriers lessen. Most people do not even contemplate cycling, but some could be persuaded in the right circumstances. Only 7% of the sample (n=184) stated that under no circumstances would they be willing to cycle to work, with conditions (weather, terrain and facilities) being the most commonly stated barrier across the stages.

Van Bekkum *et al.*, (2011) used the same Stages of Change as in Mutrie (2002), but added the category: “I am a seasonal cyclist” (although this was excluded from analysis), and assessed how the perceived barriers varied according to Stage of Change. Potential barriers were rated using an 5-point Likert scale (“not discouraging”; “slightly discouraging”; “moderately discouraging”; “very discouraging”; “stops me from cycling”), and included items such as danger on the roads; bad weather; darkness; hilliness; exhaust fumes; distance from work; carrying belongings; storage at home; school run; time taken to cycle; changing and showering facilities; physical effort involved; storage at work; expense of buying a cycle; casual clothing; health problems; and lack of water proof clothing. Statistical analysis was performed on the results using a one-way ANOVA to assess whether perceptions differed by stage of change, with results suggesting that there are differences between the different stages. By stage of change, the most significant barriers were as follows:

- Respondents in pre-contemplation: danger on the roads, bad weather and darkness

- Respondents in contemplation, preparation and action: danger on the road, bad weather and natural terrain
- Respondents in maintenance: danger on the road, bad weather and manmade terrain

Overall, the most significant differences between Stages of Change were seen around danger on the roads, physical effort and natural terrain. Interestingly, while all respondents worked in the same (cycle friendly) workplace, their perceptions were still different.

A study by Thigpen *et al.* (2015) used the TTM approach to cycling commuting in UC Davis Campus, California. The environment was very cycle-friendly: 55% of individuals living in Davis or on the campus commuted by cycling and the city boasted over 100 miles of cycling paths in an area of roughly 10 square miles (26 km^2). In this cross-sectional analysis, data came from an online survey, with a sample size of 2,439 respondents. Individuals were divided into five Stages of Change based on the answers to four survey questions related to: frequency of cycling, main mode to commute to campus, willingness to cycle to campus and intention to cycle to campus in the next 6 months.

Factor analysis of 10 attitudinal questions found three underlying factors to explain respondents' Stages of Change: pro-cycling attitude, pro-automobile attitude and sense of safety. A multimodal logistic regression model of significant variables was then estimated from the data. Results show that attitudes toward bicycling and perception of barriers were important determinants of stage of change. Interestingly, age, gender, number of children and socioeconomic level were not identified as statistically influential.

Results show the explanatory variables most related to each stage, and the hypothetical effect of different kinds of policy interventions is measured for pre-contemplation individuals. Of all the interventions, the most effective intervention in moving individuals out of pre-contemplation stage is "Access to a bicycle", but none of the interventions manage to take individuals to the Action stage, let alone Maintenance. However cumulative effects of policy intervention scenarios on the probabilities of hypothetical individuals' being in each stage do take the individuals to Maintenance, with a minimum of four interventions needed to reach this point.

Even though this is a cross-sectional study in a cycle-friendly community, and the policy scenarios are hypothetical, the results suggest important aspects of Stage of Change in relation to policy interventions. One is that cumulative packages of intervention policies have a high probability of moving individuals to the Maintenance stage. Findings are also consistent with previous studies (Gatersleben & Appleton, 2007) suggesting that attitudes toward bicycling and perception of barriers are important determinants of the Stages of Change.

Taken together, these studies demonstrate the applicability of the TTM to cycling, and the evident differences between Stages of Change indicates that stage-tailored interventions could be particularly effective.

2.2 Factors associated with cycling for transport

This study aims at exploring the environment influences cycling behaviour. In the PASTA project, data regarding built and social environment was collected, allowing for the analysis of these two environmental dimensions.

Individual, socio-demographic factors need to be considered in order to account for basic differences that might affect people's behaviour (Section 2.2.1).

Built environment can be assessed objectively or by perceptions. Objective measures use geo-located information about the built environment (Section 2.2.2.1), whereas this same built environment generates perceptions of the different elements of cycling infrastructure, traffic safety, crime and comfort (Section 2.2.2.2).

The main aspects of social environment that have been found relevant for cycling (Section 2.2.3) are social norms (Section 2.2.3.1) and social support (Section 2.2.3.2).

2.2.1 Socio-demographic factors

There are a variety of socio-demographic factors that have been included in active mobility studies, for example, gender, age, physical ability, level of education, household income, household structure (and the presence, or otherwise, of children), vehicle access (to both car and non-motorised modes), driver's licence status, ethnicity, employment and working situation.

Handy *et al.* (2014) reviewed studies identifying key factors associated with transport cycling and found that socio-demographic characteristics have a strong connection to cycling, particularly gender, income and age. Aldred, Woodcock and Goodman (2015) explored the literature in search of research pertaining to gender and age. They found substantial variation in the broader Western European context in terms of gender and age differences in cycling participation. In low-cycling contexts there was a predominant prevalence of male cyclists, whereas in high-cycling contexts, no large differences exist, or women were over-represented. Authors argue that assessing age is especially important as the health benefits of cycling are the largest at older ages. In countries with higher levels of cycling, negative age gradients existed, but the proportion of trips cycled by those in the older age groups remained high. Declining use of cycles with age was more pronounced in low-cycling countries (Aldred, Woodcock & Goodman, 2015).

The influence of income on cycling is a complex issue. Heinen *et al.* (2010) report that having a high social status reduced the probability of cycling, based on studies from the United States (Moudon *et al.*, 2005) and Scotland (Ryley, 2006). In contrast, in a study exploring the differences between the 2001 and 2009 National Household Travel Surveys in the United States, Pucher *et al.* (2011) found that the highest income quartile experienced the biggest increase in cycling. This poses questions around equity and the role of the gentrification processes. The provision of safe and good-quality cycling infrastructure in lower-income neighbourhoods becomes important in order to compensate for these inequalities, as the potential health and economic benefits of cycling might be greater in lower-income communities (Noyes *et al.*, 2014).

In terms of employment status, studies in the Netherlands indicate that part-time workers commute more frequently by bicycle (Heinen, van Wee & Maat, 2010; Engbers & Hendriksen, 2010). Results from Heesch *et al.* (2014) for Brisbane, Australia, found the same pattern. Heinen *et al.* (2010) suggest this might be related to part-timers living closer to their workplaces, but there is a lack of evidence for this.

Heinen *et al.* (2010) argue that evidence for the relationship between cycling, age and income is mixed because most of the research simply uses survey results to draw links between socio-economic factors and cycling and the research tends not to examine whether any relationships found are causal, meaning that we are unable to draw any conclusions in this respect. Authors add that large differences exist between different countries, perhaps due to the impact of differences in countries' social and built environments, and economic circumstances.

Based on the findings of their literature review, Heinen *et al.* (2011) offered a cautious assessment of the importance of socio-economic factors: "There is a relationship between socio-economic factors and cycling to/from work, but we lack clarity on both the direction of this relationship, and its causality."

2.2.2 Built environment and cycling

The effects of the built environment on cycling behaviour have been studied by researchers in the fields of public health, epidemiology, transport and planning; as the selection of the literature cited in this section will show. The literature makes a distinction between Objective Built Environment, that is the existing characteristics of the physical environment; and Perceived Built Environment, or the subjective attributes people attach to it.

Studies that combine subjective walkability, such as those using the Neighborhood Environment Walkability Scale (NEWS) questionnaire developed by Cerin *et al.* (2006), with objective measurements, demonstrate that changes to both objective and self-reported neighbourhood characteristics have an effect on transport-related cycling behaviour (Beenackers *et al.*, 2012).

Both objective and perceived measures of the built environment are considered important as they provide insight into different relationships with the outcomes (Gebel *et al.*, 2015). For example, a range of social, economic and demographic factors are likely to influence individuals' perceptions of the built environment, which do not necessarily correspond to objective measures (Ma & Dill, 2015).

Furthermore, a study by Ma *et al.* (2014) shows that the relationship between objective and perceived environment for cycling might not be a direct one: "the direct effect of the objective environment on bicycling behaviour became insignificant when controlling for perception." The authors therefore concluded that the objective environment may only indirectly affect cycling behaviour by influencing perceptions. According to this research, an objectively good environment for bicycling is necessary but not sufficient for cycling.

2.2.2.1 Objective Built Environment

The way that an urban environment is designed can influence the propensity of inhabitants to participate in active transport (Sallis *et al.*, 2013; Aldred & Woodcock, 2008). Research suggests that neighbourhood design features that support bicycling and walking (i.e. have a high Bikeability and/or Walkability indices) not only increase cycling (Pucher, Dill & Handy, 2010) and walking (Eriksson *et al.*, 2012) but also neighbourhood-wide physical activity (Brown *et al.*, 2013). Specifically, higher urban density and mixed land use lead to a higher cycle share (Heinen, van Wee & Maat, 2010). Reviews of the correlates of cycle commuting highlight a need for a more comprehensive approach and focus on cycle-specific factors, particularly of the built environment (Heinen, van Wee & Maat, 2010; Saelens, Sallis & Frank, 2003).

Geographic information systems (GIS) have been helpful in analysing whether objective measures (physical features) of an urban environment, such as local topography, affect active transport participation (Krenn *et al.*, 2011; Evenson *et al.*, 2009). Positive associations have been shown between cycling behaviour and the physical and functional components of the urban environment, such as infrastructure, street connectivity and facility provision (Panter & Jones, 2010b; Molina-García, Castillo & Sallis, 2010; Titze *et al.*, 2008). According to a review by Heinen *et al.* (2010), cyclists prefer to cycle in environments in which cycle infrastructure is continuous and on roads with no car parking, and the preference is for dedicated infrastructure that implies as few stops as possible. However, they do not draw conclusions as to whether the presence and continuity of cycle infrastructure leads to more cycling or not. Results from the iConnect study (Ogilvie *et al.*, 2011, 2012) show that new walking and cycling infrastructure, while not having a noticeable effect on mode shift from car to walking and cycling (Brand, Goodman & Ogilvie, 2014) did have an effect on overall levels of physical activity (particularly among non-car users) (Goodman, Sahlqvist & Ogilvie, 2014; Sahlqvist *et al.*, 2013), although the infrastructure primarily attracted existing walkers and cyclists of higher socio-economic levels (Goodman *et al.*, 2013).

Some studies highlight the importance of cycling facilities such as cycle parking and showers. In their international review, Pucher, Dill & Handy (2010) highlight previous studies that showed shower facilities to have a significant impact on cycling to work. In another relevant review, Heinen, Maat & van Wee (2013) found that previous studies indicated that the presence of cycling facilities, such as showers and changing rooms, makes cycling more attractive. Buehler (2012) found that cycle parking and showers for cyclists were both related to higher levels of cycle commuting, even when controlling for other explanatory variables. Moreover, the odds for cycling to work were greater for employees with access to both showers for cyclists and cycle parking at work compared to those with just cycle parking, but no showers at work (Buehler, 2012), this was in line with previous studies assessing different packages of measures to promote cycling to work (Wardman, Tight & Page, 2007).

A Spanish study (Muñoz, Monzon & Lois, 2013) included parking at both origin (home) and destination (which includes work amongst other destinations), finding that safe parking at home was the most important perceived behavioural control factor, followed by physical fitness and safe parking at destination. This seems to indicate that the importance of cycling facilities such as parking and showers might be even higher than understood so far.

2.2.2.2 Perceived Built Environment

The existence and interaction of psychological and physical motivators and barriers require further investigation to inform active mobility policies (Panter & Jones, 2010a). For example, while it might seem most logical to invest in infrastructure such as cycle lanes and parking, some studies have found that physical barriers may not be the most discouraging to cycle commute participation (Nkurunziza *et al.*, 2012). Further, it has been stated that influencing personal perception rather than improving the physical environment itself may be relevant to changing behaviour (Dewulf *et al.*, 2012).

In comparison to motorised transport passengers, cycle commuters are more likely to report environmental elements such as aesthetics and air pollution, being these perceptions positive or negative (Panter & Jones, 2010b). It has been shown that non-cycle commuters perceive more barriers (and are therefore less motivated) to participate in cycle commuting than individuals of equivalent status who are already commuting by bicycle (Gatersleben & Appleton, 2007; de Geus *et al.*, 2008). The perception of ability (self-efficacy) to perform cycle commuting, and therefore the degree of participation, may also be influenced by cultural attitudes and road-use education (Willis, Manaugh & El-Geneidy, 2015).

It is interesting to note how the perceptions of the built environment can include micro-scale characteristics that are objectively very difficult to measure. In a paper discussing Walkability Index, Adkins *et al.* (2012) suggest that "micro-scale built environment characteristics influence user perceptions of quality". The evidence that micro-scale environmental attributes have an impact on cycling behaviour is growing (Mertens *et al.*, 2014; Soltani & Allan, 2006). The results of these studies indicate that if we measure the subjective perception of the built environment, we include the influence of the micro-scale built environment characteristics.

Perception of traffic or road safety

As a measure of the perception of the built infrastructure for cycling purposes, perceptions of safety are specifically relevant (Hull & O'Holleran, 2014). In terms of the relation between traffic safety and cycling behaviour, both objective and perceived traffic safety have been identified as crucial determinants of the decision to cycle (Jacobsen, Racioppi & Rutter, 2009; Sanders, 2015). Nevertheless, perceived ("subjective") traffic safety is not necessarily correlated with objective safety (Elvik & Bjørnskau, 2005).

Perceived traffic risk is consistently cited as a reason why people are reluctant to cycle more or even at all (Winters *et al.*, 2011; Sener, Eluru & Bhat, 2009). Sanders (2015) explored certain aspects of the variable and found that high levels of perceived traffic risk negatively influence the decision to cycle for potential and occasional cyclists, although this influence decreases with cycling frequency. In addition, cycling frequency seems to heighten awareness of traffic risk, particularly for cyclists who have experienced "near misses" or collisions. In particular, near misses were found to be more strongly associated than collisions with perceived traffic risk (Sanders, 2015).

As such, increasing perceptions of safety is primarily addressed through an effort to promote cycling. In most cases, increasing objective safety is certainly a necessary part of improving perceived safety, but it may not necessarily be sufficient. Other factors, such as providing (potential) cyclists with facilities and opportunities by which to gain positive experiences, including formal and informal learning and training options; protection from motorised traffic, such as trails and traffic calmed zones; as well as a general sense of public acceptance, support or even enthusiasm for cycling may be equally important in influencing the perceived safety of cycling (Pucher & Buehler, 2008).

Perception of security or crime safety

Titze *et al.* (2008) pointed out the need for the inclusion of crime safety in future studies as a potential relevant factor for cycling. The authors referenced the work of Cerin *et al.* (2006), in which the positive relationship found between walking for transport and the crime factor prompted the inclusion of this factor in the NEWS questionnaire. Despite Titze *et al.* highlighting the potential importance of crime for cycling, subsequent studies taking it into account have been scarce.

One of the first studies to assess perception of crime in relation to cycling was that of Geus *et al.* (2008), undertaken in a sample of 343 Flemish adults, though authors did not find any significant effects. Another of the very few studies analysing crime safety in cycling was published by Van Cauwenberg *et al.* (2012). The authors found a relationship between safety from crime and recreational cycling holds true for both males and females, but only for women in the case of cycling for transport.

Other studies seem to aggregate items of perception of road safety and perception of crime into the factor "safety". This is the case of a study by Winters *et al.* (2011), who analysed the results of a survey of 1,402 current and potential cyclists in Metro Vancouver. Of the 73 motivators and deterrents of cycling that were evaluated, the factor that had the most influence on likelihood of cycling was safety, followed by ease of cycling, weather conditions, route conditions, and interactions with motor vehicles. In this case, the factor "safety" aggregated several items, including "The risk of violent crime when cycling", which was found to be statistically strong.

Given that there is not much literature exploring crime safety in cycling, it is worth mentioning a few studies that have looked into objective crime safety and cycling. A study in Amsterdam (sample of 470 participants, aged 63-70 years old) using crime data from the police, found that cycling was negatively related to crime rates among both men and women living in low socio-economic status (SES) neighbourhoods (Kremers *et al.*, 2012). Later, in a study with a broader sample, Heesch *et al.* (2014) found that having low levels of crime in the neighbourhood was associated with utility cycling ($p < 0.05$) in a sample of 10,233 adults in Brisbane, aged 40-65 years.

Perceived comfort

Most studies assessing comfort compare different types of cycling infrastructure. Studies usually differentiate between dedicated cycling infrastructure, that is, space reserved exclusively for cycles, and shared roads or paths, in which cycle traffic mixes with motorised vehicles and/or pedestrians. Dedicated cycling infrastructure can be physically protected from traffic or just bounded by road markings. Perception of comfort can vary depending on the type of cycling infrastructure. Additionally, different studies define cycle comfort differently, though with a common inclination to relate it to safety.

Li *et al.* (2012) use the word ''comfort'' as a generic term reflecting the level of satisfaction a cyclist gets from using a facility, and introduce two ways in which this has been explored in the literature. The first is to evaluate the Bicycling Level of Service (e.g. measuring the volume and speed of vehicles and pavement conditions in an urban streets) and the other is to measure the hindrances encounter during travelling by bicycle (e.g. number of passing events and path width). The authors found that slope and high traffic volume, especially from heavy vehicles, but also including cycle traffic, were negatively associated with comfort, whereas all variables related to providing more space for cyclists were positively associated (Li *et al.*, 2012).

Dill and McNeil (2013) categorised Portland's cyclists and non-cyclists into four typologies and focused on the group "Interested but Concerned" to evaluate comfort in relation to a number of aspects. The group "Interested but Concerned" was assigned to participants who revealed intention to cycle more in the future. Results showed the need for cyclists to be separated from road traffic, concern about traffic volume and speed, lack of cycle infrastructure and destinations nearby, and time constraints as important for the increase of cycling in this group. These elements seem to be aligned with other findings to date. This study included many other aspects, such as clothing, helmet wear, presence of rain and darkness but they did not present results for all typologies. Even if they had, it would have been difficult to compare these aggregated categories to those in other studies.

In their study, Dill *et al.* (2014) explored gendered perceptions of several types of cycling infrastructure. They found that protected lanes were perceived to be more comfortable than unprotected lanes by both men and women, but women's level of agreement was stronger than men's. The authors stated that, "safety and comfort are related, but different concepts" and found that signals, signs, and streets markings were also important, especially in order to make it clear who has the right of way at intersections.

Unlike the previous authors, Hull and O'Holleran (2014) emphasise that "Comfort goes hand in hand with safety" and consider cycling to be comfortable when "The cycle infrastructure allows cycle traffic to circulate smoothly e.g. flat, smooth pavement, minimum of inclines". This study used a detailed template to benchmark the Level of Service provided to cyclists in six case study cities in the Netherlands and the United Kingdom and concluded that safety, comfort and continuity were the most important factors in the design of cycling infrastructure.

2.2.3 Social environment and cycling

An individual's Social Environment is defined as one's living and working environments and community characteristics and can be "experienced at multiple scales, often simultaneously, including households, kin networks, neighbourhoods, towns and cities, and regions" (Willis, Manaugh & El-Geneidy, 2015; Barnett & Casper, 2001).

This thesis focuses on the Social Environment constructs that the PASTA project featured in its survey: Social Norms and Social Support. There is some confusion in the literature around the definitions of the different constructs related to the social environment. The possible explanations for this are numerous; different behavioural theories define and use constructs in different ways, and papers might use one or several of these theories to compose their conceptual frameworks, mixing constructs and their definitions. Moreover, constructs need to be turned into statements in order to elaborate quantitative or qualitative studies (e.g. questions for surveys or interviews), and these questions vary considerately (see 3. Materials and methods). Furthermore, some studies aggregate some of the factors into one variable to use in the modelling, which makes it difficult to differentiate the effects of each of the constructs.

This section discusses Social Norms and Social support in detail, first discussing the evolution of the constructs and then moving on to discuss the literature pertaining to the construct and cycling.

2.2.3.1 Social Norms

A social norm is what people in a specific group believe to be normal in the group, that is, behaviour that is believed to be a typical action, an appropriate action, or both (Paluck *et al.*, 2010). Paluck and co-authors' (2010) definitions are based on the work of Cialdini and Prentice (e.g. Cialdini, 2009; Prentice, 2008) from which they note that an individuals' drive to fit in with their group is the starting place for understanding the power of Social Norms. That is to say, an individual's longing to be approved by others can be used to be a key motivator of behaviour change (Allcott, 2011).

In a study in two German cities, Bamberg *et al.* (2007) concluded that Social Norms had a large impact on people's intention to use public transport. This work highlighted the importance of understanding how Social Norms influence mobility behaviour.

There are two major types of Social Norms. One type of Social norm is a Descriptive norm or the perception of "where the group is". A Descriptive norm identifies the typical attitudes or behaviours of the group. The second type is an Injunctive norm, or the perception of "where the group should be". An Injunctive norm identifies the desirable attitudes or behaviours of a group.

Descriptive and Injunctive Norms imply a certain kind of social consensus (Kormos, Gifford & Brown, 2015; Paluck *et al.*, 2010).

Although they are often measured together as Social Norms, Jacobson *et al.* (2011), drawing on the theory of Normative Conduct (Cialdini, Kallgren & Reno, 1991), illustrated how Injunctive Norms and Descriptive Norms engage in different psychological response tendencies when made selectively salient. Other works have underlined that the fact that they are not being studied independently, makes it difficult to differentiate which of them has more influence on a specific behaviour (e.g. Gärling & Fujii, 2009; Flüchter, Wortmann & Fleisch, 2014).

The Social Norms analysed in this thesis are personal-level perceived Social Norms, that is to say that they refer to the individual's belief; as opposed to societal-level perceived Social Norms, which refers to the popularity and approval level of the behaviour in question in their society (Park & Smith, 2007). The PASTA project produced survey data and hence relates to the individually reported beliefs of the respondent.

Descriptive social norm

Descriptive Social Norms are an individual's perception of what normal behaviour is for individuals like themselves (Thøgersen, 2006). Cialdini *et al.* (Cialdini, 2009; 1991) state that Descriptive Norms are relevant in behaviour change as they provide an individual with a source of information about how they should behave under certain conditions. In questionnaires, statements for Descriptive Norms are generally observations about whether people cycle or not, and the statements used tend to be quite homogenous across studies.

For Ogilvie *et al.* (2011), a Descriptive social norm would be a mediator of behaviour change. This Social norm would indirectly influence those expected to change, when the change in behaviour of early adopters may change the social environment's conduciveness to the uptake of cycling by others (Ogilvie *et al.*, 2011).

In a study in Madrid (Spain), Muñoz *et al.* (2013) applied the framework of the TPB to assess the differences between cyclists and non-cyclists. The Descriptive Norm was assessed for several groups: young people, family, friends, colleagues and migrants, and asked how much participants think these groups of people use the bicycle for transport. The authors found that young people and people in general were the groups perceived to be cycling the most, whereas family were perceived to be cycling the least.

Goodman *et al.* (2014) carried out research on the Bicycle Sharing Scheme (BSS) in London and identified that a barrier to individuals cycling was the perception of who would normally cycle. The study noticed that the specialist clothing that individuals saw cyclists wearing resulted in perceptions of cycling being a sporty activity and not something that people like them would do. In contrast, however, the authors did find that the BSS encouraged individuals to cycle for transport around London.

Goodman *et al.* (2014) conceptualise the "normalisation" of a behaviour. If this concept were analysed from a behaviour change perspective, it would be related to Descriptive Social Norms. This would be in line with previous research indicating that seeing other people cycling could be crucial in encouraging individuals to try out cycling themselves (Fishman, Washington & Haworth, 2012) and that this applies particularly if the people seen cycling are 'people like yourself'.

Goodman *et al.*'s (2014) research shows that Descriptive Social Norms can be targeted in order to move people from the Pre-contemplation stage of the Transtheoretical Model to the Contemplation stage where, as they have seen individuals like themselves cycling, they themselves believe that they can cycle. This claim would be supported by Bamberg *et al.*'s work (2011), in which authors suggest that the key to encouraging individuals to change their behaviour is making desired Social Norms more salient during the early stages of behaviour change interventions.

Injunctive norm

In contrast to Descriptive Norms, which specify what is done, Injunctive Norms specify what should be done. Injunctive Norms are the perception of whether the behaviour receives approval or disapproval by others (Thøgersen, 2006). They constitute the moral rules of the group and they motivate action by promising social rewards and punishments (informal sanctions) for a specific behaviour (Reno, Cialdini & Kallgren, 1993; Cialdini, Kallgren & Reno, 1991).

In the Theory of Planned Behaviour, the only one of these Social constructs included in the original formulation of the theory was Subjective Norms (Ajzen, 1991). Ajzen's definition of Subjective Norms was "the perceived social pressure to perform or not to perform the behavior sic]". That same year, Cialdini *et al.* (1991) published their definition of Social Norms, which included Injunctive and Descriptive Norms. For Cialdini *et al.* (ibid.), Injunctive Norms were norms that characterize the perception of what most people approve or disapprove. Later on, Subjective Norms were sometimes viewed as some kind of Injunctive Norm (e.g. Lapinski and Rimal, 2005). Injunctive Norms were missing from the first elaboration of the TPB by Ajzen in 1991, but perhaps influenced by other publications, he later modified his theory to include them (Ajzen & Fishbein, 2005). As will be discussed below, cycling studies such as that of Muñoz *et al.* (2013) have used the updated TPB framework, using Subjective Norms (which can be assimilated to Injunctive) and Descriptive Norms.

Other views of these constructs coexisted in the literature applying or discussing the TPB. For example, Thøgersen's (2006) views were that Subjective Norms should actually be included as a type of Injunctive Norm. Conversely, some studies more directly related to cycling did not differentiate between the two constructs (Subjective Norms and Injunctive Norms) at all. In some situations the authors explicitly combined the two types of norm (Eriksson & Forward, 2011) and in others it was simply implied (Forward, 2014).

Park and Smith (2007) recognised this indiscriminate use of Subjective and Injunctive Norms in the literature, but they clarified the difference between them: "subjective norms (i.e., perceptions of important others' expectation for a given individual's behavior sic]), personal injunctive perceived norms (i.e., perceptions of important people's approval of a given individual's behavior sic]". The authors (ibid.) suggested that empirical tests were needed to answer whether, in a particular domain (they used the example of organ donation), these constructs were distinct from each other or not.

The confusion between Injunctive and Subjective Norms (Lapinski & Rimal, 2005; Thøgersen, 2006; Eriksson & Forward, 2011; Forward, 2014) might be caused by the difficulty differentiating judgemental statements from social expectations. For the purpose of this thesis judgemental statements were defined as Injunctive Norms statements and social expectations as Subjective Norms.

In this thesis, the term 'Injunctive Norms' is used to refer to one of the two types of Social Norms described by Cialdini *et al.* (1991) and is equivalent to the Personal Injunctive Perceived Norms, defined by Park and Smith (2007). Statements for Injunctive Norms explore social approval and usually ask for the respondents' judgement of whether cycling is perceived as being good or bad.

Please note from now on, this section will use the definition of Injunctive Norms provided above, rather than the name of the construct used in each of the cited papers, as this has proved to be confusing in the literature.

Cycling behaviour literature has not paid much attention to Injunctive Norms, many of the studies referenced for the other factors do not include them. Those studies including them often use the TPB and refer to them as Subjective Norms or use both construct names indistinctively (see introductory text to section 2.2.3.1).

Muñoz *et al.* (2013) asked how much other people would agree with the participant taking up cycling. In this study, the Injunctive Norm to commute by bicycle only appeared to be statistically significant between bicycle users. The construct was assessed in a disaggregated way, between family, friends and colleagues, and found that family agreeing with the decision to cycle had the most impact. In the previous section, it was mentioned that family was perceived at the social group that cycled the least in this same study, which unveils an important target group to address cycling promotion policies.

Forward (2014) applied the TPB, and compared it to the TTM, in a study that is very relevant to this thesis. The author measured the Injunctive Norm by asking the participants about the acceptability of their cycling according to the perceptions of three groups of significant others: partners, friends and colleagues. The author also measured attitudes, perceived behavioural control, descriptive norms, intention and habit. Of all these factors, Injunctive Norms were the most important, followed closely by habit. Injunctive Norms were increasingly significant in the Stages towards Preparation and stayed high in Action and Maintenance (Forward, 2014).

2.2.3.2 Social support

Social support is understood to be part of Social Influence (Gabriele *et al.*, 2005; Sherwin, Chatterjee & Jain, 2014) and is generally separated from (and often compared to) Social Norms (Ball *et al.*, 2010). Statements exploring Social support ask, amongst other things, about encouragement (Ball *et al.*, 2010; Titze *et al.*, 2008; Sallis *et al.*, 1987). These statements are often formulated to reflect the extent to which the respondent believes either that other people think they should/ought to behave in a specific way or that people encourage them to cycle. The "should/ought" premise could also be understood as an expectation and be used to assess Subjective Norms, but in this thesis this premise was labelled Social Support, in order to avoid confusion with Subjective Norms (E.g. as seen in Willis, Manaugh & El-Geneidy, 2015). Also, premises asking about encouragement are not clear in the way this encouragement is performed, for which reason it might help interpretation if a more specific statement is used.

Social Support is the provision of aid and assistance through interpersonal exchange and relationships. It can come in various forms such as emotional, motivational, instrumental, and informational support (ibid.). These forms can be categorized into two types: indirect or intangible (e.g., encouragement, discussion of the importance of a specific behaviour), and direct or tangible (e.g., watching or being active with the person) (Brunet *et al.*, 2014; Sherwin, Chatterjee & Jain, 2014; Beets, Cardinal & Alderman, 2010; Beets *et al.*, 2006).

Barrera (2000, 1986) also differentiates between perceived Social Support, which is essentially the belief or faith that support is available from network members; and actual support, its mobilization and expression. This thesis will focus on the PASTA survey questions related to perceived Social Support, specifically on encouragement, which was included in Sallis *et al.*'s measurement scale for social support (1987). Webb and Sheeran (2006) performed a meta-analysis of factors influencing behaviour change and they found that, within a wide range of factors, the effect size of encouragement was second only to that of incentives.

Barrera (1986) also noted that, depending on the study's purpose, it could be important to identify the sources of support in terms of different categories of social ties with people (e.g., family members, friends, neighbours), (Gottlieb & Bergen, 2010). In cycling studies it is common to find questions related to family and friends support, addressed either separately (Titze *et al.*, 2008) or together, as "people important to you" (Ma & Dill, 2015).

Results of a study in Flanders, Belgium (Geus *et al.*, 2008) show the importance of Social Support for cycling and walking among working-aged men in the country, particularly close family, but also friends. The results of this study also suggested that when people live in a setting with adequate cycle infrastructure, individual determinants such as the psychosocial (which include Social Support) outperform the role on behaviour of environmental determinants (Geus *et al.*, 2008).

The relationship between Social Support and other cycling behaviour factors has not been sufficiently explored, although there are some studies offering some light. Using a mailout questionnaire completed by 620 people in Sweden, Eriksson and Forward (2011) found that although many respondents believe their friends and family would support them cycling, they did not have strong Descriptive Norms for cycling (i.e., their friends and family do not themselves cycle for transportation).

2.3 Conclusions from the literature review

While applications of the TTM in the context of cycling are relatively new, the Stages of Change approach to describing, understanding and targeting behaviour change seems to show particular strengths for the evaluation of the built and social environment in relation to cycling for transport. Rather than considering cycling as a binary modal choice (to cycle or not to cycle) that changes from one day to the other, a more subtle approach would be to consider changes in behaviour as a gradual process, rather than as an event. By including an analysis of behavioural stages, such an approach could shed some light on the characteristics of people in each of the Stages of Change, and on what influences their affiliation to a particular Stage.

The Theory of Planned Behaviour highlights three components that might have an influence in behaviour change; Social Norms would influence the Intention, which eventually would lead to a behavioural response. As TPB shares some of these elements with TTM, the combination of both would offer a comprehensive approach to assess cycling behaviour change.

In line with SEM, the different systems could be taken into account, thanks to the available information in the PASTA project: the individual characteristics of the microsystem could be incorporated into the analysis as Socio-Economic Status variables; the mesosystem of interpersonal relations could be captured through the Perceived Social Environment variable of Social Support; the exosystem or community level could be integrated through the Perceived Social and Built Environment variables; the macrosystem could be represented by the Objective Built Environment indices and the geographical City variable, which is further documented with the context information provided in the Study Area Section. According to the SEM, each of these levels is expected to affect people's psychology and behaviour.

The literature is not conclusive about the impact of SES factors on cycling behaviour. Each of these SES factors seem to carry a significant level of complexity that advises against focusing too heavily on them. Nevertheless, there seems to be consensus in the literature that these factors are relevant for cycling behaviour and thus it be argued that they need to be controlled for in the models.

Finally, the studies that have been referenced in this review were based in different cities. Accounting for the location would help capturing Objective and Perceived environmental characteristics that are not in the models.

3 MATERIALS AND METHODS

This thesis was developed within the framework of the PASTA project which had its own prior study design (Dons *et al.*, 2015), based on a complex and comprehensive conceptual framework (Götschi *et al.*, 2017), and collected a wide range of data over the lifetime of the project (November 2013 – November 2017). The PASTA Baseline Questionnaire of the online survey (November 2014 – December 2016) is the primary data source used here.

The PASTA project survey featured behavioural questions related to, amongst other things, transport and health (Dons *et al.*, 2015). The project deliberately oversampled active travellers, to ensure a large enough population to produce statistically sound estimations about this population group. The sample allowed for a cross-sectional inferential analysis. This modelling exercise produced the core results of this thesis: the environmental correlates of the Stages of Change towards cycling for transport.

Originally, the intention was to undertake a longitudinal analysis with the specific purpose of assessing transitions between the Stages of Change. However, in spite of the recruitment efforts (Gaupp-Berghausen *et al.*, 2019), the sample did not allow for an inferential longitudinal analysis of sufficient statistical strength for this purpose.

The following flowchart summarises the study's research design and the different steps taken. These are described in this chapter:

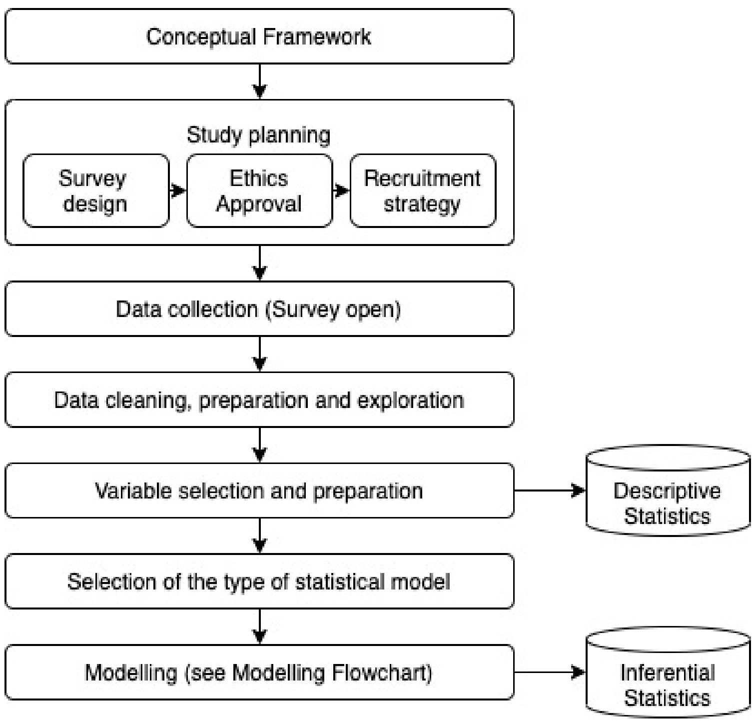


Figure 6. Sequence of research design, data collection and analyses

Details regarding the materials used in this study, mainly data from the European PASTA project, are found in Section 3.1. The conceptual framework that has shaped the research design in this thesis is described in Section 3.2 and is applied to produce the unique definition of the Stages of Change that has been used. The main methodological developments are related to the modelling exercise, detailed in Section 3.3.

