

pedestrians and bicyclists'
collision avoidance behaviour
in shared spaces

final report

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msc. transport, infrastructure & logistics

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by

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in partial fulfilment of the requirements for the degree of

Master of Science

in Transport, Infrastructure & Logistics

to be defended publicly on Thursday April 12, 2018 at 4:00 pm.

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Acknowledgements

This document is the final report towards the completion of the course TIL5060 of the MSc. Transport, Infrastructure & Logistics programme. It is intended to present the execution of the thesis project, its results, strengths and weaknesses to the thesis committee and to researchers and practitioners interested in the topic of collision avoidance behaviour of cyclists and pedestrians in shared spaces.

I would like to express my utmost gratitude to my supervisors, Serge Hoogendoorn, Winnie Daamen, and Kees Maat, for supporting me from start to finish and providing me with feedback more valuable than I could have ever hoped for. Hopefully their precepts did not fall on deaf ears.

I would also like to thank the TU Delft department of Transport & Planning and associated researchers, more specifically Priscilla Hanselaar, Edwin Scharp Peter van Oossanen, Mario Campanella, Ilse Galama, Yufei Yuan, and Erica Kinkel, for their help, thoughtful comments, kindness and support.

Enfin, j'aimerais remercier ma famille et mes amis, proches ou lointains, et plus particulièrement mon grand-père, ma mère, et Jayson, qui ont toujours cru en moi et sans le soutien desquels je ne serais sans doute pas allé jusqu'au bout de ces deux longues années de thèse.

Quentin Dumont-Freixo

*Quero ir convosco, quero ir convosco,
Ao mesmo tempo com vós todos
Pra toda a parte pr'onde fostes!
Quero encontrar vossos perigos frente a frente,
Sentir na minha cara os ventos que engelham as vossas.
Cuspir dos lábios o sal dos mares que beijaram os vossos,
Ter braços na vossa faina, partilhar das vossas tormentas,
Chegar como vós, enfim, a extraordinários portos!
Fugir convosco à civilização!
Perder convosco a noção da moral!
Sentir mudar-se no longe a minha humanidade!
Beber convosco em mares do sul
Novas selvajarias, novas balbúrdias da alma,
Novos fogos centrais no meu vulcânico espírito!
Ir convosco, despir de mim — ah! põe-te daqui pra fora! —
O meu traje de civilizado, a minha brandura de acções,
Meu medo inato das cadeias,
Minha pacífica vida,
A minha vida sentada, estática, regrada e revista!*

—ÁLVARO DE CAMPOS

Summary

The demand for pedestrians and bicycle facilities is surging in our cities, for these modes offer an efficient, practical, human-paced, social, healthy, enjoyable experience of transportation and city life. Moreover, facilitating those modes can generate benefits for both the community – healthier people, safer streets (i.e. lower crash severity), increased property value, prosperous local economy – and the authorities – lower infrastructure construction and maintenance costs, cleaner air, lower noise levels, city attractiveness.

Besides providing more quality sidewalks and cycle paths to encourage active transportation, more radical approaches such as *woonerven* and *shared spaces* have been developed, originally from the Netherlands, in an attempt to maximise well-being and traffic safety. The latter one, *shared space*, is controversial for mixing modes is considered inefficient and unsafe. More specifically, little is known on how pedestrians and cyclists avoid each other when in conflicting situations.

The **objective** of this thesis was therefore to investigate the dynamics of pedestrians and bicyclists when faced with a conflict in a shared space, in order to contribute to the design and modelling of safer shared spaces, and in an attempt to answer the **research question**: *What drives the collision avoidance behaviour of pedestrians and bicyclists in shared spaces?*

The **literature review** was conducted to provide the reader with key information to understand what shared space is and means. After noticing how current behavioural dynamics models fail to describe shared space behaviour – which is based on intelligent processes rather than automatic behaviour –, a theoretical review of task performance models and sociological research in collision avoidance behaviour was proposed.

The remainder of the project was based on the results of an online **stated-preference survey** aimed at unravelling the situational and personal *attributes* that influence pedestrians and cyclists' collision avoidance behaviour. To develop the survey, **on-site observations** of a pedestrian and bicycle shared space, as well as informal **interviews** with passersby were first conducted in Amsterdam. This exercise allowed formulating a few behavioural hypotheses that fed the design of a pilot survey. Those hypotheses allowed to narrow down a few attributes to be tested against pedestrian and cyclists' trajectory changes (speed and position). The **pilot survey** was distributed to 10 people, from whom 9 answered and provided feedback on the survey understandability.

The **final survey** consisted in 40 questions depicting conflict situations by means of images, and for which the survey respondents had to choose their preferred collision avoidance manoeuvre (3 speed choices and 3 position choices). Half of the questions depicted situations with conflicting cyclists, the other half depicting situations with conflicting pedestrians. The questions allowed to test 5 situational attributes (namely conflict point *distance*,

conflict trajectory *direction*, *eye contact* with conflicting user, *group size* of the conflicting users, and *context* of the conflict situation). The survey design was orthogonal and balanced, so that all results from further statistical analysis could be treated equally. The respondents were also required to provide personal background and transportation experience information, such as *age*, *gender*, *driving licence ownership* and *cycling frequency*, to name a few. These personal attributes were also tested for significance against collision avoidance behavioural choices.

In total, 389 respondents completed the survey. The results were first **analysed** to determine which of the tested situational and personal attributes were associated to the collision avoidance manoeuvring choices of the respondents. This was performed using Cramer's V measures of association, a statistical tool relevant to categorical variables with more than two levels. Simultaneously, the choices made by the respondents were tested for panel effect, or within-subject effects, by sampling answers without replacements of respondents, and performing t-tests to compare the samples to the population of respondents. Finally, those attributes that were associated with choices were analysed more in depth to derive behavioural hypotheses and gain insights on the validity of using an online stated-preference survey to research such behaviour.

The **findings** of the study are numerous but not conclusive to ascertain a theory or develop a behavioural model. For instance, it was found that *distance*, *direction*, *context*, *age*, *cycling frequency*, and *mode choice* for common everyday trips were the attributes most associated with the respondents choices. However, panel effects were found significant, which prevented carrying out further statistical analysis such as the estimation of the parameters of a pedestrians and cyclist collision avoidance behavioural model for shared spaces (by means of log-linear analysis). Nonetheless, several behavioural hypotheses were formulated and would be interesting to research and validate in the future, namely:

1. Cyclists anticipate conflicts to keep their momentum
2. Subjecting cyclists to motorised traffic rules impacts their behaviour in shared spaces
3. Cyclists are expected to make the most effort to avoid a collision
4. Cycling frequency amongst pedestrians impacts their collision avoidance behaviour
5. Exposure to traffic impacts pedestrian collision avoidance behaviour

Finally, **recommendations** for future research, modellers, and practitioners were drawn from this exercise. A survey can indeed be an appropriate technique to acquire a strong knowledge of the impact of personal attributes on choice, although care must be taken in identifying those attributes and model them so as to be able to use a wider range of statistical techniques. From a modelling perspective, it would be ideal to make the situational attribute levels more extreme so as to generate greater variance in the results and be able to estimate parameters with more confidence. However, the situations presented to the respondents should remain as realistic as possible. Other methods, such as a live controlled experimental setup, or virtual reality, could also be interesting to pursue to be able

to quantify the trajectory changes, rather than categorise them. For practitioners (designers and authorities), what this thesis has shown is that the design and implementation of shared spaces is embedded in both situational and personal experience, meaning that the relevance of shared space is not based on whether shared space is safe as a concept, but rather if the location and the design encourage safe behaviour. In view of the findings of this thesis, it was proposed that safe shared spaces are a function of the users' ability to see and therefore anticipate movements from others, and the users' walking and cycling experience (and therefore exposure to conflicts) in their daily lives.

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Introduction

By 2050, 66% of the world's population will be living in urban areas [[United Nations, 2014](#)]. City planners and engineers, as well as local, regional, and national authorities are anticipating this phenomenon to propose and create liveable places and spaces for everyone. It is an on-going challenge to find smart ways to accommodate the new urban citizens and their need for housing, work, leisure, and pleasure. For almost a century, and even more so since the end of World War II, their solution has often been to redesign cities to accommodate fast automobile traffic by means of mode segregation and capacity increase. This strategy uses a set of design items such as traffic lanes, signs, lights, bollards, kerbs, grade separations and so on to increase car traffic speed and flow. Although mode segregation can ensure efficiency and safety on inter-urban roads, its implementation in urban environments has encouraged car use and has led to issues such as air pollution, accidents, and obesity, to name a few. More recently, approaches based on containing sprawl, encouraging mixed-use development, favouring public and active transportation, and improving multi-modal connections have led to a slower growth in the number of car trips while maintaining mobility opportunities and safety. This is because distances between trip origin and destination have reduced significantly while accessibility to places via a variety of modes has improved.

In this new paradigm, the demand for pedestrians and bicycle facilities is surging, for these modes offer an efficient, practical, human-paced, social, healthy, enjoyable experience of transportation and city life. Moreover, facilitating those modes can generate benefits for both the community – healthier people, safer streets (i.e. lower crash severity), increased property value, prosperous local economy – and the authorities – lower infrastructure construction and maintenance costs, cleaner air, lower noise levels, city attractiveness.

It is only in recent years that some cities have been making efforts to reallocate right-of-way to best match street functionality. Pedestrianisation of commercial streets and 30 km/h residential or commercial zones are some of the most widespread examples of such efforts. In that respect, the inhabitants of the Westerkwartier neighbourhood of Delft – a 19th cen-

tury working class neighbourhood – were pioneers when they reclaimed their streets from car traffic in 1968, ahead of other cities by decades. By placing obstacles, benches, and plants in the streets, the formerly straight roadways were turned into serpentine paths to slow the cars down and allow social life to predominate. The streets became safer, and families were able to interact with each other in their newly-gained "garden." This neighbourhood was the first *woonerf*, and its principles of traffic calming, where the car drivers' line of sight is constantly changing so as to scan the whole street's width, have been applied in numerous cities in the Netherlands and beyond.

Another example of reinstating social cooperation in traffic to make it safer is that of Hans Monderman, a Dutch traffic engineer who in the 1980s formulated the design approach of Shared Space. His goal was to improve traffic safety of intersections and town centre thoroughfares, and he had observed, as in the Delft *woonerf*, that people's behaviour in traffic is influenced by the built environment rather than traffic rules. His approach to street design was therefore to remove traditional roadway design elements such as kerbs, traffic signs, traffic lights, and traffic rules. The lack of points of reference thus increased the attention level of the shared space users and forced them to acknowledge and interact with each other to resolve conflict. Although the incentives for and realms of application of *woonerf* and shared space designs may be different, both approaches rely on human intelligence and perception, rather than rules, to frame traffic behaviour.

1.1. Problem statement

These design alternatives – that is, *woonerf* and *shared spaces* – are often applied by planners and engineers in the Netherlands, although it seems that the idea of mixing modes is suffering from a lack of understanding from both the community and authorities. Most of the time, mixing modes is considered inefficient and unsafe and, in the absence of evidence to suggest the contrary, segregation remains. At a time when many cities are trying to revive their centres, alleviate traffic congestion, reduce noise levels and improve air quality, it is important to show and prove the efficiency and safety of mixed-use, calmed-traffic areas as seen through the *woonerf* and shared space examples.

Planning our cities' transportation systems suggests simultaneously thinking about the street as a space where all traffic passes by as well as a place where people interact with each other. However, the main barrier to mode mixing seems to be the lack of knowledge on the manner in which different transport modes do mix and behave with respect to one another. Implementation of shared space retrofits, such as Exhibition Road in London, Fountain Place in Poynton, as well as the Dutch towns of Drachten and Emmen, are remarkable but may be too few to convince other cities to follow their steps. Often, the fear of mixing modes prevails, and segregation remains. It is also the case that access to pedestrian malls is (almost) fully forbidden to bicyclists, e.g. Stephen Avenue in Calgary [Markusoff, 2015], Rue Prince Arthur in Montreal [Laberge, 2013], 16th Street in Denver [Murray, 2015]. The reasons adduced are often about the potential safety risk due to speed differentials, and the impact on traffic efficiency in general. More specifically, little is known on how pedestrians

and cyclists avoid each other when in conflicting situations. In the Netherlands however, cyclists are more often allowed to cycle through pedestrian areas, and these areas showcase the ability of pedestrians and bicyclists to commingle.

It is therefore urgent to ask ourselves how pedestrians and bicyclists do mix in reality. Since safety and flow of people are at stake when taking the political decision to allow mixing of modes in a shared space, it is logical to research, analyse and to a greater extent model what seems to be the root of the debate: how do pedestrians and cyclists interact? To that extent, an interaction can be described here as a collision avoidance manoeuvre that allows both parties to continue their journey towards their destination. This present thesis is therefore dedicated to further the understanding of collision avoidance behaviour of pedestrians and cyclists in shared spaces.

1.2. Knowledge gap

Traffic models are used by planners and engineers around the globe to analyse traffic patterns, predict traffic states, or assess the viability of a new transportation scheme, design, or rule. Most traffic models and simulation packages (if not all) focus on segregated systems (Aimsun, OmniTRANS, Paramics, PTV VISSIM). This is because most cities showcase mode segregation, and it is easier to observe and model such systems, where users are categorised, space is split amongst those categories, and traffic rules, right of ways regulate the movements of those categories. Car-following behaviour, pedestrian self-organisation, lane formation models are all examples of segregated systems models.

Building a model – and a subsequent simulation package – of an integrated system such as shared spaces is an intricate task that requires a deep understanding of people's relation to spatial design and other people in general. This relation is indeed different than in segregated streets; legally-binding elements such as crossing, lights, and signs convey traffic and right-of-way rules. However, in shared spaces, awareness of the other and of the surrounding environment is enhanced and social norms rather than legal rules apply, and traffic models must be adapted to reflect those phenomena.

1.3. Objectives

The premise of this thesis is twofold: (1) the safety of shared spaces is debated, which means such type of infrastructure is seldom implemented, and (2) current active transportation dynamics models lack representativity of the human abilities, skills, and intelligent processes used to resolve conflicting trajectories problems.

The goal of this thesis is therefore to investigate the dynamics of pedestrians and bicyclists when faced with a conflict – defined as an intersection of intended trajectories in time and space which would result, if both parties maintain those intended trajectories and fail to find a spatio-temporal solution, in a collision – in a shared space, in order to advance our understanding of such dynamics and to contribute to the design and modelling of safer

shared spaces. This involves investigating the collision avoidance manoeuvres employed by pedestrians and bicyclists given a certain conflict scenario.

There are therefore three objectives to this thesis:

1. To unravel the manoeuvres (trajectory changes) that pedestrians and bicyclists use when their intended trajectories are in conflict.
2. To reveal the triggers behind the selection of these manoeuvres, if applicable.
3. To provide practitioners and researchers' with recommendations on how to better fit the design and the modelling approach to the shared space reality.

1.4. Research question

The thesis work is conducted to answer the following research question:

What drives the collision avoidance behaviour of pedestrians and bicyclists in shared spaces?

In order to answer this question, it is necessary to research the following sub-questions:

1. What manoeuvres do pedestrians and bicyclists employ to avoid collision?
2. To what extent do the conflict situation and personal background attributes play a role in collision avoidance behaviour?
3. To what extent can the collision avoidance behaviour of individuals be generalised to a population?

1.5. Scope

The scope of this thesis is limited to the exploration of factors influencing collision avoidance behaviour of pedestrians and bicyclists when mixing in a shared space. It is not the intention of the author to propose a finite mathematical model of such behaviour by the end of the project. Rather, the work suggests a theoretical description of the behaviour and draw recommendations to better study, research, and design shared spaces for those users.

1.6. Report outline

This document is outlined as follows: chapter 2 presents the methodology that is adopted to answer the research question, chapter 3 outlines the literature study, chapter 4 describes the experimental setup, chapter 5 presents the analysis of the results of the experiment, chapter 6 discusses the findings, and chapter 7 summarises the work and draws recommendations for researchers, modellers, and practitioners on the topic.

2

Methodology

This chapter presents the methodology and project phases that were followed in order to answer the research question introduced in chapter 1.

2.1. Method

The goal of this project is to reveal attributes (be they situational, cultural, educational and personal) and the extent to which they influence pedestrians and bicyclists' collision avoidance behaviour. To achieve this goal, the first step is to establish a pool of potential attributes that may influence collision avoidance behaviour. The significance of these attributes must then be assessed. This can be done following two different yet complementary approaches that both have their inconveniences and advantages: stated-preference (SP), and revealed-preference (RP). With the SP approach, the researcher has more control over the experiment, and can therefore accurately represent and test a variety of attributes. Personal characteristics, such as age, sex, nationality, can also be obtained and analysed further to assess their influence on the attribute significance. However, a bias may be introduced in at least two ways: (1) the answers of SP survey respondents towards a fictitious situation may differ from what their actions would be in a real situation; and (2) the choice set offered to the respondents may not include their intended answer. Using an RP approach, the behaviour of pedestrians and bicyclists is directly observed, hence superseding the limitations of an SP approach. However, in RP experiments, the difficulty lies in assessing the presence or value of certain attributes, such as personal characteristics, stress, trip purpose, amongst other examples. Furthermore, there is a chance that the behaviour being researched does not occur, or that the variety in situations is not sufficient to generate enough variance in behaviour to draw statistically significant conclusions. By jointly using the SP and RP approaches, the significance of the attributes on the one hand, and the validity of the approaches (and therefore of the findings) on the other hand can be assessed. However, due to the difficulty of the task (classifying RP conflicts and manoeuvres, stopping cyclists to fill out a survey, etc.), coupled with time and resources constraints, only an

SP experiment is envisioned in this research.

2.2. Project phases

The method presented in the previous section is here translated into the project phases (Figure 2.1).

phase	literature review	stated-preference survey	analysis	discussion of findings	conclusions and recommendations
objectives	recap shared space theory identify the level of complexity of walking and cycling behaviour identify potential challenges of the research	generate a pool of attributes to be tested generate a set of potential responses assess the understandability of the questions generate a pool of data to analyse	test the significance of attributes test panel effects unravel manoeuvre choices	discuss the impact of the tested attributes on behaviour discuss the source of panel effects, if any derive behavioural hypotheses	determine the validity of the method summarise the findings draw recommendations for practice and research

Figure 2.1: Project phases and objectives

2.2.1. Literature review

The literature study serves several purposes, including broadening one's knowledge about a certain topic or theory, building a theoretical framework, and deriving useful methods for the remainder of the work to be achieved. For this project, the purpose of the literature review is fourfold:

- To inscribe the thesis within the context of shared space.
- To review psychological and transportation theoretical models that explain human behaviour pertaining to movement in space and interaction between and among people and their surroundings.
- To unravel the different approaches used to study collision avoidance behaviour and their findings.

2.2.2. SP experiment (pilot and final)

The SP experiment consists in an online survey whose results are then used to assess the significance and role of attributes in the selection of a collision avoidance manoeuvre. The SP survey is designed following these steps:

Interviews and observations

On-site interviews and observations are conducted in an informal way to get a first insight on manoeuvres used by pedestrians and bicyclists, but also on their ability to recall those manoeuvres. This helps developing the survey's scenarios while ensuring that the respondents are able to replicate their typical behaviour.

Survey design and distribution

A pilot survey is first built in order to assess the clarity of the survey questions, and to identify elements of the survey composition that require improvements (tested attributes, number of questions, pool of possible answers to choose from, etc.).