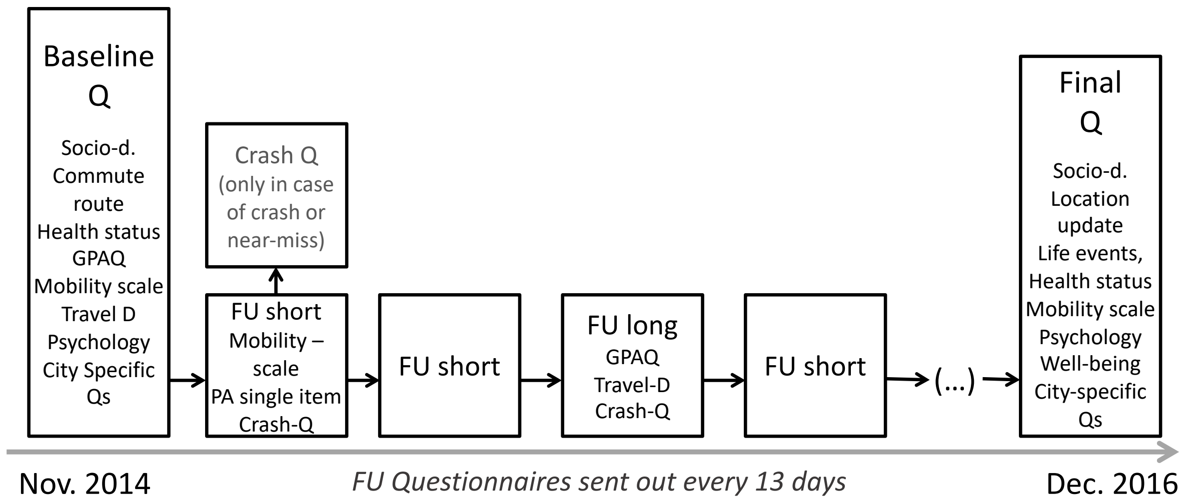
3.1 PASTA Project study design

The background information on the PASTA project can be found in Section 1.1. The following sections provide details about the European project as a source of the materials, specifically of the survey data. The primary data used in this study was produced through an online questionnaire that was part of a broader survey in the PASTA project (Section 3.1.1). The recruitment strategy is particularly useful to understand the characteristics of the sample (Section 3.1.2). Finally, details of the ethical approval of the PASTA survey are included (Section 3.1.3).

3.1.1 Survey design

The PASTA survey protocol was published by Dons *et al.* (2015), a paper on which I am a co-author. In brief, the PASTA survey used a longitudinal design, with a comprehensive baseline questionnaire, frequent follow-up questionnaires of two types (shorter and longer) and a final questionnaire. The questions were developed in English and then translated into Dutch, Swedish, Italian, German, Spanish and Catalan; I led the translation to the last two Iberian languages. The initial baseline questionnaire took approximately 30 minutes to complete and collected key socio-demographic, individual, household, health, attitudinal, behavioural and other variables that identified the person and provided information about their social context. The questions on frequency of use of different modes and the Global Physical Activity Questionnaire - GPAQ (WHO, 2019) gathered information on mobility and physical activity habits. A one-day travel diary captured detailed information about the trips the participant had made the previous day in detail (Raser *et al.*, 2018).

Thirteen days after completion of the baseline questionnaire, a short follow-up, five-minute questionnaire was sent to the participants asking about their physical activity and travel behaviour in the preceding seven days. The third follow-up questionnaire also included a one-day travel diary and took about 10 minutes to complete. If the participant reported having had a crash whilst using active mobility in one of the follow-ups, this prompted an additional crash questionnaire asking about crash circumstances, location, causes, injuries and other consequences. See Figure 7 for a representation of the survey questionnaires flow chart.



FU: Follow-up; Q: Questionnaire; Qs: Questions; PA: Physical Activity; Travel-D: Travel Diary, Socio-d: Socio-demographics; GPAQ: Global Physical Activity Questionnaire.

Figure 7. Questionnaire flow chart of the PASTA survey. Source: adapted from (Dons *et al.*, 2015).

Participants were recruited on a rolling basis and could join any time between November 2014 and November 2016. In November 2016 the Final Questionnaire was launched and was available to participants until December 2016.

The PASTA questionnaires are available on the project website: https://pastaproject.eu/fileadmin/editor-upload/sitecontent/City_survey/PASTA-questionnaires.pdf.

3.1.2 Recruitment strategy

Our work in Gaupp-Berghausen et al (2019) offers an overview of the PASTA project recruitment strategy. I participated in the design and implementation of this, including the local stakeholder engagement. The recruitment in London included a specific communication strategy for the London Borough of Newham. The borough was a partner of the PASTA project and their participation required an oversampling of population of that area, where Olympic legacy regeneration plans were expected to be put in place. An on-street furniture communication campaign was combined with rewarded computer sessions in the local community hubs, in order to reach lower income population, population with lack of computer access and literacy, language issues and ethnic minorities. This approach to recruitment made the sample more representative of the local community. As part of the opportunistic methods, a stakeholder engagement programme helped with disseminating the survey to relevant groups and institutions, which included Transport for London, the London Development Corporation, Sustrans, Living Streets, Active Newham and other. The fact that it was possible to use resources of the project for a more intense recruitment strategy in this borough contributed to the representativeness of the sample and resulted in London having a comparable sample size to the rest of the CSC in the project. As a representative of the other London-based partner, Imperial College London, I was part of the team that drafted and co-ordinated the local recruitment strategies.

In order to maximise the strengths of the study and to minimize the weaknesses a combination of different opportunistic recruitment methods was applied across the case-study cities. A standardized guide on recruitment strategy was developed for all cities in order to reach a sufficient number of participants and to ensure that participants were recruited across all cities by using the same methods, which included press releases, consistent design of promotional materials, translation of promotional materials to local languages, close collaboration with local stakeholders networks to distribute information, promotion of the study through social media and participation incentivisation through a prize lottery (except in the case of Örebro where lotteries were not permitted and compensated with applying a random sampling approach, using the resources of an existing project).

Participants were required to be of at least 18 years of age, except for in Zürich, where the minimum age was 16 years. The survey oversampled cyclists to ensure sufficient statistical power for analysis in cities with a low bicycling mode share (Raser *et al.*, 2018).

3.1.3 Ethics

For each partner city the relevant permission to collect, store and process data was obtained from the local ethics committees in the countries where the work was conducted and sent to the European Commission before the launch of the survey. The following committees approved the study:

- The ethics board of the University Hospital of Antwerp (Belgium) on October 20, 2014
- The Clinical Research Ethics Committee of the Municipal Health Care System (Barcelona – Spain) on October 1, 2014
- The Imperial College Research Ethics Committee (London – UK) on November 20, 2014
- The regional ethical board, situated at the University of Lund (Örebro – Sweden) on April 9, 2015
- RSM - Roma Servizi per la Mobilità and the Air Quality Commission of Roma Capitale Administration (Rome – Italy) on November 24, 2014
- The Austrian Data Processing Register (Vienna – Austria) on September 26, 2014
- Kantonale Ethikkommission Zürich (Switzerland) on October 28, 2014

For Imperial College London, I prepared and submitted the Ethics submission for the core module. The focus of this was on data handling and privacy in relation to the survey.

The protection of personal data is defined by national legislations and the European Directive, which changed during the project: the EU General Data Protection Regulation (GDPR) replaced the Data Protection Directive 95/46/EC on the protection of individuals with regard to the processing of personal data and on the free movement of such data.

The identity of participants is kept strictly confidential and stored securely in one place for all cities. Names are replaced by unique identifiers to anonymize the information. All participants had to agree explicitly to the conditions before registration. Data are strictly for scientific use.

The data used for these analyses is securely stored by the partner VITO (Belgium) and is in full compliance with current regulations.

On enrolment, participants registered on the PASTA website and gave informed consent through a Participant Information Sheet that introduced the PASTA survey (see p.2 of the PASTA survey https://pastaproject.eu/fileadmin/editor-upload/sitecontent/City_survey/PASTA-questionnaires.pdf).

3.2 Conceptual framework

This thesis focuses on understanding the influence of the environment on cycling behaviour. The literature review highlights the need to improve the evaluation of the impact of the built and social environments on cycling behaviour. Contextual aspects have also proved to be important to understand the environment influences cycling behaviour.

The conceptual framework of this thesis is framed by the European PASTA project conceptual framework. The following sections summarise the PASTA conceptual framework (Section 3.2.1), presents the selection of factors used for this thesis' conceptual framework (Section 3.2.2) and adapts the key operational concept used to measure behaviour change, the Stages of Change (Section 3.2.3).

3.2.1 The PASTA framework

The PASTA project conceptual framework is detailed in a paper by Götschi *et al.* (2017) (see Figure 8):

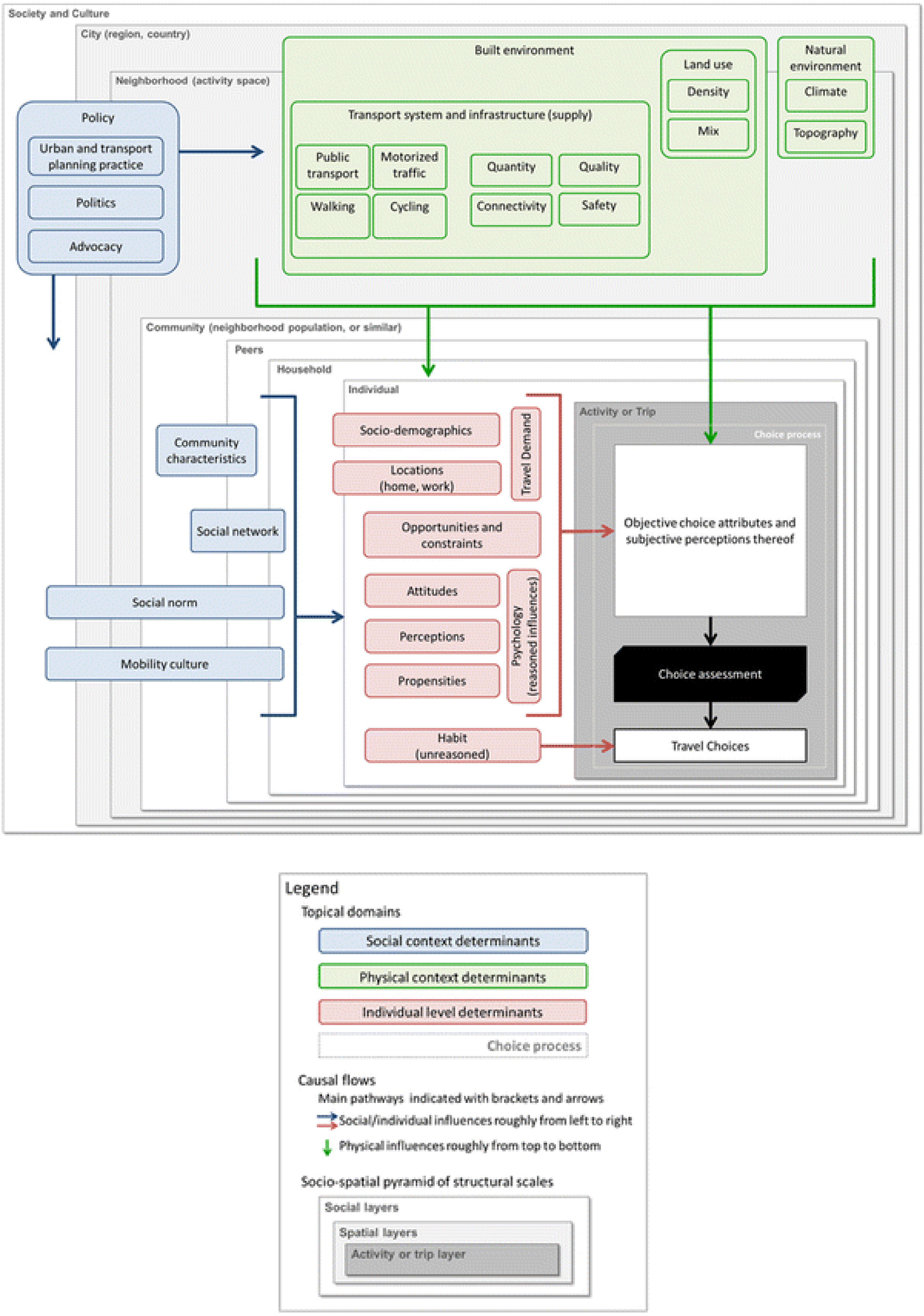


Figure 8. PASTA project framework. Source: PASTA project. Source: (Götschi *et al.*, 2017)

This framework was applied to the design of the PASTA project online survey, which is the primary data source that has been used in this thesis. See Section 3.1.1 for more details about the survey.

3.2.2 Selected factors from the PASTA framework

The PASTA project conceptual framework acted as an overarching framework for this thesis. The following figure simplifies and highlights the relevant components of the PASTA framework that are used in the conceptual framework of this thesis:

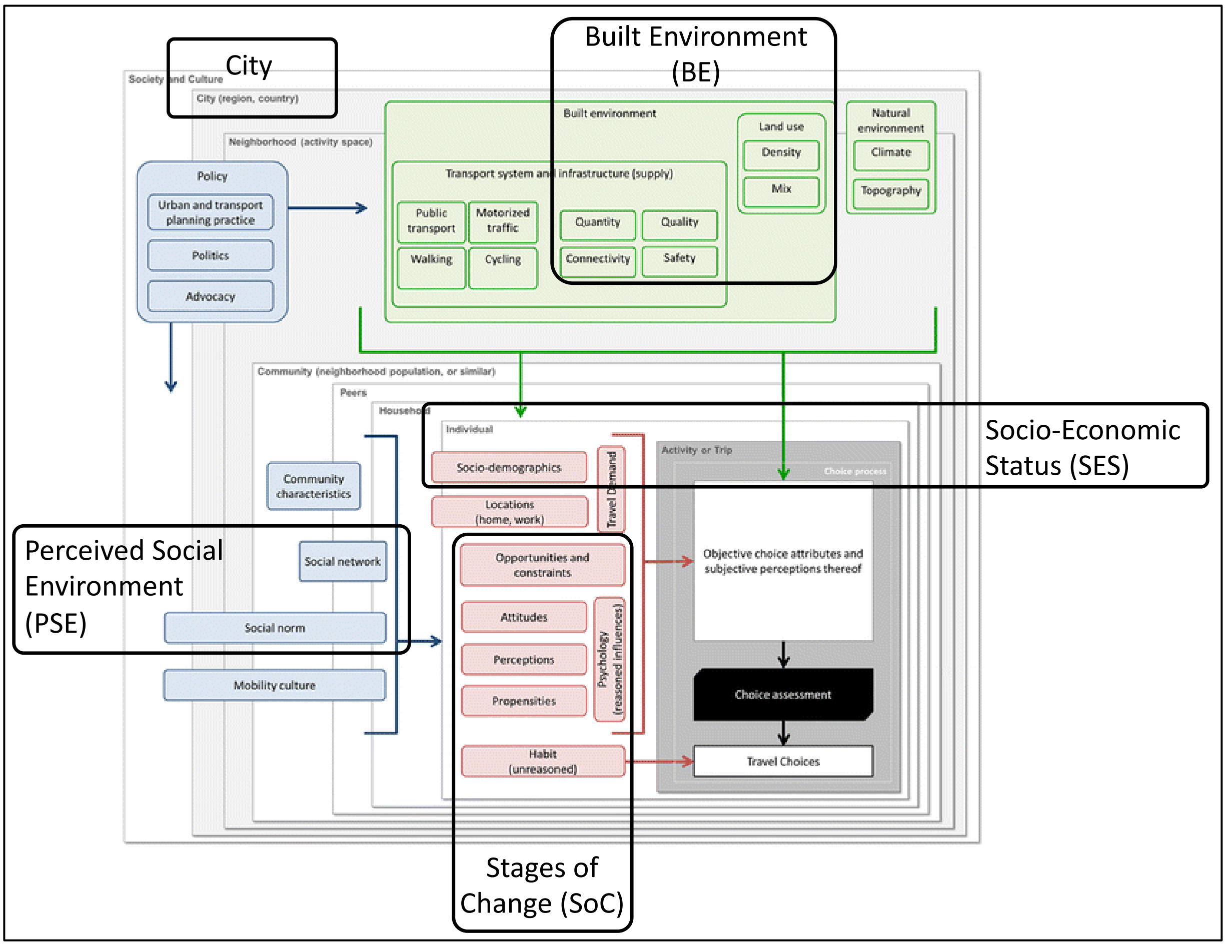


Figure 9. Selected factors from the main PASTA framework relevant to this thesis. Based on Götschi *et al.* (2017)

When exploring the associations between the built environment, social environment and personal factors and cycling as a mode of transportation, Titze *et al.* (2008) considered that "ecological models specify that physical environments, social-environments, and personal-level attributes may influence health behaviour." They further elaborate that ecological models are used to explain the complex array of factors that influence physical activity, resulting in greater emphasis on environmental correlates. The assumption is that behaviour can be better predicted when there is greater correspondence between a specific behavioural outcome measure and the specific environmental and personal variables hypothesized to be associated with that behaviour (Giles-Corti *et al.*, 2005). Consequently, behaviour-specific and context-specific ecological models can potentially be useful tools to help measure the influence of the environment on cycling behaviour.

3.2.3 Diagnosis of the Stages of Change

The Transtheoretical Model of Behaviour Change and the five Stages of Change (Prochaska et al. 1992) are described in detail in Section 2.1.3. The participants of the PASTA survey were diagnosed into the five different Stages of Change based on their responses to a specific set of questions that defined each of the stages.

I participated in the development of the questions used for the diagnosis of the Stages of Change during the early stages of the PASTA survey design. These questions were based on the literature, using the original definitions by Prochaska *et al.* (1992) of the Transtheoretical Model of Behaviour Change and its applications to cycling, as detailed in the Literature Review and further readings (Heinen, Kamruzzaman & Turrell, 2018; Thigpen, Driller & Handy, 2015; Handy, van Wee & Kroesen, 2014; Forward, 2014; Driller, Thigpen & Handy, 2014; Thigpen, 2014; Nkurunziza *et al.*, 2012; Bamberg, 2012; van Bekkum, Williams & Morris, 2011; Gatersleben & Appleton, 2007).

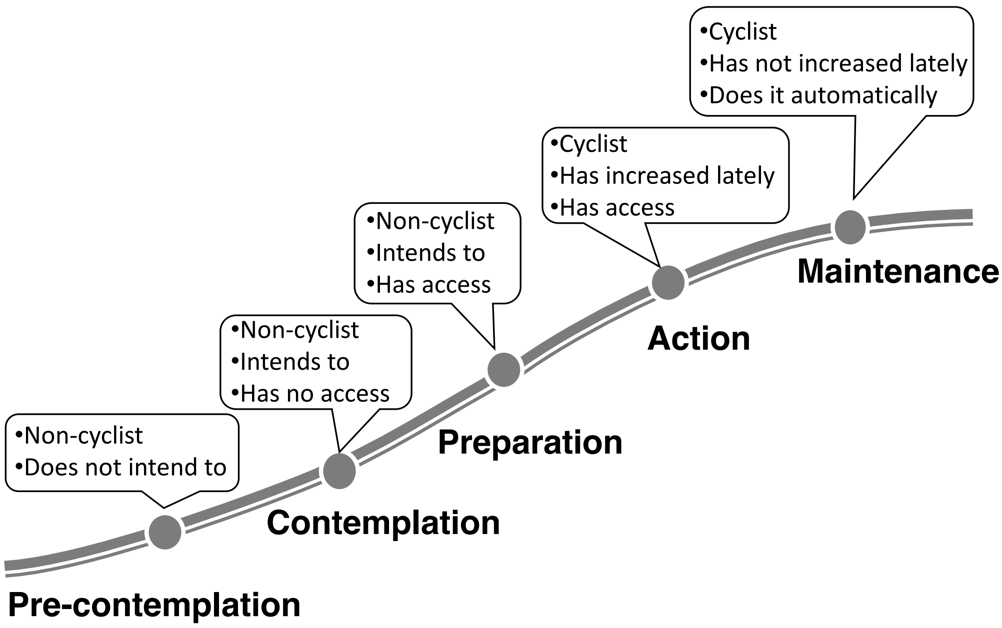


Figure 10. Participants were diagnosed to the Stages of Change based on their responses in the PASTA Baseline questionnaire.

As represented in the figure above, there were five variables used in the Stages of Change diagnosis, all of them coming from specific PASTA survey questions; "Access" (to a cycle) was a binomial question in the survey, and "Cyclist/Non cyclist" was defined based on the five levels of frequency of cycle use. The rest of the questions were converted from 5-point Likert scale answers in the original PASTA questions into 3-point Likert scale answers. The table below shows the questions from the PASTA survey that correspond to each variable. In some cases, the levels of the variables were aggregated to facilitate the diagnosis (Table 1).

Table 4. Details of the variables used in the Stages of Change diagnosis.

Variable	Question (when applicable)	Levels: *Original levels*	Levels: *Aggregated*
Cyclists	How often do you currently use each of the following methods of travel to get to and from places?	Daily or almost daily	Cyclist
		On 1-3 days per week	
		On 1-3 days per month	Non-cyclist
		Less than once per month	
		Never	
Intention	I intend to cycle more 'for travel' in the future	Very much disagree	Disagree
		Disagree	
		Neither Agree nor Disagree	n/a
		Agree	Agree
		Very much	
Access	Do you have access to a bicycle (private, or through a bike sharing scheme)?	Yes	
		No	
Increase	Over the last 12 months I have done more 'cycling for travel' than in previous years	Very much disagree	Disagree
		Disagree	
		Neither Agree nor Disagree	n/a
		Agree	Agree
		Very much	
Automatic	Cycling 'for travel' is something I do automatically without really thinking about it	Very much disagree	Disagree
		Disagree	
		Neither Agree nor Disagree	n/a
		Agree	Agree
		Very much	

The six following sections describe each of the variables in detail.

3.2.3.1 The 3-Level Stages of Change

To enable tractable modelling, the five levels of the Stages of Change were aggregated to three:

- Pre-contemplation,
- Contemplation-Preparation and
- Action-Maintenance.

This response variable simplification aimed to make the modelling parsimonious without compromising the informative quality of the results. A binomial variable was considered to provide too much simplification, a 3-level variable allowed the data to be simplified while still providing an understanding of the different Stages of Change of the PASTA population.

The simplification from the five or six (including Relapse) Stages of Change described by the TTM general literature into three levels is common in studies applying this model to cycling for transport, for example in the assessment of the change in commuters' habits undertaken by Shannon *et al.* (2006). More recently, Heinen *et al.* (2018), used the same aggregation as this thesis, from five into three levels, to explore correlates of stages of change in the use of the Brisbane bicycle-sharing scheme. In this study, they defined the three stages in this way:

- Pre-Contemplation: Individuals who had never used the BSS and who did not intend to use it in the future.
- Contemplation and Preparation: Individuals who had never used CityCycle, but who intended to use the scheme in the future, either occasionally or regularly.
- Action and Maintenance: Individuals who had used CityCycle (irrespective of future intentions).

The simplification of the five levels in three also responded to the conceptual adaptation of the TTM to cycling for transport. The blend of the two stages Contemplation and Preparation was motivated by the shared characteristic of individuals in these stages, the intention of cycling for transport in the future, which is a major psychological difference with Pre-contemplators. Action and Maintenance were both stages in which the behaviour of interest is considered to be in practice; individuals are effectively cycling for transport.

Figure 10 presents the responses to the questions that were used to define and diagnose the five different Stages that were then simplified into three, as shown in Figure 11. In this study, the simplification of the levels of the Stages of Change can be understood as follows:

- Pre-contemplation: "Not thinking about cycling"
- Contemplation-Preparation: "Thinking about cycling"
- Action-Maintenance: "Cycling"

Pre-contemplation and Contemplation-Preparation Stages might also be referred to as pre-Action Stages in this study.

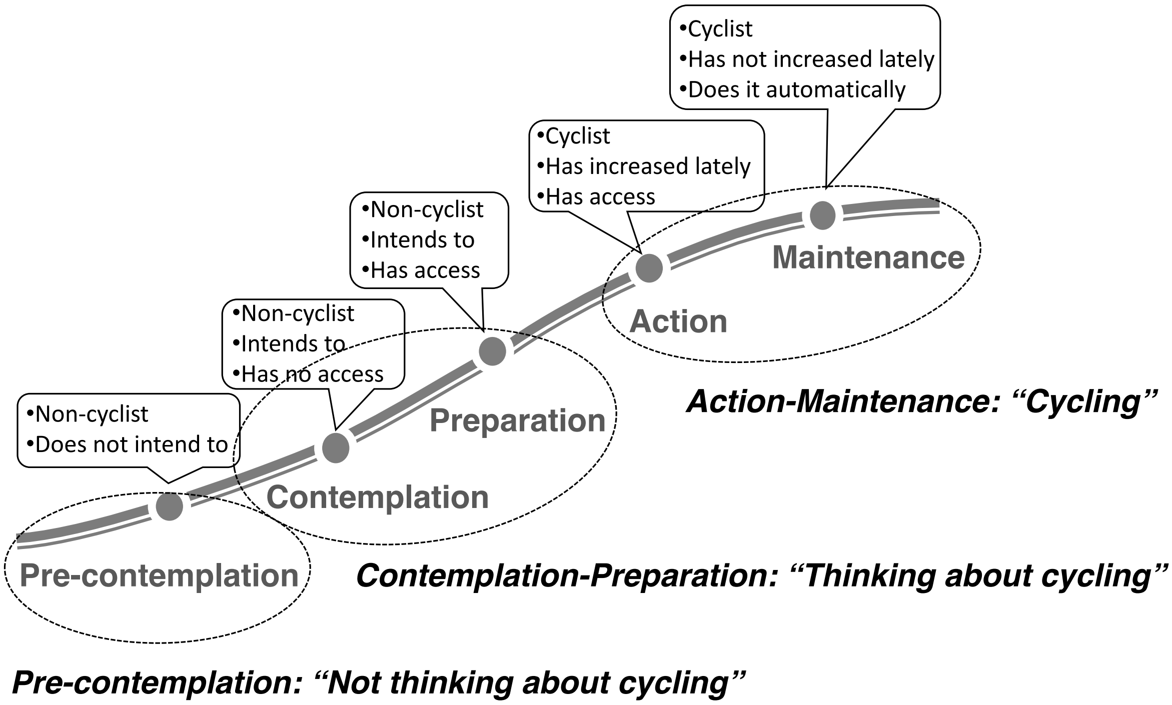


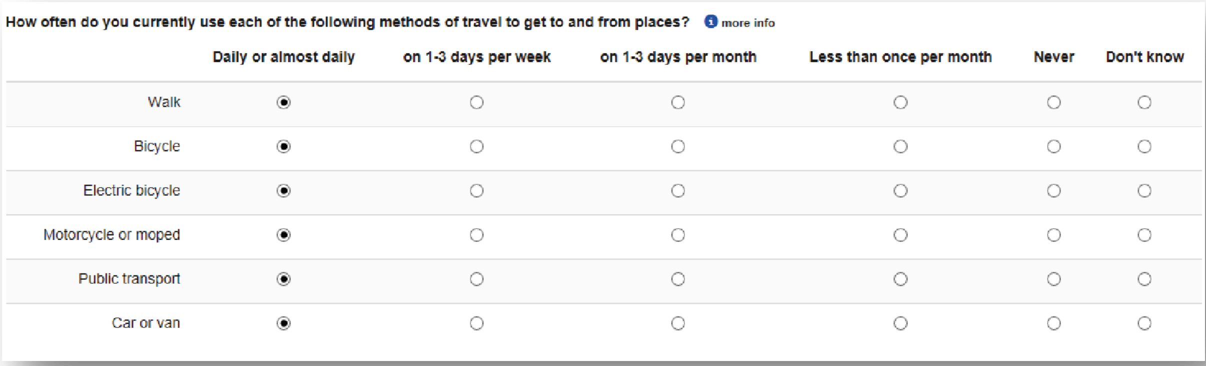
Figure 11. Simplification of the Stages of Change into three levels.

From this point onwards Stage(s) of Change refers to this simplified 3-Level approach unless stated otherwise.

3.2.3.2 The definition of cyclists and non-cyclists

The definition of the items "Cyclists" and "Non-cyclists" featured in the diagnosis of the Stages of Change was based on the concept of cycling for transport, in which people cycle one or more times per week. This binomial definition of cyclist was chosen because it was intended to identify participants who exhibited behaviour that indicated regular bicycle use for transport.

For mobility purposes, a cyclist had to cycle at least once a week to be defined as such, so "Cyclists" were those participants who cycled once a week or more and "Non-cyclists" were those who cycled less than once a week. This definition was based on the question "How often do you currently use each of the following methods of travel to get to and from places?".



How often do you currently use each of the following methods of travel to get to and from places? more info	Daily or almost daily	on 1-3 days per week	on 1-3 days per month	Less than once per month	Never	Don't know
Walk	◉	○	○	○	○	○
Bicycle	◉	○	○	○	○	○
Electric bicycle	◉	○	○	○	○	○
Motorcycle or moped	◉	○	○	○	○	○
Public transport	◉	○	○	○	○	○
Car or van	◉	○	○	○	○	○

Figure 12. Screen capture of the PASTA survey question that was used to define "Cyclists" and "Non-cyclists".

The answers for each of the "methods of travel" included five levels of intensity (Daily or almost daily, On 1-3 days per week, On 1-3 days per month, Less than once per month, Never) (Figure 12). Subjects in the two higher levels of 'Bicycle' travel intensity were assigned to "Cyclists" and the others to "Non cyclists" (Table 3). This definition of Cyclist is in line with those of other studies such as Park and Akar (2019), Maldonado-Hinarejos *et al.* (2014) or Sisson and Tudor-Locke (2008). This simplified binomial variable that was then used for the diagnosis of the Stages of Change (Figure 10).

Table 5. Baseline questionnaire question for the frequency of cycling and the binomial variable for cycling as transport derived from it.

<table>
<tr><th>PASTA Question:

How often do you currently use each of the following methods of travel to get to and from places? (Bicycle)</th><th>Binomial simplification for cycling as transport</th></tr>
<tr><td>Daily or almost daily</td><td rowspan="2">Cyclist</td></tr>
<tr><td>on 1-3 days per week</td></tr>
<tr><td>on 1-3 days per month</td><td rowspan="3">Non-cyclist</td></tr>
<tr><td>Less than once per month</td></tr>
<tr><td>Never</td></tr>
</table>

Cyclists were diagnosed as being in Action or Maintenance stage of the five Stages of Change and Non-Cyclists were diagnosed as being in the Pre-contemplation, Contemplation or Preparation Stages.

3.2.3.3 *Intention to cycle in the future*

All participants were asked about their intention to cycle in the future was included in the PASTA questionnaires using the affirmatory statement "I intend to cycle more 'for travel' in the future", answered through a 5-point Likert scale, as shown in Figure 12.

The 5-point Likert scale was converted into a 3-point Likert scale. The two positive points of the 5-point Likert scale (Very much agree and Agree) were assigned to Agree, and the two negative points (Disagree and Very much disagree) were assigned to Disagree. Responses on the neutral point were not relevant and were not aggregated.

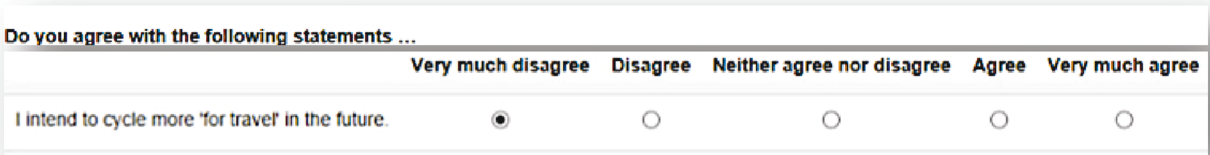


Figure 13. Screen capture of the PASTA survey question that was used to define intention to cycle in the future.

The participant's response regarding their intention to cycle was used to diagnose them into either Pre-contemplation stages ("Does not intend to" in Figure 10) or Contemplation and Preparation ("Intends to").

3.2.3.4 *Access to a bicycle*

The question about access to a bicycle included both the possibility of having access to a bike-sharing scheme or private ownership of a bicycle "Do you have access to a bicycle (private, or through a bike sharing scheme)?" (Figure 14).

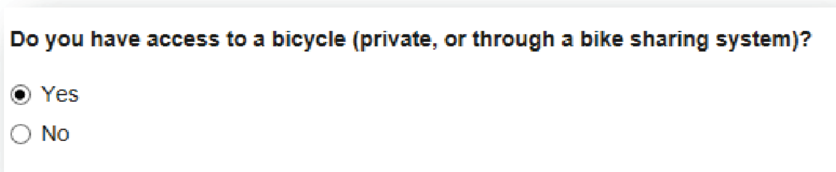


Figure 14. Screen capture of the PASTA survey question that was used to define the access to a bicycle.

People in Contemplation stage were defined as not having access to a bicycle, whereas people in Preparation and Action stated that they had access (Figure 10).

3.2.3.5 Increasing the levels of cycling over the previous 12 months

The question to find out if participants had increased their levels of cycling over the previous 12 months was included in the PASTA questionnaires with the affirmatory statement "Over the last 12 months I have done more 'cycling for travel' than in previous years", answered by a 5-point Likert scale (Figure 15).

The 5-point Likert scale was converted into a 3-point Likert scale. The two positive points of the 5-point Likert scale (Very much agree and Agree) were assigned to Agree, and the two negative points (Disagree and Very much disagree) were assigned to Disagree. The neutral point remained the same.

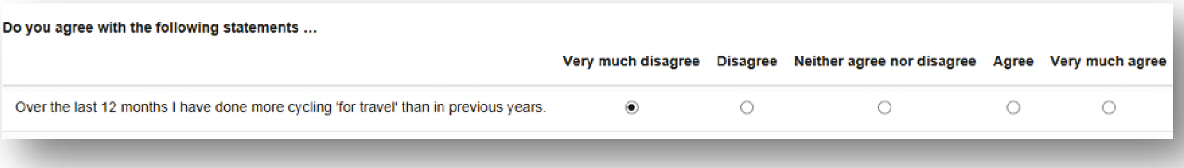


Figure 15. Screen capture of the PASTA survey question that was used to define increasing levels of cycling over the last 12 months.

Participants agreeing with having increased the level of cycling were identified as being in Action stage, whereas people in Maintenance did not agree with having increased their cycling levels lately (Figure 10).

3.2.3.6 Cycling is done automatically

The question to define whether participants cycled automatically was included in the PASTA questionnaires with the affirmatory statement "Cycling 'for travel' is something I do automatically without really thinking about it", answered by a 5-point Likert scale as shown in Figure 15.