The final survey is distributed online, via social media, to friends, family, and professional relatives of the author. The survey is setup so that anyone with the link can answer and in turn share the survey with their acquaintances. This may induce a bias in the results, since respondents may be of similar age groups and educational background. The bias of the sample population is explored before analysing the results.

2.2.3. Analysis

The respondents' answers to the survey help understanding what collision avoidance manoeuvres are chosen and why by means of statistical analysis. There, each attribute is tested for significance and degree of association with respect to collision avoidance manoeuvres choices of the respondents.

The objectives of the analysis are as follows:

- Reveal situational and personal attributes that play a role in selecting a collision avoidance manoeuvre.
- Assess the significance of those attributes on the selection of a collision avoidance manoeuvre.
- Assess the validity of using an online SP survey to research collision avoidance behaviour in shared space.

2.2.4. Discussion of the findings

The goal of the discussion is to give depth to the survey results analysis and establish an understanding on the project findings regarding:

- The influence of the tested attributes on collision avoidance behaviour
- The validity of the survey method
- The formulation of behavioural hypotheses

2.2.5. Conclusions

Finally, the conclusion chapter summarises the behavioural findings, draws the lessons learnt from the project to provide recommendations for the research, modelling, and design and implementation of shared spaces.

3

Literature review

Rather than focusing on the knowledge gap, this literature review is aimed at familiarising the reader with shared space theory (section 3.1) and providing an insight on how current behavioural dynamics models fail to mirror that theory (section 3.2). Next, task performance models (sections 3.3 through 3.4) and sociological research pertaining to collision avoidance behaviour (section 3.5) are summarised and form the starting point of the approach taken to research the topic of collision avoidance behaviour in shared spaces.

3.1. Shared Space 101

Shared space in itself is not an innovation; for thousands of years, streets and public squares have accommodated a variety of transport modes. However, with the introduction of the automobile in the early 20th century, segregation of the street into sidewalks and carriage-way quickly became a widespread design to facilitate the flow of motorised vehicles at high speeds. However, the growing number of accidents involving vulnerable road users, combined with a series of oil crises, lead to a fundamental questioning about the status of motorised vehicles in the urban lifestyle and streetscape. In 1968, for example, inhabitants of the Westerkwartier, an early 20th century neighbourhood in Delft, The Netherlands, reclaimed their streets by placing obstacles (e.g. plants, benches) rather than posting signs – which would not effectively alter motorists' behaviour – to slow motorised traffic down and enhance the social fabric of the community.

Hans Monderman, a traffic engineer in the province of Fryslân, The Netherlands, later used resembling techniques to increase traffic safety. According to him, "traffic lights are no solution, they cause people to speed like hell and brake like idiots" [Clarke, 2006, p.292]. By removing conventional traffic control devices, such as traffic lights and signage, the users of a shared space observe each other and seek eye contact in order to negotiate their trajectories. By doing so, everyone voluntarily becomes equally socially responsible for one another. As Hamilton-Baillie [2008, p.171] puts it, shared space relies on "the ability of people [...] to resolve potential conflicts through informal protocols and human interactions

prompted by clues from the built environment." Anticipation, civility, courtesy, communication, patience, and other forms of intelligent, human processes and behaviour are thus utilised, rather than imposed, legal, automatic sets of rules. In fact, shared space user behaviour is essentially the product of a risk compensation effect, where the lack of conventional, habitual points of reference induce a decrease in perceived safety, which is compensated for by slowing down and negotiating to render the conflict avoidance task more controllable.

The lack of a conventional regulatory framework also encourages the development of streetscape designs of greater quality, where space better connects to places, where shape no longer serves traffic, but rather people. [Methorst et al. \[2007, p.3\]](#) even states that although shared space is presented as a solution for traffic safety, it is rather a "reaction to the ugliness generated by an exaggerated problem solving oriented approach of traffic and transport engineering."

3.2. Limitations of current behavioural dynamics models

In the field of active transportation engineering, research has essentially focused on modelling pedestrian and bicycle dynamics distinctively. Approaches such as disutility minimisation, game theory, or collision avoidance have been used to model the behaviour of pedestrian – and at times other modes – dynamics. However, the methods employed tend to treat the resolution of conflicting trajectories as a rather rough, automatic behaviour ([Helbing and Molnár \[1995\]](#), [Fiorini and Shiller \[1998\]](#), [Blue and Adler \[1998\]](#)) with little consideration for the appreciation of the human mind. Case in point: the social force model which, as the name suggests, alters pedestrian trajectory based on individual proximity tolerance (the attraction or repulsion "force") to another person, although one could argue that people in reality are seldom attracted to or repulsed by every individual they run into on the street, and that many other factors may come at play to explain trajectory changes. Little has been done regarding the modelling of the resolution of those conflicts as an intelligent process, where human abilities and skills are at play.

3.3. Task perception and response

When summarising the way shared space functions, [Methorst et al. \[2007, p.12\]](#) assumes the following:

1. "All road users are able to detect and recognise danger and risks."
2. "The endangered ones (can) produce the correct safe response behaviour: they know what to do, are able to perform and do not make mistakes."
3. "The strongest party sets the stage."

However, this vision of human behaviour and traffic tasks performance is a rather simplistic one, and does not include differences in competences, perception, and capabilities

of individuals. It also assumes that the endangering users never produce any form of safe response behaviour.

The task-capability interface model [Fuller, 2000] [Fuller, 2005] offers a more holistic view on how drivers – and, by extension, road users – control their behaviour – or that of their vehicle – when in a conflict situation (Figure 3.1). Rather than assuming that users aim to maintain a certain level of risk (as seen in the risk compensation models), Fuller asserts that users aim to maintain a certain level of task difficulty in order to stay alert yet in control. In his model, the capability of a road user to detect a conflict and stay in control is dependant on the user's competence, altered by his or her state in the situation requiring control. Depending on the complexity of the conflict – the task demand –, the road user stays in or loses control. Fuller is not interested in the means through which control is achieved, but rather in the determinants of the control sequence response.

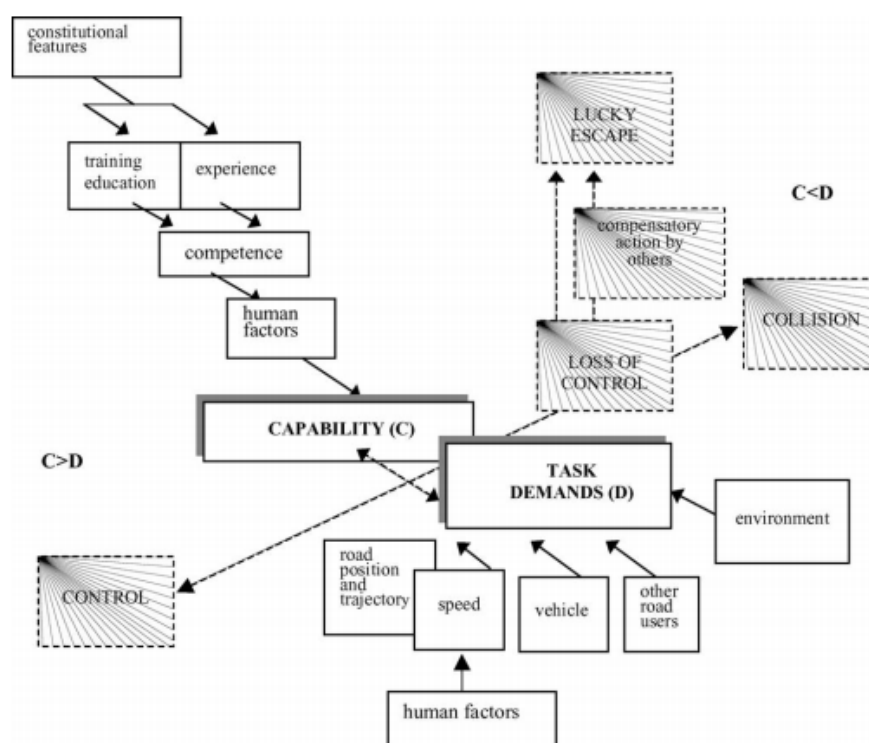


Figure 3.1: Fuller's task-capability interface model [Fuller, 2005]

It is indeed important to understand that different people have different levels of competence to start with, but also that their individual perception of task demands may vary depending on the situation they are in. Shared Space theory is in that sense an extreme application of the Sustainable Safety theory [Wegman and Aarts, 2005], which advocates for an adaption of the users' environment (the vehicles and the infrastructure) coupled with the implementation of education and training programmes – which, in the case of shared spaces, could be expressed as traffic experience –, rather than the enforcement of a constraining, punitive set of traffic rules.

Finally, there remains fundamental disparities in perception that no education of training programme may be able to eliminate. [Moody and Melia \[2014\]](#) has indeed found that demographics such as gender, age, but also personal experience and habits, play a major role in spatial perception and adaption. In their study about a square newly retrofitted into a shared space in the United Kingdom, 58% of the men surveyed reported anxiety about the new design, as opposed to a striking 91% of the women surveyed. Moreover, pedestrians under 30 years of age were more likely to adapt to the new design and view it as an interaction space in which they have equal or more priority over motorists than any other age category. Finally, people using the square daily – and therefore accustomed to delays and detours – were more accepting the layout changes (83%) than those using it less than once a week (56%). Although this study is focused on a single square, and its results cannot be generalised, it brings interesting insights on perception and reaction demographical determinants.

3.4. Task control and performance

Once a conflict is detected and the tasks to be handled are comprehended, individuals make use of their competences to control for the situation and avoid, say, a collision. Their resulting behaviour is therefore the product of their acquired knowledge (through experience and training), their skills (mental and physical, be they innate or acquired), and capability (stress, fatigue, alcohol, etc.). [Rasmussen \[1983\]](#) thus formulates three basic levels of performance explaining the constrained behaviour of individuals when controlling for a task (Figure 3.2).

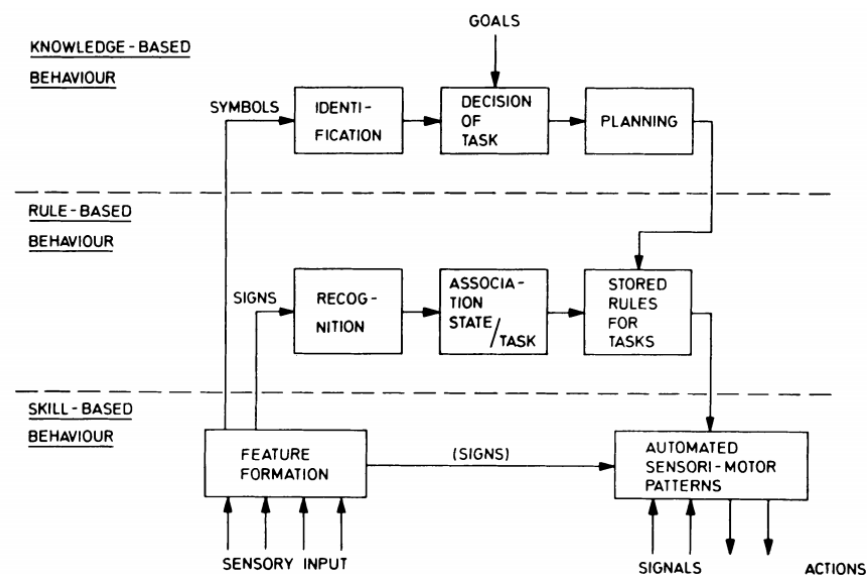


Figure 3.2: The three levels of human performance [\[Rasmussen, 1983\]](#)

Skill-based behaviour takes place with little or no conscious reasoning, and therefore results in what is called a sensory-motor performance: "In general, the skill-based perfor-

mance rolls along without the person's conscious attention, and he will be unable to describe how he controls and on what information he bases the performance" [Rasmussen, 1983, p.259]. In this state, individuals physically respond to a direct, sensory observation (e.g. the difference between the actual and intended or expected states of a system), using highly-integrated skills and subroutines. During such performances, individuals do not reason and display automatic behaviour. Tasks such as walking or cycling movements pertain to skill-based behaviour. There, the pedestrian or the cyclist sub-consciously compares his or her trajectory to the intended path, and manoeuvres accordingly (feedback control). He or she is said to rely on signals in this case, i.e. temporal-spatial continuous changes (e.g. speed, position).

Performance in familiar situations requiring cognitive efforts is called *rule-based behaviour*. Such performance is governed by the recalling of a rule or set of rules that were previously acquired by the individual, be they through repeated experience or training. Typically, "the rules used can be reported by the person" [Rasmussen, 1983, p.259]. A basic traffic rule such as right-of-way is a good example of such behaviour. In that case, a disturbance, such as an oncoming vehicle to the right, is detected, and the person manoeuvres according to a specific rule in order to resolve the conflict (feed-forward control). To trigger the use of the right-of-way rule, the individual relies on observed, physical signs, such as "coming from the right."

Finally, extra-ordinary situations requiring thorough analysis and the devise of a plan of action – hence important cognitive efforts – from the individual to resolve the problem are said to rely on *knowledge-based behaviour*. In those cases, a plan is composed so as to achieve a specific goal, and the plan's components are selected on the spot physically through trial-and-error or conceptually by assuming and predicting the behaviour of the surrounding system. In that sense, the words of Goffman [1971] – who believed that all actions are meaningful – are to be mentioned here: "Voluntary coordination of action is achieved in which each of the two parties has a conception of how matters ought to be handled between them, the two conceptions agree, each party believes that this agreement exists and each appreciates that this knowledge about the agreement is possessed by the other." In other words, trust characterises knowledge-based performance. Individuals solely rely on symbols in this case, which are abstract, mental constructs that help bring meaning to a situation.

3.5. Collision avoidance manoeuvres

When interacting in space and time, we have seen that (groups of) individuals seek signals, signs, and symbols to determine their next manoeuvre using their capabilities, and thus resolve a potential conflict, be it through a sub-conscious, automatic process or rather a cognitive one. Sociological studies have attempted to shed light on those manoeuvres and their determinants, two of which are summarised hereafter.

Jensen [2010] argues that the physical interaction manoeuvres of individuals are correlated to the relations of norms, values, and power amongst the interacting agents. He also

asserts that individuals have an "existing repertoire of actions, mobile negotiation techniques, and mobile interaction tactics" [Jensen, 2010, p.151]. Personal characteristics, culture, and experience are thus intrinsic to people's manoeuvres. In terms of collision avoidance techniques, Jensen differentiates six typologies: *group passing other pedestrian*, *group letting in stranger*, the *classic dance*, *both giving in*, the *zigzag turner*, and the *stop to pass* (Figure 3.3). Since Jensen believes, as Goffman, that such manoeuvres are related to notions of power and responsibility – which are to be compared to Rasmussen's symbols –, they could be classified as knowledge-based behaviour.

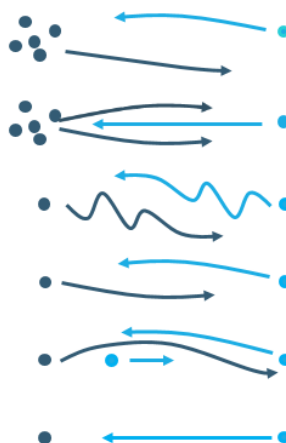


Figure 3.3: The six collision avoidance typologies [Jensen, 2010]

Haddington and Rauniomaa [2014] seem to propose another way of looking at collision avoidance manoeuvres between individuals. To them, conflict avoidance is the result of a collaboration between people, who explicitly communicate with each other. The authors speak of and oppose *traffic civility* rather than *traffic regulations*, where traffic civility consists in a set of informal rules and gestures acquired by experience and well-understood by the others. These rules and gestures are used on a voluntary basis, as opposed to traffic regulations which are mandatory. In that sense, Haddington and Rauniomaa's interpretation of conflict resolution is one translating rule-based behaviour.

3.6. Conclusions

Throughout this brief literature review, we have seen that shared spaces can be understood, analysed, and evaluated from a variety of perspectives: traffic safety, social capital, and aesthetics. In any case, shared space is always seen as a place relying on human-environment interaction and informal protocols to resolve conflicts/avoid collision, rather than conventional rules.

Those protocols are triggered by the conflict's task demand level, and resolved through the use of one's abilities. One's ability to resolve a conflict highly depends on their experience and personal traits, as well as the task demand and context.

When avoiding collision, individuals make use of their innate and acquired skills, rules,

and knowledge. It appears from this review that walking and cycling can be classified as skill-based behaviour, while collision avoidance behaviour can be seen as a rule-based performance, i.e. a performance where a set of individual or universal rules are selected from experience and applied as a (sub) routine.

However, one could also argue that in the specific case of shared space, where design does not indicate which sets of rules may apply, collision avoidance behaviour may be classified as a knowledge-based performance. This is also suggested by the principles of shared space and risk compensation theories themselves, whereby safety and collision avoidance is solely achieved due to the uncertainty of the situation and thus the requirement of individuals to take greater care in deciding upon their next move.

The research carried out in this thesis therefore aims at determining whether collision avoidance behaviour pertains to rule-based behaviour (which would mean pedestrians and cyclists do have control over the conflict situations, hence indicating that shared space safety is achievable by means of a simple design) or knowledge-based behaviour (which would indicate that pedestrians and cyclists behaviour is unpredictable, and that shared space safety is achievable by introducing a strict set of traffic rules for such spaces).

4

Stated preference survey

The main advantage of devising a survey is to gain insight on the personal characteristics, experience, and competences of the respondents to better understand their decision-making process. Throughout the survey, the goal is to reveal what situational and personal attributes play a role in determining the manoeuvres that are selected to resolve a conflict. This chapter explains the steps followed to design the online SP survey that was eventually distributed to form the basis of the analysis.

4.1. Approach

In an attempt to steer the survey design in the right direction from the get-go, on-site observations and interviews of passersby were carried out (section 4.2). These preliminary investigations allowed to get an idea of the ability of pedestrians and bicyclists to assess their own actions regarding conflict avoidance. On the one hand, this validates the method used (the survey) and on the other hand, allows to draft a preliminary set of attributes to be tested.

The next step was to create a pilot survey (section 4.3), to test the formulation of the survey questions, the quality of the response choice sets, as well as the validity of the method. The improvements suggested by the results of the pilot survey are then incorporated in the final survey design.

Finally, using the knowledge gained via the on-site work and the pilot survey, a final survey was designed and distributed (section 4.4) to collect a maximum of answers, thus creating a pool of data to analyse of the best quality and relevance possible.

4.2. Observations and interviews

On Thursday October 6, 2016, direct observation of pedestrian and bicyclist behaviour was carried out at the De Ruijterkade shared space facility (Figure 4.1), located at the north side



Figure 4.1: The De Ruijterkade shared space behind Amsterdam Central Station, The Netherlands (Source: [A City Made by People](#) [2016])

of Amsterdam Central Station, The Netherlands. This new shared space is located at the intersection of two major bi-directional cycle tracks (along De Ruijterkade and under the train station via a tunnel) where many different activities are going on: waiting for the ferry, exiting the ferry, commuting, accessing the station, meeting someone, etc. Because of this complexity of activities and therefore movements, as well as the high volumes of pedestrians and cyclists at the intersection, the cycle tracks are raised to sidewalk curb height, thus creating a uniform plateau where pedestrians and cyclists mix and carry out their activity.

The on-site observations were aimed at revealing conflict avoidance behaviour in the first place, and the impact of the site characteristics on behaviour to the extent possible. Then, passersby, including both pedestrians and cyclists waiting for the ferry, were informally interviewed to validate the observations made and assess the ability of pedestrians and cyclists to self-report their collision avoidance behaviour or experience in shared spaces. They were informally asked the following 3 questions:

1. What situations with pedestrians/bicyclists do you find most challenging in general?
2. How do you typically react to those situations?
3. What factors do you think influence your decision to do so?