Again, the 5-point Likert scale was converted into a 3-point Likert scale. The two positive points of the 5-point Likert scale (Very much agree and Agree) were assigned to Agree, and the two negative points (Disagree and Very much disagree) were assigned to Disagree. The neutral point remained the same.

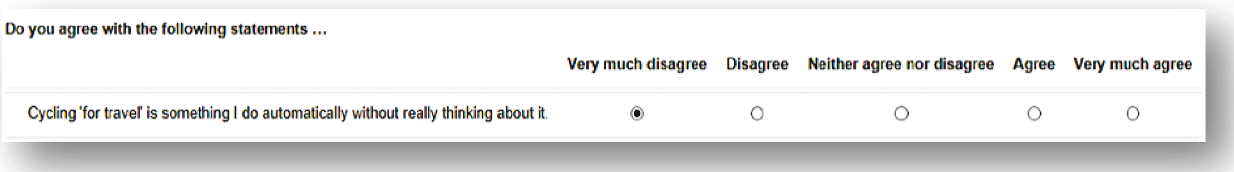


Figure 16. Screen capture of the PASTA survey question that was used to define whether participants cycle automatically.

According to the proposed diagnosis of the Stages of Change, only people in Maintenance stage agreed with cycling automatically (Figure 10).

3.3 Modelling the correlates of the Stages of Change of cycling for transport

As Koglin and Rye (2014) argued already a few years ago, there was a lack of modelling for cycling mobility that is critical to understand the marginalisation of cycling policy and planning: "if this gap could be filled, more practical changes for bicycle planning could be triggered because the case for these practical changes would be stronger". Koglin and Rye cite the work of Parkin *et al.* (2008) as an example on how modelling for cycling was starting to being explored. But it was still poorly developed in comparison with transport planning in general and planning for motorised traffic in particular. Projects like the Propensity to Cycling Tool (Lovelace *et al.*, 2017) have developed in this direction, but cycling modelling still needs more attention and dedication.

The complexity of cycling mobility systems (Macmillan & Woodcock, 2017) and the emerging availability of interesting big data (Romanillos *et al.*, 2016) might just be two of the reasons for using modelling in cycling research going forward. Macmillan and Woodcock (2017), for example, state that: "Establishing robust epidemiological evidence about the effectiveness of interventions to improve and encourage cycling is limited by methodological difficulties and expense, reinforcing the importance of modelling for understanding future implications of cycling policies."

In this thesis, statistical modelling has been designed and undertaken using the data produced in the steps described in the previous sections of this chapter, as illustrated in Figure 6.

The results presented in this thesis include:

- **Descriptive analysis:** all relevant variables are described statistically, in order to identify variation between groups by City sub-samples and Stages of Change.
    - For categorical variables, percentage breakdowns are presented for each level in each variable by Stage of Change and City.
    - For continuous variables the average (mean) and minimum and maximum levels (age) or Standard Deviation (Walkability and Bikeability) are presented.
- **Statistical modelling**: regression modelling estimated the relationship between explanatory variables and a dependent (response) outcome variable. The following sections provide details of the methods used in this analytical approach.

In order to achieve the strongest possible statistical power this analysis used data from the PASTA Questionnaire with the biggest and most socio-economically representative sample: the Baseline Questionnaire (see our paper Branion-Calles *et al.*, 2019).

All statistical computations, including the descriptive statistics and the regression models, were performed using the R programming language (R Core Team, 2018) in the desktop mode of the software RStudio, Version 1.1.463 (RStudio Team, 2018). When a specific computation or function was undertaken using a specific R package, the individual package citation has been included.

3.3.1 Multinomial logistic regression modelling

The multinomial distribution arises from situations where each trial has more than two possible outcome categories. The distribution of counts in the various categories is the multinomial.

Let *c* denote the number of outcome categories. Their probabilities are denoted by $\{\pi_1, \pi_2, \ldots, \pi_c\}$, where $\Sigma_j \pi_j = 1$. For *n* independent observations, the multinomial probability that n_1 fall in category 1, n_2 fall in category 2, . . . , n_c fall in category c, where $\Sigma_j n_j = n$, equals

$$P(n_1, n_2, \ldots, n_c) = \left(\frac{n!}{n_1!\, n_2! \ldots n_c!}\right) \pi_1^{n_1} \pi_2^{n_2} \ldots \pi_c^{n_c}$$

Multinomial logistic regression was used in this thesis to model nominal (un-ordered) response variables with more than two categories or levels. Explanatory variables can be categorical and/or quantitative. In this case, the response variable was the simplified Stages of Change, with three levels: Pre-contemplation, Contemplation-Preparation and Action-Maintenance (see Section 3.2.3.1 for more details). Explanatory variables will be listed and explained in detail in the next Section.

Logit models for a nominal response variable with three levels, pair each comparison level with a reference level. In this case, the reference level was Action-Maintenance. The models simultaneously compared all pairs of levels by specifying the odds of outcome in one level instead of another (the reference level). The pairs were *Pre-contemplation : Action-Maintenance* and *Contemplation-Preparation : Action-Maintenance*, that is to say *comparison level : reference level*. In other words, for each pair, the model produces the log odds that the response is the comparison level (Agresti, 2007:pp.173–174).

Choosing Action-Maintenance as the reference level in the multinomial model implied that the coefficients obtained would refer to the likelihood of not being cyclists (either “Not thinking about cycling" – Pre-contemplation stage, or "Thinking about cycling" – Contemplation-Preparation stage) in contrast to being cyclists (identified with the Action-Maintenance stage).

Looking at the underpinning formulas:

Let J be the number of levels of the response variable, Y (Stages of Change).

J=3 (Pre-contemplation, Contemplation-Preparation and Action-Maintenance)

Let $\{\pi_1, \pi_2, \pi_3\}$ denote the response probabilities, satisfying $\Sigma_j \pi_j = 1$. With *n* independent observations, the probability distribution for the number of outcomes of the three levels is the multinomial distribution. It specifies the probability for each possible way the *n* observations can fall in the J categories. In this case, level J=3 is the reference level, Action-Maintenance. The log odds of the reference level are:

$$\log\left(\frac{\pi_{comparison\ level}}{\pi_{reference\ level}}\right) \quad (1)$$

Using the level names of the outcome variable in formula (1) for the two pairs of levels, the log odds that the response falls in Pre-contemplation are:

$$\log\left(\frac{\pi_{Pre-contemplation}}{\pi_{Action-Maintenance}}\right) \quad (2)$$

And the log odds that the response falls in Contemplation-Preparation are:

$$\log\left(\frac{\pi_{Contemplation-Preparation}}{\pi_{Action-Maintenance}}\right) \quad (3)$$

The log odds were converted into Relative Risk Ratio (RRR) coefficients to better facilitate interpretation. RRR are obtained by calculating the exponential function of the log odds produced by the model. As explained above, RRR were produced for each pair of levels: on the one side, the RRR of Pre-contemplation against Action-Maintenance (the reference level) and on the other side, the RRR of Contemplation-Preparation against Action-Maintenance.

3.3.1.1 Selection criteria for the chosen model

The outcome variable is a categorical variable and has three levels. Before establishing this definition of the outcome variable and selecting a multinomial modelling approach, several criteria (Agresti, 2007:pp.184, 185) were tested to assess if more parsimonious alternatives were suitable:

a) A **binomial model** could have been applied, but the simplification of the five stages of change into just two levels was considered inappropriate due to the different nature of the participants diagnosed as Pre-contemplators in comparison to those diagnosed in Contemplation and Preparation stages, which at the same time are expected to be different to participants in Action and Maintenance. It was considered essential as well as parsimonious to include **three levels** out of the five original Stages of Change.

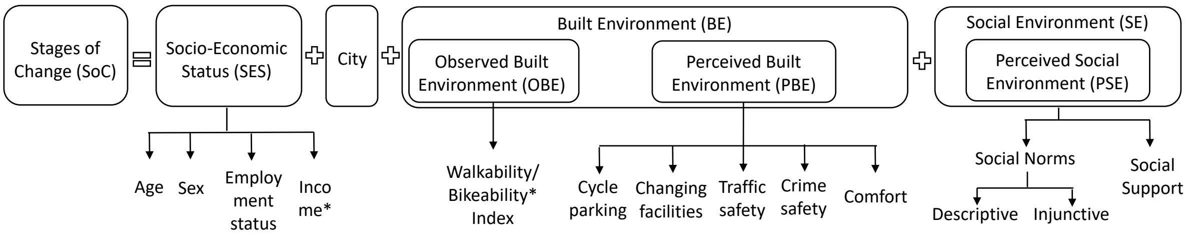
b) An ordinal logistic model was also considered, but the Stages of Change variable did not meet the two required assumptions:

   i. The outcome variable Stages of Change is not considered to be an **ordinal variable**. The Transtheoretical Model presents these Stages as following a desired order, progressing towards a specific behaviour and only contemplates Relapse after the last Stage, Maintenance (Bamberg, 2016). But this thesis aims at measuring the influence of the environment in cycling for all Stages of Change, and this influence can be positive, and make individuals progress towards performing the behaviour in the later Stages of Change; or there can be a negative environmental influence, taking them in the opposite direction, away from the behaviour. The assumption made in this thesis contemplates both possibilities; a positive and a negative influence of the environment in any given stage, subsequently creating the logic to keep this variable unordered. By considering this variable to be un-ordered, it is assumed that individuals could move between stages in any order, which removes pathway implications.

   ii. The **assumption of the proportional odds** could not be made in this case: the effects of any explanatory variables are proportional across the different categories of the ordinal outcome variable. In other words, it cannot be assumed that the explanatory variables have the same effect on the odds regardless of the category of the outcome variable.

3.3.1.2 Components of the maximal model

In multinomial logistic regression, the log odds of the outcomes are modelled as a linear combination of the predictor variables. Here, the model was fitted with exposure variables within three groupings: Socio-Economic Status, Built Environment and Social Environment, and the additional factor "City". The variables of interest were the Built Environment variables (Observed and Perceived) and the Social Environment variables (Perceived) (Figure 17) (0), whereas Socio-Economic variables and City are defined as control variables (their effects are considered constant) as conventionally found in similar studies.



* Used only in the sensitivity analyses.

Figure 17. Components of the Multinomial Logistic Regression maximal model for the Stages of Change, adjusting for SES and city and including BE and SE exposures.

Although there were sufficient samples to consider fitting two-way interactions, the inter-correlation patterns of these variables led to a decision not to include these in the maximal model. The conceptual framework defined in the Section 3.2.2, explains each of the components of the variable groups.

Baseline coefficients were established for the factor level 'Action-Maintenance' and the model produced coefficients relative to this for the two other levels: Pre-contemplation and Contemplation-Preparation (Section 3.3.1). The exponent of the coefficients provided the Relative Risk Ratio (RRR), and the standard errors were used to estimate the exponential 95% confidence intervals. Thus, results present the relative influence of each factor or variable.

In all the cases where a question was answered with a 5-point Likert scale (Strongly Agree, Agree, Neither agree nor disagree, Disagree and Strongly Disagree) it was converted into a 3-point Likert scale (Agree aggregating Strongly agree and Agree; neither agree nor disagree; and Disagree aggregating Disagree and Strongly disagree. For this study, the information added by considering the intensity of agreement/disagreement was not considered relevant. Furthermore, reducing the five points to three notably reduced the complexity of interpreting such results, making the model more parsimonious. The neutral point "Neither agree nor disagree" of the simplified 3-level Likert scale variables was not considered a basis for exclusion and thus preserved as many participants as possible in the sample. Parameter estimates for RRRs for this point, however, are not displayed in the results tables, as 'neutrality' is not considered meaningful in this analysis. The baseline reference coefficient point for all these Likert scale variables was "Disagree", thus the results tables display difference coefficients for the "Agree" point and the baseline reference level for each variable is specified therein.

Table 6. Details of the variables and their groupings used in the modelling.

Name of Variable	Question (when applicable)	Levels (reference)
Group of Variables		
SOCIO-ECONOMIC STATUS (SES)		
Age		-Continuous variable, range [16-88]
Sex		Males (reference) Females
Employment status	What is your current employment status?	Full-timer (reference) Part-timer Student Unemployed
Income (For Sensitivity Analysis only)	What was your total household income after taxes during the past 12 months?	Less than 10,000€ 10,000€ - 24,999€ 25,000€ - 49,999€ 50,000€ - 74,999€ 75,000€ - 149,999€ 150,000€ or more
CITY		
		Antwerp (reference) Barcelona London Örebro Rome Vienna Zurich
BUILT ENVIRONMENT (BE)		
OBJECTIVE BUILT ENVIRONMENT (OBE)		
Walkability		-Continuous variable, range [1-10]-
Bikeability (For Sensitivity Analysis only)		-Continuous variable, range [1-10]-
PERCEIVED BUILT ENVIRONMENT (PBE)		
Inadequate Parking	Inadequate parking for my bike at home and at my destinations make it impossible for me to cycle more	Disagree (reference) Neither Agree nor Disagree* Agree
Lack of changing facilities	The lack of changing and shower facilities at my destinations prevents me from using a bicycle	Disagree (reference) Neither Agree nor Disagree* Agree
Traffic Safety	With your day-to-day needs in mind would you say that cycling "for travel" … is safe (with regards to traffic)	Disagree (reference) Neither Agree nor Disagree* Agree
Crime Safety	With your day-to-day needs in mind would you say that cycling "for travel" … is safe (with regards to crime)	Disagree (reference) Neither Agree nor Disagree* Agree
Comfort	With your day-to-day needs in mind would you say that cycling "for travel" … is comfortable	Disagree (reference) Neither Agree nor Disagree* Agree

Group of Variables		
Name of Variable	**Question** (when applicable)	**Levels** (reference)
SOCIAL ENVIRONMENT (SE)		
PERCEIVED SOCIAL ENVIRONMENT (PSE)		
Injunctive Social Norm - Well regarded	In my neighbourhood cycling is well regarded	Disagree (reference) Neither Agree nor Disagree* Agree
Descriptive Social Norm - Common	In my neighbourhood it is common for people to cycle ´for travel´	Disagree (reference) Neither Agree nor Disagree* Agree
Social Support	Most people who are important to me think that I should cycle 'for travel' (that is getting from place to place)	Disagree (reference) Neither Agree nor Disagree* Agree

*Values for this level not included in the inferential tables

3.3.1.3 Interpretation of results

Relative Risk Ratios (RRR) can be obtained from the exponents of the multinomial logit coefficients. The RRR of a coefficient indicates how the risk (likelihood) of the outcome falling in the comparison level (Pre-contemplation or Contemplation-Preparation) compares to the risk of the outcome falling in the referent level (Action-Maintenance) changes for the variable in question (UCLA: Statistical Consulting Group, 2020). Applying this to the PASTA survey Likert-scale questions used in this thesis, this means that the RRRs can be interpreted in several ways:

- An **RRR > 1** indicates that the risk (likelihood) of being in one of the comparison levels (Pre-contemplation or Contemplation-Preparation) relative to the risk of being in the reference level (Action-Maintenance) *increases* as the variable increases, for all other variables held constant. In other words, the more someone agrees with the statement used for this variable, the more likely they will be in the comparison level. In the case of continuous variables, such as the Walkability and Bikeability indices, an RRR > 1 indicates that the risk of being in the Comparison level increases with every unit of increase of the index score.
- An **RRR < 1** indicates that the risk of being in one of the comparison levels (Pre-contemplation or Contemplation-Preparation) relative to the risk of being in the reference level (Action-Maintenance) *decreases* as the variable increases, given that the other variables in the model are held constant. In brief, the more someone agrees with the statement used for this variable, the more likely it is that they will be in the reference level. For the indices, with each increase in the Walkability/Bikeability score, the more likely it is that someone will fall into Action-Maintenance than the comparison level.
- If the **RRR = 1** (or close to 1), it suggests no difference or little difference in risk: the incidence in the comparison level and in the reference level is the same or very similar.

An alternative way to look at and interpret these comparisons would be to compute the *percent relative effect*, that is, the percent change in the comparison level (LaMorte, 2018; Andrade, 2015). Basically, we regard the reference level as having 100% of the risk and express the comparison level relative to that:

- When RRR > 1:

% increase = (RRR - 1) x 100, e.g. (3.1 - 1) x 100 = 210% increase in risk.

If we had an RRR of 3.1 for a Pre-contemplation level, that would mean that Pre-contemplation level would have a 210% increase in risk over and above the risk in the reference level, Action-Maintenance (which is 100%). In other words, the likelihood of being in Pre-contemplation is more than twice that of being in Action-Maintenance for that specific variable.

- When RRR < 1:

% decrease = (1 - RRR) x 100, e.g. (1 - 0.68) x 100 = 32% decrease in risk.

If we had an RRR of 0.68 for a Pre-contemplation level, this means people in pre-contemplation would have a 32% reduction in risk.

It is worth noting that, due to the way in which the PASTA survey questions and their answers were formulated, the interpretation of the RRR needs to account for the fact that the participants were responding to either a positive or a negative statement. For example, the variable “Comfort” comes from a positive statement found in one of the PASTA questions answers “Cycling is comfortable”. Here, positive is understood to be beneficial to the practice of cycling for transport. The results tables show the RRR related to the “Agree” level of the variables using the Likert scale, confirming the positivity of such statement. In this case, an RRR > 1 for a positive statement such as cycling being well-regarded in their neighbourhood (Injunctive Social Norm), would imply that the more positive people feel about the statement (the more they agree that cycling is well-regarded), the more likely they are to be in the comparison group (Pre-contemplation or Contemplation-Preparation).

When the statement is understood to be negative or detrimental for cycling, for example in the variable “Lack of parking facilities”, an RRR > 1 means that the more negative people feel about the statement (the more they agree there is a lack of parking facilities), the more likely they are to be in the comparison group (Pre-contemplation or Contemplation-Preparation).

Finally, regarding effect sizes, as a rough rule of thumb, RRRs < 0.50 or > 2.0 are considered 'important'. That is, if the risk is at least halved, or more than doubled. Note that we are not speaking about statistical significance, but rather importance, which means the thresholds could vary depending of the outcome studied (Streiner & Norman, 2012).

3.3.2 The explanatory variables

The variables are presented in different groupings (0): one variable for the Objective Built Environment (either Walkability or Bikebility when available); five variables for Perceived Built Environment, two related to cycling facilities (Inadequate Parking and Lack of Changing Facilities), two related to safety (Traffic Safety and Crime Safety) and Comfort; and three variables for Perceived Social Environment, two for Social Norms (Injunctive and Descriptive Social Norms) and Social Support; all of which are now explained in more detail.

3.3.2.1 Socio-economic status variables

The explanatory variables were selected from the socio-demographic questions featured in the Baseline Questionnaire. They were previously described in detail in 0.

3.3.2.2 City

Differences were expected between the seven sampled cities in many of the variables. Although it could have been considered a random effect, the decision to keep "City" as a fixed effect was based on several reflections: the factor levels are informative (Crawley, 2013); they are interesting in themselves (Gelman, 2005); and they do not represent a random sample of all cities and so we are only interested in those levels (the seven case-study cities) (Utts, 2013). Moreover, having only fixed effects contributed to the parsimony of the model.

The association between exposure and outcomes varies in the different cities featured in the sample (Figure 21). In this case, the possibility of "City" being a moderator (effect modifier) needs to be considered. According to the literature, a stratification is used to explore whether the effect differs for each of the levels of a variable (Bauman *et al.*, 2002). This sensitivity analysis has produced seven different models, one for each of the seven city samples.

3.3.2.3 Objective measures of the built environment

The construction of the Walkability Index has been adapted from the template proposed by the International Physical Activity and the Environment Network (IPEN) study featured in the paper by Adams *et al.* (2014). The IPEN study of adults (see http://www.ipenproject.org) aimed to measure the full range of variation in the built environment using geographic information systems (GIS) across 12 countries on 5 continents.

The Walkability Index features information on connectivity, population density, facility density and facility richness. GIS information layers for these four components of the Walkability Index were collected and homogenized for the seven cities of the PASTA project. The following Table provides the complete details on how each component was calculated and/or defined, and their source.

Table 7. Description of the components of the Walkability Index

Indicator	Source
Connectivity - number of junctions with node degree >1 (in order to exclude cul-de-sacs) (*n*/km2)	**Navteq[a] street intersections data (2012)**
Population density - (n inhabitants/km2)	**Census / neighbourhood data (2011-2016)[b]**
Facility density index - number of POI (*n* facilities/km2)	**Navteqa POI data set (2012). For full list of POIs see https://tinyurl.com/PASTA-POI**
Facility richness index - number of different facility types (POIs) present, divided by the maximum potential number of facility types specified (*n* facility types/74)	**Navteqa POI data set (2012). For full list of POIs see https://tinyurl.com/PASTA-POI**

Note: POI, points of interest.

[a]Navteq is licensed data under ArcGIS software. This data is prepared for use in routing analysis across Europe. It contains data on Streets and Points of Interest (POIs), so it identifies a wide range of categories in which the different POIs (e.g., schools, libraries, cinemas, banks, restaurants) are included. (See the full list in this link: https://tinyurl.com/PASTA-POI.)

[b]The source of information varied across cities: Antwerp, Barcelona, London, Rome, and Vienna: National Census (2011), Örebro: local layer (2015); and Zurich local and regional layer (2016).

The PASTA questionnaires collected addresses for both residential and work/study locations, and the Index was then calculated for all geocodable addresses located within each of the PASTA cities' administrative boundaries, using a 300 metre radial buffer. The index was calculated as the sum of deciles of each of the components, divided by 4.

A 300 metre buffer was chosen for several reasons: First, 300 metres is commonly used in epidemiological studies on built environment and health (Nieuwenhuijsen & Khreis, 2019); second, it is a distance that most of the population can walk; and third, some of the built environment indicators (e.g., facilities richness) were not available for other buffer sizes (e.g.,100 m or 500 m).

The statistical software R and its packages for spatial analysis rgdal (Bivand, Keitt & Rowlingson, 2019), raster (Hijmans, 2019), rpostgis (Bucklin & Basille, 2018) and PostgreSQL (Conway *et al.*, 2017) were used to compose the Walkability index and QGIS was used for layer preparation (Bucklin & Basille, 2018; Bivand, Pebesma & Gómez-Rubio, 2013).

Walkability as a proxy to assess the bikeability of the environment

In the absence of a Bikeability index for all the cities, the Walkability index was taken as a proxy of the nature of the built environment in regards to Active Mobility in general and of cycling in particular, as it is generally associated with higher cycling levels and several of the built environment characteristics used in the walkability scale have also been shown to be predictors of cycling (Owen *et al.*, 2010; Freeman *et al.*, 2013; Christiansen *et al.*, 2014, 2016).

Bikeability

The Bikeability Index was constructed similarly to the Walkability Index described above: it has four components and the index has been calculated for 300-m buffers around all geocodable locations in London.

The components of the Index were selected according to the literature (Winters *et al.*, 2013). Connectivity and Facility richness were shared components with the Walkability index and cycling infrastructure (both bike-sharing stations and the cycle lanes network) and hilliness were also included. The index was calculated as the sum of deciles of each of the components, divided by 5, giving a score between 1 and 10.

Table 8. Description of the components of the Bikeability Index

Indicator	Source
Bike stations density within 300m buffer (*n*/km	**OSM (and local data 2017)[a]**
Bike lanes density within 300m buffer (m/km)	**OSM (and local data 2017)[a]**
Connectivity –streets selected exclude major roads and include those with cycle path; (*n*/km2)	**OSM (and local data 2017)[b]**
Facility richness index - number of different facility types (POIs) present, divided by the maximum potential number of facility types specified (*n* facility types/74)	**Navteq[c] POI data set (2012). For full list of POIs see https://tinyurl.com/PASTA-POI**
Average hilliness/elevation within 300m buffer – Calculated from the Digital Elevation Map (DEM)	**EU-DEM, EEA (2017)[d]**

Note: OSM, Open Street Maps; EEA, European Environmental Agency.

[a] OSM layers (https://www.openstreetmap.org/export) included were complemented with Transport for London (https://data.london.gov.uk/dataset/tfl-cycle-hire-locations and https://cycling.data.tfl.gov.uk/)

[b] OSM layers (https://www.openstreetmap.org/export) included the "highway" tags 'cycleway', 'living_street', 'path', 'pedestrian', 'residential', 'service', 'track', 'track_grade1', 'track_grade2', 'track_grade3', 'track_grade4', 'track_grade5', 'unclassified', 'unknown'. Data were complemented with Transport for London's cycle network data (https://cycling.data.tfl.gov.uk/)

[c] Navteq is licensed data under ArcGIS software. This data is prepared for use in routing analysis across Europe. It contains data on Streets and Points of Interest (POIs), so it identifies a wide range of categories in which the different POIs (e.g., schools, libraries, cinemas, banks, restaurants) are included. (See the full list in this link: https://tinyurl.com/PASTA-POI.)

[d] Copernicus Land Monitoring Service - EU-DEM. EU-DEM is a digital surface model (DSM) of EEA member and cooperating countries. The EU-DEM is a 3D raster dataset with elevations captured at about every 30 metre https://www.eea.europa.eu/data-and-maps/data/copernicus-land-monitoring-service-eu-dem.

See below for a detailed map depicting the Bikeability layer in London:

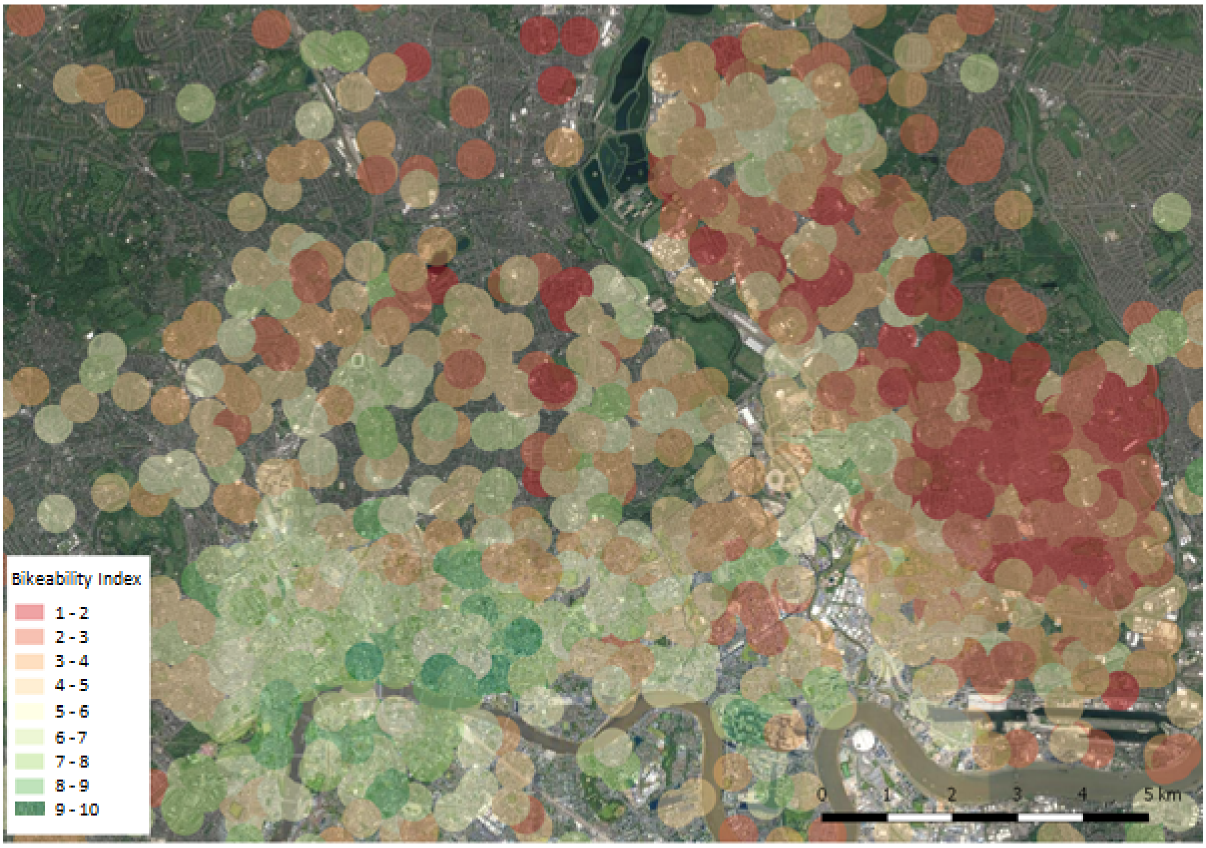


Figure 18. Visualisation of the Bikeability index for 300-m buffer PASTA survey participants geo-located residence or work/study locations, where 1 indicates the lowest level of Bikeability and 9 the highest. Background from Google Satellite.

3.3.2.4 Perception of the built environment

Besides the objective measures for the built environment expressed in the Walkability and Bikeability Indices, the perception of the cycle-friendliness of the built environment was added to the model with the inclusion of a group of variables from the questionnaire. This way, both effects (objective and perceived) could be featured in the model and their effect could be studied separately.

Studies that inspired the PASTA survey design with respect to the perception of the built environment include the IPEN study (Spittaels *et al.*, 2010) (the questions referenced belong to the Long version of the ALPHA questionnaire), the iCONNECT study (Ogilvie *et al.*, 2012; Panter & Ogilvie, 2015) and the work by Handy , Xing & Buehler (2010), and amongst others, Götschi *et al.* (2017). There are some more recent studies that evaluate perceptions of the built environment in cycling behaviour, such as the analysis described by Panter and Ogilvie (2015) as part of the iConnect project, or the work by Ma & Dill (2015), Porter *et al.* (2018) and Park and Akar (2019). More studies were published after the PASTA survey was designed and launched.

In the next sections, the PASTA questions used for each type of variable (Accessibility to infrastructure and facilities, Perception of traffic safety and of security/crime, and Comfort) will be compared with other questions used in the above-mentioned studies with the aim of illustrating how the PASTA survey design drew on existing literature and how the results will be comparable to each of the other studies. These sections add detail to the Literature Review (Chapter 2) and provide a justification of the chosen questions in this study.

Accessibility to infrastructure and facilities

Although there were no questions in the PASTA project on the perception of access to cycle paths, quiet streets or cycling destinations, which were included in studies such as those of Ma and Dill (2015), and Porter *et al.* (2018), it did include questions on the perception of adequate cycle parking and changing and shower facilities (shown as "Inadequate parking" and "Lack of changing facilities" in 0). These two variables will often be referred to with the over-arching term of "Perception of cycling facilities". The following table compares the PASTA survey questions to other questions used in the literature.

Table 9. Questions for Accessibility and barriers to infrastructure

Accessibility and barriers to infrastructure	PASTA SURVEY QUESTIONS	OTHER STUDIES
Inadequate Parking	Inadequate parking for my bike at home and at my destinations make it impossible for me to cycle more on a 5-point Likert scale where 1 = Strongly Agree, 2 = Agree, 3 = Neither agree nor disagree, 4 = Disagree and 5 = Strongly Disagree.	Perceived trueness that "Stores and other destinations have bike racks" on 4-point scale 1 = Not at all true, 2 = Somewhat true, 3 = Mostly true, 4 = Entirely true (Handy, Xing & Buehler, 2010) How true that "It is easy to find a secure rack=post to lock my bike at work place" on 4-point scale 1 = Not at all true, 2 = Somewhat true, 3 = Mostly true, 4 = Entirely true (Handy & Xing, 2010) At your work or place of study do you have a safe place to leave a bike? On a Yes or No answer (Spittaels *et al.*, 2010). There are enough parking racks for bicycles on a 5-point Likert scale where 1 = Strongly Agree, 2 = Agree, 3 = Neither agree nor disagree, 4 = Disagree and 5 = Strongly Disagree (Park & Akar, 2019).
Lack of changing facilities	The lack of changing and shower facilities at my destinations prevents me from using a bicycle on a 5-point Likert scale where 1 = Strongly Agree, 2 = Agree, 3 = Neither agree nor disagree, 4 = Disagree and 5 = Strongly Disagree.	How true that "I have access to a shower within 5 minute walk of my office". 1 = Not at all true, 2 = Somewhat true, 3 = Mostly true, 4 = Entirely true (Handy & Xing, 2010). At your work or place of study do you have showers and changing rooms? On a Yes or No answer (Spittaels *et al.*, 2010). When needed, I can find a convenient place to shower and change clothing after bicycling on a 5-point Likert scale where 1 = Strongly Agree, 2 = Agree, 3 = Neither agree nor disagree, 4 = Disagree and 5 = Strongly Disagree (Park & Akar, 2019).

Perception of traffic safety

Some studies use a variable "Safety" that integrates aspects of Traffic Safety together with aspects of security and crime. In the studies led by Handy (Handy & Xing, 2010; Handy, Xing & Buehler, 2010) they integrated five questions into the variable "Safety concern": "Average concern of being hit by a car, being hit by another cyclist while biking, being bitten by a dog, being mugged or attacked, or crashing because of road hazards on 3-point scale where 1 = Not at all concerned, 2

= Somewhat concerned, 3 = Very concerned". Recent studies such as De Geus *et al.* (2019), also used the ALPHA questionnaire (Spittaels *et al.*, 2010) and integrated traffic safety with crime in the same variable.

The so called 'safety-related variables' used in other studies, have been kept disaggregated in this model, in order to capture their individual associations with the outcome variable, especially because data come from seven different case-study cities, in which traffic safety and crime safety might be perceived differently.

The variable "Traffic safety" is related to the perception of safety in regard to traffic.

Table 10. Questions for Perception of Safety

Perception of safety	PASTA SURVEY QUESTIONS	OTHER STUDIES
Traffic Safety	With your day-to-day needs in mind would you say that cycling "for travel" … is safe (with regards to traffic) on a 5-point Likert scale where 1 = Strongly Agree, 2 = Agree, 3 = Neither agree nor disagree, 4 = Disagree and 5 = Strongly Disagree.	Safe destinations - Average perception of safety bicycling to ''your usual grocery store'', ''the nearest post office'', ''the local elementary school'', ''a restaurant you like'', ''the nearest bike shop'' on 3-point scale where 1 = Uncomfortable and I wouldn't ride there, 2 = Uncomfortable but I'd ride there anyway, 3 = Comfortable (Handy, Xing & Buehler, 2010)
		Cycling is dangerous because of the traffic in my neighbourhood, on a 4-point scale where 1 = Strongly disagree, 2 = Somewhat disagree, 3 = Somewhat agree, 4 = Strongly agree (Spittaels *et al.*, 2010)
		Cycling is unsafe because of the traffic, on a 5-point scale where 1 = Strongly agree, 2 = Somewhat agree, 3 = Neither agree nor disagree, 4 = Somewhat disagree, 5 = Strongly disagree (Supplementary material, Ogilvie *et al.*, 2012; Panter & Ogilvie, 2015)
		Safety in traffic is an important factor on a 5-point Likert scale where 1 = Strongly Agree, 2 = Agree, 3 = Neither agree nor disagree, 4 = Disagree and 5 = Strongly Disagree (Park & Akar, 2019).

Perception of security/crime

The variable "Crime Safety" is also known as "Security" and is related to the perception of safety in regard to crime; that is, the perceived risk of being a victim of crime when cycling. The questions asked in the PASTA survey that relate to Perception of Safety can be found in Table 11.