4.2.1. Conflict avoidance behaviour

It was noticed that pedestrians tend not to deviate from their intended path when in a conflict with a bicyclist. They rather slow down – or even stop if necessary – and resume to

their intended walking speed once the conflict is avoided. This allows bicyclists to better anticipate trajectories of pedestrians, and they can therefore adapt their trajectory while keeping their intended speed in order to avoid pedestrians.

Adapting direction rather than speed when bicycling also makes sense from a conservation of energy perspective; bicyclists indeed tend to be willing to keep their momentum rather than having to accelerate after making stops, in order to minimise their effort.

Finally, elderly people on foot tend to come to a complete stop more often than younger people for similar types of conflicts.

The core findings of the observations are the following:

- The behaviour of the users of the De Ruijterkade shared use facility seems to be significantly altered by the ferry schedule (both departures and arrivals).
- When in a conflict, the slowest individual or group of individuals tends to slow down without changing trajectory, while the fastest individual or group of individual deviates from their intended trajectory while maintaining speed. This suggests that collision avoidance behaviour in shared spaces may be the product of the simultaneous deployment of skill-, rule-, and knowledge-based behaviour.

4.2.2. Impact of site characteristics on behaviour

The free public ferry service originating from De Ruijterkade uses a countdown to indicate next departures towards the other side of the IJ river. It was found that when the count approaches 0, bicyclists significantly accelerate and focus on reaching the ferry as directly as possible. This tends to limit their ability to pay attention to their environment in detail, and may affect their approach to conflict anticipation and avoidance.

The De Ruijterkade shared use facility is located at the intersection of two bicycle tracks, at grade with the sidewalk. It was found that bicyclists observe the intersection with a lot of care prior to reach the raised piece of infrastructure, mostly to assess the trajectories of on-coming crossing pedestrians and bicycles. This is particularly the case when a ferry just arrives at De Ruijterkade and a sudden increase in pedestrian and bicycle flow is expected.

Pedestrians and bicyclists arriving by ferry to De Ruijterkade also exhibit precautions when exiting the ferry, as their sudden presence may highly interfere with pedestrian and bicycle traffic on De Ruijterkade. Many bicyclists are indeed walking their bicycles until reaching a lower-density location at which they can mount their bicycle and cycle at a comfortable speed.

4.2.3. Interviews

Although the sample of people interviewed can clearly not be representative of the population using the facilities of the case study site (e.g. too few people surveyed, difficulty in interviewing people on the go, in a hurry, tourists speaking foreign languages), the follow-

ing patterns were identified from the respondents:

Pedestrians' reactions

The most challenging situations for pedestrians include:

- when the flow of bicyclists is very high; and,
- when bicyclists travel in multiple directions.

The main reaction of pedestrians when faced with those situations is to slow down or stop. For simpler situations, e.g. one-on-one or when bicyclists are slow, eye contact is usually sufficient to resolve a conflict, and generally pedestrians are able to maintain their speed, meaning they slightly swerve away from their intended path ("if the cyclist sees me, we both avoid each other at the same time"). The density of the pedestrian and cyclist crowd ("when there are a lot of people everywhere") as well as travelling with children ("I don't want to take risks with my kids") are the two most common reasons explaining slowing down or coming to a stop.

Cyclists' reactions

The most challenging situations for bicyclists are more numerous and detailed, and include:

- large groups of pedestrians walking together ("large groups of pedestrians tend not to pay as much attention to their surroundings as a single person");
- (groups of) pedestrians walking towards each other while the bicyclist is trying to cross their path in between them ("I hesitate between slowing down or accelerating when people converge towards me from different directions");
- when the crowd is too dense ("it is difficult to anticipate the movements of every person");
- when in a rush and many pedestrians are in the way ("I don't like having to slow down or concentrate on avoiding people when I'm in a hurry"); and,
- when tourists do not know how to behave with respect to bicycles ("I'm never quite sure how tourists will react to any movement I make").

The techniques used to resolve conflicts are apparently highly dependent on the situation: the bell is generally used to alert distracted pedestrians so as to make eye contact and maintain speed (usually used when bicycling at a relatively high speed), swerving seems to be mostly employed to avoid an obstacle and maintain speed, while slowing down and stopping are used when densities are too high or when the situation is too complex (in combination with the bell at times).

All in all, the main factors affecting the decisions of bicyclists towards the selection of a collision avoidance manoeuvre are density of the crowd, trip purpose (when in a rush to work, the goal is to maintain a high speed), as well as pedestrian type and party (tourists vs. locals, single person vs. group).

Summary

Several remarks can be made from the interviews. First of all, pedestrian respondents gave much less detailed answers than the bicyclists. This could indicate that pedestrians do not classify situations as challenging as easily as bicyclists, meaning that they have a higher tolerance to situation complexity. This could be due to the fact that pedestrians have more degrees of freedom than bicyclists regarding their behaviour, e.g. sudden lateral movement or immediate stopping. It could also mean that pedestrians are simply less aware of their surroundings, or trust the bicyclists' skills to avoid them. This level of trust may be found because pedestrians typically have priority over other transport modes by law, and they thus expect the other modes to 'do the work' to not collide with them.

Last but not least, walking is inherent to the human nature, and as such pedestrian collision avoidance behaviour may be conceptualised as a subconscious process, thus explaining the difficulty of pedestrians to recall and describe specific conflicting situations. In that sense, pedestrian collision avoidance behaviour may pertain to the realm of skill-based behaviour. On the other hand, bicycling consists in using a tool – the bicycle – according to some specific rules (directionality of bicycle ways, yielding norms, etc.), hence rendering the processes of detecting and avoiding collisions as more conscious tasks, or rule-based performance.

Nevertheless, although pedestrians may not be as able as bicyclists to recall their behaviour in conflicting situations, presenting a survey describing and depicting specific conflicts forces the respondents to make conscious decisions to avoid imminent hypothetical collisions. This will allow to test the degree to which collision avoidance is a conscious behaviour – that is, whether a pattern of behaviour can be found in the respondents' choices.

4.2.4. Conclusions

The on-street interviews and observations were initially aimed at assessing the feasibility of conducting an online survey on collision avoidance behaviour. It was found that discrepancies may exist in the level of consciousness of collision avoidance behaviour (detection, decision, recalling) among pedestrians and bicyclists. The online survey will, to some extent, allow to assess whether these discrepancies are significant. If, for examples, pedestrians' choices are random, a possible explanation is that collision avoidance behaviour is too subconscious for people to recall their actions. Another possibility would be that pedestrians' choices are not random, but however do not relate to reality, although it could be argued that the chances of a sample consistently choosing the exact same unrealistic collision avoidance manoeuvres are slim.

It was also observed that the characteristics of a site (location, categories of users, sched-

ule of services, etc.) may significantly influence behaviour. The SP survey will therefore be designed to include contextual variables, and collect information on age and gender, for example.

4.3. Pilot survey

An SP survey typically consists in presenting the respondents with successive choice sets – a set of alternatives – for which a choice must be made – the preferred alternative. The purpose of such a survey is to investigate on the factors influencing the choice of that preferred alternative. The choice sets must therefore showcase clear attribute differences from one to another, so as to evaluate both the effects of an attribute and its levels.

For this project, the respondents (either described as pedestrians or bicyclists) are presented with a series of conflicting situations for which they must select a preferred collision avoidance manoeuvre. This section presents the design process of the survey, as well as its results and implications.

4.3.1. Survey design

The pilot survey consists in a series of questions formed with images depicting the different levels of attributes to be tested. The respondents then choose their preferred trajectory manoeuvre based on the image seen and contextual information given. The steps to develop the sets of attributes to be tested and of response manoeuvres choices are described hereafter.

Attributes and levels

Collision avoidance behaviour may be described as the end decision of an individual based on the (conscious or subconscious) evaluation of many situational and personal attributes (e.g. relative speed, risk-taking behaviour, etc.). Through the interviews and observations, a set of such attributes can be drafted:

1. Speed of the conflicting user(s): speed seems to be the most determining factor in the establishment of a power relation amongst the two modes. It was indeed observed that the slower mode typically alters its speed, when the faster mode alters its trajectory.
2. Density: people may react differently when facing a single person or a crowd.
3. Direction: people may avoid collisions in different ways based on the trajectories' interception angle.
4. Distraction: as reported in the interview, eye contact is important to establish trust and coordinate movements with one another in order to share the burden of avoiding collision.

5. Context: the power relationship between the two modes may be altered whether one is in a rush, strolling with friends, accompanied by children, etc.
6. Personal attributes, such as Age (the elderly seem to be more cautious than other age categories, which may explain some variance in collision avoidance behaviour) and Cultural background (e.g. tourists may react differently than locals, although this was not directly observed and is therefore a hypothesis).

Personal attribute cannot be tested the same way as the other, situational attributes. The choice situations proposed to the survey respondents therefore include attributes 1 through 5. Personal attributes such as Age and Cultural background are tested using open-ended questions.

In order to test the significance, as well as to estimate the impact (parameters) of the situational attributes, attribute levels are defined. These attribute levels, combined with one another, serve as the basis for the situations to be designed and proposed to the respondents. They are as seen in Table 4.1.

Table 4.1: Attributes and attribute levels of the SP survey

Attribute	Levels	Comment
Speed	low high	the speed describes that of the conflicting (group of) individual(s)
Group Size	1 person 3 people 6 people	the group size indicated the size of the conflicting (group of) individual(s)
Direction	frontal 45 degree	the direction indicated whether the imminent collision is frontal or sideways
Eye Contact	without with	the eye contact attribute serves as a proxy to describe distraction
Context	alone (base case) in a rush to work shopping with friends	the context attribute aims at assessing the impact of trip purpose and its effect on risk-taking behaviour onto collision avoidance behaviour

Choice situations

5 attributes are tested in the experiment, with either 2 or 3 levels each. The total number of possible combinations (or choice situations thereof) from the perspective of a pedestrian or a cyclist, is thus $2^3 \times 3^2 = 72$. A survey design which would test all those combinations is called a full factorial design. However, a full factorial design would require asking the respondents to answer too many questions (72 questions as a cyclist, and 72 questions as a pedestrian), which would be very time consuming and boring. The risk of respondents

answering at random or simply not finishing the survey would therefore be high and the results insignificant.

In order to find a statistically sound fractional factorial design to the survey, two design requirements must be observed: orthogonality of the attributes (attributes must not be correlated), and attribute level balance (every level of an attribute must appear an equal number of times across the design).

Basic Plans [Addelman, 1962] are typically used to ensure orthogonality and attribute balance in designing stated choice surveys. Basic Plan 5 as per this reference is the basic plan with the minimum number of choice situations (16) that can effectively comply with the orthogonality and attribute balance principles for a survey formed by 2 three-level attributes (columns 1* and 2* of the second block of Table 4.2) and 3 two-level attributes (columns 07, 08 and 09 of the third block of Table 4.2).

Table 4.2: Pilot survey design according to Basic Plan 5

Trial	4 levels					3 levels					2 levels														
	1	2	3	4	5	1	2	3	4	5	0	0	0	0	0	0	0	0	0	1	1	1	1	1	
	*	*	*	*	*	*	*	*	*	*	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	1	1	2	3	0	1	1	2	1	0	0	0	0	1	1	0	1	1	1	0	0	1	1	0
3	0	2	2	0	1	0	2	2	1	1	0	0	0	1	0	1	1	0	1	1	1	0	0	1	1
4	0	3	3	1	2	0	1	1	1	2	0	0	0	1	1	0	1	1	0	0	1	1	1	0	1
5	1	0	1	1	1	0	1	0	1	1	0	0	1	1	0	0	0	1	1	0	1	1	0	1	1
6	1	1	0	3	2	1	1	0	1	2	0	0	1	1	0	1	1	0	0	1	1	0	1	0	1
7	1	2	3	2	0	1	2	1	2	0	0	0	1	1	1	0	1	1	0	1	0	1	0	0	0
8	1	3	2	0	3	1	1	2	0	1	0	0	1	1	1	0	1	0	1	0	0	0	1	1	0
9	2	0	2	2	2	0	0	2	2	2	0	1	0	1	0	0	0	1	0	1	1	0	1	0	1
10	2	1	3	0	1	0	1	1	0	1	0	1	0	1	0	1	1	1	0	0	0	0	0	1	1
11	2	2	0	1	3	0	2	0	1	1	0	1	0	1	1	0	1	0	0	0	0	1	1	1	0
12	2	3	1	3	0	1	1	1	1	0	0	0	1	1	1	0	0	1	1	1	1	0	0	0	0
13	3	0	3	3	3	0	1	0	1	1	0	1	0	0	0	0	1	1	0	1	1	0	1	1	0
14	3	1	2	1	0	1	1	2	1	0	0	1	1	0	0	1	1	0	1	0	1	1	0	0	0
15	3	2	1	0	2	0	2	1	0	2	0	1	1	0	1	0	0	1	1	0	0	0	1	0	1
16	3	3	0	2	1	0	1	0	2	1	0	1	1	0	1	0	0	0	0	1	0	1	0	1	1
Excluded columns	1	-	0	0	0	2	-	0	0	0	3	-	0	0	0	4	-	1	1	1	5	-	1	1	1
	*	-	1	2	3	*	-	4	5	6	*	-	7	8	9	*	-	0	1	2	*	-	3	4	5

Note that trial pairs 6 & 16 and 8 & 14 are the same, hence reducing the design to 14 questions for each mode. As a result, the 14 choice situations described in table 4.3 are developed.

Table 4.3: Pilot survey choice situations for each mode

Trial	Distance	Direction	Eye Contact	Group Size	Context
1	far	facing	no	alone	alone
2	far	crossing	yes	alone	shopping
3	close	facing	yes	alone	rushing
4	close	crossing	no	alone	shopping
5	far	crossing	yes	medium	alone
6	far	facing	no	medium	shopping
7	close	crossing	no	medium	rushing
8	close	facing	yes	medium	shopping
9	close	facing	yes	large	alone
10	close	crossing	no	large	shopping
11	far	facing	no	large	rushing
12	far	crossing	yes	large	shopping
13	close	crossing	no	medium	alone
14	far	crossing	yes	medium	rushing

Choice alternatives

For each of the 28 choice situations (14 for each mode) that the SP pilot survey respondent is presented with, a preferred manoeuvre must be chosen. Based on the interviews and observations, 5 basic manoeuvres are proposed at this stage:

1. Accelerate
2. Decelerate
3. Stop
4. Step/swerve aside
5. Do nothing

For each situation, respondents must choose one and only one manoeuvre, thus making a choice between altering their speed (first three choices) or their direction (last two choices).

Pilot survey composition and dissemination

The survey is based on the questions developed thanks to Basic Plan 5, and also includes a section to collect personal characteristics such as age, gender, and origin, as well as an open-ended question section to let the respondents describe freely their impressions about the survey and make suggestions for improvement in view of the final survey.

The choice situations developed using Basic Plan 5 are illustrated by means of images built in Adobe Photoshop. Images are chosen over textual description for they allow not to

explicitly describe the attributes being tested. This way, respondents are not encouraged to pay attention to specific attributes so as to replicate real decision-making processes as much as possible, in which pedestrians and cyclists are not asked to look for specific cues in their surroundings. Besides offering a good compromise between SP and RP experimental techniques, this setup also allows for testing not only the significance of attributes, but also the relevance of the survey tool to study collision avoidance behaviour.

The pilot survey is distributed to a limited number of participants to quickly gather preliminary data to identify flaws (e.g. choice alternatives, survey length), assess whether the attribute levels are well differentiated and understood by the participants, and get a first look at the impact of attributes and their levels on collision avoidance behaviour.

Images

The images depicting the scenarios shown in the survey are created using Adobe Photoshop. An image showing the shared space at the intersection of Grote Breedstraat, Boterstraat, Koornmarkt and Oranjewal in the town of Dokkum, The Netherlands, is used as background for all pictures (courtesy of Mobycon B.V.). Choosing a space with no recognisable infrastructural details to neither pedestrians or bicyclists is ideal here in order to let the respondents base their answers on the conflict situation only, irrespective of the surroundings.

Pedestrians and bicyclists cut outs are then added to the background image according to the choice situations of Basic Plan 5 of the survey. This is done twice: once for the pedestrians using bicyclists cut outs, and once for the bicyclists using pedestrian cut outs. The context attribute is not depicted in the images, but rather explicitly described to the respondent, since this would be a known attribute level in a real situation. Therefore, situations pairs 5 & 14 and 7 & 13 of Table 4.3 use the same images, yielding 12 images to be created for each mode. A total of 24 images is thus produced.

Open-ended questions

Respondents were given the chance to comment on the quality and understandability of the survey so as to improve the final survey design. Questions about the images, but also about the proposed manoeuvres were developed.

Personal information

Age, gender, country of origin, and city of residence of the respondents were asked. Age, especially the elderly, may indeed be a significant factor in the selection of a collision avoidance manoeuvre. The origin of the respondent may capture cultural background differences, which may include traffic rules and norms, experience with and as pedestrians and bicyclists, experience in shared spaces, amongst other. Finally, city of residence may capture more subtle differences in experience with pedestrians and bicyclists; for instance, a resident of Amsterdam may have a completely different experience with bicyclists than a resident of a small Dutch village (higher traffic flows, higher densities, noise, tourists, etc.).

Distribution platform

The pilot survey was distributed to a total of 10 people via Google Forms. These people were selected according to several criteria: cultural background (Canadian, Costa Rican, Dutch, French, Italian), age (24-48), gender, background education (civil engineering, mechanical engineering, transportation engineering, electrical engineering, urbanism, architecture), and occupation (student, consultant, civil servant). The pilot survey as presented to the respondents via Google Forms can be found in [Appendix A](#).

4.3.2. Analysis of the results of the pilot survey

9 out of the 10 people contacted for the pilot survey responded. At first glance, their answers to the choice situations show some variance. The respondents' characteristics and their feedback are used to determine whether this variance is the product of actual attribute impact on choice, random effects due to the impossibility to identify the attribute, or a combination of both. Altogether, the pilot survey results analysis is used to design the final survey.

The analysis of the pilot survey results is carried out with the following objectives in mind:

1. Identify survey design flaws from the respondents' feedback
2. Assess the impact of the tested attributes on collision avoidance manoeuvring choices
3. Validate the hypotheses from the on-site observations and interviews

Feedback

Quality of the survey

The clarity of the questions asked was rated 3.8/5 on average. The quality of the images was rated 4.4/5, and the relevance of the proposed choices was rated 3.9/5 on average. Some work therefore needs to be done to improve the clarity of the questions, and the comments left in the open-ended question are used to that end.

Suggestions for improvement

The following issues were raised by the respondents:

- Task description: a more detailed description of the task would be welcome, as some respondents were not sure about the speed at which they were hypothetically going, nor whether every situation represented a conflict.
- Distance and group size attributes: some respondents thought there were 3 levels, however the intention was to only display 2.
- Context attribute: the case where the respondent is hypothetically the walking/cycling alone was found to be difficult to imagine.

- Manoeuvre choice: there is no possibility to select multiple manoeuvres, which was a problem for two respondents who wanted to select both "I swerve aside" and "I slow down" at times, especially when being a cyclist. Moreover, the formulation of the *do nothing* option may have been misleading.

Collision avoidance manoeuvring choices

Figures 4.2 and 4.3, produced using MATLAB, depict the manoeuvre choice distribution of bicyclists and pedestrians over all attribute levels included in the pilot survey. The size of the disks show the relative preference of the respondents for the five proposed manoeuvres given an attribute level. The lines show how respondents who have chosen a manoeuvre for a given attribute level have changed their choices given an other level of that attribute. The thicker and darker the line, the more respondents have chosen the same pair of manoeuvres.

Note that for the *group size* attribute, disks represent the proportions for a single person, and a large group (4 or 6 people) conflicting with the respondent. This is because respondents found it difficult to differentiate between a medium and a large group of people (see the feedback analysis above).

Cyclists' choices

Overall, bicyclists show a clear preference for the "swerve aside" manoeuvre, except when shopping with friends or rushing to work ("do nothing" is then preferred). "Slowing down" is usually the second-most chosen manoeuvre. Cyclists also tend to maintain or switch between their two most preferred manoeuvres. Table 4.4 shows the cases for which each manoeuvre is the most chosen. The results correspond to intuitive expectations: accelerating is mostly used when in a rush, stopping is mostly adopted when facing a large group of pedestrians, etc.

Table 4.4: Attribute levels for which each bicycle manoeuvre is the most chosen.

Manoeuvre	Mostly used when:
I accelerate	rushing to work
I slow down	biking alone
I stop	facing a large group of pedestrians
I swerve aside	pedestrian(s) walking towards the bicyclist
I don't do anything	shopping with friends & rushing to work

Finally, when looking at the changes in choices given attribute level changes, one can see that the choices of the respondents show a higher dispersion for the attributes *eye contact*, *direction*, and *distance*, as opposed to *group size* and *context*. For example, respondents who prefer swerving aside when detecting a conflict from far away chose to swerve aside, slow down, stop or accelerate when detecting a close conflict. The challenge is therefore to explain the dispersion over those manoeuvres. This is done by finding similar changes over all attributes. Table 4.5 summarises the influencing factors for switching

from a manoeuvre to another; note that only causal links true for at least two thirds of the respondents are retained here - it is assumed that, with such a low number of respondents, the change in manoeuvres observed for a minority of respondents is insignificant. The relationships shown in the table can be read in both directions. Care must however be taken in interpreting those observations; it is indeed not clear at this stage whether switching from "swerving aside" to "slow down" is due to a single change in *distance*, *direction*, *eye contact*, and *context* or a combination of those changes.

Table 4.5: Causes of bicycle manoeuvre changes

Manoeuvre change	Causal link	Attribute
swerve aside ↔ accelerate	far ↔ close	<i>distance</i>
swerve aside ↔ slow down	far ↔ close	<i>distance</i>
	facing ↔ crossing crossing ↔ facing	<i>direction</i>
	yes ↔ no no ↔ yes	<i>eye contact</i>
	alone ↔ shopping rushing ↔ shopping	<i>context</i>
	far ↔ close	<i>distance</i>
swerve aside ↔ stop	facing ↔ crossing	<i>direction</i>
	yes ↔ no	<i>eye contact</i>
	small ↔ large	<i>group size</i>
	alone ↔ shopping rushing ↔ shopping	<i>context</i>
	yes ↔ no	<i>eye contact</i>
do nothing ↔ swerve	small ↔ large	<i>group size</i>
	yes ↔ no	<i>eye contact</i>
slow down ↔ stop	yes ↔ no	<i>eye contact</i>

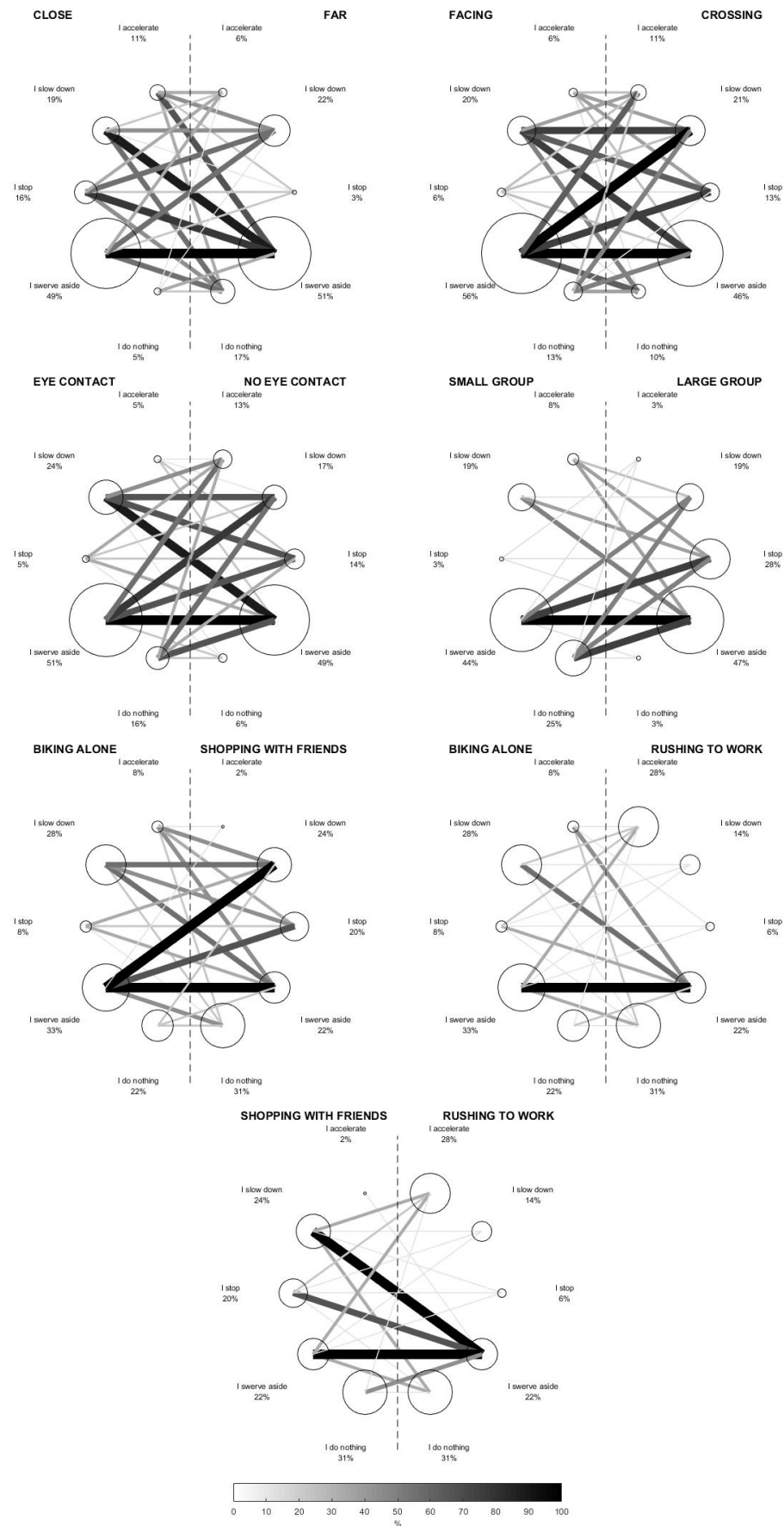


Figure 4.2: Bicycle manoeuvres. For each attribute level, disk size shows the relative inclination towards a manoeuvre pair. For each manoeuvre pair, the thickness and darkness of the lines show the percentage of respondents who have chosen that pair.

Pedestrians' choices

The same analysis is performed for pedestrians. Overall, they show no clear preference for a single manoeuvre, except when facing (a) cyclist(s) ("I step aside") or when far away from the oncoming cyclist ("I don't do anything"). There is also no clear tendency to maintain a specific manoeuvre at all cost; it therefore seems that all manoeuvres are used by most respondents in any situation. Table 4.6 shows the cases for which each manoeuvre is the most chosen. The results correspond to intuitive expectations: accelerating is mostly used when in a rush, slowing down is mostly adopted when cyclists cross the path of pedestrians (as observed during the observation phase), etc.

Table 4.6: Attribute levels for which each pedestrian manoeuvre is the most chosen.

Manoeuvre	Mostly used when:
I accelerate	rushing to work
I slow down	bicyclist(s) biking across the pedestrian's path
I stop	bicyclist(s) close to the pedestrian
I swerve aside	bicyclist(s) biking towards the pedestrian
I don't do anything	bicyclist(s) far from pedestrian

Finally, when looking at the changes in choices given attribute level changes, one can see that the choices of the respondents show a higher dispersion for the attributes *context*, *eye contact*, and *distance*, as opposed to *direction* and *group size*. Table 4.7 summarises the influencing factors for switching from a manoeuvre to another; again, only causal links true for at least two thirds of the respondents are retained here, the relationships shown in the table can be read in both directions, and those causal relations may or may not be simultaneous.

Table 4.7: Causes of pedestrian manoeuvre changes

Manoeuvre change	Causal link	Attribute
slow down ↔ step aside	far ↔ close	<i>distance</i>
	crossing ↔ facing	<i>direction</i>
	no ↔ yes	<i>eye contact</i>
	alone ↔ shopping shopping ↔ alone alone ↔ rushing	<i>context</i>
do nothing ↔ step aside	far ↔ close	<i>distance</i>
	crossing ↔ facing	<i>direction</i>
do nothing ↔ slow down	far ↔ close	<i>distance</i>
	yes ↔ no	<i>eye contact</i>
	large ↔ small shopping ↔ alone alone ↔ shopping rushing ↔ alone	<i>group size</i>
step aside ↔ stop	yes ↔ no	<i>eye contact</i>
slow down ↔ stop	alone ↔ shopping	<i>context</i>
slow down ↔ accelerate	alone ↔ rushing shopping ↔ rushing	<i>context</i>

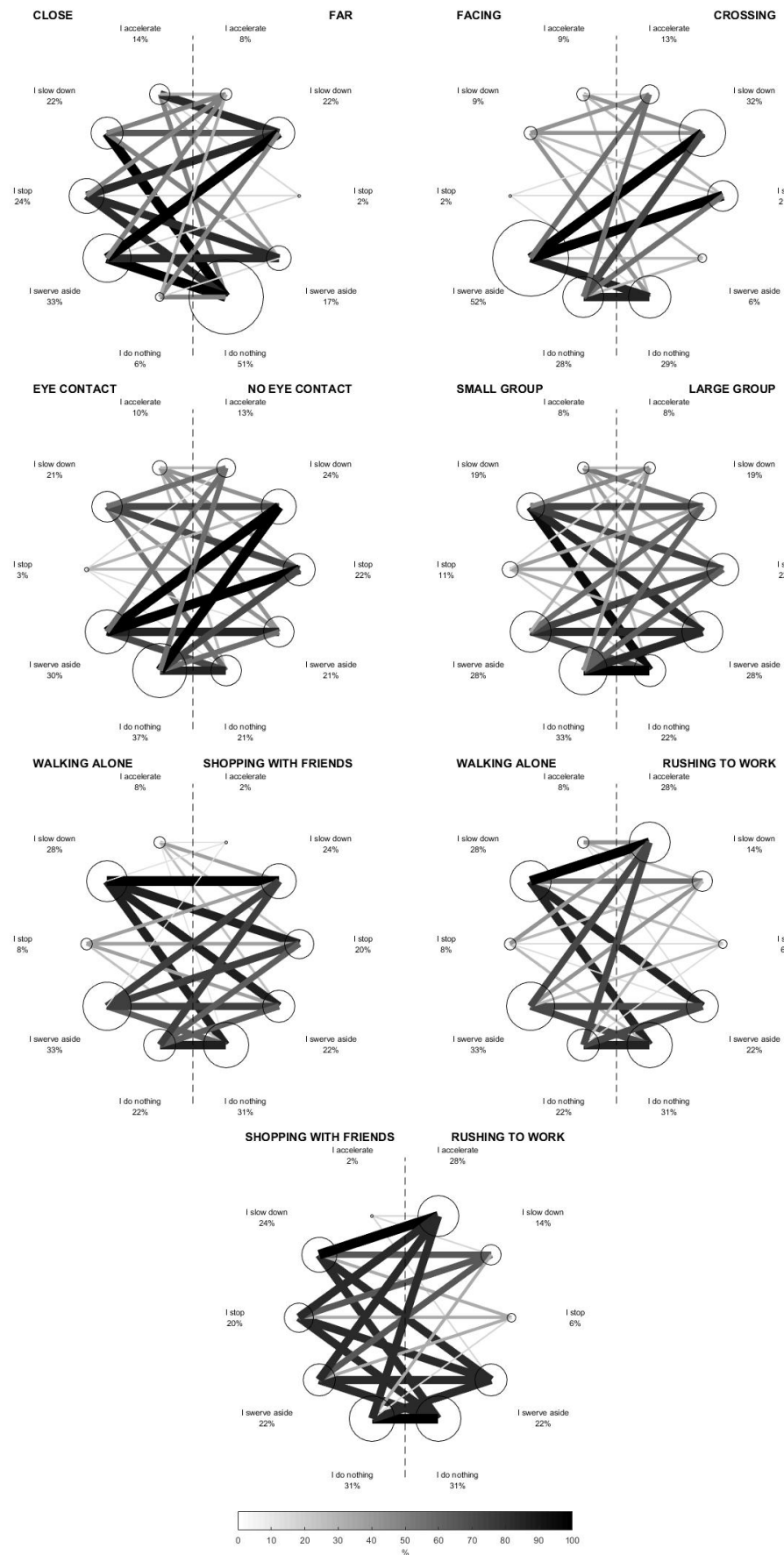


Figure 4.3: Pedestrian manoeuvres. For each attribute level, disk size shows the relative inclination towards a manoeuvre. For each manoeuvre pair, the thickness and darkness of the lines show the percentage of respondents who have chosen that pair.

Individual preferences

Every respondent has chosen a variety of manoeuvres depending on the situations presented to them. When looking at the personal characteristics of the respondents and their answers, one can observe the following (although the limited number of respondents may not yield significant correlations):

- Respondents originally from the Netherlands (2) have a more distinct preference for a certain manoeuvre (typically "I swerve aside" or "I don't do anything") than those who grew up outside the Netherlands (more dispersion).
- Female respondents (5) tend to be more cautious ("I slow down" and "I stop" selected more frequently) than male respondents.
- People with no experience biking in the Netherlands (2) make use of less manoeuvres than others.

Limitations

When analysing the pilot survey results, a couple of limitations can be formulated. First of all, the limited number of participants does not yield statistically representative or significant results, and the conclusions drawn from their analysis must therefore be carefully interpreted. Next, the survey design used is not a full factorial design, which means that the effect of changing one attribute level only cannot be isolated. At least two attributes were indeed changed for every situation in order to limit the number of questions. However, after having talked to the pilot survey respondents, it seems that the 28 questions took less than 5 minutes to answer, which means that the number of questions in the final survey could potentially be increased.

Furthermore, the images shown in the survey are not as realistic as a real conflict situation. However they do provide a strong control over the attribute levels under study, which strengthen the ability of respondents to distinguish between situations. Moreover, the images shown to the respondents were showing people of different gender and clothing style - mostly due to the difficulty of finding pedestrians and bicyclists cut outs relevant to this survey - which may have also biased the respondents' manoeuvre choices to some extent. The final survey design should therefore aim at minimising the effect of those uncontrolled variables. A choice must be made between realism of the situation and attribute control.

Finally, the list of proposed manoeuvres may not be exhaustive enough in order to allow respondents to effectively express their preferred course of action, as mentioned in the feedback section of the survey and observed in the respondents' answers - the manoeuvre changes between "swerve/step aside" and "slow down/stop" show the highest number of causal links for both modes. The proposed choices of the final survey should therefore allow respondents to freely combine speed and position changes to best describe their preference towards trajectory adjustments.

4.3.3. Improvements to the survey

Considering the analysis of the pilot survey results, as well as the feedback from the respondents, the following improvements are integrated to the final survey:

- **Attributes** The *group size* attribute is reduced to 2 levels (1 and 3 people) in order to be able to test for more combinations of attribute levels overall, and to avoid such inconsistencies as the ones found in the pilot survey answers - most probably due to the fact that it is difficult to create images that exactly depict the intended changes in attribute levels. The *context* attribute levels are also changed. Respondents indeed had trouble imagining the difference between biking alone and shopping with friends, for instance. The main reasons to this could be that both the trip purpose and the number of accompanying people are changing, and that in reality one's behaviour in such contexts are probably very similar. Hence the following levels are included in the final survey: *biking/walking*, *biking/walking with friends* (change in number of people), and *biking/walking in a rush to catch a train* (change in purpose with a clear and simple goal).
- **Task description** It is explicitly stated that collisions are imminent in all situations so as to force respondents to make a choice in order to avoid them.
- **Images** The images are constructed with cut outs of the same two people for the entire survey to minimise gender and clothing style bias in the answer. Furthermore, the distinction between the *distance* attribute levels is stressed, and the *direction* attribute level *crossing* is adjusted so that people in the images are coming from the left in order to avoid respondents thinking too much about the *priority to the right* rule.
- **Manoeuvre choice** Instead of proposing a defined set of manoeuvres to the survey respondents, respondents are now free to select both a speed and a position manoeuvre. The advantage of this formulation is twofold: (1) the potential combinations of speed and position adjustments are exhaustive while (2) being easy to imagine by the respondents, thus preventing long sentential formulations that could take time to read and understand.
- **Personal background information** More questions concerning the transport habits and traits of characters towards transportation are included in the final survey. These questions are aimed to give a portrayal of respondents so as to obtain qualitative insights on their answers. The premise of this research is indeed that pedestrians and cyclists are intelligent road users and therefore make use of their experience and skills to avoid conflicts.
- **Choice sets** The choice sets are different than those presented in the pilot survey and are explained in the section hereafter.

4.4. Final survey design

The improvements suggested by the analysis of the pilot survey results are all integrated in the final design of the survey. Because of those improvements, and because the objective

of this thesis is to assess the impact of certain attributes on collision avoidance behaviour, the choice situations presented to the respondents are updated (less attribute levels, more questions). The final survey is then distributed to collect the data needed to carry on the analysis.

4.4.1. Final choice situations

More care is taken in ensuring attribute level balance and the ability to analyse the impact of changing the level of a single attribute (as opposed to simultaneous changes in the pilot survey).

There are 4 attributes (*distance*, *direction*, *eye contact*, and *group size*) with 2 levels, and 1 attribute (*context*) with 3 levels. To design the choice situations, we are first interested in changes in the first 4 attributes only (those which the respondents can actually see in the images). A first set of questions will therefore aim at unravelling the effect of those attributes. Then, the *context* attribute is introduced in order to test its impact in combination with each of the 4 other attributes. A second set of questions is therefore prepared. The two sets of questions are finally compared to eliminate redundancies. This way, the impact of each of the 5 attributes being tested in the choice situations can be isolated during the analysis phase, and orthogonality and balance of attribute levels is maintained.

Two basic plans from [Addelman \[1962\]](#) are used successively in order to compose the final set of choice situations. The first set of questions is developed using Basic Plan 4, which gives the possibility to make pairwise comparisons between questions to identify the impact of changing a single attribute level on collision avoidance behaviour. Basic Plan 4 uses two-level attributes only and outputs 12 questions (Table 4.8). At this stage, the *context* variable does not vary and is fixed to its *biking/walking* level. The 4 other attributes are modelled using columns 01, 02, 03 and 04. Note that trials 4 and 12 are the redundant.