Table 11. Questions for Perception of security/crime

Perception of security/crime	PASTA SURVEY QUESTIONS	OTHER STUDIES
Crime Safety	With your day-to-day needs in mind would you say that cycling "for travel" … is safe (with regards to crime) on a 5-point Likert scale where 1 = Strongly Agree, 2 = Agree, 3 = Neither agree nor disagree, 4 = Disagree and 5 = Strongly Disagree.	Cycling is dangerous in my neighbourhood during the night because of the level of crime, on a 4-point scale where 1 = Strongly disagree, 2 = Somewhat disagree, 3 = Somewhat agree, 4 = Strongly agree (Spittaels *et al.*, 2010)
		The level of crime or antisocial behaviour means cycling is unsafe, on a 5-point scale where 1 = Strongly agree, 2 = Somewhat agree, 3 = Neither agree nor disagree, 4 = Somewhat disagree, 5 = Strongly disagree (Supplementary material, Ogilvie *et al.*, 2012; Panter & Ogilvie, 2015)
		Safety from crime is an important factor on a 5-point Likert scale where 1 = Strongly Agree, 2 = Agree, 3 = Neither agree nor disagree, 4 = Disagree and 5 = Strongly Disagree (Park & Akar, 2019).

Comfort

Being comfortable when cycling or having a pleasurable cycling experience has been measured in a number of studies before and since the PASTA survey. These studies and the question related to comfort in this study are detailed in Table 12.

Table 12. Questions for Pleasure/comfort

Pleasure/comfort	PASTA SURVEY QUESTIONS	OTHER STUDIES
Comfort	With your day-to-day needs in mind would you say that cycling "for travel" ... is comfortable on a 5-point Likert scale where 1 = Strongly Agree, 2 = Agree, 3 = Neither agree nor disagree, 4 = Disagree and 5 = Strongly Disagree.	(three aggregated questions) "Average comfort biking on an off-street path or quiet street, two-lane-local-street with or without bike lane, four-lane-street with or without bike lane", on 3-point scale where 1 = Uncomfortable and I wouldn't ride on it, 2 = Uncomfortable but I'd ride on it, 3 = Comfortable (Handy, Xing & Buehler, 2010; Handy & Xing, 2010)
		My local neighbourhood is a pleasant environment for cycling, on a Yes or No answer (Spittaels *et al.*, 2010)
		The routes are pleasant for walking or cycling, on a 5-point scale where 1 = Strongly agree, 2 = Somewhat agree, 3 = Neither agree nor disagree, 4 = Somewhat disagree, 5 = Strongly disagree (Supplementary material, Ogilvie *et al.*, 2012; Panter & Ogilvie, 2015)

Titze *et al.* (2008) use an aggregated measure for Physical Discomfort composed of "Cycling is tiresome", "cycling is unsafe", and "cycling is stressful". In the PASTA baseline questionnaire, we asked about safety in relation to traffic and crime separately.

3.3.2.5 Social environment

The social environment includes Social Norms and Social Support.

Unlike other studies (Titze *et al.*, 2008; Ma & Dill, 2015) in which Social Norms and Social Support questions were integrated into a single social environment variable, this analysis studies the effect of these variables separately.

Social Norms

The two types of Social Norms (see section 2.2.3.1 for the definition of Social Norms): Descriptive and Injunctive; were included in the PASTA survey and featured in this model, as components of the Social Environment (Table 13).

Table 13. Questions for Social Norms

Social Norms	PASTA SURVEY QUESTIONS	OTHER STUDIES
Descriptive Norm	In my neighbourhood it is common for people to cycle ´for travel´, on a 5-point Likert scale where 1 = Strongly Agree, 2 = Agree, 3 = Neither agree nor disagree, 4 = Disagree and 5 = Strongly Disagree.	(2 of 5 questions aggregated in the Social Environment variable) "Members of my household frequently use cycling for transportation", "many of my friends use the bicycle for transportation", on a 4-point scale ranging from "strongly disagree" (1) to "strongly agree" (4). (Titze *et al.*, 2008)
		"I see people in my neighbourhood cycling for travel". On a 5-point scale where 1 = Strongly agree, 2 = Somewhat agree, 3 = Neither agree nor disagree, 4 = Somewhat disagree, 5 = Strongly disagree (Supplementary material, Ogilvie *et al.*, 2012; Panter & Ogilvie, 2015)
		(3 of the 5 questions aggregated in the Social Environment variable) "People I live with ride a bike to get to places, such as errands, shopping, and work"; "Many of my friends ride a bike to get to places, such as errands, shopping, and work"; "Many of my co-workers ride a bike to get to work." On a 5-point scale from strongly disagree (1) to strongly agree (5). (Ma & Dill, 2015)
		(translated from Spanish) "How much do you think the following groups of people use the bicycle to go to work/study?"; groups: Young people, Family, Friends, Colleagues, Migrants. On a 6-point scale from not at all used (1) used a lot (6). (Appendix D, Muñoz López, 2016)

Social Norms	PASTA SURVEY QUESTIONS	OTHER STUDIES
Injunctive social norm	"In my neighbourhood cycling is well regarded". On a 5-point scale where 1 = Strongly Agree, 2 = Agree, 3 = Neither agree nor disagree, 4 = Disagree and 5 = Strongly Disagree.	The people in my life whose opinions I value most would approve of me cycling for travel, on a 5-point scale where 1 = Strongly agree, 2 = Somewhat agree, 3 = Neither agree nor disagree, 4 = Somewhat disagree, 5 = Strongly disagree. (Supplementary material, Ogilvie *et al.*, 2012; Panter & Ogilvie, 2015)
		"How acceptable is your partners'/ friends'/ colleague's perception of you biking?". On a 7-point scale from completely acceptable (1) to completely unacceptable (7). (Forward, 2014)
		"My closest friends accept me cycling./My family/partner accept me cycling./My work colleagues accept me cycling." On a 5-point scale from strongly disagree (1) to strongly agree (5). (Bourke, Craike & Hilland, 2019, based on Forward, 2014)
		(translated from Spanish) For non-cyclists "If you decided to cycle to work/study, how much do you think the following groups of people would agree with that?" For cyclists "Regarding your decision to cycle to work/study, how much do you think the following groups of people would agree with that?"; groups: Family/Friends/Colleagues. On a 6-point scale from wouldn't agree at all (1) to would completely agree (6). (Appendix D, Muñoz López, 2016)

Both Social Norms were measured for a specific spatial scale, the neighbourhood, in order to be able to assess them in relation to the built environment objective measures, which were calculated in a comparable spatial scale (Figure 18). Taking "neighbourhood" as a reference also helped to locate the people of influence for this type of behaviour, those with the same spatial reference as the participant.

The Injunctive Norm varied in terms of the formulation of the question, instead of the perception of others acceptance of participant's cycling, it assessed whether cycling was "well regarded", implying the perception of other people's judgement.

Social support

Table 14 depicts the PASTA question around social support and the associated research.

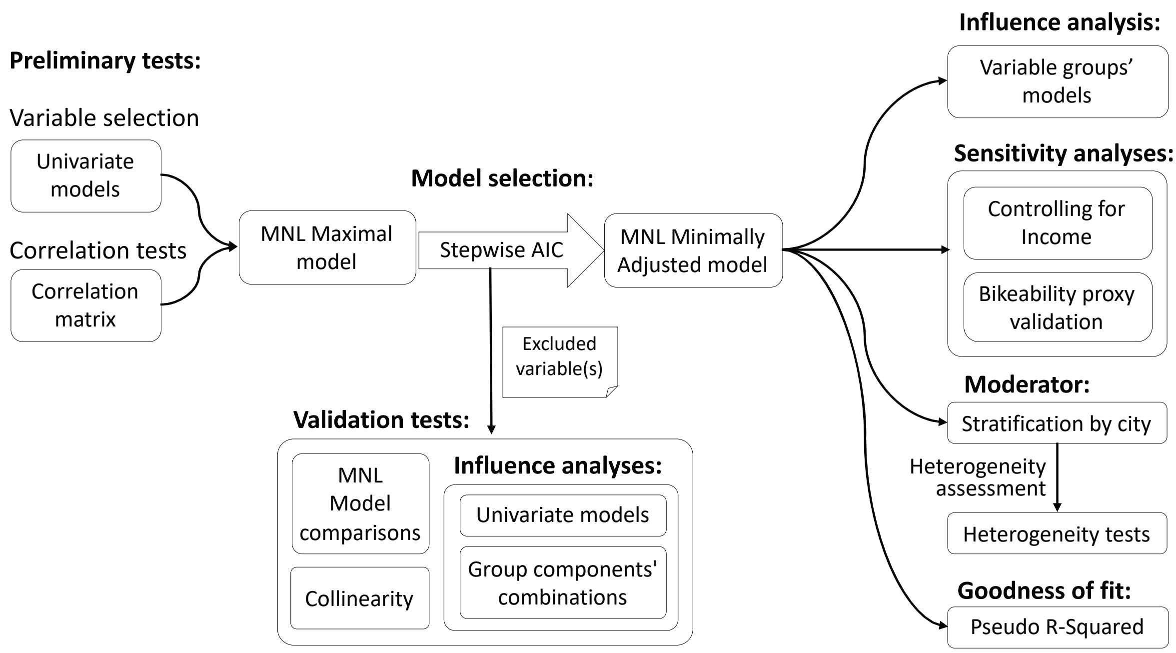
Table 14. Questions for Social support

Social support	PASTA SURVEY QUESTIONS	OTHER STUDIES
Social support	Most people who are important to me think that I should cycle 'for travel' (that is getting from place to place), on a 5-point Likert scale where 1 = Strongly Agree, 2 = Agree, 3 = Neither agree nor disagree, 4 = Disagree and 5 = Strongly Disagree.	(2 of 5 questions aggregated in the Social Environment variable) “My friends and acquaintances encourage me to use a bicycle for transportation”, “Family members encourage me to use the bicycle for transportation”, on a 4-point scale ranging from “strongly disagree” (1) to “strongly agree” (4). (Titze *et al.*, 2008) “How often (during the past year) members of their family encouraged them to be physically active” on a 5-point Likert scale from “never” (1) to “very often” (5). (Ball *et al.*, 2010) (Questions aggregated in the Supportive Social Environment variable) “Most people who are important to me, for example my family and friends, think I should bike more”; “Most people who are important to me, for example my family and friends, would support me in using a bike more”. (Ma & Dill, 2015)

This question is similar to the ones used in previous studies to evaluate social support.

3.3.3 Modelling flowchart

The flowchart below shows each of the different steps taken in the statistical modelling. These steps are explained in detail in the following sections:



Note: MNL: multinomial, AIC: Akaike Information Criterion, BE: Built Environment, SE: Social Environment.

Figure 19. Flowchart of the modelling design.

3.3.4 Preliminary tests for the selection of variables

Preliminary tests helped determine the appropriateness of the variables chosen for the model. One of these preliminary tests focused on the individual influence of each variable using univariate models. The other preliminary test focused on uncovering potential dependencies between the variables, using correlation tests.

3.3.4.1 Variable selection/appropriateness

Univariate models were performed for each variable in order to validate the selection of the variables. The association between each built and social environment variable and the outcome (adjusting/controlling for SES and City) was estimated with the aim of selecting only those with an identifiable predictive power on the outcome level.

3.3.4.2 Correlation

Correlation tests between all pairs of variables constitute a correlation matrix. The correlation matrix is used in multinomial and other regression models to test for collinearity and, in general, to test the model's stability (Alin, 2010).

The correlation tests and the corresponding coefficients obtained depended on the type of variables paired:

Table 15. Type of variables and their correlation methods

Type of variables	Correlation test	Coefficient	P-Value	R package
Continuous variable vs. continuous variable	Spearman's Rank correlation (Mukaka, 2012)	rho	Chi-squared test	Hmisc (Harrell, 2018)
Continuous variable vs. nominal or ordered categorial variable	Linear regression (Crawley, 2013:p.458)	Squared root of R^2	p-value associated with the computed value of F	Base (R Core Team, 2018)
Nominal vs. Nominal categorical variables (2 or more levels)	Cramér's V (Navarro, 2018:p.370)	V	Chi-squared test	lsr (Navarro, 2015)
Ordered vs. Ordered categorical variables (more than 2 levels)	Spearman's Rank correlation (Mukaka, 2012)	rho	Chi-squared test	Hmisc (Harrell, 2018)

Correlation coefficients were interpreted according to general guidance in the field of behavioural science (Hinkle, Wiersma & Jurs, 2003):

Table 16. Rule of Thumb for Interpreting the Size of a Correlation Coefficient. Source: Hinkle, Wiersma & Jurs, 2003.

Size of Correlation	Interpretation
.90 to 1.00 (−.90 to −1.00)	Very high positive (negative) correlation
.70 to .90 (−.70 to −.90)	High positive (negative) correlation
.50 to .70 (−.50 to −.70)	Moderate positive (negative) correlation
.30 to .50 (−.30 to −.50)	Low positive (negative) correlation
.00 to .30 (.00 to −.30)	Negligible correlation

3.3.5 Model selection

The statistical model selected for this study needed to be the best fit to the data. Firstly, a model with all the variables of interest needed to be estimated. This is called the Maximal model. Given that the selection of variables was guided by the literature, it was likely that many of them would be significant. But in order to find the best model fit to the data, the Maximal model needed to be simplified. The key principle of the simplification process is parsimony (also called Occam's razor): "the correct explanation is the simplest explanation" (Crawley, 2013:p.390). The model should be as simple as possible but not simplistic, the model is not as good a fit as the maximal model, but not significantly so.

The principle of parsimony means that models should have as few parameters as possible and that they should be simplified until they are *minimal adequate*.

In this study, the maximal model was estimated, with the above-mentioned exposure variables acting as explanatory variables of the outcome or response variable, Stages of Change, and its three levels: Pre-contemplation, Contemplation-Preparation and Action-Maintenance.

The model was simplified through a backward stepwise simplification process assessed using the Akaike Information Criterion (AIC), in which a variable is retained in the model only if its removal causes a significant increase in deviance. In other words, an explanatory variable would only be retained in a model if it contributes significantly to improve the fit of the model (Crawley, 2013:pp.391–392).

In order to verify that the simplification was parsimonious but that there was no significant loss of explanatory power, validation tests were prepared for any excluded variables. Tests included a comparison between the Maximal and Minimal Adequate models and influence analyses. On the one hand, the influence of each of the variables in the model was estimated using univariate models. On the other hand, the influence of the excluded variable(s) within its variable group (that is, either BE or SE as shown in Figure 17 and 0) was estimated by using models that included different combinations of the variables in the group.

3.3.5.1 Multinomial model comparisons

An ANOVA (ANalysis Of VAriance) is commonly used to compare two regression models and see whether they differ in explanatory power (Crawley, 2013:p.477). Here the analogue appropriate to multinomial models uses Likelihood Ratio (LR) tests in the stepwise simplification to compare the Maximal model, containing all the selected variables of interest, with the gradually simplified interim models and the Minimal Adequate model obtained after the process of stepwise term deletion was completed.

3.3.5.2 Collinearity

As a preliminary test, the correlation matrix showed any relations between any pair of variables. If any strong correlations were found, a collinearity test would be necessary. Nevertheless, it is possible to have data in which no pair of variables had a high correlation, but in which several variables together might be interdependent (Allison, 2012). Collinearity (also called Multicollinearity) is a strong linear relationship among two variables in a model, which reduces the precision of coefficient estimates (Crawley, 2013:p.497).

Collinearity was tested once the Minimal Adequate model had been determined, in order to assess if there was any near-linear relation between explanatory variables. Although the literature is not clear in signalling which collinearity test would be most appropriate for a multinomial regression, the modification of the variance-inflation factor (VIF), generalized variance-inflation factor (GVIF) is accepted for non-linear regression models (Fox, 2015:p.357). The use of GVIF is suggested when some of the variables have more than one degrees of freedom, which is the case in this model. The derived expression of GVIF is then used to make the measure comparable across all the variables in the model (Fox & Monette, 1992):

$GVIF^{1/(2\times df)}$ where df is the degrees of freedom associated with the term.

VIF and its derived expression GVIF inform the degree to which the estimated variance of the regression coefficient of a particular variable is increased due to this variable's correlation with the other variables in the model. Thus, a VIF of 10 indicates that (all other things being equal) the variance of the regression coefficient of a particular variable is 10 times greater than it would have been had the variable been linearly independent of the other variables in the model. Namely, VIF tells us how much the variance has been increased by this lack of independence (O'Brien, 2007).

In relation to the example given above, the literature suggests that an acceptable threshold for the VIF measure is 10 (Dormann *et al.*, 2013; O'Brien, 2007). Given that $GVIF^{1/(2\times df)}$ is analogous to taking the square root of the VIF, its threshold is therefore 3.2 (Fox & Weisberg, 2011:p.325).

Collinearity was tested using the R package "car" created by Fox *et al.* (2018).

3.3.5.3 Influence analysis: univariate models

The univariate models had already been estimated in the preliminary test for the selection of variables. After knowing which variables were excluded, univariate models were compared with the results of each of the variables within the Minimal Adequate model to check if there were any notable differences between them.

3.3.5.4 Influence analysis: variable combinations within groups

As explained in section 3.3.1.2, two groups of variables of interest are used in this study, Built Environment and Social Environment variables.

When a variable was found not to offer sufficient explanatory power to be kept in the Minimal Adequate model, all possible combinations of a variable group were performed. In these tests, models with all the variables in a specific group were tested against models featuring different combinations of the remaining variables (including all of the other variables and one-by-one each of the other variables one-to-one). The objective was to assess the impact of the discarded variable in relation to other variables in the same group and potentially observe if the absence of this variable was creating a loss of information, or else, if the loss of information was minimal thanks to the presence of the rest of the variables in the same group. With each combination of variables in the models, a simple observation of the coefficients' p-values was used to assess whether variables were losing explanatory power.

3.3.6 Influence analysis: variable groups

In addition to the Minimal Adequate model, the individual influence of Built Environment and Social Environment was estimated separately by two different models for each group of variables. Similar to methods observed in already cited studies such as Heesch *et al.* (2014), the two regression models were computed to examine the separate and joint influence of built environment and social environment on the Stages of Change for cycling behaviour, controlling for city and for socio-economic variables. A measure of goodness of fit, McFadden's pseudo R-squared in combination with AIC was used to assess these models.

3.3.7 Sensitivity analyses

One of the two sensitivity analyses included in this research design accounted for the variable household income in the Minimal Adequate Model configuration and the other aimed to test the validity of using Walkability as a proxy of Bikeability in the London sample.

3.3.7.1 Controlling for Income

The Income variable was not included in the Maximal model because of the number of missing values, which would have created a general loss of statistical power. The variable "Income" is a categorical ordinal variable with 7 levels (for more information see section 3.3.2.1).

In this sensitivity analysis, the Minimal Adequate model was fitted with Income as an extra variable, and the RRRs of the rest of the variables of the model were estimated and compared with the original configuration of the Minimal Adequate model (that is, without Income).

Using an Akaike Information Criterion–based stepwise selection method, the Minimal Adequate model controlling for Income was estimated and compared with the original Minimal Adequate model.

3.3.7.2 Bikeability proxy validation for London

As explained in Section 0, the value of the Walkability Index variable was used as a proxy for the Bikeability Index in the representation of the Objective Built Environment. Although the literature has used the Walkability Index as a factor associated with cycling, Bikeability is preferable, as it is designed specifically for cycling mobility and includes cycling-specific components.

The use of Walkability as a proxy of Bikeability was due to the absence of the input information and calculations necessary to obtain the Bikeability Index for all the cities. Nevertheless, efforts were made to obtain the Bikeability Index for London. With the availability of this resource, the validity of the use of the Walkability index could be tested, at least for a single city, London.

As a sensitivity analysis, the Minimal Adequate model was run for London and compared with a model in which the Walkability variable had been substituted for the Bikeability one.

3.3.8 City as a moderator: stratification by city

As explained above, the Minimal Adequate model was designed as a fixed-effects model, including city as a fixed effect (see Section 3.3.2.2 for the reasons city was included as a fixed effect instead of a random effect). Nevertheless, each city has a unique combination of built and social environment contexts. The combination of these might affect the relationship between said variables and cycling behaviour (Section 2.2). For this reason, the factors that associate cycling environment and cycling behaviour might be moderated by the variable city.

When testing for a moderator, a stratification is recommended (Bauman *et al.*, 2002). The stratification involved applying the same configuration of the Minimal Adequate model but removing the city variable and using the subsample for each of the cities instead. Coefficients were produced and RRRs were estimated in the same way as explained for the Minimal Adequate model (Section 3.3.1.3).

3.3.8.1 Heterogeneity assessment

A heterogeneity assessment was conducted to complement the table of results and further investigate if there was more variability in the explanatory variables than could be expected by chance between the different cities. A series of tests and graphics to assess heterogeneity between different studies or sub-samples has been developed in the literature pertaining to meta-analyses. The heterogeneity assessment consisted of the computation of heterogeneity coefficients Cochran's Q (Chi-squared test, simply referred to as 'Q') and Inconsistency (I^2 or I^2) as advised by the literature (Higgins *et al.*, 2003). Inconsistency can be considered to be the amount of variability not caused by sampling error.

The formula used for quantifying inconsistency is:

$$I^2 = \left(\frac{Q - df}{Q}\right) \times 100\%$$

where Q is the chi-squared statistic and df is its degrees of freedom.

The importance of the observed value of I^2 depends on the magnitude and direction of the effects, and on the strength of evidence for heterogeneity (e.g. p-value from the Chi^2 test). Due to these conditions, the suggested thresholds for the interpretation of the I^2 statistic are not rigid. A rough guide to interpretation is as follows (Higgins *et al.*, 2019):

- 0% to 40%: might not be important;
- 30% to 60%: may represent moderate heterogeneity;
- 50% to 90%: may represent substantial heterogeneity;
- 75% to 100%: considerable heterogeneity.

Lastly, forest plots were produced to demonstrate effect estimates and confidence intervals, which provide a visual aid for heterogeneity assessments (Lewis & Clarke, 2001).

Coefficients Q and I^2 were computed using the R package "metafor" (Viechtbauer, 2017). Forest plots were also produced for each of the variables and comparison levels with the "metaviz" R package (Kossmeier, Tran & Voracek, 2019).

3.3.9 Goodness of fit of the models

Logistic regression does not have an equivalent to the R-squared that is found in linear regression. Given that the models performed in this thesis are all multinomial logistic regression, an alternative measure was selected, the McFadden's pseudo R-squared (McFadden, 1973). This log likelihood ratio R-squared, sometimes referred to as "deviance R-squared", is one minus the ratio of the full-model log-likelihood (L_c) to the intercept-only log-likelihood (L_{null}),

$$R^2_{MF} = 1 - \frac{\log(L_c)}{\log(L_{null})}$$

The likelihood contribution of each observation is a probability and ranges between 0 and 1. If the model has no predictive ability, the likelihood value for the current model will not be much larger than the likelihood of the null model. Hence the ratio of the two log-likelihoods will be close to 1, and McFadden's pseudo R-squared will be close to zero. Conversely, if the model explains almost all the variation in the model, the probabilities observed will be very close to 1, and so will be the likelihood value for each observation. The log of 1 is 0, and so the log-likelihood value $\log(L_c)$ will be close to 0. Then the McFadden's pseudo R-squared will be close to 1. McFadden warned about the values of his pseudo R-squared being lower than those of the R-squared index and according to him, values of 0.2 to 0.4 represent an excellent fit (McFadden, 1979).

Some authors do not recommend McFadden's pseudo R-squared for comparison of models if they do not have the same number of explanatory variables. The reason for this is that McFadden's pseudo R-squared always increases with any additional predictor. To make the test more useful in model selection, it can be combined with a measure of information criteria (AIC was used in this thesis) (Shtatland, Kleinman & Cain, 2002).

McFadden's pseudo R-squared was computed using the R package DescTools (Signorell, 2020).

4 RESULTS

Having diagnosed and allocated all participants to one of the three Stages of Change, the built and social environment factors associated with the three Stages were explored. Descriptive statistics of the study population in each Stage were generated and then the variables were estimated with multinomial regression models.

4.1 Characteristics of the study population

The general sample of the PASTA survey included all participants with valid answers to the questionnaires. Cleaning and preparation of the data frame was carried out by the team at VITO (Belgium), the partners in charge of the platform for data collection and storage. All the researchers within the PASTA project had access to a dashboard in the data collection platform and downloaded the data as the survey progressed. Two data scripts for Data Cleaning and Preparation, which corrected some numeric formats and organised the data into ready-to-calculate rows and columns were also available. When the survey closed, the data was stored on an FTP server, already cleaned and prepared. This was defined as the definitive PASTA survey population.

The survey featured a series of questionnaires (Figure 7); only the Baseline was used in this analysis. Participants who answered the Baseline questionnaire were assigned to a Stage of Change using the set of questions described in Section 3.2.3. This diagnosis was also performed for participants who answered the Final questionnaire.

The following sections include tables summarizing the relevant variables for the Baseline Questionnaire and also for the Final Questionnaire. For both Questionnaires, the population is presented by Stage of Change. For the Baseline Questionnaire, the population is also presented by city.

4.1.1 Description of the general sample

The study population used in this thesis is a sub-sample of the PASTA survey population. The sub-sample was created using a number of questions to diagnose participants first in the five Stages of Change and then in a more manageable and still meaningful three Stages of Change.

In the following sections, both the sample (the PASTA project population) and the sub-sample (the study population) are described.

4.1.1.1 PASTA survey population

A total of 12,825 people registered for the PASTA survey; however, 2,134 never started the baseline questionnaire (attrition rate of 16.6 %). Thus, the population of the baseline questionnaire was 10,691. The attrition rates varied between the cities; see Gaupp-Berghausen *et al.* (2019:fig.3) for more information.

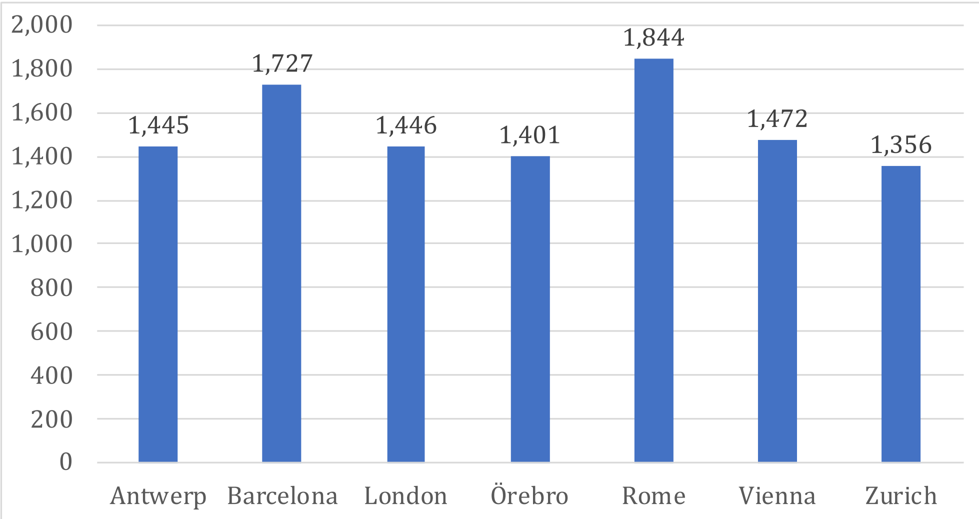


Figure 20. Population in the Baseline Questionnaire presented by city (n=10,691).

The characteristics of cyclists in the PASTA survey have already been well-described. As a broad overview, Raser *et al.* (2018) showed that of all PASTA participants, 97% know how to ride a cycle and 80% have access to a cycle. Forty-four percent of participants reported at least one cycling trip in the trip diaries. Of these, 85% cycled 30 minutes or more per day. An average cycle trip took 27 minutes and was approximately 5 km long. Male cyclists cycled on average 50 minutes per day, females approximately 42 minutes.

Of those who cycle as a mode of transport, 77% think that it saves time, 57% find it comfortable, but only 23% consider it safe with regards to the risk of traffic crashes. An overwhelming 92% agree with the statement that cycling for travel offers personal health benefits, and those for whom health is an important criterion when choosing their mode of transport cycle approximately 10% more frequently than the rest (Raser *et al.*, 2018).

4.1.1.2 Population with assigned cycling behaviour status

The Baseline questionnaire contained all the necessary questions to diagnose participants into the Stages of Change (Figure 10). Participants who did not answer the survey questions that allowed the Stages of Change diagnosis were excluded. The loss of samples due to diagnosis has been carefully minimised by defining each of the Stages of Change in the most comprehensive way, supported by the literature (Section 3.2.3).

In all, N= 7,684 participants (Figure 21) of an original N= 10,691 (Figure 20) were assigned to a Stage of Change.

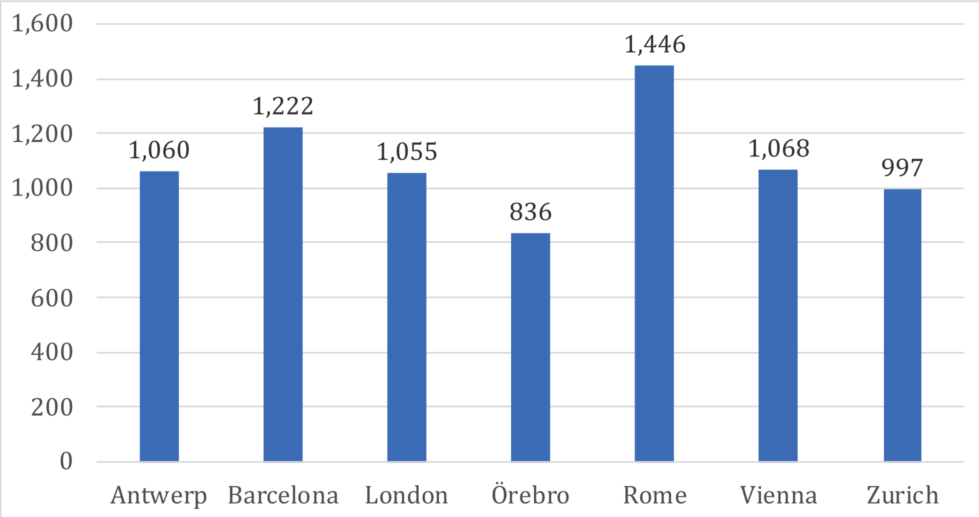


Figure 21. Population of the Baseline Questionnaire diagnosed into the Stages of change presented by city (n=7,684).

4.1.2 Description of the study population

In addition to the summary tables presented below, the text draws attention to some of the features by category (Stages of Change in Table 17 and Cities in Table 18).

4.1.2.1 Population by Stages of Change

The following table describes all the variables from the Baseline Questionnaire involved in this study by Stage of Change.

Table 17. Demographic and environmental characteristics of participants (N= 7,684) by Stage of Change in the Baseline Questionnaire

Baseline Questionnaire	**% of Respondents**	**Precontemplation**	**Contemplation -Preparation**	**Action-Maintenance**	**Total sample**
Stage-diagnosed participants	100.0 (N=7,684)	22.9 (N= 1,762)	25.7 (N= 1,972)	51.4 (N=3,950)	100.0 (N=7,684)
Socio-Economic Status (SES)					
Age	99.9 (N=7,683)				
Mean (min, max)		41.9 (16.1, 87.8)	37.4 (16.1, 80.9)	41.0 (16.8, 76.5)	39.6 (16.1, 87.8)
Sex	100.0 (N=7,684)				
Female		64.6	55.8	49.2	54.4

Baseline Questionnaire	% of Respondents	Preconte-mplation	Contemplation -Preparation	Action-Maintenance	Total sample
Employment status	96.9 (N=7,443)				
Full-time employed		58.0	56.9	63.7	60.6
Part-time employed		15.2	14.3	18.7	16.8
Student		13.0	21.0	11.7	14.4
Home duties/ unemployed/ retired/ sickness leave/ parental leave		13.8	7.8	5.9	8.2
Income	63.9 (N=5,241)				
Less than 10,000€		9.2	18.1	9.4	11.3
10,000€ - 24,999€		18.6	23.8	19.3	20.2
25,000€ - 49,999€		34.6	27.6	35.2	33.4
50,000€ - 74,999€		19.7	16.0	21.8	20.1
75,000€ - 99,999€		11.0	7.9	8.1	8.7
100,000€ - 149,999€		5.3	5.0	4.3	4.6
150,000€ or more		1.6	1.6	1.9	1.7
City					
	100.0 (N=7,684)				
Antwerp		2.3	4.4	23.6	13.8
Barcelona		26.6	12.8	12.7	15.9
London		24.8	10.5	10.4	13.7
Örebro		6.2	8.6	14.1	10.9
Rome		9.5	35.5	14.7	18.8
Vienna		14.8	15.3	12.8	13.9
Zurich		15.8	12.9	11.7	13.0
BUILT ENVIRONMENT (BE)					
Objective Built Environment (OBE)					
Walkability	94.6 (N=7,270)				
Mean (SD)		5.08 (2.22)	4.93 (2.33)	5.24 (2.25)	5.13 (2.27)
Bikeability (only London)	13.4 (N=1,032)				
Mean (SD)		3.85 (1.93)	3.84 (1.73)	4.03 (1.68)	3.92 (1.79)
Perceived Built Environment (PBE)					
Inadequate Parking	86.1 (N=6,616)				
Disagree		52.4	52.4	76.8	65.5
Neither Agree nor Disagree		19.3	14.2	8.5	12.2
Agree		28.3	33.4	14.7	22.3
Lack of changing facilities	86.1 (N=6,616)				
Disagree		47.0	42.1	72.1	59.2
Neither Agree nor Disagree		22.5	17.7	12.4	15.9
Agree		30.5	40.2	15.5	24.9
Traffic Safety	100.0 (N=7,684)				
Disagree		78.0	61.4	42.5	55.5
Neither Agree nor Disagree		16.5	20.6	26.8	22.8
Agree		5.5	18.0	30.7	21.7

Baseline Questionnaire	% of Respondents	Preconte-mplation	Contemplation -Preparation	Action-Maintenance	Total sample
Crime Safety	100.0 (N=7,684)				
Disagree		33.0	25.4	10.6	19.5
Neither Agree nor Disagree		42.7	38.3	34.0	37.1
Agree		24.3	36.3	55.4	43.4
Comfort	100.0 (N=7,684)				
Disagree		52.6	22.8	5.8	20.9
Neither Agree nor Disagree		28.4	26.9	14.3	20.8
Agree		19.0	50.3	79.9	58.3
SOCIAL ENVIRONMENT (SE)					
Perceived Social Environment (PSE)					
Injunctive Social Norm - Well regarded	83.6 (N=6,635)				
Disagree		26.5	19.7	17.9	20.1
Neither Agree nor Disagree		41.8	36.3	28.6	33.4
Agree		31.7	44.0	53.5	46.5
Descriptive Social Norm – Common	86.0 (N=6,609)				
Disagree		36.2	39.6	27.1	32.2
Neither Agree nor Disagree		35.1	31.7	27.1	30.0
Agree		28.7	28.7	45.8	37.8
Social support	83.6 (N=6,635)				
Disagree		71.4	41.2	33.5	43.6
Neither Agree nor Disagree		22.7	34.5	33.0	31.2
Agree		5.9	24.3	33.5	25.2

Slightly over half the sample fell into the Action-Maintenance stage. This was expected as a result of the intentional oversampling of active travel participants (see Section 3.1.2 for more details on the recruitment strategy).