Table 4.8: Final choice situations (1/3): 2-level attributes variation according to Basic Plan 4

Trial	2 levels										
	0	0	0	0	0	0	0	0	0	1	1
	1	2	3	4	5	6	7	8	9	0	1
1	0	0	0	0	0	0	0	0	0	0	0
2	1	1	0	1	1	1	0	0	0	1	0
3	0	1	1	0	1	1	1	0	0	0	1
4	1	0	1	1	0	1	1	1	0	0	0
5	0	1	0	1	1	0	1	1	1	0	0
6	0	0	1	0	1	1	0	1	1	1	0
7	0	0	0	1	0	1	1	0	1	1	1
8	1	0	0	0	1	0	1	1	0	1	1
9	1	1	0	0	0	1	0	1	1	0	1
10	1	1	1	0	0	0	1	0	1	1	0
11	0	1	1	1	0	0	0	1	0	1	1
12	1	0	1	1	1	0	0	0	1	0	1

The second set of questions is developed using Basic Plan 5 (which tolerates both 3- and 2-level attributes), in which the 4 attributes previously tested (columns 04, 05, 06 and

07) and *context* (column 1*) are varied. Basic Plan 5 thus yields an extra 16 questions (Table 4.9).

Table 4.9: Final choice situations (2/3): Adding the effect of context according to Basic Plan 5

Trial	4 levels					3 levels					2 levels														
	1	2	3	4	5	1	2	3	4	5	0	0	0	0	0	0	0	0	0	1	1	1	1	1	
	*	*	*	*	*	*	*	*	*	*	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	1	1	2	3	0	1	1	2	1	0	0	0	0	1	1	0	1	1	1	0	1	1	1	0
3	0	2	2	0	1	0	2	2	1	1	0	0	0	1	0	1	1	0	1	1	1	0	0	1	1
4	0	3	3	1	2	0	1	1	1	2	0	0	0	1	1	0	1	1	0	0	1	1	1	0	1
5	1	0	1	1	1	1	1	0	1	1	1	0	1	1	0	0	0	1	1	0	1	1	0	1	1
6	1	1	0	3	2	1	1	0	1	2	0	1	1	0	1	1	0	0	0	1	1	0	1	0	1
7	1	2	3	2	0	1	1	2	1	2	0	0	1	1	1	0	1	1	1	0	1	0	1	0	0
8	1	3	2	0	3	1	1	2	0	1	0	1	1	1	1	0	1	0	1	0	0	0	1	1	0
9	2	0	2	2	2	2	0	2	2	2	1	0	1	0	0	0	1	0	1	1	0	1	1	0	1
10	2	1	3	0	1	2	1	1	0	1	1	0	1	0	1	1	1	1	0	0	0	0	1	1	1
11	2	2	0	1	3	2	2	0	1	1	1	0	1	1	0	1	0	0	0	0	1	1	1	1	0
12	2	3	1	3	0	2	1	1	1	0	1	0	1	1	1	0	0	1	1	1	1	0	0	0	0
13	3	0	3	3	3	1	0	1	1	1	1	1	0	0	0	0	1	1	0	1	1	0	1	1	0
14	3	1	2	1	0	1	1	2	1	0	1	1	1	0	0	1	1	1	0	1	0	1	1	0	0
15	3	2	1	0	2	1	2	1	0	2	1	1	1	0	1	0	1	0	1	1	0	0	0	1	0
16	3	3	0	2	1	1	1	0	2	1	1	1	1	0	1	0	0	0	0	1	0	1	0	1	1
Excluded columns	1	-	0	0	0	2	-	0	0	0	3	-	0	0	0	4	-	1	1	1	5	-	1	1	1
	*	-	1	2	3	*	-	4	5	6	*	-	7	8	9	*	-	0	1	2	*	-	3	4	5

Out of those 16 questions, we can assume that *context* level 1 corresponds to *biking/walking*, which means that these 8 trials are redundant with those produced by Basic Plan 4 (except one trial which is substituted to the redundant 4 & 12 trial pair). We are therefore left with $12 + 16 - 8 = 20$ trials, or choice situations.

All in all, for each mode, the 20 choice situations shown in Table 4.10 are presented to the respondents.

4.4.2. Distribution

The final survey, which can be found in Appendix B, was distributed via social media (Facebook, Twitter, LinkedIn), academic and professional networks (McGill University, TU Delft, Mobycon B.V.) as well as friends and family of the author, the goal being to reach a variety of people in terms of age, educational background and culture. However, it was well understood that strong biases would be nonetheless observed, for the survey is only in electronic form, and the social network of the author may be young, educated, and sharing similar interests for transportation.

Table 4.10: Final choice situations (3/3): Summary

Trial	<i>distance</i>	<i>direction</i>	<i>eye contact</i>	<i>group size</i>	<i>context</i>
1	close	facing	yes	1 person	none
2	far	crossing	yes	3 people	none
3	close	crossing	no	1 person	none
4	far	facing	no	3 people	none
5	close	crossing	yes	3 people	none
6	close	facing	no	1 person	none
7	close	facing	yes	3 people	none
8	far	facing	yes	1 person	none
9	far	crossing	yes	1 person	none
10	far	crossing	no	1 person	none
11	close	crossing	no	3 people	none
12	far	facing	no	1 person	none
13	close	facing	yes	1 person	with friends
14	close	crossing	no	1 person	with friends
15	far	facing	no	3 people	with friends
16	far	crossing	yes	3 people	with friends
17	close	facing	yes	3 people	rushing to train
18	close	crossing	no	3 people	rushing to train
19	far	facing	no	1 person	rushing to train
20	far	crossing	yes	1 person	rushing to train

5

Analysis

389 people fully completed the survey in a period of 48 days. This chapter describes the methodology and statistical tools adopted to analyse the survey results, and presents the results of the analysis in an attempt to identify those attributes that are associated with collision avoidance behaviour. The survey is analysed following three main axes:

1. Understanding the characteristics, experience, and opinion of the sample population, and the impact this may have on the results (Appendix C).
2. Identifying, if any, significant attributes affecting collision avoidance manoeuvre choice, in an attempt to model shared space behaviour.
3. Unravelling the different manoeuvres used by pedestrians and bicyclists to avoid a collision in different situations (Appendix D) to derive behavioural hypotheses.

In order to identify the extent to which the tested attributes affect collision avoidance behaviour, the survey respondents' answers must be subjected to thorough statistical analysis to first determine whether the findings can be generalised to the population (i.e. checking for fixed or within-subject effects), to then assess the impact of such attributes on collision avoidance behaviour (modelling stage).

5.1. Descriptive statistics of the sample

The full sample population descriptive statistical analysis can be found in Appendix C. Here is a summary of the main findings:

- The average respondent is 34.9 years old and 55.3% male.
- An overwhelming majority of respondents cycles or walks for main trip purposes (work/university, shopping, reaching public transit), and 55.5% of them cycle on a daily basis.

- Respondents who cycle frequently are those who learned how to ride a bicycle at a young age.
- The sample population is quite split over the question whether cyclists should be allowed in pedestrian areas (60% disagreeing or somewhat disagreeing).
- Cycling at a young age boosts self-confidence, which in turns increases the chance of cycling more frequently.
- 5.7% of female respondents have no access to a bicycle vs. 2.8% of male respondents.
- Female respondents learned how to bike later than male respondents, and they cycle less frequently than male respondents.
- Respondents are mainly from the Netherlands, France, and Canada.

5.2. Analysis methodology

There exists three types of variables, namely scale (continuous or discrete), ordinal, and nominal (a.k.a. categorical) variables. The majority of the survey variables are of nominal type, i.e. they do not present any natural order, while *age* and *age at which cycling was learned* are scale variables, and questions pertaining to statement agreement can be seen as scale or ordinal.

In view of this information, log-linear analysis is deemed the most appropriate statistical tool to assess attribute significance and impact. Log-linear analysis, according to Field [2013] is a statistical tool aimed at "analys[ing] more complex contingency tables in which there are three or more [categorical] variables."

Two major drawbacks of using log-linear analysis can however be mentioned at this point:

1. Panel effects, i.e. fixed or within-subject effects, cannot be modelled and thus cannot be tested for significance.
2. As the number of variables grows, the number of main and interaction effects to be tested for significance follows a power function of type $2^k - 1$ (Pascal triangle), e.g. with 5 variables only, 31 effects would be estimated and tested for significance (i.e. 1 5-way interaction, 5 4-way interaction, 10 3-way interaction, 10 2-way interaction, 5 one-way interaction and 1 main effects). In log-linear analysis, only the highest-order significant interaction effect must be interpreted, although the interpretation of 4-way (or more) interaction effects is typically difficult if not impossible to comprehend.

To palliate these two problems, one can (1) carry out hypothesis tests to determine the significance of panel effects and thus confirm or infirm the use of the log-linear analysis modelling technique, and (2) pre-select the entering variables of the saturated model (hence the saturated model would only consists in variables that are *believed* to play a role in determining the choice of respondents).

5.2.1. Panel effects: hypothesis testing

The objective of the hypothesis test is to determine whether panel effects significantly affect the choices made by the survey respondents. If panel effects were to exist in the dataset, this would mean that choices made by a random sample of unique respondents would not follow the same distribution as the whole population. Conversely, if panel effects were insignificant, a random sample would yield a statistically equal outcome as the whole population.

The following hypotheses are thus formulated:

H0 The panel effects are not significant (no within-subject correlation hence all choices are independent from one another).

H1 The panel effects are significant (within-subject correlation hence choices of each respondent are correlated).

A t-test is used to accept or reject the null hypothesis by determining whether the mean choice behaviour of a sample of unique respondents is statistically different from that of the whole population. To that end, a sample is composed by a random selection of choices for each of the 20 questions for each transport mode (pedestrian and cyclist) while ensuring that each randomly sampled choice is made by a unique respondent (i.e. sampling respondents without replacement). Several samples must be created in that way in order to approach an assumed normal population distribution for the t-test. The minimum number of samples to be created is calculated as follows:

$$n = \left(\frac{Z_{\alpha/2}}{2e} \right)^2 \quad (5.1)$$

where:

$Z_{\alpha/2}$ is the standard score given a confidence level α

e is the random sampling error

5.2.2. Saturated model: entering variables pre-selection

Since mostly nominal variables are used in the survey, choice behaviour is defined here as the degree of association between those variables and the choices made by the respondents.

Cramer's V measure of nominal association is therefore used to represent the degree of association between the survey variables and the respondents' choices. Cramer's V is a χ^2 -based measure that is applicable to nominal variables consisting of more than 2 levels (as opposed to the ϕ measure). Cramer's V also corrects the χ^2 value for sample size and degree of freedom, thus norming the statistics to allow comparison of degree of association with respect to other variables. It is calculated as follows:

$$V = \sqrt{\frac{\chi^2}{n \times \min(r-1, c-1)}} \quad (5.2)$$

where:

χ^2 is the Pearson's chi-squared test statistic

n is the sample size

r is the number of levels of the survey variable being tested

c is the number of levels of the choice variable being tested

A Cramer's V measure of association can therefore be computed for each of the survey variables with respect to the respondents' choices. Based on the magnitude of the Cramer's V values, one can select entering variables for a saturated log-linear model. There exists several Cramer's V interpretation scales, with varying degrees of precision. For this research, the scale presented Table 5.1 is used.

Table 5.1: Measure of association interpretation scale

Cramer's V	Effect size
0.0 - 0.2	very small
0.2 - 0.4	small
0.4 - 0.6	moderate
0.6 - 0.8	strong
0.8 - 1.0	very strong

5.2.3. Process and tools

Both hypothesis testing and entering variable pre-selection tasks can be performed at once. For instance, one can draw a series of random samples from the respondents, compute Cramer's V measures of association for each of the survey variables with respect to position and speed choices (hence looking for meaningful entering variables), and compare, for each variable, the mean Cramer's V over the samples to that of the population to assess the significance of panel effects (hypothesis testing).

To create the random samples, the stratified random sampling process shown in Figure 5.1 is used for each mode in IBM SPSS Statistics 24.

For each mode, the samples thus created are exported to MATLAB.

In MATLAB, for each sample, χ^2 statistics – using the *Statistics and Machine Learning Toolbox* – and Cramer's V measures of effectiveness are computed for each survey variable with respect to position and speed choice. The same analysis is performed over the entire

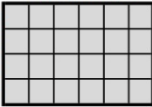
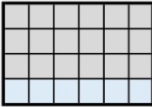
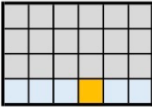
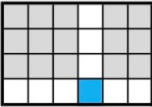
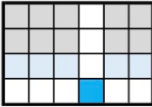
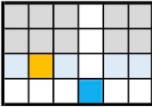
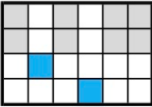
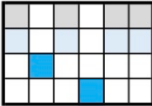
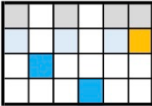
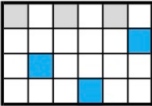
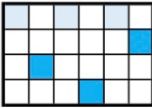
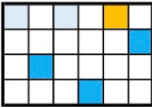
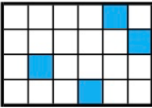
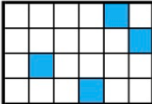
ITERATION	PROCESS	DESCRIPTION
START	<div style="display: flex; align-items: center;"> <div style="writing-mode: vertical-rl; transform: rotate(180deg); font-weight: bold; margin-right: 5px;">QUESTIONS</div> <div style="border: 1px solid black; padding: 5px; text-align: center;"> RESPONDENTS  </div> </div>	Population
1	<div style="display: flex; justify-content: space-around;">    </div>	Respondent 4's answer to Question 1 is selected and Respondent 4 is removed from the pool.
2	<div style="display: flex; justify-content: space-around;">    </div>	Respondent 2's answer to Question 2 is selected and Respondent 2 is removed from the pool.
3	<div style="display: flex; justify-content: space-around;">    </div>	Respondent 6's answer to Question 3 is selected and Respondent 6 is removed from the pool.
4	<div style="display: flex; justify-content: space-around;">    </div>	Respondent 5's answer to Question 4 is selected and Respondent 5 is removed from the pool.
END	<div style="display: flex; align-items: center;"> <div style="writing-mode: vertical-rl; transform: rotate(180deg); font-weight: bold; margin-right: 5px;">QUESTIONS</div> <div style="border: 1px solid black; padding: 5px; text-align: center;"> SAMPLE  </div> </div>	Sample

Figure 5.1: Process to create a sample of answers without respondent replacement (hypothetical dataset). Grey: remaining pool of answers to sample from; light blue: current question for which a randomly sampled answer must be selected; white: discarded answers to sample from; yellow: randomly selected answer for the current question; dark blue: answer(s) already sampled in previous questions.

population (hence assuming no panel effects). Since the Cramer's V measures are direct indications of the impact of each variable taken independently onto the respondent's position and speed choices, one can select the entering variables of the saturated model for the log-linear analysis by selecting those variables with the highest Cramer's V.

Finally, hypothesis testing is used to assess whether the samples (controlled for panel effects) behave statistically equally to the population (with no assumed panel effects at this stage). The Cramer's V measures are therefore averaged for each variable over all samples, and compared to the corresponding population variable's Cramer's V. If the average sample behaviour is significantly different than that of the population, panel effects are at play and no general model can be estimated. This process is illustrated in figure 5.2.

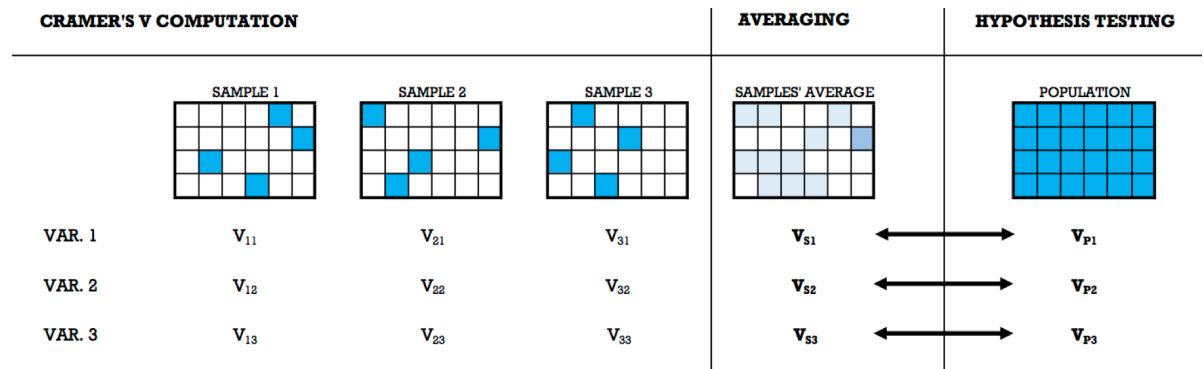


Figure 5.2: Process to determine the existence of panel effects.

5.3. Results

Using a 95% confidence interval and assuming a 5% maximum random sampling error, a minimum of 385 samples (yielding 1 answer for each of the 40 questions every time) must be drawn in order to approach the population's distribution. In total, 389 samples were randomly drawn from the population so as to exactly match the number of observations in the population.

5.3.1. Measure of association

For each mode and for each survey variable, Cramer's V measures are computed with respect to the position and speed choices of respondents. As mentioned earlier, a Cramer's V value close to 1 indicates a strong degree of association between the given attribute and the respondents' choices.

Figures 5.3 through 5.6 display the probability distribution of the Cramer's V measures over all the samples (each point corresponds to one of the 389 samples), and compares it to the normal distribution (dotted lines). For clarity and to ease the interpretation, the attributes are split in 4 categories: conflict scenario attributes (the choice situations), personal characteristics attributes, personal experience and habits attributes, and character and opinion attributes. One can observe three phenomena on those graphs:

1. How probable it is that an attribute is strongly associated with position and speed choices (e.g. "there is a 50% chance that attribute X is strongly associated – i.e. Cramer's V above 0.6 – with choice Y").
2. How close the probability distribution resembles that of a normal distribution (i.e. how closely the 389 samples distribution matches the normal line).
3. How important the variance in the degree of association is (e.g. a mild slope indicates a high variance)

Several key observations can be made from figures 5.3 through 5.6:

Cyclists' position choice

- There is a 50% chance that the *distance* and *direction* attributes are moderately associated (Cramer's V above 0.4) with position choice across the samples.
- There is a 50% chance that the *age* attribute is moderately associated (Cramer's V above 0.4) with position choice across the samples.
- The variance in the degree of association probability of the *distance* and *direction* attributes is more important than for other conflict scenario attributes.

Pedestrians' position choice

- There is about a 50% chance that the *direction* attribute is strongly associated (Cramer's V above 0.6) with position choice across the samples, hence more than for cyclists, however distance does not seem to be as associated with position choice than for cyclists.
- The *context* attribute is consistently less associated to position choice than any other conflict situation attribute (its variance is less important).
- There is at least a 50% chance that the *age* attribute is moderately associated (Cramer's V above 0.4) with position choice across the samples.
- *Fearing cyclists* does not seem to be more associated with position choice than other opinion statements.
- There is a 50% chance that *cycling frequency* is moderately associated (Cramer's V above 0.4) with position choice, more than for cyclists' position choice.

Cyclists' speed choice

- There is a 50% chance that the *distance* and *context* attributes are moderately associated (Cramer's V above 0.4) with speed choice across the samples. This makes sense if, for example, we consider that the *rushing to train* level of the *context* attribute is a disincentive to slow down. The *direction* attribute is less associated with speed choice (25% chance of Cramer's V above 0.4) than with position choice (50% chance of Cramer's V above 0.4)
- There is at least a 50% chance that the *age* attribute is moderately associated (Cramer's V above 0.4) with speed choice across the samples.
- There is at least a 50% chance that *cycling frequency* is moderately associated (Cramer's V above 0.4) with speed choice.

Pedestrians' speed choice

- There is about a 50% chance that the *distance*, *direction* and *context* attributes are moderately associated (Cramer's V above 0.4) with speed choice across the samples.
- There is at least a 50% chance that the *age* attribute is moderately associated (Cramer's V above 0.4) with speed choice across the samples.

- The variance in the degree of association probability of the *age* attribute is more important than for other personal characteristics attributes.
- There is at least a 50% chance that *cycling frequency* is moderately associated (Cramer's V above 0.4) with speed choice, more than for cyclists' speed choice.
- There is at least a 50% chance that the respondents' main mode of transportation to work/school, for shopping, or to reach public transportation is moderately associated (Cramer's V above 0.4) with speed choice.

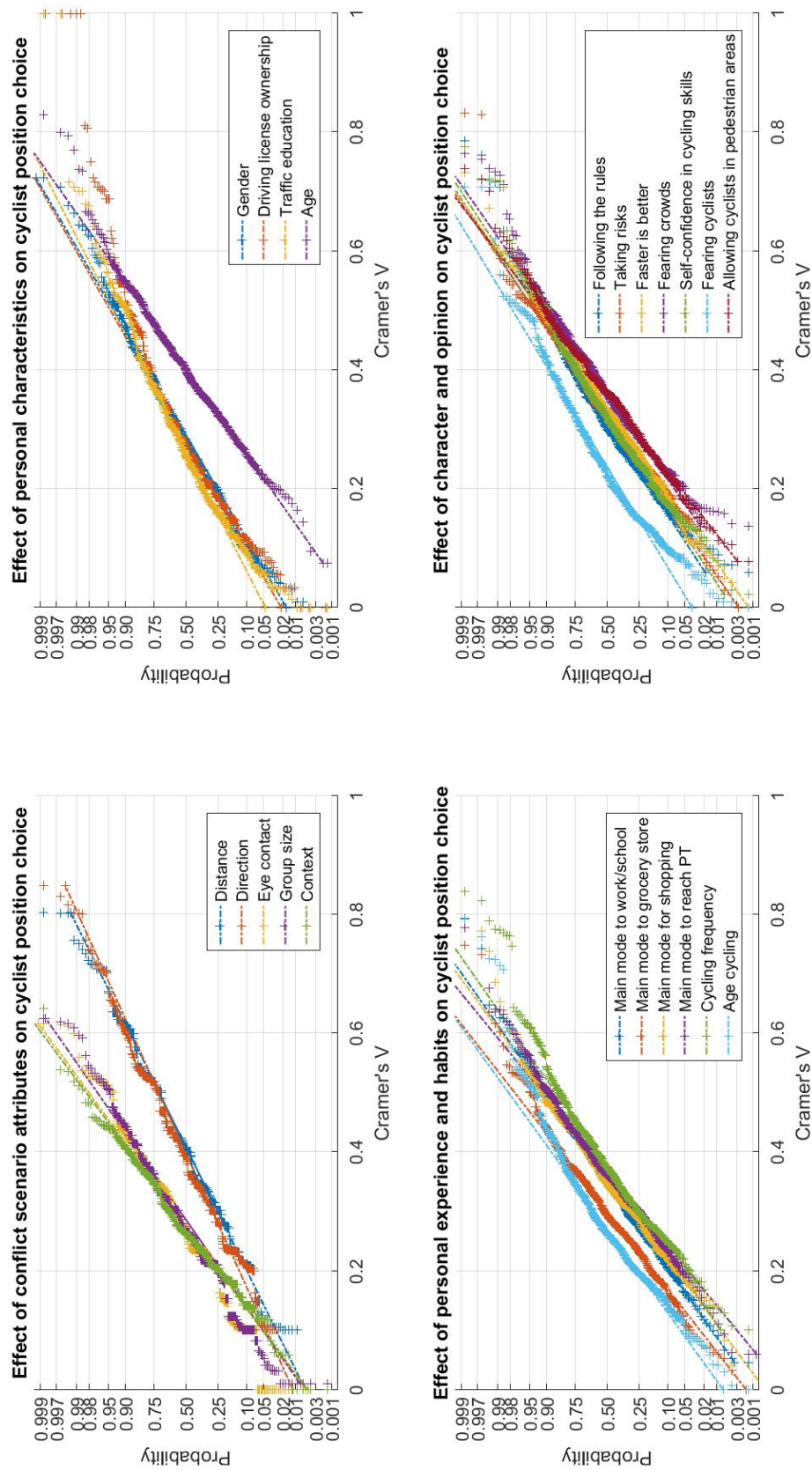


Figure 5.3: Attributes' degree of association to cyclists' position choice

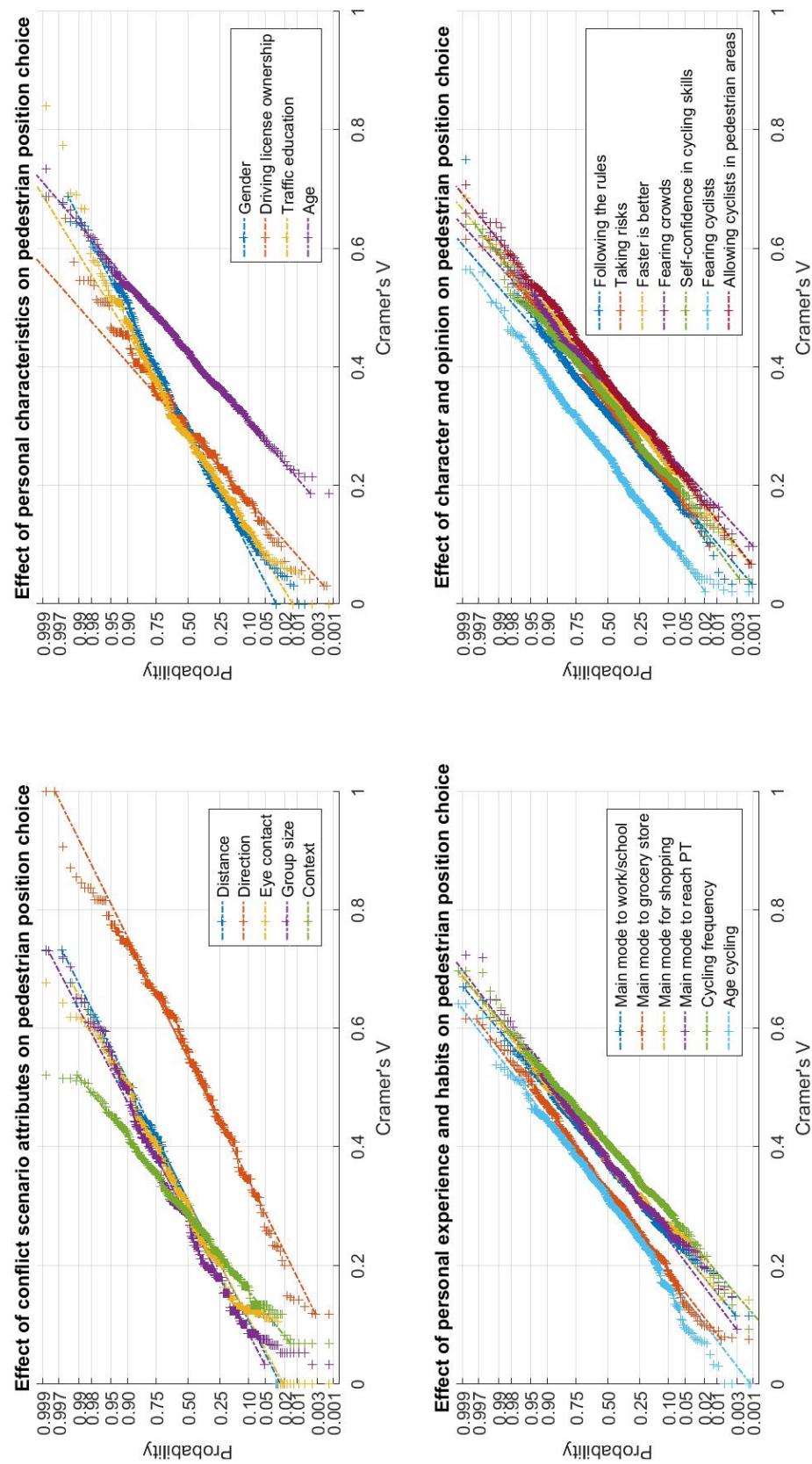


Figure 5.4: Attributes' degree of association to pedestrians' position choice

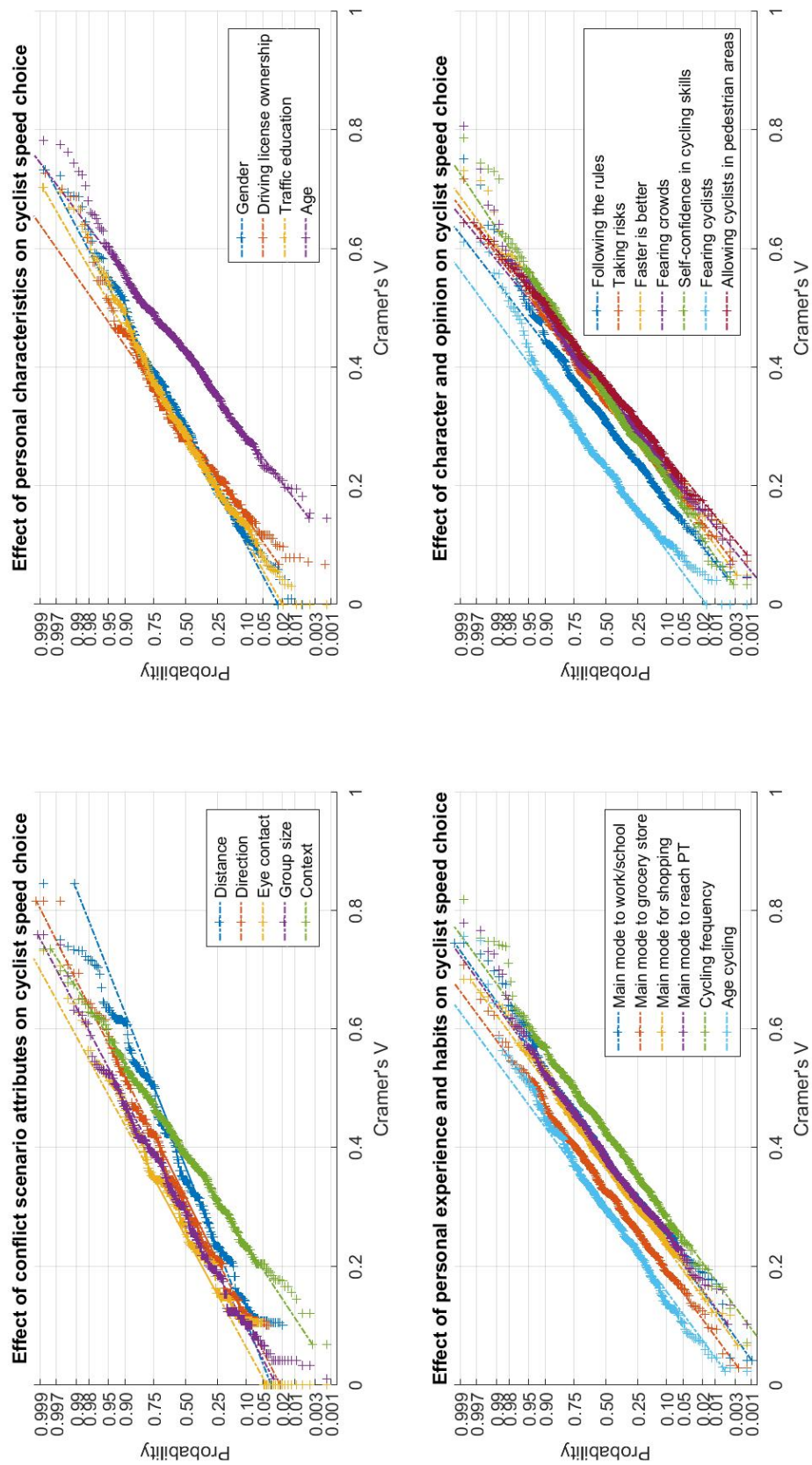


Figure 5.5: Attributes' degree of association to cyclists' speed choice

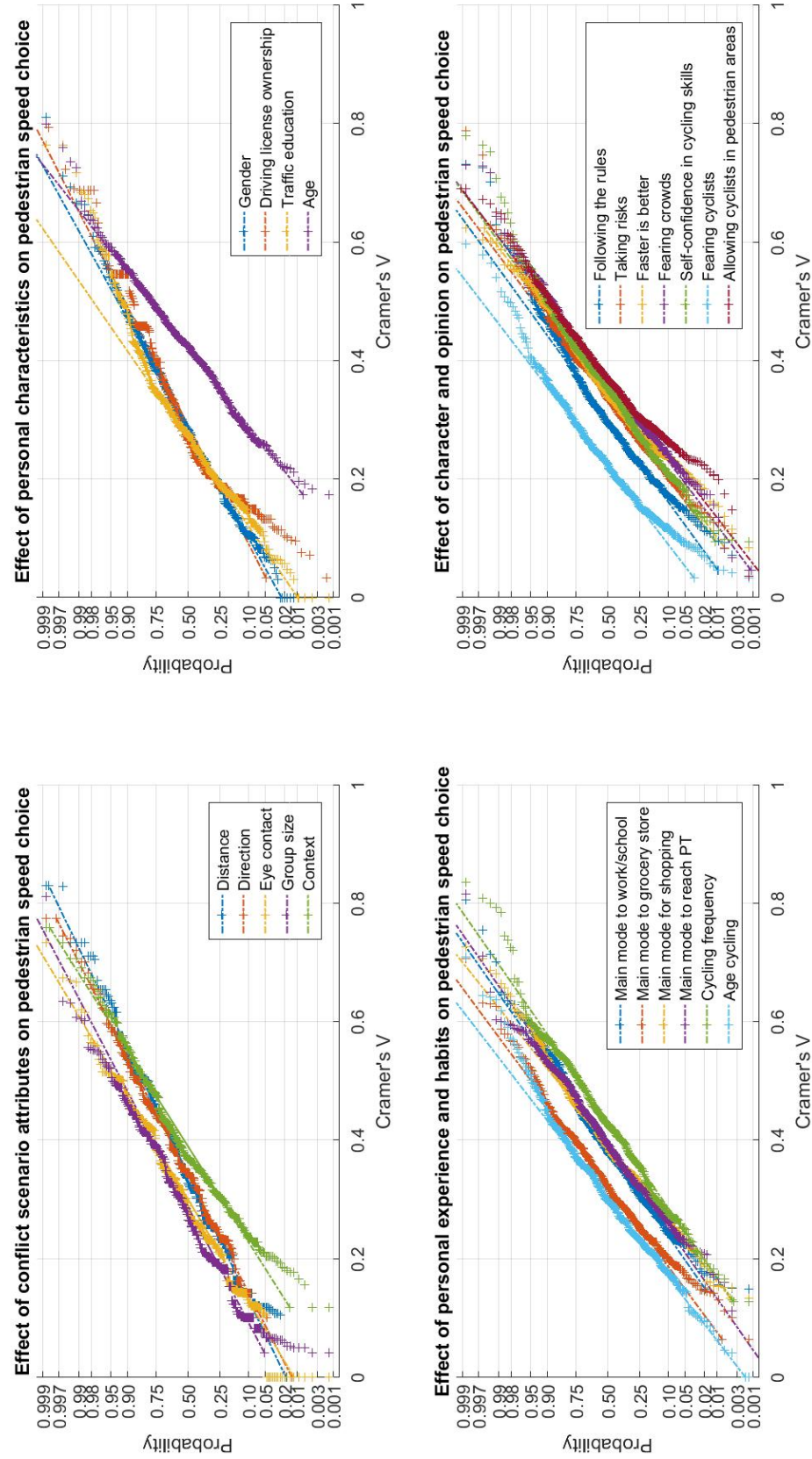


Figure 5.6: Attributes' degree of association to pedestrians' speed choice

5.3.2. Generalisation of the findings

Although some attributes were found to be moderately to strongly associated with position and speed choices of pedestrians (more specifically: *distance*, *direction*, *age*, *context*, *cycling frequency*), it was also observed that the variance in the degree of association is quite important, which means that depending on the sample, the degree of association of those attributes with position and speed choices can be much lower or much higher. This would indicate that one may not be able to generalise the findings presented in the subsection above to the overall population of respondents. This would signify that panel effects, or within-subject effects, are significant.

Population and sample distributions and means

To explore this last assertion, histograms are built to gain insight on the shape of the distribution of the respondents' sensitivity to each variable (Cramer's V). To that end, the Freedman-Diaconis rule is used to calculate the histogram bin width for each variable. The resulting number of bins is set to:

$$b = \frac{\max - \min}{2 \times IQR \times n^{-1/3}} \quad (5.3)$$

where:

\max is the maximum value in the dataset

\min is the minimum value in the dataset

IQR is the inter-quartile range of the dataset

n is the number of observations

Figures 5.7 through 5.10 show the resulting histograms. In each histogram, the red and green vertical lines represent population mean and combined-samples mean, respectively. If the distribution approaches the normal distribution, and if the means are relatively close, this indicates that one may be able to generalise the findings to the population, and vice versa.

The first observation that can be made from figures 5.7 through 5.10 is the notable discrepancy between population (red line) and combined-samples (green) means across all attributes, with the exception of *distance*, *direction* (for both position and speed choices), and *context* (for speed choices only), suggesting panel effects may be significant.

Moreover, one can effectively see that most distributions approach a normal distribution, although at times positively skewed (which can also be observed, although less obvious, as the departures from the dotted normal lines in figures 5.3 through 5.6). This means that a t-test is well suited to run hypothesis testing to assess panel effects significance, since this type of tests assumes a normal distribution.