The three Stages varied little in mean age. Sixty-five percent of participants in pre-contemplation were women, though the sex ratio was nearer equal in the other stages.

Most participants were employed (77.4% including both full-timers and part-timers), the greatest proportion of whom were found in the Action-Maintenance group. A further 14.4% were students with the remainder unemployed or having a variety of home-based occupations.

In our sample, the highest proportion of cyclists had a mid-level income, with those in the richest brackets not considering cycling much at all. Participants with low income levels were more often thinking about cycling than cycling.

Barcelona and London stood out as the cities with the highest proportion of participants "Not thinking about cycling", Rome was by far the city with the most participants "Thinking about cycling" and Antwerp leads with the highest proportion of people "Cycling" (Table 17).

The mean values of the Walkability and Bikeability indices for the three Stages are broadly concordant.

The pattern observed for the Objective Built Environment was largely mirrored in participants' responses about the Perceived Built Environment. Cycling participants showed the highest positive perceptions of available facilities (parking and changing facilities/showers) and comfort. On a parallel note, participants who were not even thinking about cycling had the most negative perception of Traffic Safety.

Perceptions of the Social Environment were not as strong as those related to the Built Environment; participants were more reluctant to show positive views of their social environment. The exception is the widely shared (71.4%) negative perception of Social Support held by participants in Pre-contemplation.

Interestingly, there was some evidence that the majority of participants held strong opinions on the variables, as the neutral level of the Likert scale "Neither agree nor Disagree" was used less than 25% of the time in most of the Perceived Built Environment variables except for Crime Safety, for which it was over 37%. It was around a third in most cases for the Perceived Social Environment variables, though Pre-contemplators used it more (42%) when thinking about how cycling is regarded.

4.1.2.2 Population by city

As the sample was non-random, we cannot conclude that the differences in transport behaviour we see in the sample are representative of the overall population. Nonetheless, substantial variation in cycling pattern in the case study cities appeared in the arising data and model variables (Table 18).

Table 18. Demographic and environmental characteristics of participants (N= 7684) by City in the Baseline Questionnaire.

Baseline Questionnaire	Subsample [% of Respondents]	Antwerp	Barcelona	London	Örebro	Rome	Vienna	Zurich	Total sample
Stage-diagnosed participants per city [%]	100.0 (N=7,684)	13.8 (N= 1,060)	15.9 (N= 1,222)	13.7 (N=1,055)	10.9 (N=836)	18.8 (N=1,446)	13.9 (N=1,068)	13.0 (N=997)	100.0 (N=7684)
Stages of Change [%]									
	100.0 (N=7,684)								
Pre-contemplation		3.8	38.4	41.4	13.1	11.7	24.4	27.9	22.9
Contemplation-Preparation		8.1	20.6	19.7	20.3	48.3	28.3	25.6	25.7
Action-Maintenance		88.1	41.0	38.9	66.6	40.0	47.3	46.5	51.4
Socio-Economic Status (SES)									
Age [years]	99.9 (N=7,683)								
Mean (min, max)		41.6 (18.3-79.8)	36.5 (18.0-87.8)	39.7 (18.0-79.9)	43.8 (18.8-78.4)	39.3 (18.1-78.7)	38.4 (18.0-87.7)	39.1 (16.1-78.5)	39.6 (16.1, 87.8)
Sex [%]	100.0 (N=7,684)								
Female		53.4	60.2	59.8	64.2	37.9	54.8	58.0	54.4
Employment status [%]	96.9 (N=7,443)								
Full-time employed		69.8	60.9	63.6	65.2	68.1	45.8	49.2	60.6
Part-time employed		20.2	12.9	13.5	8.8	11.0	20.1	32.4	16.8
Student		2.5	18.6	12.0	12.0	17.0	22.8	13.8	14.4
Home duties/ unemployed/ retired/ sickness leave/ parental leave		7.5	7.6	10.9	14.0	3.9	11.3	4.6	8.2

Baseline Questionnaire	Subsample [% of Respondents]	Antwerp	Barcelona	London	Örebro	Rome	Vienna	Zurich	Total sample
Household Income [%]	63.9 (N=5,241)								
Less than €10,000		0.8	8.9	5.2	6.0	40.0	15.9	4.0	11.3
€10,000 - €24,999		15.1	29.6	10.5	18.3	36.0	26.4	5.7	20.2
€25,000 - €49,999		48.5	43.3	27.3	41.7	17.4	35.9	17.0	33.3
€50,000 - €74,999		29.0	12.1	24.2	25.9	3.8	16.6	28.3	20.1
€75,000 - €99,999		4.6	5.0	19.4	6.6	1.3	3.5	20.9	8.7
€100,000 - €149,999		1.7	0.8	10.2	1.3	0.7	0.9	17.3	4.7
€150,000 or more		0.2	0.3	3.2	0.2	0.8	0.8	6.8	1.7
BUILT ENVIRONMENT (BE)									
Objective Built Environment (OBE)									
Walkability Index	94.6 (N=7,270)								
Mean (SD)		4.94 (2.44)	5.89 (1.84)	4.90 (1.98)	4.11 (2.22)	5.31 (2.37)	5.40 (2.25)	4.83 (2.33)	5.13 (2.27)
Bikeability Index	13.4 (N=1,032)								
Mean (SD)		N/A	N/A	3.92 (1.79)	N/A	N/A	N/A	N/A	3.92 (1.79)
Perceived Built Environment (PBE)									
Inadequate Parking [%]	86.1 (N=6,616)								
Disagree		85.7	42.9	60.0	90.3	45.9	66.1	82.9	65.4
Neither Agree nor Disagree		6.9	19.0	16.6	6.0	16.2	10.4	6.8	12.2
Agree		7.4	38.1	23.4	3.7	37.9	23.5	10.3	22.4
Lack of changing facilities [%]	86.1 (N=6,616)								
Disagree		83.5	44.2	58.2	80.1	35.2	58.5	69.5	59.2
Neither Agree nor Disagree		9.5	25.1	18.8	12.8	19.2	12.3	10.9	15.9
Agree		7.0	30.7	23.0	7.1	45.6	29.2	19.6	24.9

Baseline Questionnaire	Subsample [% of Respondents]	Antwerp	Barcelona	London	Örebro	Rome	Vienna	Zurich	Total sample
Traffic Safety [%]	100.0 (N=7,684)								
Disagree		42.1	63.3	67.6	25.0	61.1	56.9	63.4	55.5
Neither Agree nor Disagree		25.4	19.9	19.6	32.5	19.4	24.8	21.5	22.8
Agree		32.5	16.8	12.8	42.5	19.5	18.3	15.1	21.7
Crime Safety [%]	100.0 (N=7,684)								
Disagree		5.8	21.7	27.7	16.9	27.7	16.6	16.1	19.5
Neither Agree nor Disagree		34.3	38.7	38.1	40.3	41.9	33.2	31.7	37.1
Agree		59.9	39.6	34.2	42.8	30.4	50.2	52.2	43.4
Comfort [%]	100.0 (N=7,684)								
Disagree		9.2	21.1	29.1	13.5	17.9	29.0	26.0	20.9
Neither Agree nor Disagree		16.5	18.7	26.6	19.9	17.6	25.6	22.0	20.8
Agree		74.3	60.2	44.3	66.6	64.5	45.4	52.0	58.3
SOCIAL ENVIRONMENT (SE)									
Perceived Social Environment (PSE)									
Injunctive Social Norm – Well regarded [%]	83.6 (N=6,635)								
Disagree		5.0	13.7	26.8	6.3	26.3	37.9	22.2	20.2
Neither Agree nor Disagree		17.2	37.6	34.4	42.2	34.3	31.5	38.6	33.3
Agree		77.8	48.7	38.8	51.5	39.4	30.6	39.2	46.5
Descriptive Social Norm – Common [%]	86.0 (N=6,609)								
Disagree		13.6	26.2	28.2	10.7	64.8	36.4	29.3	32.2
Neither Agree nor Disagree		18.0	36.3	28.3	32.3	26.6	35.4	34.7	30.0
Agree		68.4	37.5	43.5	57.0	8.6	28.2	36.0	37.8
Social support [%]	83.6 (N=6,635)								
Disagree		34.7	47.4	45.4	32.0	51.3	45.9	42.7	43.5
Neither Agree nor Disagree		25.9	34.2	32.1	39.7	28.3	32.2	28.5	31.2
Agree		39.4	18.4	22.5	28.3	20.4	21.9	28.8	25.3

There was substantial variation in cycling behaviour between the seven case study cities in our sample. Cities with the highest proportion of Action-Maintainers were, in descending order: Antwerp, Örebro, Vienna, Zurich and Barcelona, ranging from 88.1% to 41.0%. The only city in which Contemplation-Preparation dominated was Rome, with 48.3% of residents in this Stage. Pre-contemplators were the largest category in London with 41.4% of participants in this Stage; the lowest proportion of this group is, by far, in Antwerp, where only a 3.8% of their participants were not even thinking about cycling.

Örebro, the smallest city, was the city with the oldest mean age (43.8 years) in the sample. Barcelona had the youngest at 36.5 years. Örebro also had the highest percentage of women respondents (64.2%), whereas Rome had the lowest (37.9%). In all of the cities, full-time employment dominated the sample, but the pattern of other employment levels varied.

The pattern of household income in most cities was normally distributed, but Rome's sample skewed toward the lower income range (less than €24,999) and in Zurich the reverse was observed (more in the > €50,000).

The Walkability Index of the OBE varied more between cities (from 4.11 in Örebro, to 5.89 in Barcelona) than between the three cycling Stages (from 4.93 in Contemplation-Preparation to 5.24 in Action-Maintenance).

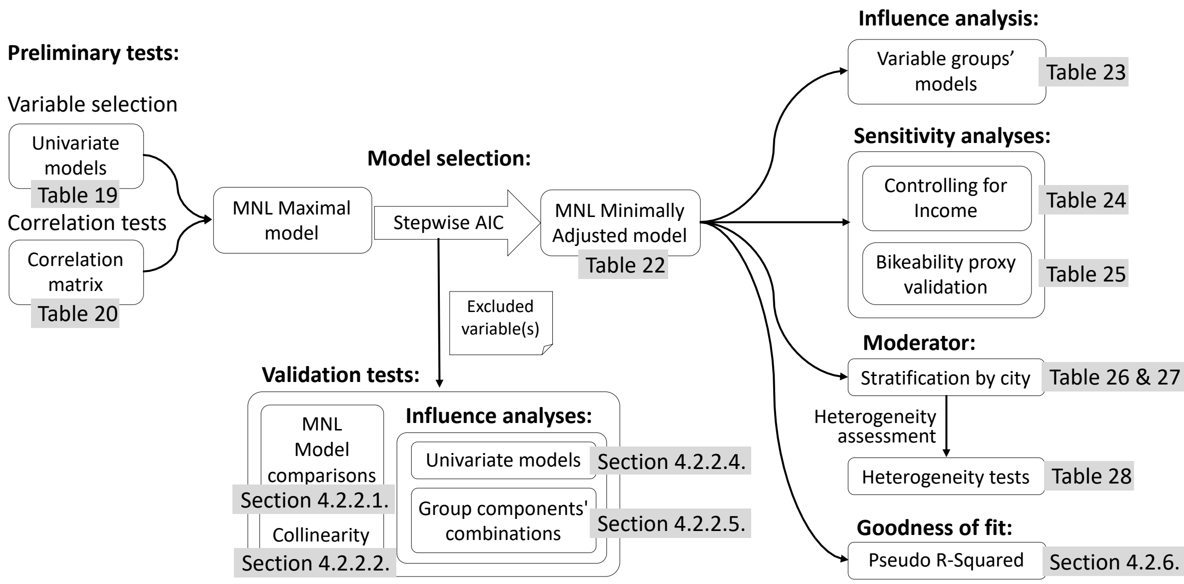
The Antwerp and Örebro samples showed the most positive perceptions of available facilities (Parking and Shower/Changing facilities) and Comfort of cycling. Barcelona and Rome also had a relatively high positive perception of Comfort. Antwerp and Örebro were also leaders in having a positive perception of Traffic Safety, but the prevalence was smaller than for the previously mentioned three variables. Crime Safety had a slightly different distribution, with Antwerp, Zurich and Vienna perceived to be the safest from crime.

On the negative side of PBE, Barcelona leads for Inadequate Parking, followed by Rome; Rome leads in Lack of changing and shower facilities, followed by Barcelona; Traffic Safety is the most negatively perceived in London, followed by Barcelona and Zurich; Crime Safety is equally perceived in negative terms by Londoners and Romans; participants who rated cycling least Comfortable are those from London and Vienna.

The perception of the Social Environment is strongly positive for Social Norms in Antwerp, and although less strong for Social Support, still the highest of all cities. Örebro consistently shows high shares for the three, in relation to the rest of the cities. The most negative perceptions of SE can be observed for Vienna for the Injunctive Social Norm and for Rome, with more than half of the participants thinking that Cycling is not Common (Descriptive Social Norm) and perceiving negative Social Support.

4.2 Correlates of the Stages of Change towards cycling for transport

The multinomial modelling approach enabled the statistical identification of correlates and thus the potential drivers that motivate people to cycle. This section presents the results of this analysis and Figure 22 presents a 'guide to the process' to assist in navigating the section.



Note: MNL: multinomial, AIC: Akaike Information Criterion, BE: Built Environment, SE: Social Environment.

Figure 22. Flowchart of the modelling design with indications to the Sections or Tables in which each of the items can be found.

4.2.1 Preliminary tests

Preliminary tests indicate appropriate selection of variables to proceed with and include in the Maximal Model.

4.2.1.1 Variable selection

All the variables included in the survey displayed some explanatory power in the initial univariate models and were thus included in the Maximal Model (Table 19).

Table 19. Associations expressed as Relative Risk Ratios (RRR) for each of the variables included in the Maximal model (Univariate models), all adjusted by socio-economic status and city.

	Univariate models RRR (95% CI)	
	Pre-contemplation	Contemplation-Preparation
BUILT ENVIRONMENT (BE)		
OBJECTIVE BUILT ENVIRONMENT (OBE)		
Walkability	0.90 (0.88, 0.93)	0.89 (0.87, 0.91)
Bikeability (London only)	0.95 (0.87, 1.03)	0.90 (0.82, 1.00)
PERCEIVED BUILT ENVIRONMENT (PBE)		
Inadequate Parking	2.21 (1.86, 2.62)	2.33 (1.98, 2.73)
Lack of changing facilities	2.79 (2.35, 3.31)	3.01 (2.57, 3.51)
Traffic Safety	0.12 (0.09, 0.15)	0.47 (0.41, 0.55)
Crime Safety	0.17 (0.14, 0.20)	0.36 (0.30, 0.42)
Comfort	0.02 (0.02, 0.03)	0.15 (0.12, 0.18)
SOCIAL ENVIRONMENT (SE)		
PERCEIVED SOCIAL ENVIRONMENT (PSE)		
Descriptive Social Norm	0.51 (0.43, 0.61)	0.83 (0.70, 0.98)
Injunctive Social Norm	0.53 (0.44, 0.64)	1.20 (1.01, 1.43)
Social Support	0.09 (0.07, 0.11)	0.71 (0.61, 0.83)

CI: Confidence Interval; BE: Built Environment; SE: Social Environment. Reference group for the outcome variable: Action-Maintenance. Highlighted in green, CI not including 1.

4.2.1.2 Correlation between variables

Correlation between model variables was considered to have little influence on the model as few correlations were detected, and these were low or lower moderate (Table 20).

Table 20. Correlation coefficients for all the variables of the Maximal model, plus Income.

	Socio-Economic Status					Built Environment						Social Environment		
	Age^{c}	**Sex^{n}**	**Employment status^{n}**	**Income^{o}**	**City^{n}**	**Walkability^{c}**	**Inadequate Parking^{o}**	**Lack of changing facilities^{o}**	**Traffic Safety^{o}**	**Crime^{o}**	**Comfort^{o}**	**Injunctive Social Norm^{o}**	**Descriptive Social Norm^{o}**	**Social Support^{o}**
Age^{c}	1.00													
Sex^{n}	-0.07*	1.00												
Employment status^{n}	**-0.55***	0.16*	1.00											
Income^{o}	0.20*	-0.04	-0.21*	1.00										
City^{n}	-0.16*	-0.17*	0.16*	0.27*	1.00									
Walkability^{c}	-0.07*	0.02	0.04*	-0.15*	-0.22*	1.00								
Inadequate Parking^{o}	-0.09*	-0.03	0.08*	-0.12*	-0.27*	0.10*	1.00							
Lack of changing facilities^{o}	-0.12*	-0.05*	0.11*	-0.12*	0.26*	0.04	**0.56***	1.00						
Traffic Safety^{o}	0.02	-0.07*	-0.02	0.06*	-0.20*	-0.06*	-0.21*	-0.19*	1.00					
Crime Safety^{o}	-0.05*	-0.07*	-0.04*	0.08*	-0.16*	0.05*	-0.20*	-0.20*	**0.41***	1.00				
Comfort^{o}	-0.04*	-0.07*	-0.04*	-0.05*	-0.15*	0.08*	-0.13*	-0.18*	**0.41***	**0.31***	1.00			
Injunctive Social Norm – Well reg.^{o}	0.02	0.07*	-0.04*	0.07*	-0.24*	0.02	-0.12*	-0.10*	0.19*	0.12*	0.14*	1.00		
Descriptive Social Norm – Common^{o}	-0.03	0.14*	-0.04*	0.13*	**-0.32***	0.11*	-0.17*	-0.17*	0.19*	0.13*	0.12*	**0.56***	1.00	
Social Support^{o}	-0.03	-0.03	0.03	0.03	-0.13*	0.05*	-0.05*	-0.06*	0.21*	0.17*	0.25*	0.23*	0.20*	1.00

In bold: correlation coefficient values above 0.30 or below -0.30.
*P<0.01
Superscripts: “c”, continuous variable; “n”, nominal categorial variable; “o”, ordered categorical variable.
See Table 15 for the statistical tests used for each pair of variables.

Notes: the Bikeability variable has not been included, as this matrix was computed for the general sample of the study. In Section 4.2.4.2, the correlation coefficient for Bikeability vs. Walkability is presented in relation to the London subsample.

The strongest correlations found were in the lower ranges of 'moderate' correlation (rho=0.56) and they were between the pairs of variables Lack of changing facilities : Inadequate parking; and Descriptive Social Norm : Injunctive Social Norm. The rest of the correlations fell in the Low range and were between the pairs Crime Safety : Traffic Safety, and Comfort : Traffic Safety (both rho=0.41). Finally, there was a Low, almost negligible correlation between Comfort and Crime (rho=0.31). All of these correlations were statistically significant ($P < 0.01$).

The only other correlation was between the control variables Age and Employment Status (moderate). This might hint at the collinearity that will later be found for Age, see Section 4.2.2.2.

4.2.2 Model selection

A stepwise simplification procedure produced a parsimonious model, the Minimal Adequate model. In this process, only one variable did not offer sufficient explanatory power to be retained, which strongly justifies the initial selection of variables.

4.2.2.1 Multinomial model comparisons

The Descriptive Social Norm did not have sufficient explanatory power to be retained in the model, all other explanatory variables were retained. The forward stepwise procedure showed a negligible change in the AIC (Maximal model AIC = 8,709 and Minimal Adequate model AIC = 8,702). Additionally, an ANOVA between both models did not identify any significant change in explanatory power of the model due to the simplification (LR=1.10, d.f. =4, p=0.89), which supported the reduction of this variable.

4.2.2.2 Collinearity

Even though the correlation matrix did not indicate any strong correlation between any pair of variables, a posterior collinearity test was applied to make sure that no linear relations between pairs of variables could be compromising the precision of the coefficient estimates (Table 21).

The General Variance Inflation Factor GVIF, and its normalised version $GVIF^{1/(2\times df)}$ were used to estimate this (see Section 3.3.5.2).

Table 21. Normalised General variance-inflation factor results for the collinearity assessment of the variables included in the Minimal Adequate model

Variables in the Minimal Adequate model	GVIF	Df	GVIF^(1/(2*Df))
SOCIO-ECONOMIC STATUS (SES)			
Age	18.52	1	4.30
Sex	3.15	1	1.78
Employment status	5.13	3	1.31
CITY			
City	126.70	6	1.50
BUILT ENVIRONMENT (BE)			
OBJECTIVE BUILT ENVIRONMENT (OBE)			
Walkability	8.09	1	2.84
PERCEIVED BUILT ENVIRONMENT (PBE)			
Inadequate Parking	4.38	2	1.45
Lack of changing facilities	4.83	2	1.48
Traffic Safety	2.11	2	1.21
Crime Safety	7.36	2	1.65
Comfort	6.49	2	1.60
SOCIAL ENVIRONMENT (SE)			
PERCEIVED SOCIAL ENVIRONMENT (PSE)			
Injunctive Social Norm - Well regarded	6.89	2	1.62
Social Support	2.31	2	1.23

GVIF, Generalised variance-inflation factor; Df, Degrees of freedom. Highlighted in green, GVIF^(1/(2*Df))>3.2.

The threshold for $GVIF^{1/(2\times df)}$ was established as 3.2. The only variable with a collinearity measure above the threshold was Age, with a $GVIF^{1/(2\times df)}$ = 4.3. This collinearity does not create any problems in regard to the model, as this affects only the estimates of the variable Age, which is a control variable. Furthermore, the correlation matrix did not show any strong correlations for this variable. In this situation, collinearity can be ignored and no further action is required (Johnston, Jones & Manley, 2018; O'Brien, 2017; Allison, 2012a).

4.2.2.3 Predictors for each of the variables in the Minimal Adequate model

Relative Risk Ratios for both of the comparison levels (Pre-contemplation and Contemplation-Preparation) of the outcome variable, the Stages of Change, are presented in Table 22. The total sample for the Minimal Adequate model was n=6,194. For guidance interpreting RRRs, see Section 3.3.1.3. Results in percent relative effect for the Minimal Adequate model are included in Table 27.

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Table 22. Associations expressed as Relative Risk Ratios (RRR) between Built and Social Environment, and Stages of Change, adjusting for Socio-Economic Status and City in the Minimal Adequate Model (n=6,194).

	STAGES OF CHANGE (Reference level: Action-Maintenance)	
	Pre-contemplation	**Contemplation-Preparation**
Variables in the Minimal Adequate model	**RRR (95% CI)**	**RRR (95% CI)**
SOCIO-ECONOMIC STATUS (SES)		
Age (Continuous variable)	1.02 (1.01, 1.03)	0.99 (0.99, 1.00)
Females (Reference: Males)	1.88 (1.57, 2.25)	1.73 (1.49, 2.00)
Employment status (Reference: Full-timer)		
Part-timer	0.88 (0.69, 1.13)	0.87 (0.71, 1.06)
Student	1.36 (1.03, 1.79)	1.48 (1.19, 1.84)
Unemployed	2.62 (1.87, 3.66)	2.33 (1.74, 3.12)
CITY (Reference: Antwerp)		
Barcelona	19.94 (12.65, 31.43)	4.01 (2.92, 5.51)
London	13.70 (8.66, 21.68)	3.37 (2.42, 4.68)
Örebro	2.91 (1.74, 4.88)	2.04 (1.45, 2.86)
Rome	4.84 (3.00, 7.79)	10.67 (7.91, 14.39)
Vienna	6.41 (4.02, 10.22)	4.37 (3.19, 5.98)
Zurich	10.61 (6.68, 16.85)	4.73 (3.45, 6.50)
BUILT ENVIRONMENT (BE)		
OBJECTIVE BUILT ENVIRONMENT (OBE)		
Walkability (Continuous variable)	0.95 (0.91, 0.99)	0.89 (0.86, 0.92)
PERCEIVED BUILT ENVIRONMENT (PBE)		
Inadequate Parking (Reference: Disagree)	1.34 (1.06, 1.69)	1.58 (1.31, 1.91)
Lack of changing facilities (Reference: Disagree)	1.54 (1.23, 1.93)	2.01 (1.67, 2.41)
Traffic Safety (Reference: Disagree)	0.47 (0.35, 0.64)	0.86 (0.71, 1.04)
Crime Safety (Reference: Disagree)	0.51 (0.40, 0.66)	0.64 (0.52, 0.79)
Comfort (Reference: Disagree)	0.04 (0.03, 0.05)	0.19 (0.15, 0.23)
SOCIAL ENVIRONMENT (SE)		
PERCEIVED SOCIAL ENVIRONMENT (PSE)		
Injunctive Social Norm – Well regarded (Reference: Disagree)	0.96 (0.76, 1.21)	1.52 (1.24, 1.85)
Social Support (Reference: Disagree)	0.15 (0.11, 0.20)	0.88 (0.73, 1.05)

RRR: Relative Risk Ratio; CI: Confidence Interval. Reference group for the outcome variable: Action-Maintenance. Highlighted in green, CI not including 1.

The RRRs identified as important statistically (when the 95% CI interval does not include 1) from this sample are highlighted in green in this table (and in all other tables showing RRRs). Continuous variables tend to show RRRs closer to one partly due to the nature of their interpretation (see Section 3.3.1.3). For example, the model identified a 2% increase in the risk of being in Pre-contemplation for each additional year of age.

Of the Socio-Economic Status variables, gender showed the biggest influence on Stage of Change, with women less likely to be in Action-Maintenance; they had an 88% greater risk of being in Pre-contemplation and a 73% of being in Contemplation-Preparation than men.

The reference level for cities is Antwerp, the city with the highest proportion of people cycling (Table 18; see Section 4.2.5 for a stratification by city).

Improvements in Walkability significantly increase the odds of being in Action-Maintenance, with changes making less of an influence on those who are in Pre-contemplation than those in Contemplation-Preparation.

People who agreed that Inadequate parking and Lack of facilities were barriers to cycling were less likely to be cycling (in Action-Maintenance stage), and these perceptions acted as stronger deterrents for those in Contemplation-Preparation than for those in Pre-contemplation.

People who agreed that cycling was safe with regards to both traffic and crime and were comfortable cycling were more likely to be cycling (in Action-Maintenance stage), with these perceptions having a larger positive influence on those in Pre-contemplation than on those in Contemplation-Preparation (except for the Traffic Safety variable, which was not statistically significant enough for the coefficient of Contemplation-Preparation stage).

People who felt cycling was well regarded within their neighbourhoods (Injunctive norm) were more likely to be in Contemplation-Preparation vs Action-Maintenance; the variable had no effect on Pre-contemplators. Inversely, those who felt people important to them supported their traveling by bicycle (Social Support) were less likely to be in Pre-contemplation than in Action-Maintenance (that is, more likely to cycle), with no effect on the likelihood of being in Contemplation-Preparation vs Action-Maintenance.

4.2.2.4 Influence analysis of the excluded variable: univariate models

The variable Descriptive Social Norm had explanatory power in the univariate preliminary tests (Table 23), although it lost its power when integrated into a model with all the other variables.

4.2.2.5 *Influence analysis of the excluded variable: Variable group components´ combinations*

Descriptive Social Norm was part of the perceived social environment (PSE) group of variables. In order to test the significance of Descriptive Social Norm, several combinations of the component variables of its PSE group were additionally estimated within the framework of the multivariate maximal model. The Descriptive Social Norm only displayed explanatory power when estimated as the only representative of the PSE group. Whenever any other of the PSE group variables were also included, they obscured any effect of Descriptive Social Norm.

The Descriptive Social Norm variable was moderately correlated with the Injunctive Social Norm (Table 11, rho= 0.56, P < 0.001). Both variables are Social Norms, thus the correlation might indicate that they two may describe similar patterns related to Social Norms.

4.2.3 Influence analysis: variable groups

In order to assess the overall effect of the BE and SE groups of variables, the Minimal Adequate model with each of the variable groups removed was estimated (Table 23).

Table 23. Associations expressed as Relative Risk Ratios (RRR) for each of the variables included in the Minimal Adequate model for each group of variables (BE only and SE only), all adjusted by SES and city.

	BE only RRR (95% CI)		**SE only RRR (95% CI)**	
	Pre-contemplation	Contemplation-Preparation	Pre-contemplation	Contemplation-Preparation
BUILT ENVIRONMENT (BE)				
OBJECTIVE BUILT ENVIRONMENT (OBE)				
Walkability	0.94 (0.90, 0.97)	0.89 (0.87, 0.92)		
PERCEIVED BUILT ENVIRONMENT (PBE)				
Inadequate Parking	1.31 (1.05, 1.64)	1.54 (1.28, 1.85)		
Lack of changing facilities	1.53 (1.23, 1.90)	2.04 (1.70, 2.44)		
Traffic Safety	0.43 (0.32, 0.58)	0.87 (0.71, 1.06)		
Crime Safety	0.47 (0.37, 0.60)	0.65 (0.53, 0.80)		
Comfort	0.04 (0.03, 0.04)	0.19 (0.15, 0.24)		
SOCIAL ENVIRONMENT (SE)				
PERCEIVED SOCIAL ENVIRONMENT (PSE)				
Injunctive Social Norm			0.75 (0.62, 0.91)	1.27 (1.06, 1.52)
Social Support			0.09 (0.07, 0.12)	0.70 (0.59, 0.82)

CI: Confidence Interval; BE: Built Environment; SE: Social Environment. Reference group for the outcome variable: Action-Maintenance. Highlighted in green, CI not including 1.

Relative Risk Ratios do not vary much when one of the variable groups is removed from the Minimal Adequate model (Table 22 vs. Table 23). Although changes are small in both models, predictors in the "SE only" show a more noticeable change. In the "SE only" model compared to the Minimal Adequate model, all variables become significant, and all display a stronger effect except for a slightly lower effect of the Injunctive Social Norm on Contemplation-Preparation.

4.2.4 Sensitivity analysis

4.2.4.1 Controlling for Income

The variable Income was not included in the Maximal model because of the number of missing values in the category (36.1%), nevertheless it is considered a relevant variable in this type of studies and thus a sensitivity analysis was performed on the Minimal Adequate model, controlling for Income.

Table 24. Associations expressed as Relative Risk Ratios (RRR) between Built and Social Environment and Stages of Change, adjusting for Socio-Economic Status and City in the Minimal Adequate Model (n=6,194) compared with the Model controlling for Income (n=4,923).

	Minimal Adequate model		**Minimal Adequate model controlling for Income**	
	Pre-contemplation	**Contemplation-Preparation**	**Pre-contemplation**	**Contemplation-Preparation**
	RRR (95% CI)	**RRR (95% CI)**	**RRR (95% CI)**	**RRR (95% CI)**
BUILT ENVIRONMENT (BE)				
Objective Built Environment (OBE)				
Walkability	0.95 (0.91, 0.99)	0.89 (0.86, 0.92)	0.94 (0.90, 0.99)	0.89 (0.86, 0.92)
Perceived Built Environment (PBE)				
Inadequate Parking	1.34 (1.06, 1.69)	1.58 (1.31, 1.91)	1.29 (0.99, 1.68)	1.51 (1.22, 1.88)
Lack of changing facilities	1.54 (1.23, 1.93)	2.01 (1.67, 2.41)	1.45 (1.12, 1.87)	2.08 (1.69, 2.56)
Traffic Safety	0.47 (0.35, 0.64)	0.86 (0.71, 1.04)	0.41 (0.29, 0.59)	0.76 (0.61, 0.96)
Crime Safety	0.51 (0.40, 0.66)	0.64 (0.52, 0.79)	0.55 (0.42, 0.73)	0.64 (0.50, 0.80)
Comfort	0.04 (0.03, 0.05)	0.19 (0.15, 0.23)	0.04 (0.03, 0.06)	0.21 (0.16, 0.27)
SOCIAL ENVIRONMENT (SE)				
Perceived Social Environment (PSE)				
Injunctive Social Norm	0.96 (0.76, 1.21)	1.52 (1.24, 1.85)	0.87 (0.67, 1.14)	1.44 (1.15, 1.81)
Social Support	0.15 (0.11, 0.20)	0.88 (0.73, 1.05)	0.16 (0.12, 0.22)	0.93 (0.75, 1.14)

RRR: Relative Risk Ratio; CI: Confidence Interval. Reference group for the outcome variable: Action-Maintenance. Highlighted in green, CI not including 1.

As observed in Table 24, there were not many differences in the RRRs when Income was controlled for. Whenever differences were observed, they were very small (only at the level of a few centesimal digits) and, they always maintained direction (RRR being smaller or bigger than 1).

A stepwise regression using an Akaike Information Criterion (AIC) was used to test the strength of the model controlling for Income. The model obtained after applying the AIC-based selection method excluded the variable Income, meaning that this variable was not explanatory enough to be retained. This result supported the decision to exclude the variable Income from the model, in addition to avoid loss of data due to missing Income values.

4.2.4.2 Bikeability proxy validation for London

A 95% Spearman rank correlation test between Walkability and Bikeability variables was performed (rho=0.48, $P < 0.05$), there is thus a moderate positive correlation between these variables (Hinkle, Wiersma & Jurs, 2003; Mukaka, 2012) and supports the use of Walkability as a proxy.

As seen in Table 23, the univariate model using Bikeability instead of Walkability for London indicates that the variable is not sufficiently explanatory to be included in a hypothetical model. It is unknown if this would change were the Bikeability sample were larger (the number of fitted values in the univariate model is 1,014).

The Minimal Adequate model was run for the city of London – also included in Table 26 – and compared with a model in which the Walkability variable was substituted for the Bikeability one. The results of the two London models are presented in Table 25:

Table 25. Associations expressed as Relative Risk Ratios (RRR) in the Minimal Adequate model for London (n=785) compared with the model using Bikeability (n=818) instead of Walkability.

	Minimal Adequate model for London		Minimal Adequate model for London with Bikeability instead of Walkability	
	Pre-contemplation	Contemplation-Preparation	Pre-contemplation	Contemplation-Preparation
	RRR (95% CI)	RRR (95% CI)	RRR (95% CI)	RRR (95% CI)
BUILT ENVIRONMENT (BE)				
Objective Built Environment (OBE)				
Walkability	1.05 (0.93, 1.18)	0.95 (0.84, 1.06)		
Bikeability			0.93 (0.82, 1.07)	0.88 (0.77, 1.01)
Perceived Built Environment (PBE)				
Inadequate Parking	1.33 (0.71, 2.49)	1.47 (0.80, 2.71)	1.36 (0.73, 2.52)	1.56 (0.86, 2.83)
Lack of changing facilities	1.28 (0.68, 2.44)	2.31 (1.28, 4.17)	1.28 (0.68, 2.41)	2.16 (1.21, 3.84)
Traffic Safety	0.62 (0.27, 1.44)	0.52 (0.24, 1.11)	0.62 (0.27, 1.43)	0.56 (0.27, 1.14)
Crime Safety	0.54 (0.28, 1.04)	0.71 (0.38, 1.34)	0.50 (0.26, 0.95)	0.72 (0.39, 1.34)
Comfort	0.02 (0.01, 0.04)	0.12 (0.06, 0.24)	0.02 (0.01, 0.04)	0.11 (0.05, 0.22)
SOCIAL ENVIRONMENT (SE)				
Perceived Social Environment (PSE)				
Injunctive Social Norm	1.49 (0.82, 2.70)	1.89 (1.05, 3.41)	1.63 (0.90, 2.94)	1.96 (1.09, 3.52)
Social Support	0.11 (0.05, 0.22)	0.57 (0.31, 1.02)	0.11 (0.06, 0.23)	0.60 (0.33, 1.07)

RRR: Relative Risk Ratio; CI: Confidence Interval. Reference group for the outcome variable: Action-Maintenance. Highlighted in green, CI not including 1.