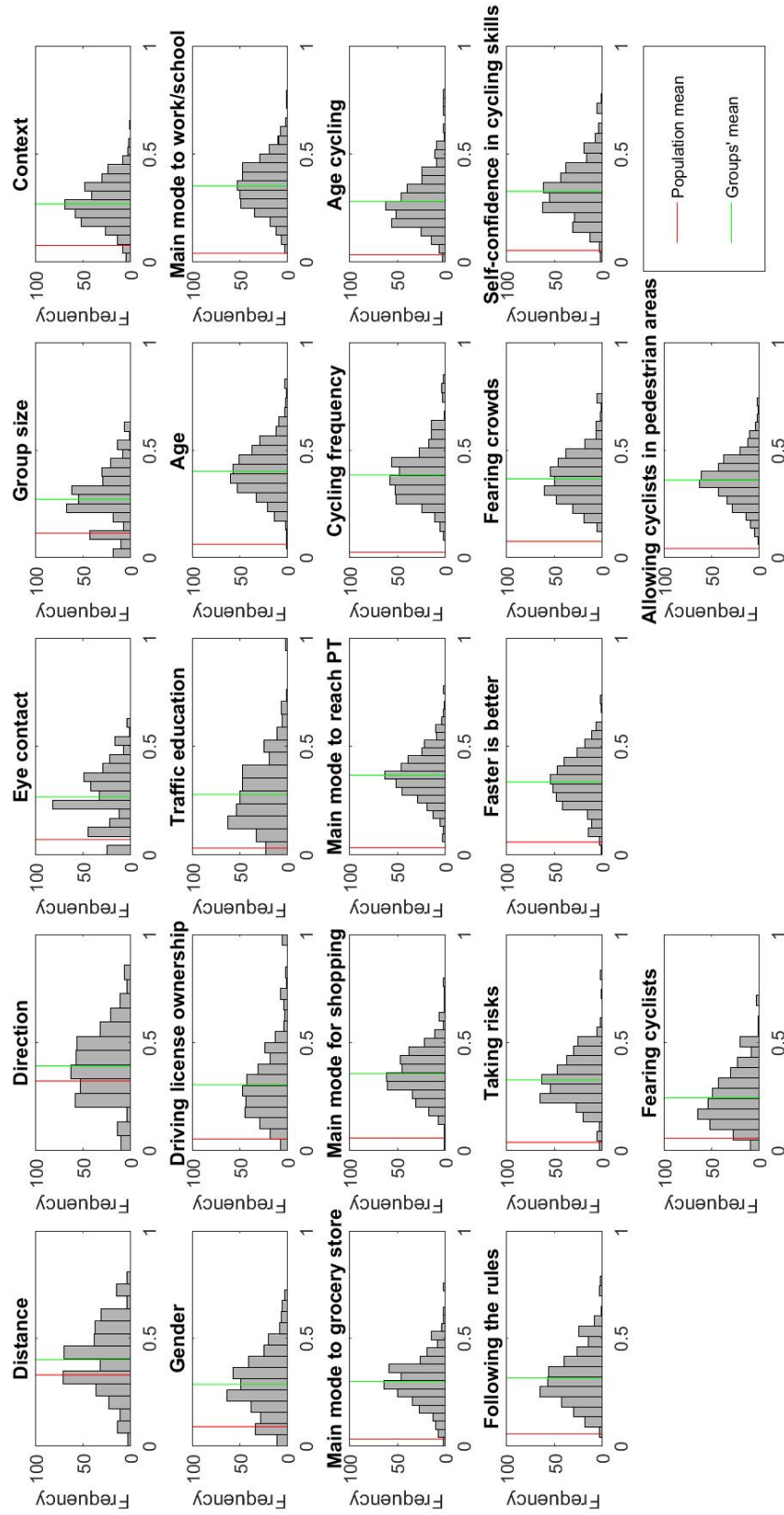


Figure 5.7: Attribute degree of association population and sample distribution and mean with respect to cyclists' position choice

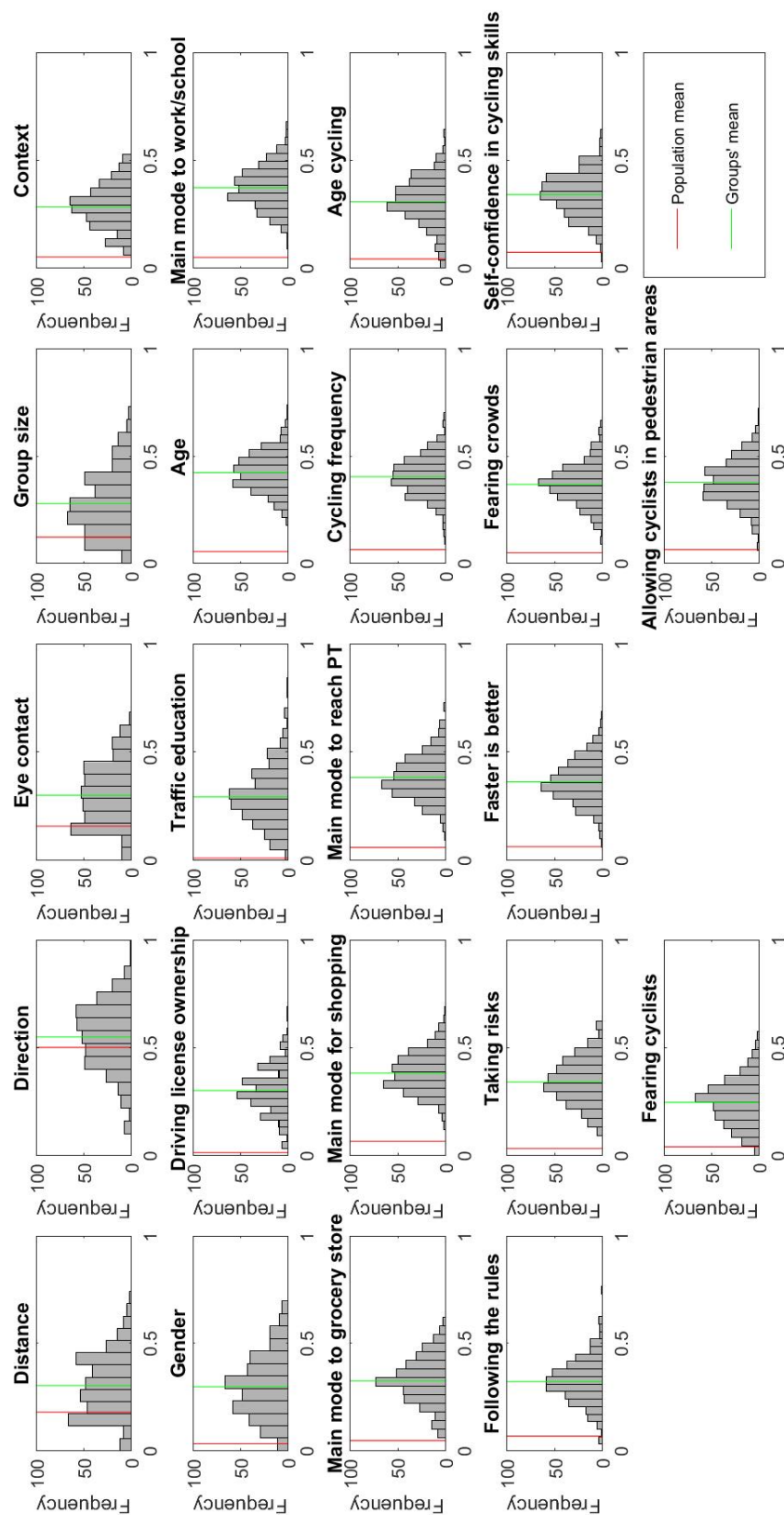


Figure 5.8: Attribute degree of association population and sample distribution and mean with respect to pedestrians' position choice

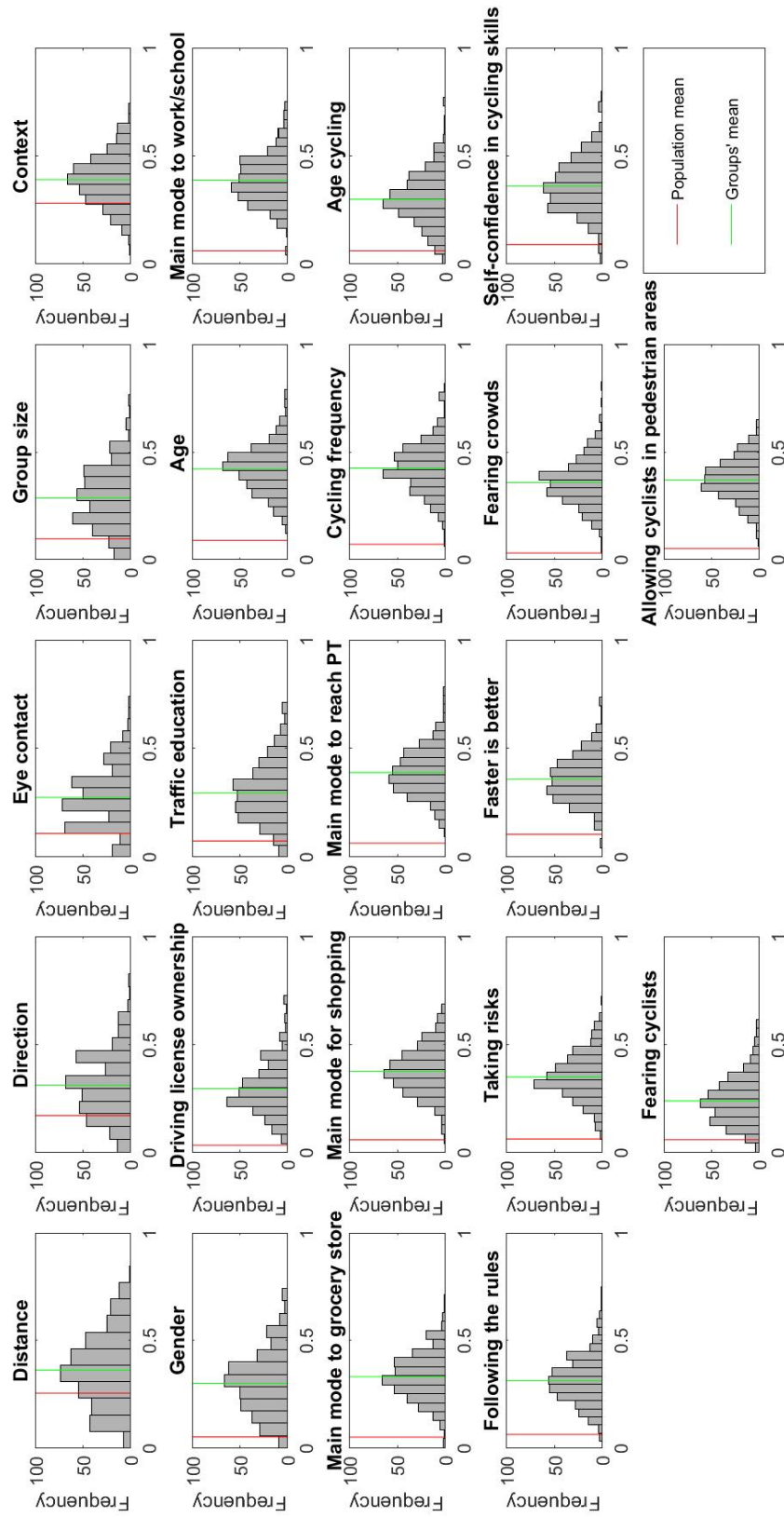


Figure 5.9: Attribute degree of association population and sample distribution and mean with respect to cyclists' speed choice

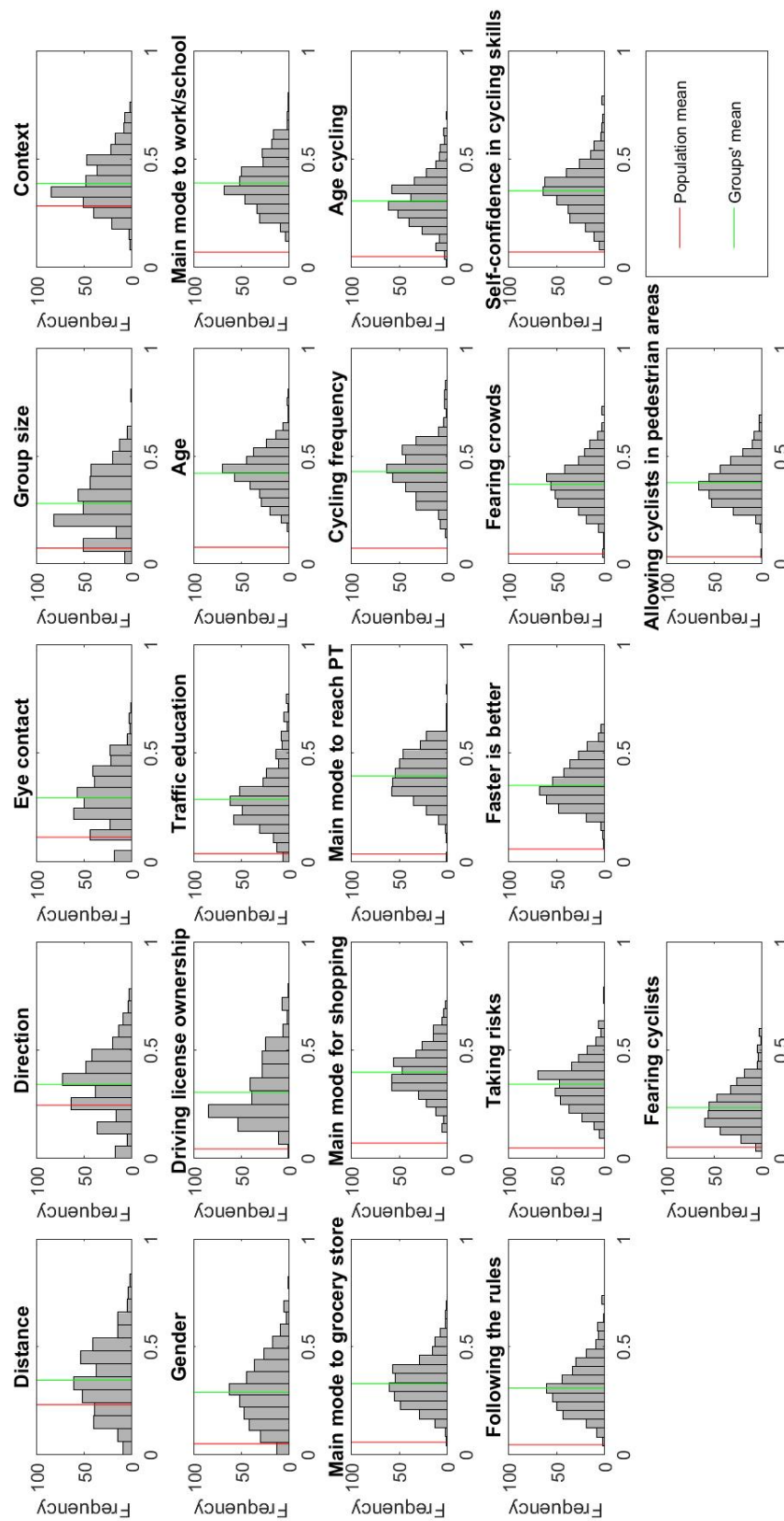


Figure 5.10: Attribute degree of association population and sample distribution and mean with respect to pedestrians' speed choices

Hypothesis testing

T-tests are carried out to assess panel effects for each attribute with respect to each mode's position and speed choices. This is done by comparing the samples' mean Cramer's V measures to those of the population. In total, 88 t-tests were performed (4 choices × 22 attributes).

The test rejected the null hypothesis (i.e. "The panel effects are not significant (no within-subject correlation hence all choices are independent from one another)") in all 88 cases, at both 95% and 90% levels. P-values were close to 0, meaning that panel effects are statistically significant.

5.4. Collision avoidance manoeuvres

Although no attribute was found to be statistically significantly correlated to cyclists and pedestrians' position and speed choices through the survey, it is worth delving more into those that were found to have a strong association with the respondents' choices and whose population and sample means were relatively close (*distance* and *direction*) to better understand the impact of attribute level on collision avoidance manoeuvring. Furthermore, similar in-depth analysis can be carried out for those attributes whose impact in the survey strongly differed from the field observations (*eye contact* and *group size*).

5.4.1. Distance

It was found earlier that the *distance* attribute is highly associated to the position choices of cyclists and pedestrians. Figures 5.11 and 5.12 show how a change in the *distance* attribute level (*close* vs. *far*, i.e. the conflict being imminent or latent) affects respondents' position choices given their travel mode.

The impact of the *distance* attribute on position choices can be summarised as follows:

- No matter the conflict point distance, cyclists almost always choose not to go straight (in 95.6% and 90.4% of the *close* and *far* cases, respectively), confirming the field observation that cyclists prioritise position change over speed change to keep their momentum.
- Cyclists seem to anticipate – and therefore avoid – conflicts more often than pedestrians, since 90.4% of them make a position change when the conflict is far, as opposed to 58% of pedestrians in the same situation.
- It is also interesting to see that as the conflict gets closer, the common traffic rule of passing oncoming traffic to the right is applied by a majority of cyclists (56% of them choose to go right in that case), whereas pedestrians tend to have no clear rule: 33% choose to go right, 46% choose to go left.

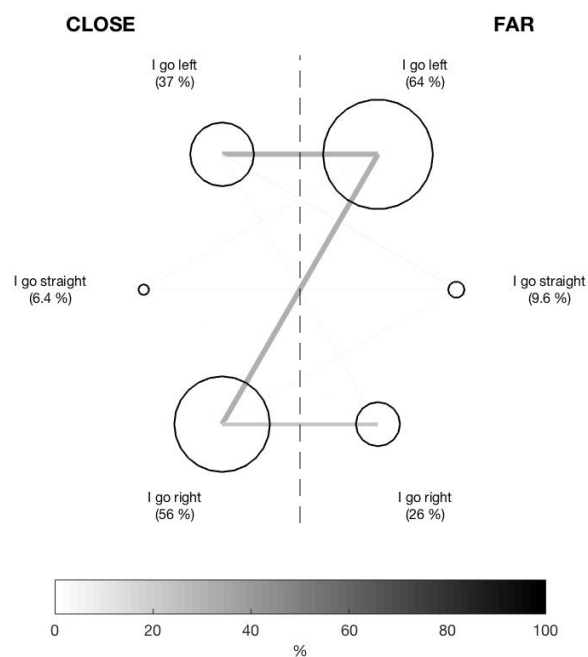


Figure 5.11: Cyclists' position choices and their changes with respect to conflict distance (n=1556)

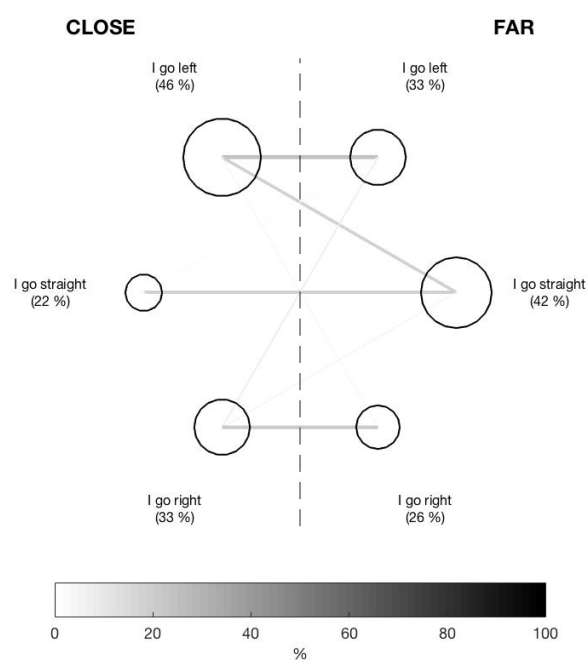


Figure 5.12: Pedestrians' position choices and their changes with respect to conflict distance (n=1556)

It was also found that the *distance* attribute is consistently associated to the speed choices of both cyclists and pedestrians in all scenarios. Figures 5.13 and 5.14 show how a change in the *distance* attribute level (*close* vs. *far*, i.e. the conflict being imminent or latent) affects respondents' speed choices given their travel mode.

The impact of the *distance* attribute on speed choices can be summarised as follows:

- Both cyclists and pedestrians seem not to alter their speed when a conflict is located far enough from them – 62% and 78% of cyclists and pedestrians, respectively, choose to maintain their current speed in that case
- Both cyclists and pedestrians tend to slow down when the conflict becomes imminent (*close*), although cyclists seem to be the ones making the most cautious effort to avoid the conflict – 56% of cyclists choose to slow down in that case, whereas the majority of pedestrians (55%) keep their current speed.
- Cautious behaviour amongst cyclists seems to be an inherent constant for 25% of them (slowing down no matter the conflict's distance).