All RRRs associated with the indices lack sufficient statistical strength. However, as this is the focus of this sensitivity analysis, it is worth making some observations. This validation test showed that when using Bikeability instead of Walkability the differences were very small. In the majority of cases, results follow the tendencies and directions already observed with the use of Walkability.

This said, there was a change of direction in the Pre-contemplation coefficients between the indices. With an increase in the Bikeability index, participants were more likely to be in the reference groups rather than in Action-Maintenance than in the other Stages. In contrast, with an increase in the Walkability index, respondents were only more likely to be in Pre-contemplation than in Action-Maintenance, but less likely to be in Contemplation-Preparation. In other words, this change of direction would mean that, with a better walking environment (a higher

Walkability score) people were more likely to be “Not thinking about cycling” rather than being “Cycling”, but with a better cycling environment (or a higher Bikeability score) people were less likely to be “Not thinking about cycling” than “Cycling”. But again, this change was small in both models, and all RRRs associated with the indices lack sufficient statistical strength.

Regarding the other variables, the most noticeable change is that Crime Safety becomes a significant deterrent for Pre-contemplators once the model is adjusted for Bikeability instead of Walkability.

The only other variable with a change of more than 10 percentage points and sufficient statistical significance is the Lack of Changing Facilities. The people in the Contemplation-Preparation Stage are 116% more likely to perceive a Lack of Changing Facilities than those in Action-Maintenance in the Bikeability model, but this likelihood was 15 percentage points higher in the Walkability model (131%).

4.2.5 City as a moderator: Stratification by city

As explained in Section 3.3.8, the variable city was considered a moderator in this study. In this case, a stratification is recommended by the literature (Bauman *et al.*, 2002). Seven models, one for each city sample, were produced; each one used the same configuration as the Minimal Adequate model but without fitting the variable city. The results are shown in Table 26:

Table 26. Models for each of the seven cities, adjusted for Socio-Economic Status, with associations expressed as Relative Risk Ratios between Built and Social Environment and Stages of Change, adjusting for Socio-Economic Status in models for each of the 7 cities.

	Antwerp RRR (95% CI)		Barcelona RRR (95% CI)		London RRR (95% CI)		Örebro RRR (95% CI)		Rome RRR (95% CI)		Vienna RRR (95% CI)		Zurich RRR (95% CI)	
	Pre-contemplation	Contemplation-Preparation	Pre-contemplation	Contemplation-Preparation	Pre-contemplation	Contemplation-Preparation	Pre-contemplation	Contemplation-Preparation	Pre-contemplation	Contemplation-Preparation	Pre-contemplation	Contemplation-Preparation	Pre-contemplation	Contemplation-Preparation
BUILT ENVIRONMENT (BE)														
Objective Built Environment (OBE)														
Walkability	0.95 (0.79, 1.14)	0.83 (0.75, 0.93)	0.81 (0.73, 0.91)	0.79 (0.71, 0.88)	1.05 (0.93, 1.18)	0.95 (0.84, 1.06)	0.97 (0.83, 1.13)	0.89 (0.79, 0.99)	1.04 (0.94, 1.15)	0.92 (0.87, 0.98)	0.93 (0.84, 1.02)	0.95 (0.87, 1.03)	0.90 (0.82, 0.99)	0.84 (0.77, 0.92)
Perceived Built Environment (PBE)														
Inadequate Parking	8.38 (2.30, 30.46)	2.76 (1.23, 6.19)	0.86 (0.53, 1.38)	1.51 (0.95, 2.38)	1.33 (0.71, 2.49)	1.47 (0.80, 2.71)	2.30 (0.53, 9.95)	1.21 (0.36, 4.13)	1.46 (0.80, 2.68)	1.29 (0.92, 1.82)	1.88 (1.09, 3.22)	2.45 (1.56, 3.87)	1.77 (0.86, 3.67)	2.09 (1.10, 4.00)
Lack of changing facilities	0.42 (0.07, 2.72)	2.18 (0.99, 4.79)	1.77 (1.08, 2.92)	1.38 (0.86, 2.22)	1.28 (0.68, 2.44)	2.31 (1.28, 4.17)	2.08 (0.66, 6.54)	4.24 (1.86, 9.69)	1.69 (0.88, 3.23)	1.84 (1.30, 2.61)	2.29 (1.36, 3.85)	3.29 (2.11, 5.11)	1.06 (0.60, 1.86)	1.71 (1.02, 2.85)
Traffic Safety	0.57 (0.14, 2.35)	1.01 (0.55, 1.87)	0.44 (0.24, 0.82)	0.54 (0.31, 0.93)	0.62 (0.27, 1.44)	0.52 (0.24, 1.11)	0.32 (0.12, 0.89)	0.72 (0.36, 1.42)	0.16 (0.04, 0.72)	1.13 (0.77, 1.66)	0.24 (0.10, 0.60)	0.79 (0.47, 1.34)	0.54 (0.26, 1.11)	0.67 (0.36, 1.23)
Crime Safety	0.51 (0.13, 1.95)	0.47 (0.19, 1.14)	0.38 (0.22, 0.67)	0.37 (0.22, 0.63)	0.54 (0.28, 1.04)	0.71 (0.38, 1.34)	0.83 (0.29, 2.33)	0.91 (0.42, 1.96)	0.16 (0.07, 0.38)	0.51 (0.34, 0.77)	1.06 (0.56, 1.99)	1.50 (0.83, 2.72)	0.48 (0.26, 0.91)	0.66 (0.36, 1.23)
Comfort	0.03 (0.01, 0.08)	0.44 (0.19, 1.02)	0.04 (0.02, 0.07)	0.21 (0.10, 0.43)	0.02 (0.01, 0.04)	0.12 (0.06, 0.24)	0.04 (0.02, 0.10)	0.10 (0.05, 0.22)	0.01 (0.01, 0.03)	0.11 (0.06, 0.20)	0.05 (0.03, 0.09)	0.25 (0.15, 0.42)	0.11 (0.06, 0.19)	0.25 (0.15, 0.42)
SOCIAL ENVIRONMENT (SE)														
Perceived Social Environment (PSE)														
Injunctive Social Norm	1.51 (0.20, 11.06)	1.28 (0.35, 4.62)	1.01 (0.56, 1.84)	1.66 (0.87, 3.14)	1.49 (0.82, 2.70)	1.89 (1.05, 3.41)	0.40 (0.12, 1.25)	0.81 (0.27, 2.40)	0.82 (0.43, 1.55)	1.83 (1.28, 2.62)	0.91 (0.53, 1.59)	1.45 (0.92, 2.29)	0.56 (0.32, 0.97)	0.72 (0.42, 1.25)
Social Support	0.74 (0.25, 2.20)	1.42 (0.78, 2.58)	0.06 (0.03, 0.12)	0.45 (0.27, 0.75)	0.11 (0.05, 0.22)	0.57 (0.31, 1.02)	0.09 (0.03, 0.34)	0.61 (0.32, 1.16)	0.17 (0.05, 0.52)	1.47 (1.02, 2.11)	0.21 (0.11, 0.43)	0.78 (0.49, 1.26)	0.16 (0.09, 0.31)	0.84 (0.51, 1.37)

RRR: Relative Risk Ratio; CI: Confidence Interval. Reference group for the outcome variable: Action-Maintenance. Highlighted in green, CI not including 1.

Table 27. Models for each of the seven cities, adjusted for Socio-Economic Status, with associations expressed in percent relative effect between Built and Social Environment and Stages of Change, adjusting for Socio-Economic Status.

[%]	Minimal Adequate		Antwerp		Barcelona		London		Örebro		Rome		Vienna		Zurich	
	Pre-contemplation	Contemplation-Preparation	Pre-contemplation	Contemplation-Preparation	Pre-contemplation	Contemplation-Preparation	Pre-contemplation	Contemplation-Preparation	Pre-contemplation	Contemplation-Preparation	Pre-contemplation	Contemplation-Preparation	Pre-contemplation	Contemplation-Preparation	Pre-contemplation	Contemplation-Preparation
BUILT ENVIRONMENT (BE)																
Objective Built Environment (OBE)																
Walkability	-5	**-11**	-5	**-17**	**-19**	**-21**	+5	-5	-3	**-11**	+4	-8	-7	-5	**-10**	**-16**
Perceived Built Environment (PBE)																
Inadequate Parking	+34	+58	**+738**	**+176**	-14	+51	+33	+47	**+130**	+21	+46	+29	+88	**+145**	+77	**+109**
Lack of changing facilities	+54	**+101**	**-58**	**+118**	+77	+38	+28	+31	**+108**	**+324**	+69	+84	**+129**	**+229**	+6	+71
Traffic Safety	**-53**	-14	-43	+1	**-56**	-46	-38	-48	**-68**	-28	**-84**	+13	**-76**	-21	-46	-33
Crime Safety	-49	-36	-49	**-53**	**-62**	**-63**	-46	-29	-17	-9	-84	-49	+6	+50	**-52**	-34
Comfort	**-96**	**-81**	**-97**	**-56**	**-96**	**-79**	**-98**	**-88**	**-96**	**-90**	**-99**	**-89**	**-95**	**-75**	**-89**	**-75**
SOCIAL ENVIRONMENT (SE)																
Perceived Social Environment (PSE)																
Injunctive Social Norm	-4	+52	+51	+28	+1	+66	+49	+89	+40	+81	+82	+83	-9	+45	-44	-28
Social Support	**-85**	-12	-26	+42	**-94**	**-55**	**-89**	-43	**-91**	-39	**-83**	+47	**-79**	-22	**-84**	-16

Note: Highlighted in green, CI not including 0%. In **bold**, where risks are halved (>-50%) or doubled (>+100%) in 3-levelled variables (all PBE and PSE variables) and where risks increased or decreased more than 10% for the 10-levelled variable (Walkability). Reference group for the outcome variable: Action-Maintenance. Highlighted in green, CI not including 1.

These results have been presented as both RRR and percent relative effect to make it easier to observe the size of the effects in Table 27, in comparison to the results for the Minimal Adequate model from Table 22. The biggest effect sizes (that is, the absolute percent relative effect) indicate which variables were the most influential in determining the affiliation to the three Stages of Change.

The variables in our dataset for which more than half of the cities had an RRR that had enough statistical strength to be of note were Comfort and Social Support. On the other hand, the perception of cycling being well-regarded is the variable for which the fewest cities had strong results.

Zurich, Barcelona and Rome presented the largest number of coefficients with sufficient statistical strength, in contrast with Antwerp showing strong risk differences for only three of the variables in some of the Stages.

Walkability had a moderate influence on those 'Not thinking about cycling' but the effects were bigger for those 'Thinking about cycling'. Barcelona stands out as the city with the highest predictors for this variable; with people being 20% less likely to be in the comparison level rather than in Action-Maintenance for each additional unit increase in the Walkability index.

The two variables related to the perception of cycling facilities (Inadequate parking and Lack of changing facilities) report the highest positive risks, with the Lack of changing facilities and showers being the one with the strongest results. Antwerp's case was notable not only for featuring the variable with the strongest effects (Inadequate parking) of all the models, but also because the results for the Pre-contemplation level of this same variable went in a different direction from the Minimal Adequate model. In Antwerp, people not thinking about cycling perceive parking to be much more inadequate than people who are thinking about cycling, whereas in the complete dataset it is the other way around. Effect sizes for both Inadequate parking and Lack of changing facilities were also very high in Vienna and Örebro, with both of them statistically strong for both Stages of Change in Vienna.

Regarding the variables related to safety, the effects were, in general, the most modest of the PBE group, but still risks were halved in many instances. Although generally results went in the same direction as in the Minimal Adequate model, Vienna presented an exception (although not sufficiently strong) with a higher likelihood of people in pre-Action feeling less worried about crime than people cycling.

Comfort maintains both statistical strength and very high effect size even in the general model, for which it can be considered to be the most robust variable in the model. The likelihood of feeling that cycling is comfortable is overwhelmingly lower in pre-Action stages, especially in Pre-contemplation.

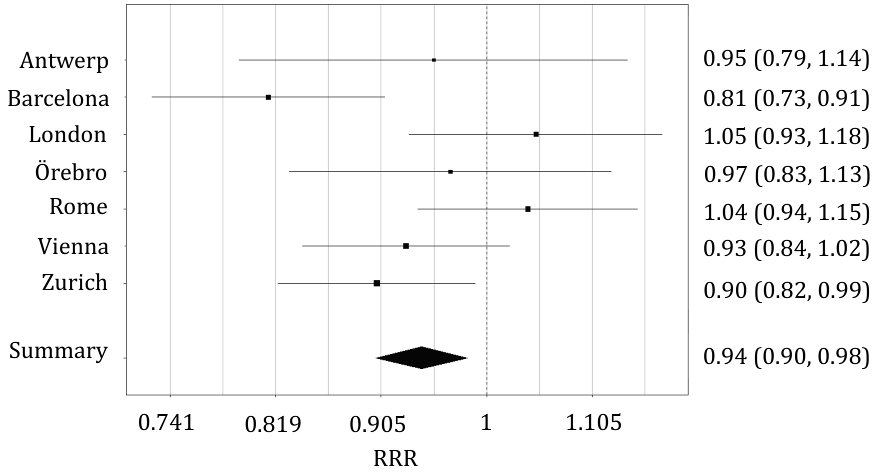
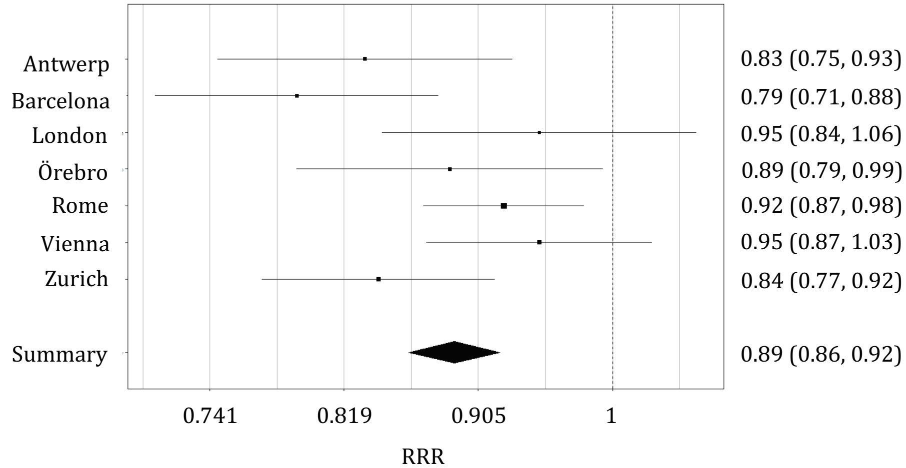
Findings show significant and strong impact of the SE, consistently across cities except for Antwerp. Of the SE variables, Social support presents the strongest results and biggest effect sizes especially in Pre-contemplation. People in that stage are much less likely to feel they have the social support they need to cycle. Antwerp is an exception that presumably lowers the impact size and contributes to the loss of statistical strength for people thinking about cycling.

The results of the Injunctive social norm are the weakest and most mixed of the table, with cities demonstrating opposite effects: in Zurich for example, people in pre-Action are less likely to think cycling is well-regarded in their neighbourhood, but in Rome and London the effect is the opposite, with people in pre-Action more likely to think cycling is well-regarded.

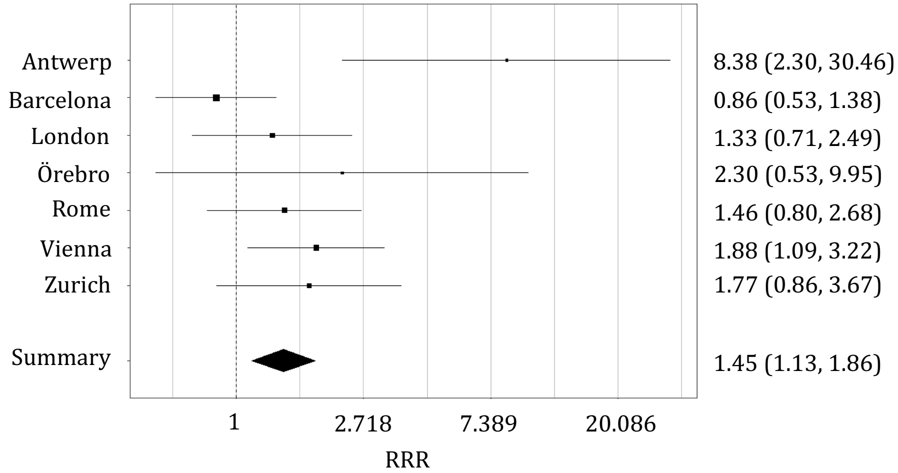
4.2.5.1 Heterogeneity assessment

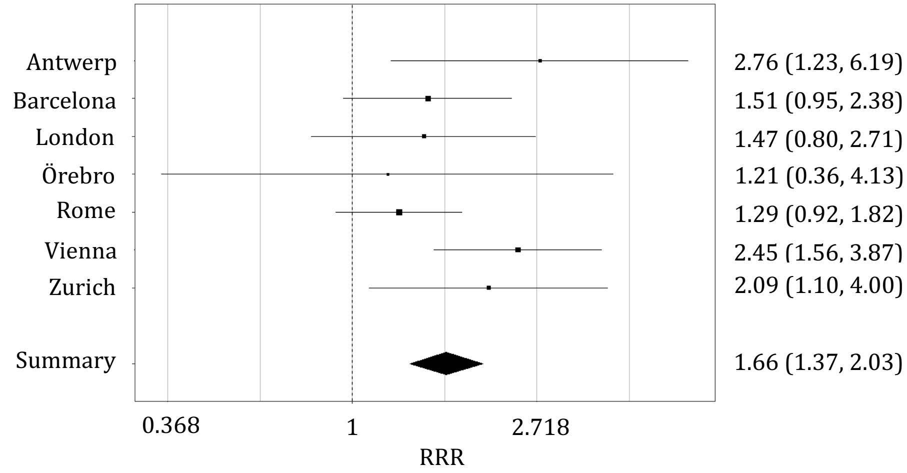
Heterogeneity tests involved computing coefficients Q and I^2 (also referred-to as I^2) and the visual representation on a forest plot of the RRR for each of the cities by comparison level (Pre-contemplation and Contemplation-Preparation) and variable.

Table 28. Forest plots for each variable using the RRR presented in Table 22, and adding the Summary RRR and heterogeneity coefficients "Cochran's Q" and "I^2" of the associations of each of the factors with the Stages of Change, presented for the two comparison levels Pre-contemplation and Contemplation-Preparation (Reference: Action-Maintenance).

<table>
<tr><th colspan="2">BUILT ENVIRONMENT (BE)</th></tr>
<tr><td>Objective Built Environment (OBE)</td><td></td></tr>
<tr><td>Walkability</td><td></td></tr>
<tr><td>Pre-contemplation
Minimal Adequate model RRR (95%) = 0.95 (0.91, 0.99)</td><td>Contemplation-Preparation
Minimal Adequate model RRR (95%) = 0.89 (0.86, 0.92)</td></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td>Q(df = 6) = 0.8073, p-val = 0.9919
I^2 (total heterogeneity / total variability): 0.00%</td><td>Q(df = 6) = 0.6054, p-val = 0.9963
I^2 (total heterogeneity / total variability): 0.00%</td></tr>
</table>

Perceived Built Environment (PBE)	
Inadequate Parking	
Pre-contemplation Minimal Adequate model RRR (95%) = 1.34 (1.06, 1.69)	Contemplation-Preparation Minimal Adequate model RRR (95%) = 1.58 (1.31, 1.91)

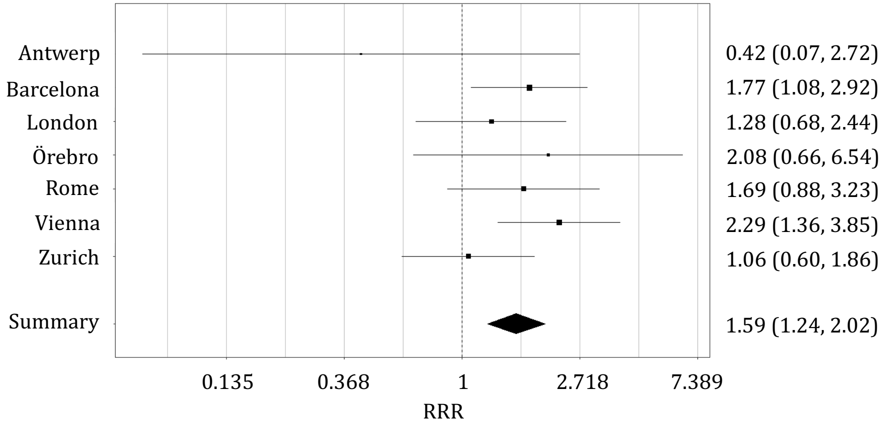




Q(df = 6) = 6.2069, p-val = 0.4004 I^2 (total heterogeneity / total variability): 0.00%	Q(df = 6) = 2.0301, p-val = 0.9169 I^2 (total heterogeneity / total variability): 0.00%

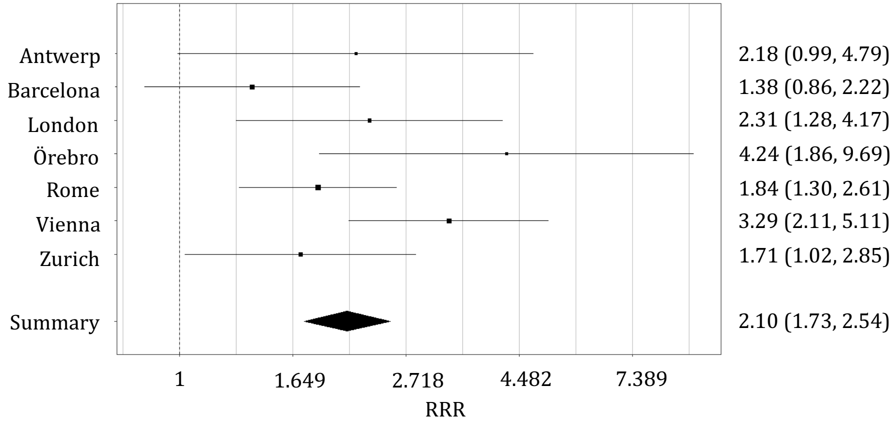
Lack of changing facilities

Pre-contemplation
Minimal Adequate model RRR (95%) = 1.54 (1.23, 1.93)



Q(df = 6) = 3.1812, p-val = 0.7858
I^2 (total heterogeneity / total variability): 0.00%

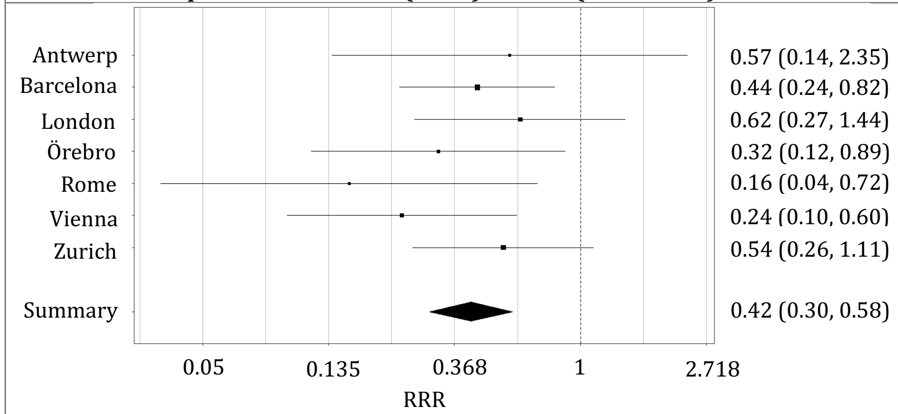
Contemplation-Preparation
Minimal Adequate model RRR (95%) = 2.01 (1.67, 2.41)



Q(df = 6) = 3.0603, p-val = 0.8012
I^2 (total heterogeneity / total variability): 0.00%

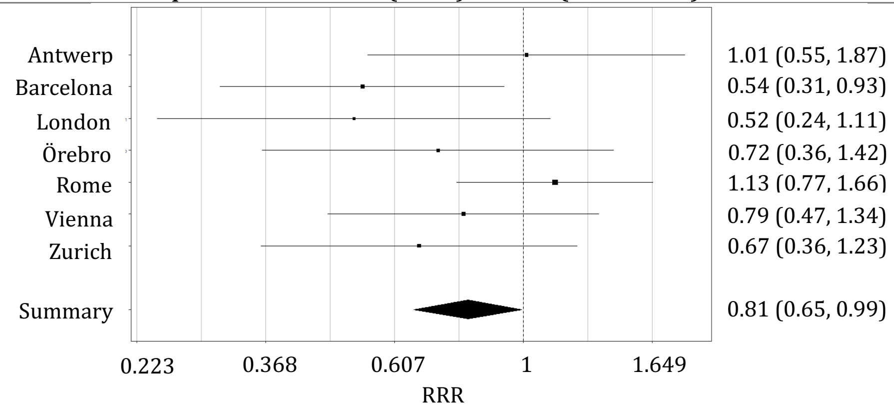
Traffic Safety

Pre-contemplation
Minimal Adequate model RRR (95%) = 0.47 (0.35, 0.64)



Q(df = 6) = 2.6376, p-val = 0.8528
I^2 (total heterogeneity / total variability): 0.00%

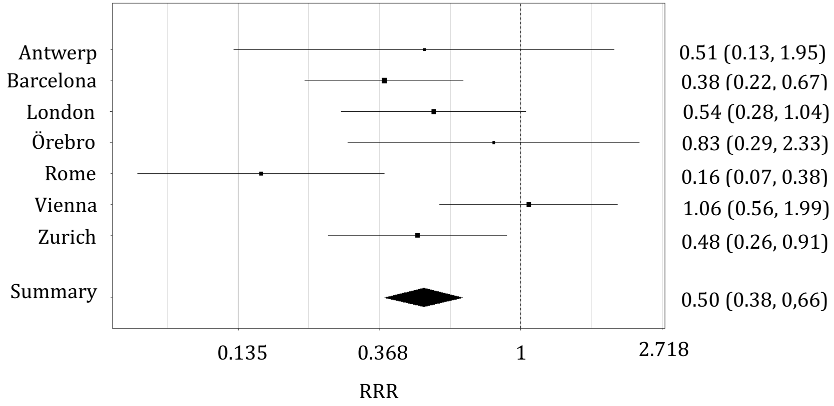
Contemplation-Preparation
Minimal Adequate model RRR (95%) = 0.86 (0.71, 1.04)



Q(df = 6) = 1.9487, p-val = 0.9244
I^2 (total heterogeneity / total variability): 0.00%

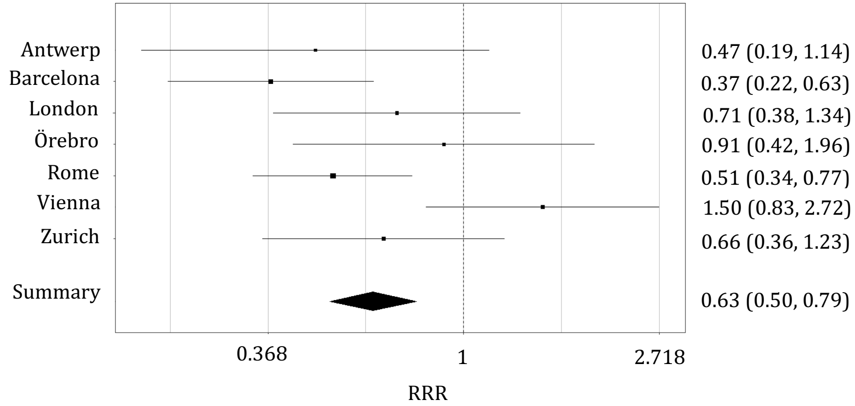
Crime Safety

Pre-contemplation
Minimal Adequate model RRR (95%) = 0.51 (0.40, 0.66)



Q(df = 6) = 5.4501, p-val = 0.4875
I^2 (total heterogeneity / total variability): 0.00%

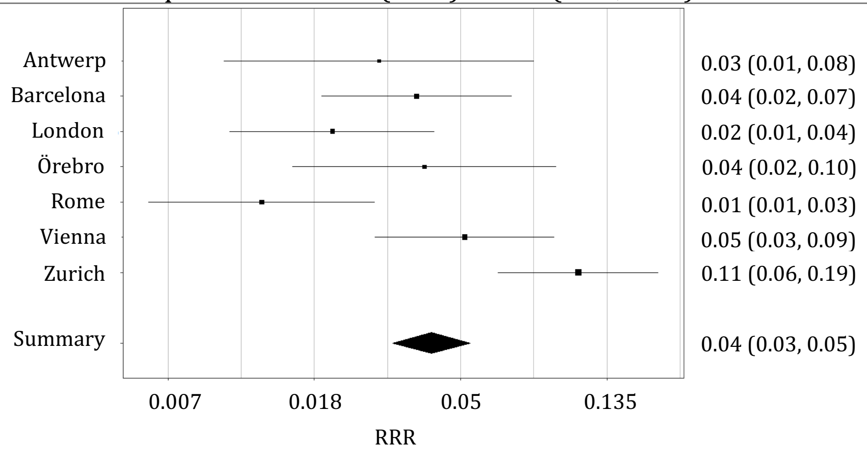
Contemplation-Preparation
Minimal Adequate model RRR (95%) = 0.64 (0.52, 0.79)



Q(df = 6) = 4.2492, p-val = 0.6430
I^2 (total heterogeneity / total variability): 0.00%

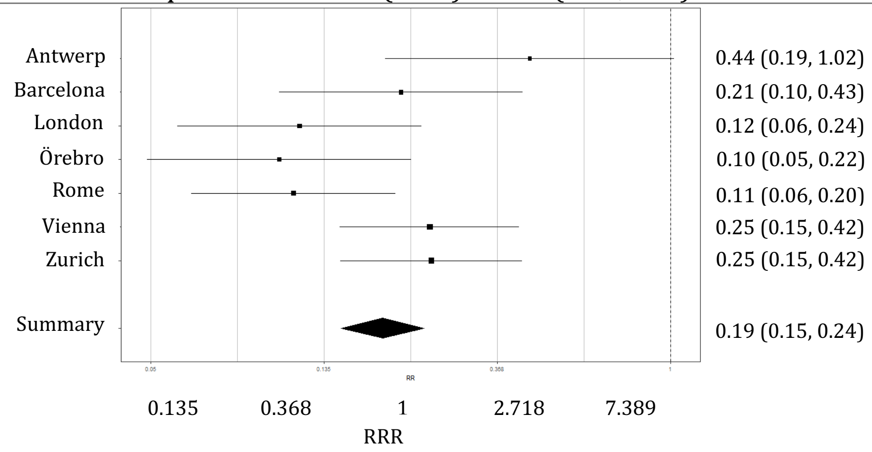
Comfort

Pre-contemplation
Minimal Adequate model RRR (95%) = 0.04 (0.03, 0.05)

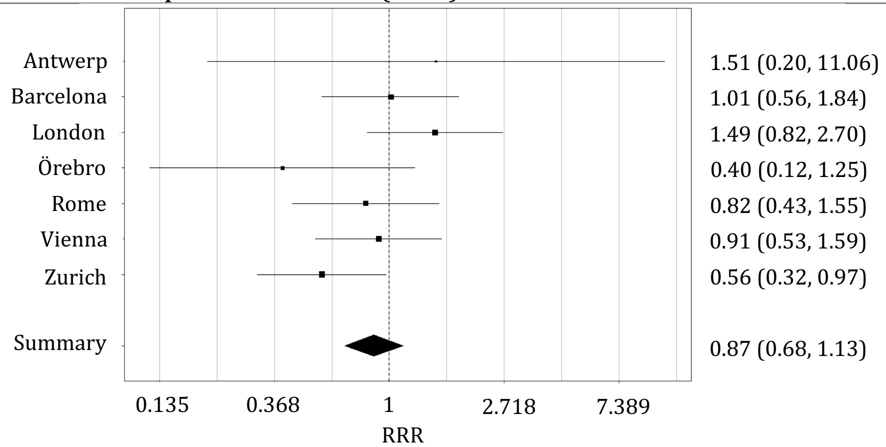
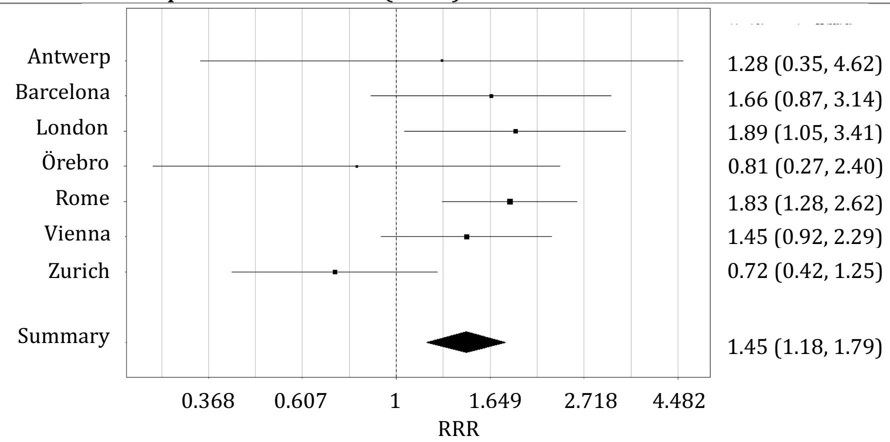


Q(df = 6) = 8.5922, p-val = 0.1978
I^2 (total heterogeneity / total variability): 33.11%

Contemplation-Preparation
Minimal Adequate model RRR (95%) = 0.19 (0.15, 023)

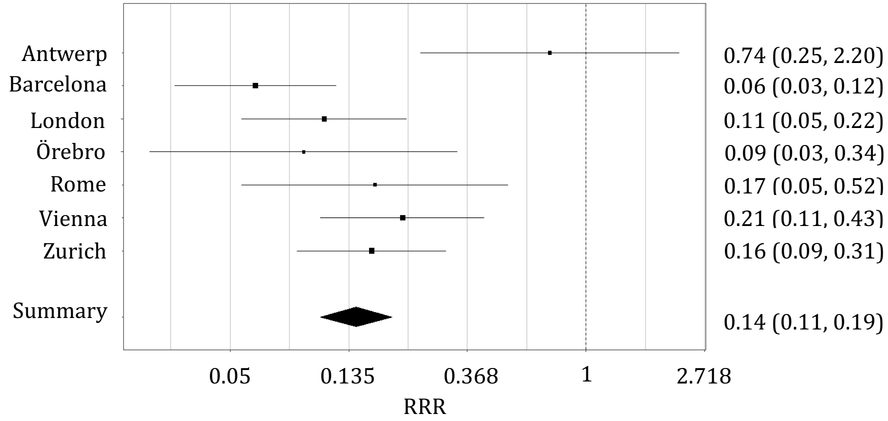


Q(df = 6) = 4.7300, p-val = 0.5789
I^2 (total heterogeneity / total variability): 0.00%

<table>
<tr><td colspan="2">SOCIAL ENVIRONMENT (SE)</td></tr>
<tr><td>Perceived Social Environment (PSE)</td><td></td></tr>
<tr><td>Injunctive Social Norm</td><td></td></tr>
<tr><td>Pre-contemplation
Minimal Adequate model RRR (95%) =</td><td>Contemplation-Preparation
Minimal Adequate model RRR (95%) =</td></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td>Q(df = 6) = 3.1116, p-val = 0.7947
I^2 (total heterogeneity / total variability): 0.00%</td><td>Q(df = 6) = 2.8959, p-val = 0.8218
I^2 (total heterogeneity / total variability): 0.00%</td></tr>
</table>

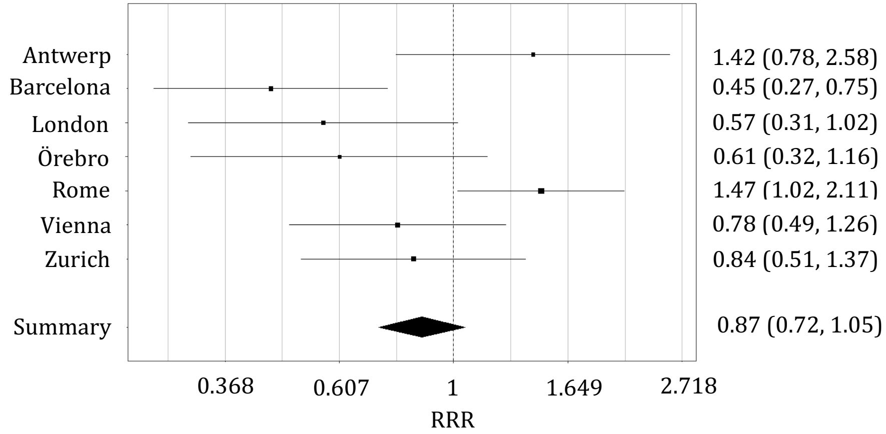
Social Support

Pre-contemplation
Minimal Adequate model RRR (95%) =



Q(df = 6) = 7.8490, p-val = 0.2494
I^2 (total heterogeneity / total variability): 19.60%

Contemplation-Preparation
Minimal Adequate model RRR (95%) =



Q(df = 6) = 4.9090, p-val = 0.5555
I^2 (total heterogeneity / total variability): 0.00%

Shadowed: I^2 > 30%, see Section 3.3.8.1 for interpretation of this coefficient

The only variables that demonstrate any heterogeneity were Comfort and Social Support, with the latter not even reaching the lowest threshold of importance. Comfort had 33.11% of inconsistency, which falls within the thresholds of both no importance and moderate importance (Table 28). It should also be noted that the p-values for the Q coefficients used in the computation of I^2 are bigger than 0.10 - the threshold usually used for p-values in heterogeneity assessment, rather than the conventional level of 0.05. For these reasons, this inconsistency should not be considered to be important. No further tests are advised in this case (Higgins *et al.*, 2019).

4.2.6 Goodness of fit

McFadden's pseudo R-squared was used to assess the goodness of fit of the models. The test can only establish comparison between models with exactly the same number of variables, which means the Minimal Adequate Model could only be compared with the City models. Values of McFadden's pseudo R-squared have been also computed for the SE and the BE models, although they cannot be compared with the rest of the models.

Table 29. Goodness of fit of the models (McFadden's pseudo R-squared)

Model	McFadden's pseudo R-squared
Minimal Adequate model (Table 22)	0.31
Antwerp (Table 26)	0.22
Barcelona (Table 26)	0.30
London* (Table 26)	0.33
Örebro (Table 26)	0.28
Rome (Table 26)	0.25
Vienna (Table 26)	0.25
Zurich (Table 26)	0.20
Built Environment (BE) (Table 23)	0.28
Social Environment (BE) (Table 23)	0.17

* The London Walkability and Bikeability models report the same values. Values between 0.2 and 0.4 in this test are considered to indicate an excellent fit of the model.

5 DISCUSSION

5.1 Study summary and principal findings

This study analyses a sample of participants of an on-line survey that was launched in seven Case-Study Cities within the European project PASTA (Physical Activity through Sustainable Transport Approaches). The 7,684 participants have been assigned to one of three Stages of Change, using the psychological framework first proposed by Prochaska and Velicer (1997), the Transtheoretical Model.

A statistical model has been used to measure the associations of built and social environment with the Stages of Change. Each participant of the PASTA questionnaire has been diagnosed into one of the five Stages of Change based on the answers to specific questions. The variables that defined these Stages of Change referred to whether participants (1) were defined as cyclists or non-cyclists based on their frequency cycling for travel (more than once a week), (2) had the intention of cycling for transport in the future, (3) had access to a bicycle (private or shared), (4) had increased cycling over the previous 12 months, and (5) cycled for travel automatically, without thinking about it.

The model has been fit with Objective and Perceived Built Environment variables and Perceived Social Environment variables, controlling also for Socio-Demographic variables and for the participants' City. Stepwise simplification of the model only failed to retain one variable, the Descriptive Social Norm, belonging to the SE variable group and based on the question "In my neighbourhood, it is common for people to cycle 'for travel'". The two other SE variables were retained: Injunctive Social Norm, from the question "In my neighbourhood cycling is well regarded" and Social Support "Most people who are important to me think that I should cycle 'for travel'". All BE variables were retained in the model, including those about Objective and Perceived BE. The OBE was measured through the Walkability index (a score ranging from 1 to 10). Perceived BE variables featured perceptions on the availability of cycle parking ("Inadequate parking for my bike at home and at my destinations make it impossible for me to cycle more"), changing facilities and showers ("The lack of changing and shower facilities at my destinations prevents me from using a bicycle"), Traffic Safety ("With your day-to-day needs in mind would you say that cycling 'for travel' is safe with regards to traffic") , Crime Safety (same question as Traffic Safety but ending in "… is safe with regards to crime") and Comfort (same question as Traffic Safety but ending in "… is comfortable"). All questions in relation to PBE and PSE were assessed with a 5-level Likert scale, simplified to a 3-level scale, "Agree", "Neither agree nor disagree" and "Disagree".

All models were controlled for SES variables Age, Sex, Employment Status and Income (0) and all but the stratified models were also controlled for City.

Results for the SES variables show that men who did not cycle regularly were more likely than women to be contemplating cycling, and the likelihood of not thinking about cycling rose with age. With these effects accounted for in the models, the results show that variables in both the built and social environment have strong associations with the cycling stage of change to which people were diagnosed. All variables have noticeable effects, that is, with a RRR which 95% CI does not include the null value. For BE, variable effect sizes are greatest for Comfort and for the perceptions of cycling facilities (Inadequate cycle parking and lack of changing facilities). For the SE variables, Social Support is the most important effect, and particularly for Pre-contemplators. An additional goodness-of-fit measure, the McFadden pseudo R-squared, reports that the model has an excellent fit.

Sensitivity analyses have confirmed (1) the validity of Walkability as a proxy for Bikeability for the London sample, (2) the lack of importance of income as a variable in this model and (3) the overall homogeneity of the results across cities, which does not support City as a moderator of the effect of BE and SE in the Stages of Change for Cycling for Transport and thus emphasises the generality of the findings.

5.2 Interpretation of results

5.2.1 Built environment and social environment groups of variables

Results confirm that both built and social environment are important in explaining cycling behaviour. Both groups of variables included independent and significant factors explaining Stages of Change in cycling for transport, with effects remaining essentially unchanged when one of the two groups was excluded from the model (compare Table 22 and Table 23). For the BE, there were objective and perceived factors included in the models. It was found that both were significant, in line with the literature (Porter *et al.*, 2018).

Other studies had found that psychosocial correlates (which correspond to some of the SE variables included in this thesis) seemed to outperform the role of BE correlates; this was first demonstrated in settings with a good provision of cycle infrastructure such as Flanders (Belgium) (de Geus *et al.*, 2008; Simons *et al.*, 2017), and later in less well-provided settings such as Brussels (Belgium) (de Geus *et al.*, 2019). Here, although we have some indication of effect sizes (Table 27), it is not possible to be conclusive about the relative importance of SE versus BE. Results in this thesis challenge the Belgian studies showing that in cities with high cycling modal share, like Antwerp and Örebro, SE predictors were weak (See Figure 1 and Table 26). In Antwerp, SE predictors do not even have enough statistical power. Similarly, in Örebro only one in the four SE predictors was statistically sufficient – and by a narrow margin. In general, the level of cycling in the different CSC does not seem to influence the effect size of each group of variables. These results seem to indicate that it is not generally clear which factors make either SE or BE more important than the other in any given city, though it is clear that they both matter.

Influence analysis and goodness of fit tests indicate that both groups of variables are strong predictors of the Stages of Change, with the SE group of variables slightly less strong than BE. This can be observed by the subtle variation in the SE estimates when removing BE variables and also, by the pseudo R-squared value of the SE model being just below the excellent fit threshold. This can be due to the SE group having a smaller number of variables than the BE group, but it might also be related to SE predictors showing less strength than the BE predictors when the model is stratified by cities, especially the Injunctive Social Norm.

5.2.2 Measures of Objective Built Environment

In this analysis, two measures of the OBE have been used, the Walkability index for the general sample and the Bikeability index, which was only available for London.

Recent studies offer some support to the use of Walkability as a measure of OBE for cycling. The review by Smith *et al.* (2017) finds a consistent positive effect of Walkability on active transport and physical activity, but it does not specify the effect in relation to cycling. This tendency to aggregate various types of physical activity was also noticed by Wang and Yang in their review (2019), but they highlight an exception in the work of Grasser *et al.* (2017) who found that whatever measure of walkability was used, the use of cycling for transport was positively influenced by it.

Before discussing the results, note that while all PBE and PSE variables are derived on a 3-point scale (disagree/neutral/agree), the Walkability and Bikeability indices are derived on a 10 point scale. Hence the interpretation of a one unit increase in the OBE score is necessarily different to the other variables and effect sizes are expected to be much smaller (see 3.3.1.3. for a complete explanation).

The influence of the Walkability index was greater for people in Contemplation-Preparation ("Thinking about cycling") than on those in Pre-contemplation ("Not thinking about cycling"), suggesting that people thinking about cycling may pay more attention to their built environment. This might be due to people in Contemplation-Preparation making an active assessment of the conditions affecting their consideration of cycle for transport. This tendency was also shared with the Bikeability estimates for London.

Using the Walkability Index as the variable for OBE in the model made very little difference to using the Bikeability Index, at least in the case of London. When replacing Walkability with Bikeability in the London-based sensitivity analysis, non-significant results were found for both indices, although the effect estimates were a little stronger for the Bikeability index. In London, the Bikeability score seemed to capture a little better the dimensions of the cycling environment, particularly the influence on people thinking about cycling. In city-specific analyses, Walkability failed to explain differences between Pre-contemplators and active cyclists in Antwerp, Örebro, Rome and Vienna, and failed to influence those in Contemplation-Preparation in Vienna and London, too (Table 26). In contrast, the pooled analysis does maintain the significant positive influence of Walkability on cycling (Table 22).

When the London model accounts for Bikeability instead of Walkability, social norms and safety concerns become slightly more important, while changing facilities slightly less so. Accounting for Bikeability seems to help capture more precisely some of the influences on the Stages of Change. These results showed that Bikeability is likely to be a better measure than Walkability to explain the cycling Stages of Change, although this hypothesis could not be confirmed for other cities due to lack of data availability.

5.2.3 Cycling facilities: Inadequate Cycle Parking and Lack of changing facilities

Heinen *et al.*'s review (2010) showed that previous studies consistently found adequate parking to be important for commuter cyclists. Nevertheless, the evidence was not conclusive regarding the influence of showers on cycling frequency or modal share, although cyclists valued them. But authors also mention that having no cycling facilities in the workplace can be a barrier to commute by cycle, which seem to support the inclusion of these variables in cycling behaviour models. The results in this thesis are in line with the evidence about the importance of parking and also contribute with unambiguous evidence about the importance of both showers and changing facilities. Furthermore, it adds new insights to the literature by measuring the influence of cycling facilities on the Stages of Change.

In consonance with the results in this thesis, a study by de Geus *et al.* (2008) found that workplace cycling facilities (including showers and safe cycle parking) included in the environmental variables were statistically strong estimates for cycling for transport. It should be noted that this study focused on workplace mobility whereas data in this thesis refer in general, to all locations.

In the Stages of Change defined in this thesis, both Pre-contemplators and Contemplation-Preparators are non-cyclists, but results show there is a difference in the way cycling facilities influence the membership to these two Stages. Of the PBE factors, the two facilities variables -

Inadequate parking and Lack of changing facilities and showers - are the only two that exert a stronger influence on Contemplation-Preparators than on Pre-contemplators. This provides new information about the perceptions of non-cyclists of the provision of cycle parking and showers. That is to say, in comparison to people who are thinking about cycling (Contemplation-Preparators), those not thinking about cycling (Pre-contemplators) seem to be more concerned about Safety and Comfort but less concerned about parking and other cycling facilities such as showers. These cycling facilities are an inseparable part of a cycling trip; they are key to determining if the trip can take place (parking) and how comfortable it will be to cycle for that particular trip (changing facilities and showers). The difference between the perceptions of the two groups might be due to people who are not interested in cycling being less aware of the key role of parking or changing facilities, and relatively more concerned about the cycling environment along the way.

5.2.4 Perception of traffic safety

The perception of traffic safety, although statistically significant in the univariate models for both comparison groups (Table 19), lost significance in the fully adjusted models explaining Contemplation-Preparators (Thinking about cycling) in reference to Action-Maintainers. This is in line with previous studies (Thigpen, Driller & Handy, 2015; van Bekkum, Williams & Morris, 2011), where perception of Traffic Safety was found to be more strongly associated with the earlier Stages of Change.

Cycling research in general has consistently identified perception of traffic unsafety as an important barrier to cycling (Heinen, van Wee & Maat, 2010). An aggregate measure of Traffic and Crime safety, was shown to be the most important deterrent to cycling in Metro Vancouver (Winters *et al.*, 2011). A similar aggregate metric was used in Kerr *et al.'s* (2016) comparison of 17 cities in 12 countries around the world and found that perceived safety was positively associated with any cycling for transport but also that it was negatively associated with the amount of cycling among those who cycled. This negative association is also consistent with Sanders' findings (2015). These results seem in line with our findings and may suggest that people who are not thinking about cycling have a stronger perception of the environment being unsafe compared to those who cycle. This might indicate that in order to make cycling policies more influential to this specific group of non-cyclists (those not thinking about cycling) it is not only necessary to build high quality infrastructure but also implement communication campaigns and other non-infrastructural interventions (as already noted by Pucher & Buehler, 2008). Of all PBE variables, traffic safety along with crime safety are the two variables that lost significance most often across the 7 cities, which could also indicate the local context is especially relevant for these issues (Table 26).

5.2.5 Perception of crime safety

The results of this thesis indicate that the perception of Crime Safety has an influence on cycling behaviour. This influence is significant enough for both Stages of Change and a bit stronger for Pre-contemplators, in line with the other safety measure, traffic safety. As shown in the literature review (Section 0), evidence was unclear and inconclusive, but with hints that there might be an association, especially for certain population groups. Most of the studies reviewed before the PASTA survey tended to aggregate perceptions of road and crime safety (Winters *et al.*, 2011; Kerr *et al.*, 2016). Amongst the studies that looked specifically to Crime Safety, one by Van Cauwenberg *et al.* (2012) suggested there might be a link with gender inequalities, as perceived crime was associated with lower rates of cycling in women. Some of the authors of the afore-mentioned paper continued researching this issue in Belgium (Flanders), this time in a qualitative study using cycle-along interviews, finding that perception of crime was not as a concern for older adults' transportation cycling (Van Cauwenberg *et al.*, 2018) .

The lack of literature assessing perceived Crime Safety in cycling lead to including objective crime safety studies in the literature review, for additional guidance (Section 0). These studies indicate that there is an effect of objective Crime Safety in cycling behaviour, which could potentially be reproduced at a perceptive level. A more recent study by Sun *et al.* (2017) about the bike-sharing scheme in Chicago is a good example of the influence of objective Crime Safety. The authors were able to map the on-street and off-street crime events close to the bike-sharing stations. They found a negative and strong association between both on- and off-street crime and arrivals to bike-sharing stations, indicating that, if people had a choice, they did not park in areas with higher crime rates. Similarly, a recent study undertaken in New York City found that an increase in crime of 1% has an impact of 2.11% reduction on cycle ridership (actually, much bigger than the reduction found for walking, which was 0.06%) (Caros & Chow, 2020).

Perception of Crime Safety in relation to cycling appears to be a complex concept with at least two dimensions attached to it, according to Appleyard and Ferrell (2017); "property", which perception appears from placing personal property at risk; and "exposed", when crime risk perception originates from potentially exposing themselves to threats of personal injury. Property crimes are linked to secure parking, amongst others, which has been treated in this study as a separate perception of the built environment. Correspondingly, our results show a significant correlation, although negligible in size, between Perception of crime and Inadequate parking (rho=-0,20, P < 0.01) (Table 20).

The “exposed” dimension proposed by Appleyard and Ferrell (2017), which could be understood as the threat to physical integrity, is in itself also a complex issue that deserves specific attention. Depending on which population groups are exposed (objective) or feel exposed (perception) to crime, there might be inequalities; for example, with lower-income, gender or ethnic groups being more exposed than other, more privileged groups (Lusk *et al.*, 2019).

The relationship between perceived Crime Safety and cycling for transport is still inconclusive, but the results presented in this thesis indicate there is a relationship, especially for Pre-contemplators, and that this should be explored in further research (see section 5.6).

5.2.6 Comfort

Comfort was found to have the biggest effect on cycling Stages of Change in the model estimated in this thesis. It is also the most consistently significant variable across all cities in the city-specific models. The source for this variable, as for the rest of PBE and PSE variables used in this thesis, is a PASTA survey question formulated in a simple way to avoid participants’ burden (Table 12). In the case of comfort, this is a bigger limitation than for the other variables, as this is complex a concept that can mean different things for different people. At the same time, the variable Comfort in cycling has been treated in different ways in the research. Authors tend to consider cycling comfort in relation to perception of traffic safety (Fitch, Carlen & Handy, 2020) and related infrastructural features such width for the volume, smooth surfaces and smooth changes in slope (Parkin, 2018:p.41), or similarly, slope in relation to physical effort, and space (Li *et al.*, 2012). Dill *et al.*, added signalisation (2014), as comfort in relation to the level of information. Linking Comfort to perceived built infrastructure and traffic safety was probably what Handy *et al.* had in mind when suggesting perception of comfort could be enhanced through training for cyclists, for adults as well as children (2010).

Results, in line with the afore-mentioned literature, show that, although low, correlations were found between Comfort and Crime Safety (Table 20, rho=0.31, P<0.01), and Comfort and Traffic Safety (Table 20, rho=0.41, P<0.01). The notable importance of Comfort in the model, however, suggests that the correlated variables might not be the only factors that play a role in the perception of cycling comfort.

Some studies aggregate several variables including comfort under a single factor, providing only partial conclusions. Muñoz *et al.* (2016) found that their aggregated variable for safety and comfort (including sweat, safe for pedestrians, stress, low accident risk and pollution safe) was perceived as an important facilitator for cycle commuting in the city of Vitoria-Gasteiz (Spain), although only for car commuters. Authors interpreted this from the view that safety and comfort were probably seen as deterrents by car commuters due to their lack of experience, but that they were not major barriers to cycle commuting for non-car commuters due to the recent built environment improvements the city had made for pedestrians and cyclists. In a study in Denver, Colorado, assessing the role of attitudes, socio-demographics, and the built environment in cycle commuting, Piatkowski and Marshall (2015) grouped Comfort-related variables "Too much cargo to carry" and "Can't get sweaty before work" in the factor Security and comfort. They found strong agreement that this factor was associated with the decision not to cycle and the decision to cycle less in their models.

Sweatiness offers different dimensions in its analysis in regards to comfort, it seems to relate both to the perceived effort that infrastructure can cause, but also to objective and perceived stress (Blanc & Figliozzi, 2016; Barberan, de Abreu e Silva & Monzon, 2017), and finally, to the perception that commute cycling requires achieving certain speed, which could be part of the projection that non-cyclists make of cyclists as needing to wear sporty clothing (Aldred, 2015).

The importance of Comfort in this model calls for a more profound understanding of the complexities surrounding it: what is understood by cycling comfort, how it is experienced and perceived and how it influences cycling behaviour.

5.2.7 Social Norms

The fact that the Descriptive Social Norm lost explanatory power with the stepwise regression indicates that the ´perception of cycling as being well-regarded in the neighbourhood´ contributes to explaining the affiliation to the Stages of Change, whereas 'perceiving cycling as something common' only has explanatory power if there are no other PSE variables included in the model. Information about both predictors is offered separately, following the evolution of behavioural psychology literature. Separating the two Social Norms allows this study to contribute to the academic knowledge by showing a more salient and direct influence of Injunctive Social Norms compared to Descriptive Social Norms in cycling behaviour. That is to say that the perception of cycling being socially approved is more important for people thinking about cycling than how normal and frequent cycling is perceived to be.

Even more important than the statistical strength of the Injunctive Norm in relation to the Descriptive Social Norm is the fact that its effect goes in an apparently unexpected direction. Findings show that people perceiving that cycling is well-regarded in their neighbourhood are 52% more likely to be in Contemplation-Preparation rather than in Action-Maintenance (Table 27). This direction is already observed in the univariate models (Table 19, RRR= 1.20, 95% CI (1.01, 1.43)), but the descriptive statistics provide the expected direction of a higher percentage of people perceiving cycling as being well-regarded in the Action-Maintenance stage (Table 17), which suggests this effect is modified by SES and city. The stratification by city shows that this effect seems to be led by two cities, London and Rome, the only cities with statistically strong estimates for Contemplation-Preparators for this variable (Table 26). These are cities with an aggressive traffic environment; Rome had the highest car ownership rates (Figure 2) and car modal share (Figure 1) of the seven cities, whereas London had the highest perceptions of road unsafety (Table 18), which might make cyclists perceive that their neighbours are not so positive about cycling. Predictors for Pre-contemplators are not significant enough, although they were in the univariate model (Table 19, RRR= 0.53, 95% CI (0.44, 0.64)) and in the SE only model (Table 23, RRR= 0.75, 95% CI (0.62, 0.91)). Once we account for BE variables, Injunctive Social Norms cease to be significant for Pre-contemplators, which indicates that SE on their own is not so powerful to explain membership to the Stages of Change, BE needs to be taken into account.

In study with participants in four municipalities in Sweden, Forward (2014) combined TPB with the TTM, offering more comparable results with this thesis'. Results in this thesis show that people who perceived cycling as well-regarded in their neighbourhoods were more likely to be in Contemplation-Preparation than in Action-Maintenance (results were not statistically strong for Pre-contemplators). Forward found a significant linear relationships between stage of change and subjective norm ($F(1, 316) = 47.45$, $p < .001$), that is to say Injunctive Norms were increasingly significant in the Stages towards Maintenance, although with a small decrease in the Action stage (Forward, 2014). This difference might have been due to the urban environments being more cycle-friendly in the Swedish municipalities than in London and Rome.

Predictors indicate that people thinking about cycling are more likely to perceive that cycling is well regarded than people actually cycling. This could seem counter-intuitive, as people who cycle already should be perceiving a positive social influence. But actually, this result is consistent with literature assessing the effects of social influence (which includes Social Norms); as Sherwin *et al.* explain (2014), when an individual starts cycling and sustains this behaviour, social influence becomes less important.

Cialdini's seminal paper (1991) is a reminder that the salience of each of the Social Norms depends on the context; at any given time, an individual's action is likely to conform to the norm that is currently most salient even if other norms dictate contrary conduct. Context can change rapidly, and it can make certain Social Norms become salient as other become unimportant. Recent literature has suggested that it is important to pay greater attention to how these norms change through disruption (Marsden *et al.*, 2020). For example, in a context of disruptive changes such as public transport strikes, terrorist attacks on public transport, high cost of fuel, or the

Covid-19 global pandemic, cycling can become much better regarded than it was before, and more desirable than other modes of transport.

What the results of this thesis add is that Injunctive Norms are important to get people to the stage in which they are thinking about cycling, but results are inconclusive for people not thinking about cycling. There is little evidence in the literature exploring this, except for Orsini and O'Brien's (2006) study, in which they suggest that a cycling programme targeting friends of existing cyclists are more likely to succeed than those aimed more generally at non-cyclists. Policies oriented at connecting people who already cycle (and thus, think positively about cycling) with people who are thinking about cycling, will cultivate in the latter the perception that cycling is well regarded and thus support them in their change of behaviour towards cycling.

5.2.8 Social support

Defined by the question 'Most people who are important to me think that I should cycle for travel', Social Support was perceived to be very low for people not thinking about cycling, compared to those cycling (Table 22; RRR=0.15, 95% CI (0.11-0.20)). Estimates were not strong enough to predict the effect on those in Contemplation-Preparation. This association, however, was significant when removing the BE variables (Table 23), which might suggest that BE features are more important for those thinking about cycling than the support from people close to them, or even that a good BE might compensate the absence of Social Support for them.

The Social Support predictor's for Pre-contemplators is sufficiently significant for all cities except for Antwerp, and associations for those thinking about cycling become significant in city models for Barcelona and Rome (Table 27). This might imply that policies aimed at making cycling accessible for people who are not thinking about cycling should consider integrating a strong Social Support component.

Sherwin *et al.* (2014) suggestion of Social Influence not being so important when people start cycling or maintain it would also apply to Social Support, as Bartle *et al.* found in their qualitative study (2013). This thesis specifies that Social Support would be important for Pre-contemplators, whereas Social Norms would be important for Contemplation-Preparators. In other words, for people not thinking about cycling, Social Support would be key to change their behaviour towards cycling for transport, whereas Social Norms would only be effective to get people thinking about cycling.

As described in the literature review (2.2.3.2), there are different types of Social Support measures, depending on either the closeness of those who provide the support, as illustrated by Ma and Dill (2015), or the type of support they provide, which for de Geus *et al.* (2019), were accompaniment and encouragement. De Geus *et al.*'s (ibid.) found that encouragement (which is the type of Social Support used in this thesis) significantly increased the likelihood of being a cyclist. Their model combined BE and several psychosocial variables (including SE variables), making it similar to the one in this thesis.

For both Social Norms and Social Support, the literature proposes policies that encourage social interaction (Bartle, 2011; Savan, Cohlmeyer & Ledsham, 2017). As discussed for Social Norms (Orsini & O'Brien, 2006), ideally this interaction should happen between people who cycle (in Action-Maintenance), and people who do not cycle (in Pre-contemplation and Contemplation-Preparation), this way they can offer both a positive role model (Social Norm) and coaching and support (Social Support) to those who are still hesitating.

5.2.9 TTM Constructs and processes

Although this thesis offers a cross-sectional view in which only associations can be established not causality, it is useful to analyse our findings in the light of the TTM processes that Prochaska et al. (2008) associated with the transitions between stages (Section 2.1.3). In this analysis, three of the processes are linked to the relevant variables from the model (Figure 23):

- **Environmental re-evaluation** is an individual's appraisal of the relationship between a specific behaviour and the local environment, both physical and social. It would encompass two of the variables used in the models:
    - **All PBE variables**: Biehl et al. (2018) argued for a multifaceted interpretation of this Environmental re-evaluation, that includes the subjective evaluation of the built environment. This would place our five PBE variables within this process, making it much broader than just driving the transition between Pre-contemplators and Contemplators, as the authors noted in their study.
    - **Injunctive Social Norm (SE)**, assessed by the statement "cycling is well-regarded in my neighbourhood". This variable is both included in Environmental re-evaluation and in the process of Social liberation, which seems to be more focused on capturing the influence of these social norms in behaviour change.
- **Social liberation** refers to the realization that prevailing injunctive social norms favour behavioural change:
    - **Injunctive Social Norm (SE)**, assessed by the statement "cycling is well-regarded in my neighbourhood".
- **Helping relationships** is trusting, accepting, and using the support of caring for others to change behaviour.

- **Social Support (SE)**, assessed by the statement "People important to me think I should cycle for transport".

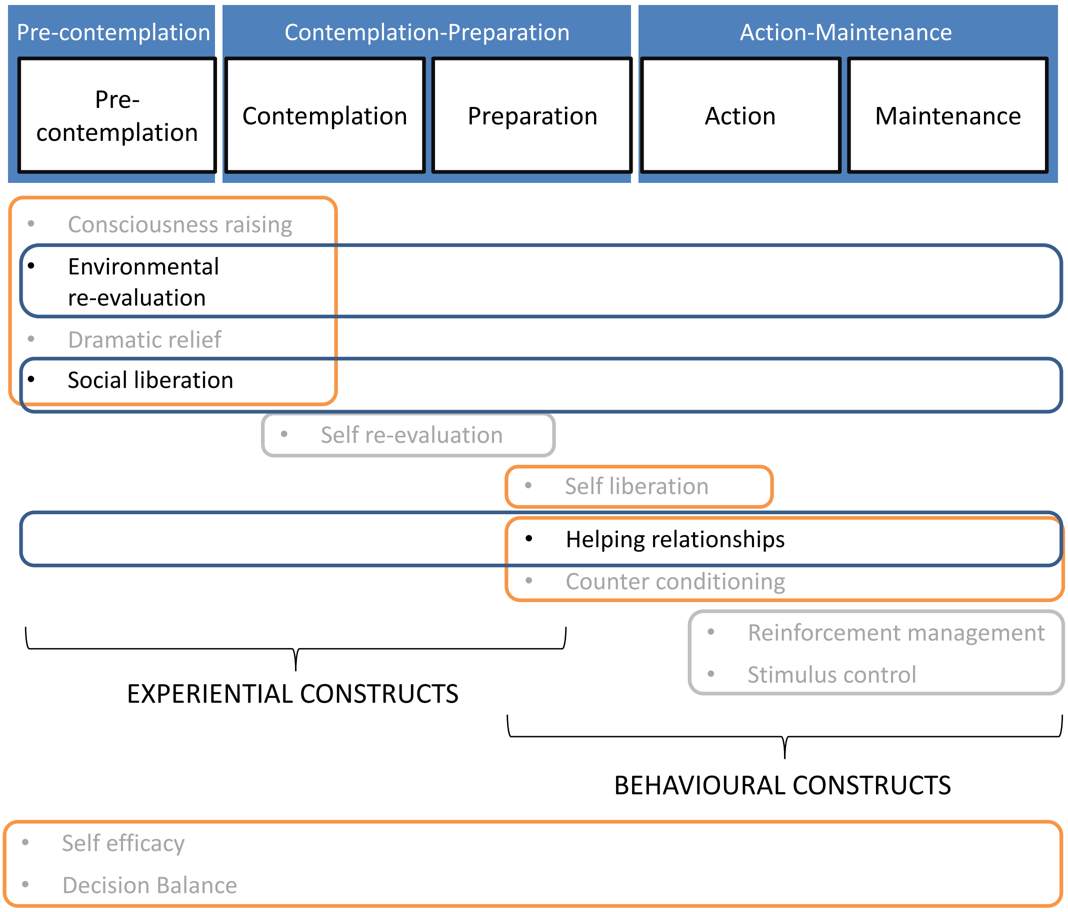


Figure 23. Constructs and processes that influence the transitions between Stages of Change. In blue squares the simplified three stages. Blue frames suggest the extension of the three processes that are relevant to this study. In grey processes that have not been assessed in this study. Source: adapted from ProChange (2019).

This analysis continues by exploring the potential processes linked to the transitions relevant for this study, Pre-contemplation in relation to Action-Maintenance and Contemplation-Preparation in relation to Action-Maintenance

Pre-contemplators in relation to Action-Maintainers

- BE:
  - **Perception of traffic safety** is only significant enough for Pre-contemplators, meaning that people who are not even thinking about cycling perceive a higher traffic risk than people cycling. As the relation is between the first and last Stages of Change, the Environment re-evaluation process should cover all the transitions. This is a nuance that is not apprehended by just extending the process to all transitions, as the relation between each of the previous stages with the final ones

(Action and Maintenance) might be different for each stage, and the different possibilities of transitioning from each of the stages to another might be influenced differently by this variable.

  - **Crime safety** and **Comfort** have a stronger effect for Pre-contemplators than for Action-Maintainers, meaning that people who are not thinking about cycling perceive higher crime unsafety and discomfort in relation to cycling. This supports Environmental re-evaluation being extended towards the Action stage, covering the two transitions assessed in this study, as all predictors are significant enough.

- SE:
  - **Social Support** is more influential to Pre-contemplators than to Contemplation-Preparators in relation to Action-Maintainers. In order to make cycling accessible for people who are not thinking about cycling, they need to be provided with social support. Social Support is related to the process described in the TTM as Helping relationships, although in the TTM it is placed in the transition between Preparation and Action, whereas results in this thesis would extend the influence of this process back to the stage of Pre-contemplation. This would make it a process that influences behavioural change throughout the stages.

Contemplation-Preparators to Action- Maintainers:

- BE:
  - **OBE**: the influence of Walkability and Bikeability indices was greater for people thinking about cycling than for those not thinking about cycling. This supports the extension of the process Environmental re-evaluation to cover the transition to the Action Stage (Figure 23).
  - The two **facility variables** - Inadequate parking and Lack of changing facilities and showers - are the only two that exert a stronger influence on Contemplation-Preparators than on Pre-contemplators. This supports the extension of the process of Environmental re-evaluation towards the Action Stage.
- SE:
  - Results show that Social Norms, in particular, **Injunctive Social Norms** (perceiving cycling as well-regarded in the neighbourhood) are more important for Contemplation-Preparators, than for Pre-contemplators. This finding could be related both to the processes of Self-liberation and Environmental re-evaluation. If applied to the TTM, these results would support a displacement or at least, an extension of this processes towards the stage of Action.

In conclusion, results in this thesis advocate for the extension of three of the processes of the TTM to cover the transitions between all Stages of Change. This would account for associations of BE and SE variables found to be significant enough between the two comparison levels (Pre-contemplation and Preparation-Contemplation) and the reference level (Action-Maintenance).

5.3 Strengths and limitations

This study used one of the largest cohorts ever recruited over seven cities on the subject of transport, psychology and health. Having such a large sample has most certainly contributed to find robustness in the models.

The comprehensive conceptual framework that has been used to explain behaviours features both social and environmental factors. Gathering contextual factors has proved a useful source of information to deepen the interpretation of the results, especially for the comparison between cities.

The novel definition of the Stages of Change through the combination of several variables each, allowed for a more precise diagnosis. Using Stages of Change as the outcome variable offers more information than the more common outcomes cyclist/non-cyclist or cycling time used in other studies. However, due to the uniqueness of the definition of the Stages of Change, comparability with other studies had to be handled with care and transparency.

The use of stages to understand behaviour change has shown pros and cons throughout this thesis; the main disadvantage is that Stages of Change is not sufficiently used in the literature to have comparable studies for each of the factors studied in this thesis.

Studies combining the TTM of the Stages of Change with Built and Social Environment variables are scarce. Studies define the stages of cycling behaviour change differently and they explore the effects of a wide variety of constructs (attitudes, perceptions, barriers, facilitators…). The framework created in this thesis for the application of the TTM is unique; the definition of the Stages of Change is unique, and the selection of variables to be included in the model are unique too, to the author's knowledge. This is challenging for the comparison with other studies, as there is none that uses the same definition of the stages nor involves the same variables. For the sake of comparability, some concessions have been made. Often in this thesis, studies using the comparison between cyclists and non-cyclists have been compared with the Stages of Change, which is just one of the components of the Stages of Change (Table 5).

The advantage of using the Stages of Change as the outcome is that they integrate complexity by featuring several items in each of the Stages (Figure 11). Even when simplified to three stages instead of five, there is more information condensed in each of the predictors resulting from the model than other outcomes such as cyclists/non-cyclists or time cycling would provide. This generates very specific insights to tailor policies for the individuals in each of the Stages (Table 30).

Multinomial models allow us to evaluate complex outcomes such as the Stages of Change, with three levels, one being the reference level (Action-Maintenance) and the others being the comparison levels (Pre-contemplation and Contemplation-Preparation). Predictors are produced in relation to the reference level, which prevents comparison between levels (likelihood of being in Pre-contemplation instead of being in Contemplation-Preparation). This analysis does not provide insights into factors that would enable a progression from Pre-contemplation to Contemplation-Preparation, which would provide a finer level of details in engaging people in progressing gradually towards action. This sacrifice is embedded in the choice of the type of model (Multinomial) and the choice of the reference level, which, guided by the research question, needed to feature the Stage of Change in which people are cycling.

The data does have several limitations, common to these type of survey studies. One being the self-selection bias, whereby participants self-select because of their interest in the survey themes. This bias is difficult to avoid, as the dissemination efforts need to use some kind of thematic content and specific targets, that makes it difficult to keep the themes hidden. Convenience sampling approaches and the need to have access to the internet to access the web-based survey, might have played a role in having more young and highly educated people in the sample than in the census data composition (Gaupp-Berghausen *et al.*, 2019).

All perceived measures of the social and the built environment were self-reported, and thus subject to biases and limitations such as lack of honesty (respondents might offer the more socially accepted answer instead of being truthful), introspective ability (respondents might not be able to assess themselves accurately) and the interpretation of the questions (the wording might be confusing for some participants or have different meanings for different individuals). Complementing with an objective measure helps counterbalance biases from self-reporting, which has been done for the BE factors, with the addition of the Walkability and Bikeability indices. However, finding comparable data across cities and doing the calculations of these complex indices is time consuming. This could only be done for all cities for one of the indices, the Walkability index. Data for the Bikeability index was incomplete and available resources focussed on calculating this for one of the cities, London. Using the two indices allowed comparison between them and assessment of similarities and differences in their effect on the Stages of Change in London with a sample of 1,005 participants.

The behavioural models combined in this thesis have certain limitations accounting for the automatic thinking processes determining behaviour, they are not able to measure how much of the decision to engage in cycling for transport is made in a less conscious, much more intuitive way (Kahneman, 2012). Although the design of this study does not allow for such analysis, the extend of these limitations could be informed by longitudinal, mixed-methods studies in which behaviour change estimates at each given time could be compared against subsequent estimates over-time and participants could be interrogated about their behavioural change processes.

From cross-sectional data, only correlations can be inferred but not causations. For instance, it can be established from the PASTA data that people who are not thinking about cycling have a stronger negative perception of traffic safety compared to cyclists. This does not prove, however, that changing people's perception of traffic safety will make them cycle. Similarly, results show how the Social Support is significantly different between Pre-contemplators and cyclists, but this does not necessarily mean that providing Social Support to those who are not thinking about cycling will be effective in progressing them to cycling. As Walta (2018) clearly exposes in her paper, longitudinal analyses such as randomized control trials, natural experiments and observational studies, also encounter strong limitations. Funding to apply randomized control trials in cycling research is prohibitive, natural experiments and observational studies offer some opportunities, but their cost is still high and circumstantial factors make it difficult to infer causal relations anyway. Researchers are exploring how to make longitudinal studies more robust through intensification of data collection, exploring available contact databases, finding an appropriate control population or using sophisticated statistical methods, while some of them advocate to complement this quantitative approaches with qualitative ones (Aldred, Croft & Goodman, 2019; Walta, 2018).

5.4 Implications for research and recommendations

The conceptual framework used in this thesis combines several theories and frameworks (the TPB, the TTM and the SEM). The framework led to an accurate selection of variables for the model, to the extent that only one of the variables was not retained. The fact that both groups of variables studied in this thesis, BE and SE, keep their strength when the other was removed from the model (Table 23) suggests that research should not focus solely on one of these groups. If studied independently, the influence of the SE on the BE and vice versa would remain uncovered and challenge the relevance of the results. Using a combined conceptual framework also allowed for a comprehensive interpretation of the results, by integrating contextual information for each of the CSCs. This combination also offered different levels of interpretation, e.g. putting in relation the Stages of Change, each of the environmental factors, and the TTM constructs and processes.

This supports the choice of working with combinations of models when a single conceptual framework is insufficient, and to collect contextual information that supports the interpretation of the results.

A level of inconsistency has been detected in the definitions and applications of certain psychological constructs among studies, this is especially confusing for Injunctive Social Norm (that has been interchangeably used with Subjective Norm) and Social Support (with many different types of support that can produce different effects). There are several reasons why this inconsistency might appear. The first one is related to the depth of psychological constructs, which makes them difficult to compare across studies, especially if sufficiently detailed definitions of these constructs, applied to the context of cycling for transport, is not provided. This is linked to different psychological frameworks naming their constructs differently, and that these frameworks are constantly evolving and that, from these, new ones emerge. Another reason that hinders comparability of different studies is the process of formulation of psychological constructs into questionnaire questions. Many of these studies use questionnaires in which the construct needs to be formulated into a question. This process of formulation can end up communicating the construct in different ways. For this reason, it would be useful to always include the question formulation in the papers, so that other researchers can understand how the construct has been formulated and whether or not it is comparable to their research. As shown in Sections 3.3.2.4 and 3.3.2.5 question formulations have only been found in a few instances.

5.5 Implications and suggested interventions for policy and practice

Some policy implications have been touched upon in Section 5.2, but a complete list of implications and interventions for each of the variables (or influence factors) is featured below (Table 30). These are based in the interpretation of the results of the Minimal Adequate model (Table 22) and the points made about the constructs and processes (Section 5.2.9). The effect size of each variable is included for the two Stages of Change, Pre-contemplation and Contemplation-Preparation, in comparison to the reference one, Action-Maintenance. It must be noted that all suggestions are then directed to non-cyclists as defined by this study (those cycling less than three times a week, Table 5, divided in the two comparison Stages), with the goal of making cycling available for them.

Table 30. Policy implications and suggested interventions for the two Stages of Change for each variable, depending on effect size.

Variables / Influence factors	Effect size* (high, moderate, not influential here)		Policy implications and suggested interventions
	Pre-contemplation**	Contemplation-Preparation**	
Objective Built Environment			
Walkability and Bikeability	Moderate	High	• Building quality, inclusive cycling infrastructure. **Example**: making sure the cycle network covers all areas in the city, so that all the population has access to cycling. • Inform the population about the offer of cycling infrastructure, especially those who intend to cycle (in Contemplation-Preparation) and may have already access to a cycle (Preparation). **Example**: engaging cycling businesses and provide them with information to give to customers getting ready for cycling by buying cycles and accessories.
Perceived Built Environment			
Inadequate Cycle Parking	Moderate	Moderate	• Quality, safe cycle parking provision that is adequate to the context. **Example**: developing detailed cycle parking planning, integrated within the cycling and wider mobility policies.
Lack of changing facilities	Moderate	High	• Employers' travel plans should consider the provision of changing facilities and showers for their employees. **Example**: Periodically informing employees about the location and conditions of use of the changing facilities for cyclists, whether they cycle or not, especially to those who have expressed interest or participated in cycle to work schemes.
Traffic Safety	High	Not influential here	• Improving road safety (objective measure) and communication campaigns targeted to the broad public (and specially to car drivers, more likely to be in Pre-contemplation) that improve the perception of safety and provide directions on how to cycle safely. **Example**: campaigns about the blind spot and how to behave safely around heavy vehicles (HGV).

Variables / Influence factors	Effect size* (high, moderate, not influential here)		Policy implications and suggested interventions
	Pre-contemplation**	Contemplation-Preparation**	
Crime Safety	Moderate to High	Moderate	• Engagement of the security forces (Police) in cycling policies. **Example**: Invite Police officers to bring their expertise in crime safety to cycle planning and participatory processes. • Matching crime data (objective and perceived) with cycling infrastructure location. **Example**: use the relevant georeferenced crime data (cycle theft, sexual harassment, street crime) to improve security in specific cycle infrastructure spots (including cycle parking).
Comfort	High	High	• Improving the quality of infrastructure, including maintenance, smoothness and inclusiveness parameters (e.g., width). **Example**: pothole-reporting apps. • Accessing information about types of cycles and accessories, ergonomics in cycling (e.g., saddle height). **Example**: Encourage shopping in local cycle businesses that offer a higher quality customer service to help clients get products adjusted to their needs.
Perceived Social Environment			
Injunctive Social Norms (perception that cycling is well-regarded)	Not influential here	Moderate	• Cultivating a positive cycling discourse in policy documents and campaigns across all policy areas. **Example**: Campaigns on specific benefits of cycling (e.g., health), representing diversity in cycling so that everyone can relate.
Social Support	High	Not influential here	• Offering schemes and opportunities that encourage the interaction between cyclists and non-cyclists in a positive context, especially if they are from the same family or group of friends. **Example**: providing opportunities in which families and groups of friends can try cycling in a friendly and supportive context (community hubs, parks, festivals).

*Effects are high (Table 27) when risks are halved (>-50%) or doubled (>+100%) in 3-levelled variables (all PBE and PSE variables) and where risks increased or decreased more than 10% for the 10-levelled variable (Walkability). **in reference to Action-Maintenance

5.6 Further research

Although the data used in this thesis was exceptionally rich and varied, due to the large sample size and the multi-centred approach, methodological limitations of a web-based survey made it difficult to retrieve detailed information about some of the influence factors. All questions in the PASTA survey were closed questions to avoid participants' burden and thus minimise attrition rates. This has restricted the interpretation of the results for some factors, especially Comfort and perception of Crime Safety. Comfort and Crime Safety in cycling mobility have not been sufficiently explored in the literature and comprehensive definitions of both are still missing.

The notable effect of Comfort found in this study, calls for a deeper exploration of its meaning and how it relates to the context. Although low, a correlation between Comfort and Traffic Safety has been found in the data, but there are other meanings of comfort explored in the literature that have not been specified in the PASTA questionnaires. For example, the relationship of comfort with having an effective riding space as exposed by Li *et al.* (2012) suggests that comfort is not just an additional feature "good to have" for the cycling built environment, but that it might become critical to make cycling available to those who depend on having enough space to use the cycling infrastructure. This is the case of people with disabilities who ride wider, non-conventional cycles as their mobility aid (Andrews, Clement & Aldred, 2018; Clayton, Parkin & Billington, 2017).

Although this thesis offers strong evidence of the negative impact of Crime Safety in cycling behaviour, more research is needed to define this item more in-depth and explore the relationship between objective and perceived Crime Safety in relation to cycling mobility. As introduced in Section 5.2.5, further research could use separated questions in relation to the two dimensions of crime, "property" and "exposed" stated by Appleyard and Ferrell (2017). This thesis found quantitative evidence of the effect of perceived Crime Safety in cycling mobility, in a model that controls for gender - so the effect is strong, independent of gender. However, findings by Lusk *et al.* (2019) showing that lower-income, gender or ethnic groups are more exposed than other, more privilege groups, suggest that these equity issues should be taken into account. Recent literature has also unveiled inequalities in the way traffic and crime safety affect cycling (for traffic safety: Yu & Lin, 2015; for both: Lusk *et al.*, 2019).

Gender inequalities seem also to be revealed in this thesis. In the model which included both Social and Built Environment variables (for traffic safety: Yu & Lin, 2015; for both: Lusk *et al.*, 2019), females were found to be almost twice less likely to be in pre-Action stages than males, with the effect being greater for those ´Not thinking about cycling´. The literature is clear about the influence of environmental factors for women's cycling, such as perception of safety (Akar, Fischer & Namgung, 2013) and the preference for dedicated infrastructure (Aldred, Woodcock & Goodman, 2015). Results in this thesis suggest that environmental variables are relevant for gender-specific affiliation to Stages of Change. If this affiliation was explored further, it could help understand female's behavioural psychology in relation to cycling. In order to explore gender-related and other inequalities, stratification by gender, income and other socio-economic status variables, in relation to BE and SE factors would help uncover the differences between groups.

Several authors have suggested using qualitative or mixed methods in cycling behaviour studies, arguing that this would allow to understand better the relationships between environment and cycling attitudes and behaviour, and contrast behavioural change interpretations (Handy, van Wee & Kroesen, 2014; Walta, 2018; Aldred, Croft & Goodman, 2019). Some studies have already advanced in using qualitative methods from social sciences and anthropology, such as Guell *et al* applying the ethnographic method of photo-elicitation interviews to assess the impacts of the Cambridge busway on active travel (2012), Van Cauwenberg *et al.* (2018) using cycle-along interviews to assess environmental influences on cycling for transport and Spotswood *et al.* (2015) using Social Practice Theory to explore views and experiences of both cyclists and non-cyclists.

Qualitative and mixed methods approaches would be helpful to further explore the reasons and mechanisms behind the affiliation of individuals to each of the Stages of Change and, in particular, to define and better interpret specific factors that seem to have complex impacts on individuals, such as Comfort and Crime Safety.

6 CONCLUSION

Based on a combination of theories and frameworks, this thesis aimed at finding the associations between built and social environment and the Stages of Change towards cycling for transport, in a cross-sectional study. The novelty of the conceptual approach led to a refined definition of the Stages of Change, capturing the complexity of cycling behaviour change in a unique way.

Extensive survey data from seven cities in Europe provided a solid sample with which to build statistical models. The sample had some over-representation of younger and more highly educated people, which are common outcomes of self-selection bias and biases derived from targeted recruitment efforts and web-based surveys. Dependent variables for objective and perceived BE and for perceived SE were included in the models. All perceived factors were obtained from Likert-scale questions in the survey, whereas for BE an objective measure calculated with external data was included.

Multinomial models performed well in all test and validation procedures; sensitivity analyses were reassuring. Results bring the research field closer to understanding how the different environmental factors exert influence on cycling behaviour change and which policies may work best for people in each pre-cycling stage.

The PASTA project survey provided data on some of the most relevant influence factors for cycling for transport identified in the literature. That most of these factors were retained in the model confirms that the initial selection, guided by the literature, was robust. Parallelisms with cycling/non-cycling outcomes were used, as there are very few studies looking at both BE and SE factors in relation to the Stages of Change. In most cases, results were similar to those found in the literature. Thanks to the selection of variables and to the choice of maintaining their disaggregation, this thesis contributes to highlighting elements such as the prominence of Comfort and the non-negligible effect of Crime Safety. The importance of changing facilities and showers also adds strength to the findings of other studies. These results suggest policy efforts should show more care for cyclists by providing a dignifying level of quality, comfort and safety in their spaces, facilities and infrastructures similar to what is offered to motorized vehicles. Caring for people who cycle also applies to the policy recommendations for the SE variables, which focus on creating and supporting positive messages and communities around cycling for transport.

Results for the SES factors, especially gender and income, point out at the need to 1) Study these factors more in-depth, if possible, with mixed methods that help disentangle their complexities; and 2) Integrate an equity and accessibility approach when studying behaviour change, so that cycling for transport can be accessible for everyone, regardless of gender, income, or any other socio-economic characteristic.

The use of Stages of Change as an outcome has helped to recognise change as a gradual process and not as an event, as the cycling/non-cycling duality seemed to entail. The variables used in this thesis could be identified with some the processes described in the original TTM (PBE variables with Environmental re-evaluation, Injunctive Social Norm with Social liberation and Social Support with Helping relationships). By doing this, it could be observed that these TTM processes needed to be present across more transitions between Stages than they had been originally described for, which strengthens findings in the literature pointing out at adapting these processes to the specific behaviour being analysed, in this case, cycling for transport.

The SEM was used to include OBE measures in the models and contextual city info for the interpretation of the results. Although it was intensive in terms of consuming time and resources, the effort of putting together information to calculate the indices and document the mobility landscape for every CSC has provided a more nuanced and comprehensive way of explaining the results. This has unveiled details such as SE predictors not being so relevant in cities with a high cycling modal share, different from other studies on the subject. OBE measures were integrated in the models as the Walkability index (for all cities) and the Bikeability index (only for London). A sensitivity analysis comparing both indices for the city of London, showed that using Bikeability strengthened the effect of some of the factors, which could make it a better measure than Walkability, although this could not be confirmed for the rest of the cities.

Policy recommendations from this thesis focus on making cycling more accessible for everyone, with the advantage that different policies can be tailored to different groups: those who do not even think about cycling might need to get the message that cycling can be safe and comfortable and that there are cycling facilities and infrastructures available for them. For those who are already thinking about cycling, safety and comfort are also important, but having access to facilities would also add up. Having opportunities to exchange views about cycling with cyclists who are close to them might get them closer to the decision.

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APPENDIX: ACADEMIC ACTIVITIES

Internships

I have already undertaken two stages in CREAL, Barcelona (also partners of the PASTA project):

1. for 5 weeks from mid-February 2014 to end of April 2014. In that stage, I learned about the methodology used to exploit the data of a previous project (TAPAS) in terms of practical statistical analysis and theoretical geographic analysis.
2. For 5 weeks from mid-July to end of August 2015. In this stage I trained in clinical protocol – the Health Add-on – of the PASTA project, to be able to deliver it back in London.

Training

Internal training (from the Graduate School and the Centre for Academic English at Imperial College London):

- Regression modelling (February 2014)
- Research Skills Development Course (June 2014)
- Stress management (September 2014)
- Assertiveness (October 2014)
- Time management (October 2014)
- Introduction to Teaching & Learning for Doctoral Students & GTAs (February 2015)
- Assessment & Feedback for Doctoral Research Students & GTAs (February 2015)
- Preparing for Leadership (April 2015)
- Effective Public Engagement (May 2015)
- Efficient Reading (May 2015)
- Negotiation Skills for Researchers (June 2015)
- Project Management for Researchers (July 2015)
- Understanding Yourself & Others 1: Intro to the Myers-Briggs Personality Model (October 2015)
- Practical Guidance for your Application for AFHEA (November 2015)
- "Writing a Research Paper" course from the Centre for Academic English with 8 sessions of two hours each from 28th Apr to 16 Jun 2015.

External training:

- GIS for Transport Applications workshop (GIS4TA), 16th and 17th November 2017, University of Leeds.

- ESRC Impact Evaluation Training Course (7-8 June 2016) at the University of Cambridge.
- R for the analytical and environmental sciences: introductory workshop, 14th June 2016, MRC-PHE Researchers Society.
- Computing: Introduction to R-Programming - 4th-5th May 2016, Imperial College London
- R for the Analytical and Environmental Sciences: Intro to Graphics, 21st September 2016, MRC-PHE Researchers Society.
- Two Executive courses from the 'Global Challenges in Transport' Programme at the Transport Studies Unit of the University of Oxford:
    - 'New Technologies and Changing Behaviours' from 17th – 20th March 2015.
    - 'Governance, Policy and Delivery' 30th June - 3rd July 2015.
- Understanding Society: Training course for transport analysts, 29th and the 30th of April 2014, University of Essex.

Presentations

Below, a list of presentations (either oral or posters) in various conferences, symposiums and seminars that I have done so far:

- Co-organizer, presenter and chair in the Cycling and Society Virtual Symposium 2020.
- BRT+ Webinar Series: Adapting City's Mobility System after Covid-19. Session 1: Active Transport. "Barcelona's active mobility Covid-19 response" Video here. 10th June 2020.
- Co-organizer and chair in the Cycling and Society Symposium 2019 at the University of Chester (UK).
- Royal Geographical Society Annual Conference 2019, London. Oral presentation "The dark side of bike-sharing: Assessment of existing and discontinued station-based and floating bike-sharing schemes in Spain".
- Co-organizer and chair in the Cycling and Society Symposium 2018 at the University of the West of England (UK).
- Co-chair of the following sessions in the Royal Geographical Society Annual Conference 2018:
    - Critical perspectives on accessibility and equity in the changing cycling landscape (1): Bikesharing
    - Critical perspectives on accessibility and equity in the changing cycling landscape (2)
    - Changing landscapes for evaluating the accessibility, equity and inclusivity of transport and mobility (1): concepts, metrics and applications across different mobility practices

  - Changing landscapes for evaluating the accessibility, equity and inclusivity of transport and mobility (2): the specificities of cycling
- Latin American Studies Association Congress 2018, 23rd-26th May, Barcelona, Spain. Oral presentation.
- XV edition of the Iberian Congress "The Bicycle and the City" 2018, 16th- 20th May, Valencia, Spain. Chair of one session and two oral presentations.
- Royal Geographical Society Annual Conference 2017, August 2017, two oral presentations.
- International Conference on Transport and Health, 27th-29th June, Barcelona. Poster.
- "La Ciudad de las Bicis" (City of bicycles), 27-30 April 2017, Zaragoza. Content co-organizer for the theme of "Cycling cities", Chair of the opening session about Cycling Regulations and co-ordinator and presenter of the conference conclusions.
- International Society for Environmental Epidemiology (ISEE) 2016, 1st-4th September, Rome, Italy.
- Non-Communicable Disease Forum: Transport Systems and Health, Imperial College London, 17 December 2015. Oral presentation.
- MRC-PHE Centre for Environment and Health's Training Programme Annual Meeting. Imperial College London, 13th November 2015. Poster presentation.
- LSHTM Transport & Health Group Seminar. London School of Hygiene and Tropical Medicine (LSHTM), 2nd November 2015. Oral presentation.
- Making London Nature Smart Symposium. 24th September 2015. Zoological Society of London. Poster presentation.
- 14th International Conference on Travel Behaviour Research. Windsor, 19-23 July 2015. Co-chair and oral presentation in a workshop "Active travel and physical activity – bridging the gap".
- 1st AIBR (Network of Iberoamerican Anthropologists) International Conference of Anthropology. Madrid, 7-10 July 2015. Oral presentation. From this conference, the opportunity of publishing a paper in a special number of the journal <u>Revista de Antropología Experimental</u>.
- CEP PhD Research Symposium 2014 with a poster (June 2014) and in 2015 with a presentation (June 2015).

Publications

Related to the PASTA Project:

- Branion-Calles, M., Götschi, T., Nelson, T**., Anaya-Boig, E.,** Avila-Palencia, I., Castro, A., Cole-Hunter, T. et al. 'Cyclist Crash Rates and Risk Factors in a Prospective Cohort in Seven European Cities'. Accident Analysis & Prevention 141 (1 June 2020): 105540. https://doi.org/10.1016/j.aap.2020.105540
- Branion-Calles, M., Winters, M., Nelson, T., de Nazelle A., Int Panis, L., Avila-Palencia, I., **Anaya-Boig, E.**, Rojas-Rueda, D., Dons, E., and Götschi, T. 'Impacts of Study Design on Sample Size, Participation Bias, and Outcome Measurement: A Case Study from Bicycling Research'. Journal of Transport & Health 15 (1 December 2019): 100651. https://doi.org/10.1016/j.jth.2019.100651
- Castro, A., Gaupp-Berhausen, M., Dons, E., Standaert, A., Laeremans, M., Clark, A., **Anaya, E.** et al. 'Physical Activity of Electric Bicycle Users Compared to Conventional Bicycle Users and Non-Cyclists: Insights Based on Health and Transport Data from an Online Survey in Seven European Cities'. Transportation Research Interdisciplinary Perspectives, 6 June 2019, 100017. https://doi.org/10.1016/j.trip.2019.100017
- Gascon, Mireia, Götschi, T., de Nazelle, A., Gracia, E., Ambròs, A., Márquez, S., Marquet, O., **Anaya-Boig, E.**, et al. 'Correlates of Walking for Travel in Seven European Cities: The PASTA Project'. Environmental Health Perspectives 127, no. 9 (September 2019): 097003. https://doi.org/10.1289/EHP4603
- Kahlmeier, Sonja, **Anaya Boig, E.,** Castro Fernandez, A., Smeds, E., Benvenuti, F., Eriksson, U., Iacorossi, F., et al. 'Assessing the Policy Environment for Active Mobility in Cities—Development and Feasibility of the PASTA Cycling and Walking Policy Environment Score'. International Journal of Environmental Research and Public Health 18, no. 3 (January 2021): 986. https://doi.org/10.3390/ijerph18030986
- Avila-Palencia, I., Laeremans, M., Hoffmann, B., **Anaya-Boig, E.**, Carrasco-Turigas, G., Cole-Hunter, T., de Nazelle, A., Dons, E., Götschi, T., Int Panis, L., Orjuela, J.P., Standaert, A., Nieuwenhuijsen, M.J., 2019. Effects of physical activity and air pollution on blood pressure. Environmental Research 173, 387–396. https://doi.org/10.1016/j.envres.2019.03.032
- Avila-Palencia, I., Int Panis, L., Dons, E., Gaupp-Berghausen, M., Raser, E., Götschi, T., Gerike, R., Brand, C., de Nazelle, A., Orjuela, J.P., **Anaya-Boig, E**., Stigell, E., Kahlmeier, S., Iacorossi, F., Nieuwenhuijsen, M.J., 2018. The effects of transport mode use on self-perceived health, mental health, and social contact measures: A cross-sectional and longitudinal study. Environment International 120, 199–206. https://doi.org/10.1016/j.envint.2018.08.002
- Gaupp-Berghausen, M., Raser, E., **Anaya-Boig, E**., Avila-Palencia, I., de Nazelle, A., Dons, E., Franzen, H., Gerike, R., Götschi, T., Iacorossi, F., Hössinger, R., Nieuwenhuijsen, M., Rojas-

Rueda, D., Sanchez, J., Smeds, E., Deforth, M., Standaert, A., Stigell, E., Cole-Hunter, T., Int Panis, L., 2018. Evaluating different recruitment methods in a longitudinal survey: Findings from the pan-European PASTA project (Preprint). Journal of Medical Internet Research. https://doi.org/10.2196/11492

- Raser, E., Gaupp-Berghausen, M., Dons, E., **Anaya-Boig, E.**, Avila-Palencia, I., Brand, C., Castro, A., Clark, A., Eriksson, U., Götschi, T., Int Panis, L., Kahlmeier, S., Laeremans, M., Mueller, N., Nieuwenhuijsen, M., Orjuela, J.P., Rojas-Rueda, D., Standaert, A., Stigell, E., Gerike, R., 2018. European cyclists' travel behavior: Differences and similarities between seven European (PASTA) cities. Journal of Transport & Health. https://doi.org/10.1016/j.jth.2018.02.006
- Laeremans, M., Dons, E., Avila-Palencia, I., Carrasco-Turigas, G., Orjuela, J.P., **Anaya, E.**, Cole-Hunter, T., de Nazelle, A., Nieuwenhuijsen, M., Standaert, A., Van Poppel, M., De Boever, P., Int Panis, L., 2018a. Short-term effects of physical activity, air pollution and their interaction on the cardiovascular and respiratory system. Environment International 117, 82–90. https://doi.org/10.1016/j.envint.2018.04.040
- Laeremans, M., Dons, E., Avila-Palencia, I., Carrasco-Turigas, G., Orjuela-Mendoza, J.P., **Anaya-Boig, E.**, Cole-Hunter, T., de Nazelle, A., Nieuwenhuijsen, M., Standaert, A., Van Poppel, M., De Boever, P., Int Panis, L., 2018b. Black Carbon Reduces the Beneficial Effect of Physical Activity on Lung Function: Medicine & Science in Sports & Exercise 1. https://doi.org/10.1249/MSS.0000000000001632
- Dons, E., Laeremans, M., **Anaya-Boig, E.**, Avila-Palencia, I., Brand, C., Nazelle, A. de, Gaupp-Berghausen, M., Götschi, T., Nieuwenhuijsen, M., Orjuela, J.P., Raser, E., Standaert, A., Panis, L.I., Consortium, on behalf of the P., 2018. Concern over health effects of air pollution is associated to NO2 in seven European cities. Air Qual Atmos Health 1–9. https://doi.org/10.1007/s11869-018-0567-3
- Dons, E., Rojas-Rueda, D., **Anaya-Boig, E.**, Avila-Palencia, I., Brand, C., Cole-Hunter, T., de Nazelle, A., Eriksson, U., Gaupp-Berghausen, M., Gerike, R., Kahlmeier, S., Laeremans, M., Mueller, N., Nawrot, T., Nieuwenhuijsen, M.J., Orjuela, J.P., Racioppi, F., Raser, E., Standaert, A., Int Panis, L., Götschi, T., 2018. Transport mode choice and body mass index: Cross-sectional and longitudinal evidence from a European-wide study. Environment International 119, 109–116. https://doi.org/10.1016/j.envint.2018.06.023
- Duran, A.C., **Anaya-Boig, E.**, Shake, J.D., Garcia, L.M.T., Rezende, L.F.M. de, Hérick de Sá, T., 2018. Bicycle-sharing system socio-spatial inequalities in Brazil. Journal of Transport & Health 8, 262–270. https://doi.org/10.1016/j.jth.2017.12.011
- Laeremans, M., Dons, E., Avila-Palencia, I., Carrasco-Turigas, G., Orjuela, J.P., **Anaya, E.**, Brand, C., Cole-Hunter, T., Nazelle, A. de, Götschi, T., Kahlmeier, S., Nieuwenhuijsen, M.,

Standaert, A., Boever, P.D., Panis, L.I., 2017. Physical activity and sedentary behaviour in daily life: A comparative analysis of the Global Physical Activity Questionnaire (GPAQ) and the SenseWear armband. PLOS ONE 12, e0177765. https://doi.org/10.1371/journal.pone.0177765

- Dons, E., Laeremans, M., Orjuela, J.P., Avila-Palencia, I., Carrasco-Turigas, G., Cole-Hunter, T., **Anaya-Boig, E**., Standaert, A., De Boever, P., Nawrot, T., Götschi, T., de Nazelle, A., Nieuwenhuijsen, M., Int Panis, L., 2017. Wearable Sensors for Personal Monitoring and Estimation of Inhaled Traffic-Related Air Pollution: Evaluation of Methods. Environ. Sci. Technol. 51, 1859–1867. https://doi.org/10.1021/acs.est.6b05782
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- Gerike, R., Nazelle, A. de, Nieuwenhuijsen, M., Panis, L.I., **Anaya, E.**, Avila-Palencia, I., Boschetti, F., Brand, C., Cole-Hunter, T., Dons, E., Eriksson, U., Gaupp-Berghausen, M., Kahlmeier, S., Laeremans, M., Mueller, N., Orjuela, J.P., Racioppi, F., Raser, E., Rojas-Rueda, D., Schweizer, C., Standaert, A., Uhlmann, T., Wegener, S., Götschi, T., Consortium, on behalf of the P., 2016. Physical Activity through Sustainable Transport Approaches (PASTA): a study protocol for a multicentre project. BMJ Open 6, e009924. https://doi.org/10.1136/bmjopen-2015-009924

Related to the TAPAS Project (previous to PASTA, I learned and collaborated with this project during my internship in CREAL, Barcelona):

- Curto, A., Nazelle, A. de, Donaire-Gonzalez, D., Cole-Hunter, T., Garcia-Aymerich, J., Martínez, D., **Anaya, E.**, Rodríguez, D., Jerrett, M., Nieuwenhuijsen, M.J., 2016. Private and public modes of bicycle commuting: a perspective on attitude and perception. European Journal of Public Health ckv235. https://doi.org/10.1093/eurpub/ckv235

Other publications in the timescale of the PhD thesis:

- **Anaya-Boig, E**. 'Integrated Cycling Policy. A Framework Proposal for a Research-Based Cycling Policy Innovation'. In Cycling Societies: Innovations, Inequalities and Governance, edited by Dennis Zuev, Katerina Psarikidou, and Cosmin Popan, 296. Routledge Studies in Transport, Environment and Development. Routledge, 2021.

https://www.routledge.com/Cycling-Societies-Innovations-Inequalities-and-Governance/Zuev-Psarikidou-Popan/p/book/9780367336615

- **Anaya-Boig, E**. 'Cycling Policies'. In International Encyclopedia of Transportation, edited by Roger Vickerman and Maria Attard, 1st Edition. Elsevier, 2021. https://www.elsevier.com/books/international-encyclopedia-of-transportation/vickerman/978-0-08-102671-7
- **Anaya Boig, E.**, 2018. Expert comment on Schabus, E. 'Promoting active travel for all in European urban regions – A review of evaluated initiatives'. In: Katherina Grafl, Heike Bunte, Katrin Dziekan, Holger Haubold, et al. (eds.). Framing the Third Cycling Century. Bridging the gap between research and practice. German Environment Agency and European Cyclists Federation. Available from: https://www.umweltbundesamt.de/sites/default/files/medien/1410/publikationen/181128_uba_fb_third_cycling_century_bf_small.pdf

Teaching

- Professional Effectiveness Student Programme Leader (Student Shapers), Graduate School, Imperial College London, June 2019-September 2020.
- Invited teacher in the master's programme in Regional and Population Studies (UAB), with a session on "Integrated cycle mobility planning". November 2018.
- Administrative assistant of convenors of two options (43 students), Environmental Resource Management and Pollution Management, of the Environmental Technology MSc. Course of 2017-2018.
- Teacher in the Geographic Information Systems Module of the Environmental Resource Management option of the Environmental Technology MSc. Course of 2017-2018.
- Assistant convenor and teacher at the Imperial College Biological Science BSc students for the Year 2 Resource Management Course 2017-2018 (32 students).
- PhD students' representative, Centre for Environmental Policy, Imperial College London. Course 2016-2017. Awarded the best postgraduate representative team by the Imperial College Union.
- Demonstrator of Statistics for the Environmental Technology MSc Students since 2015. Co-ordinator of the team of demonstrators for the course 2016-2017.
- Co-tutor of master's students' assignments and dissertations in the Environmental Technology MSc at Imperial College London. Courses 2013-14, 2014-15, 2015-16.

Editorial activities

- Member of the editorial board of the Active Travel Studies journal.
- Guest Co-editor of the Special Issue "Critical perspectives on bicycle-sharing schemes across the globe", Transport Research Part A: Policy and Practice.
- Guest Co-editor of the Special Issue "Geographies of bike-sharing and emerging forms of shared micro-mobility", Journal of Transport Geography.

Abstract and paper reviewer

- Reviewer of Academic Journals, most of them recorded in this Publons profile, and including Transport Research A, Case studies on Transport Policy, Transport Policy, Journal of Maps, Journal of Transport and Health, Research in Transportation Business & Management, Journal of Transport Geography, Proceedings of the Institution of Civil Engineers Journal Municipal Engineer
- Coordination of abstract review of the Cycling and Society Symposium, 2017-2020. Local organiser of 2017 Symposium at Imperial College London with 65 attendees.

Academic networks

- Member of the Royal Geographical Society (UK), Transport Geography Research Group. Since 2017. Membership Secretary from 2020.
- Member of the Transport Planning Society (UK). Since 2018.
- Member of the Athena-Swan committee at the Centre for Environmental Policy, Imperial College London, since 2018.
- Member of the Women, Equity and Research Committee of the Society of Spanish Researchers in the UK (SRUK-CERU), since 2017.
- Member of the Support Committee for the Cycling and Society Research Group. Since 2016.
- Member of the Scientists for Cycling network (European Cyclists Federation), since 2010.