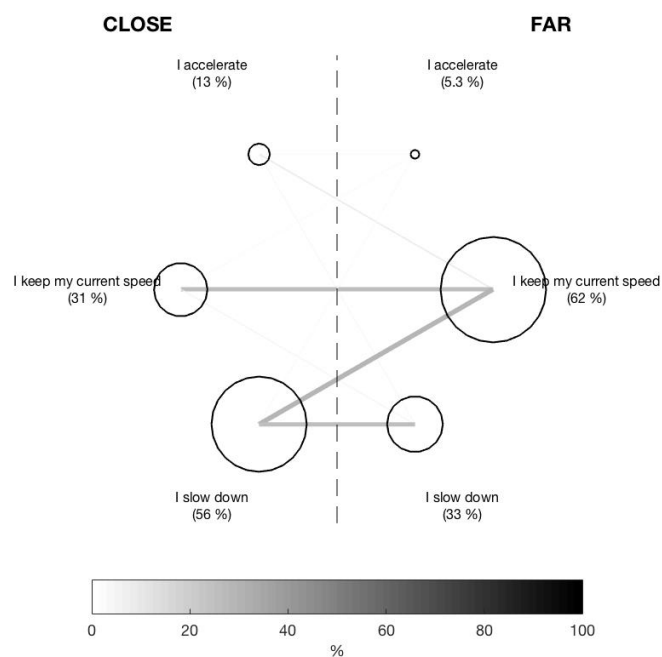


Figure 5.13: Cyclists' speed choices and their changes with respect to conflict distance (n=1556)

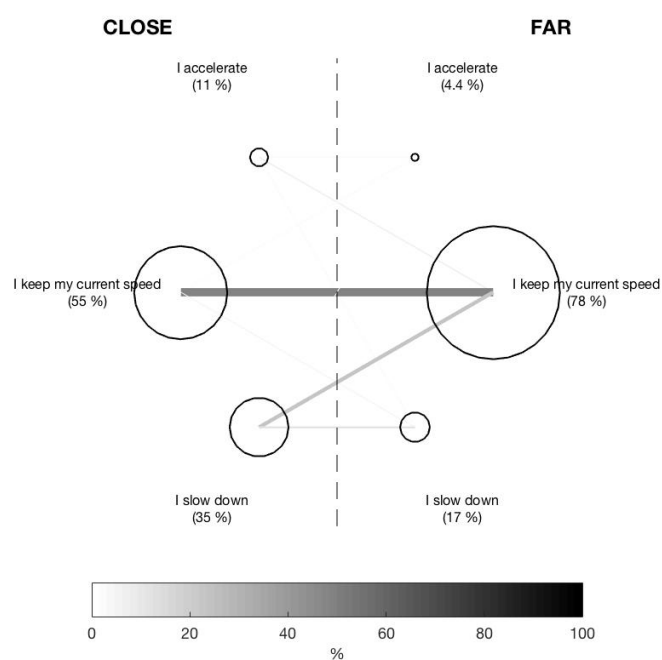


Figure 5.14: Pedestrians' speed choices and their changes with respect to conflict distance (n=1556)

5.4.2. Direction

While conflict *distance* seems to be mostly associated with speed choice for both modes, *direction* seems to primarily influence position choice. Figures 5.15 and 5.16 show how a change in the *direction* attribute level (*facing* vs. *crossing*) affects respondents' position choices given their travel mode.

The impact of the *direction* attribute on position choices can be summarised as follows:

- As a general rule, both cyclists and pedestrians seem to clearly apply the common traffic rule of passing opposing, *facing* traffic to the right (60% and 49%, respectively).
- Pedestrians seem to leave the task of avoiding more complex conflicts – i.e. a conflict where the trajectories are *crossing* – to cyclists: in those cases, 87% of cyclists make a position change, while the majority of pedestrians (51%) choose to keep a straight trajectory.

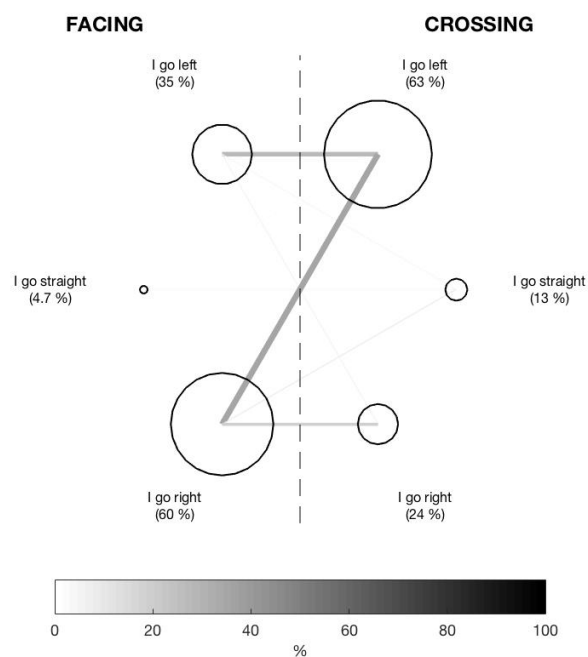


Figure 5.15: Cyclists' position choices and their changes with respect to conflict direction (n=1556)

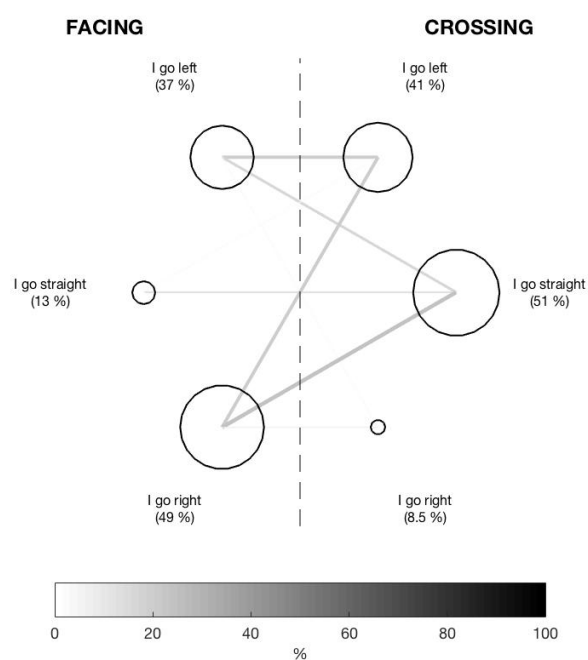


Figure 5.16: Pedestrians' position choices and their changes with respect to conflict direction (n=1556)

This last observation is confirmed when looking at the cyclists and pedestrians' speed choices with respect to a change in conflict *direction* in greater detail (Figures 5.17 and 5.18.

One can effectively see that:

- Cyclists carry more of the conflict avoidance task burden than pedestrians: they choose to lose their momentum in 48% of conflicts with crossing trajectories, as opposed to pedestrians, who simply maintain their speed no matter the conflict's direction.

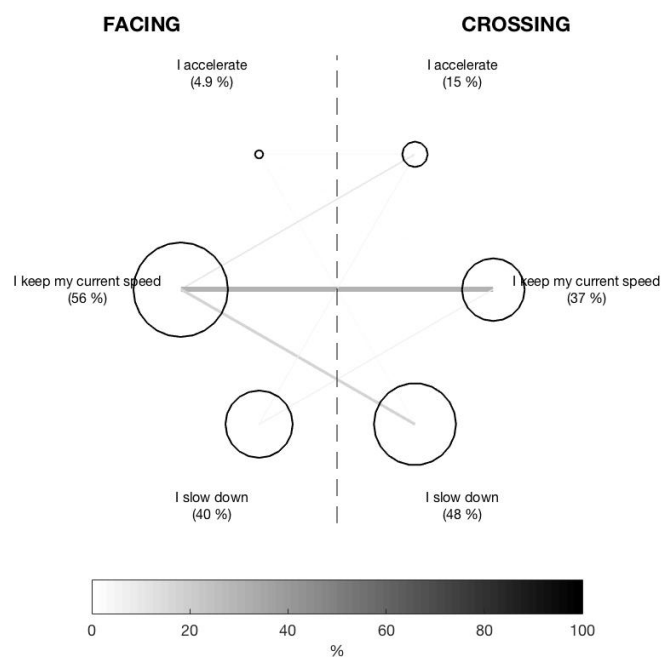


Figure 5.17: Cyclists' speed choices and their changes with respect to conflict direction (n=1556)

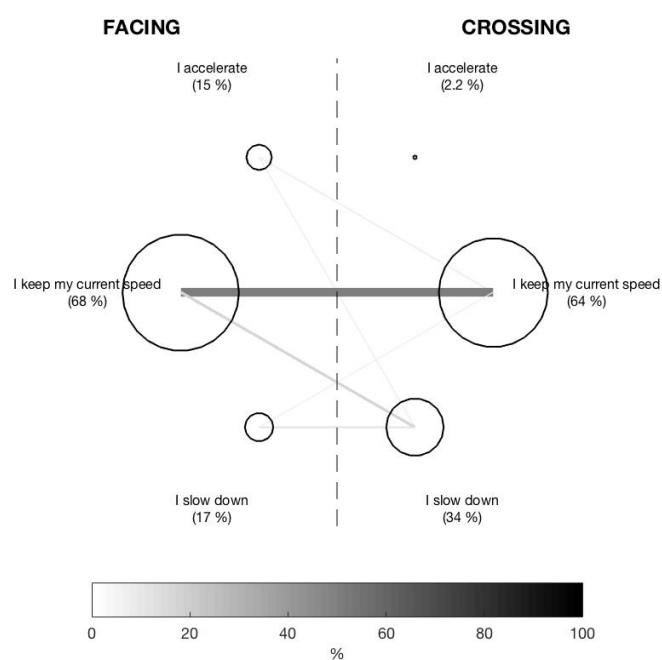


Figure 5.18: Pedestrians' speed choices and their changes with respect to conflict direction (n=1556)

5.4.3. Eye contact and group size

When observing and interviewing cyclists and pedestrians in the field, it was found that eye contact and group size had strong effects on conflict avoidance behaviour, mostly with respect to speed (section 4.2). However, the online survey did not seem to capture those real-world observations in an effective way, as can be seen in Figures 5.19, 5.20, 5.21, 5.22, 5.23, 5.24, 5.25 and 5.26: note the similar proportions of each possible choice for either attribute levels, and the lack of choice changes between such levels (as seen with the "horizontal connectors" throughout all the figures).

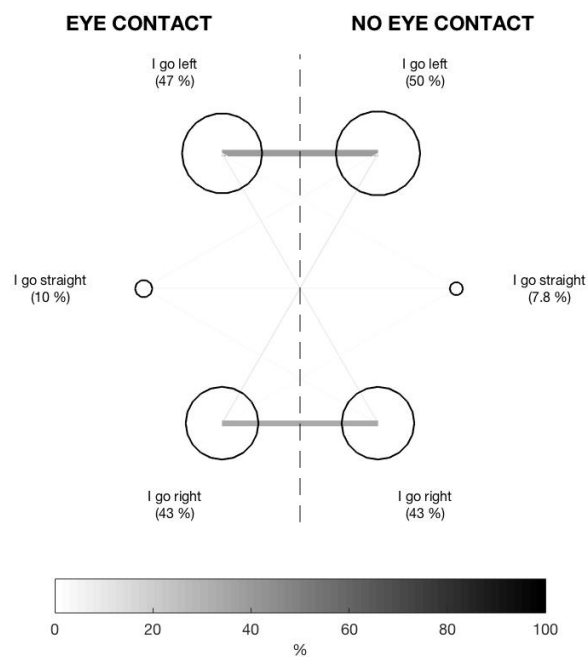


Figure 5.19: Cyclists' position choices and their changes with respect to the presence of eye contact (n=1556)

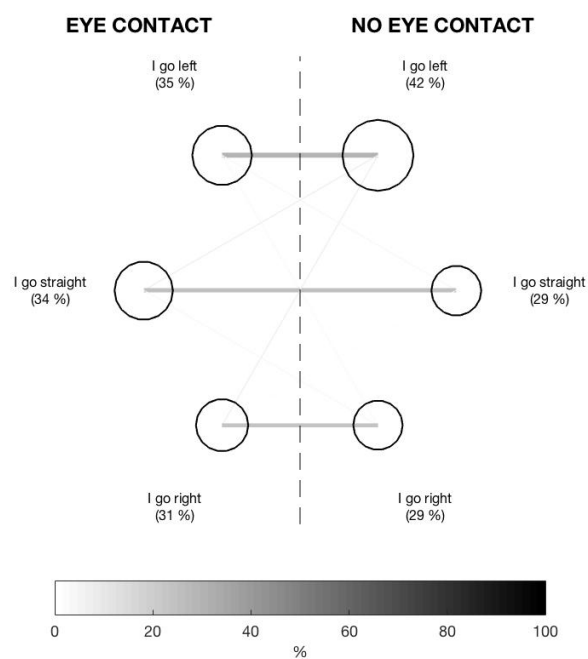


Figure 5.20: Pedestrians' position choices and their changes with respect to the presence of eye contact (n=1556)

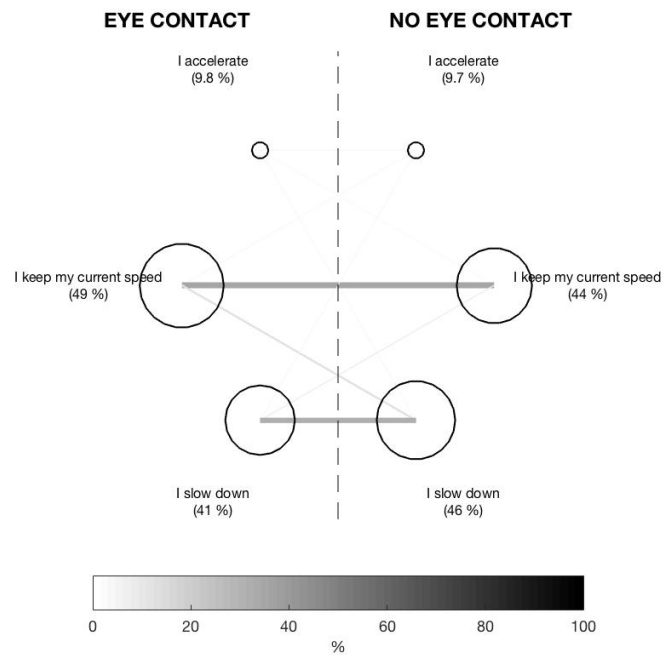


Figure 5.21: Cyclists' speed choices and their changes with respect to the presence of eye contact (n=1556)

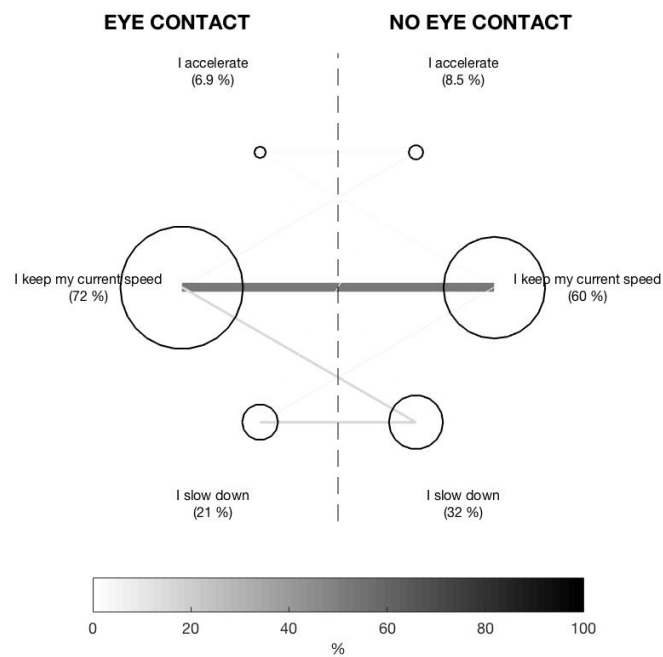


Figure 5.22: Pedestrians' speed choices and their changes with respect to the presence of eye contact (n=1556)

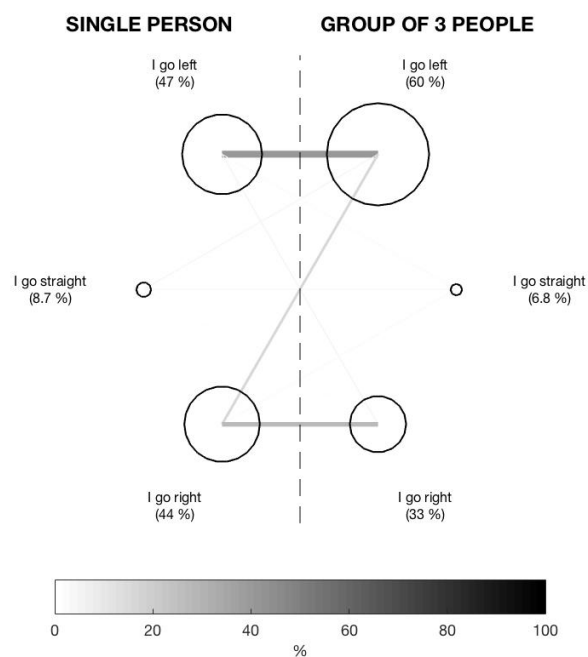


Figure 5.23: Cyclists' position choices and their changes with respect to conflicting group size (n=1556)

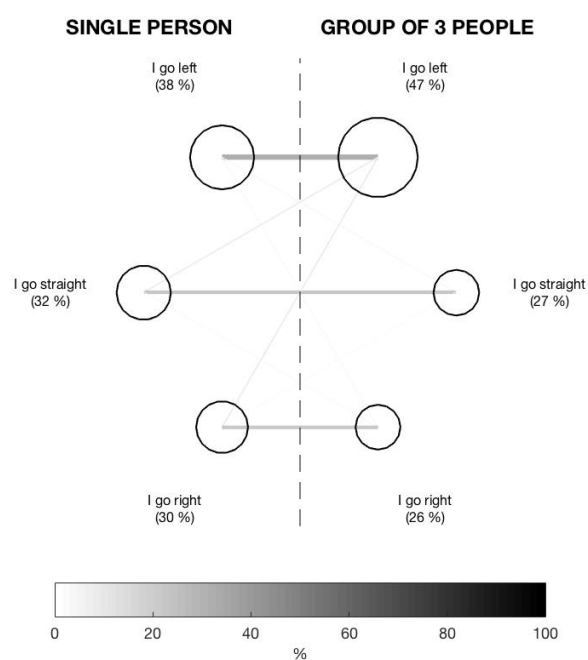


Figure 5.24: Pedestrians' position choices and their changes with respect to conflicting group size (n=1556)

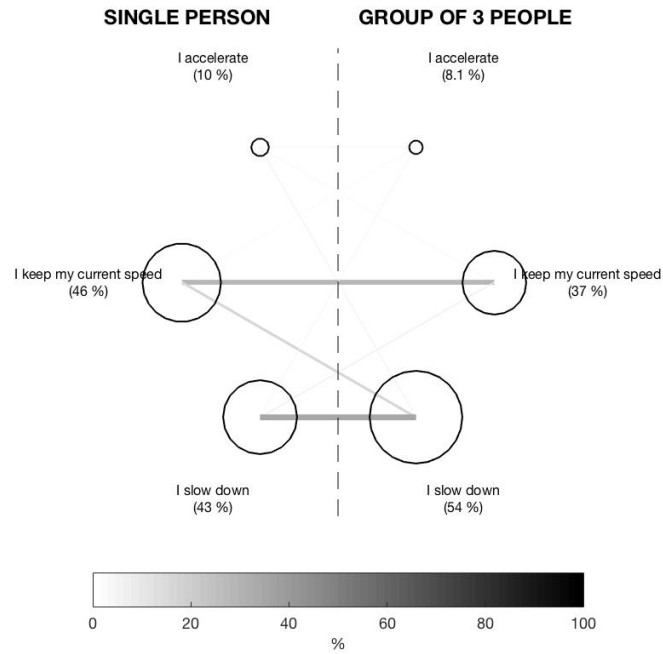


Figure 5.25: Cyclists' speed choices and their changes with respect to conflicting group size (n=1556)

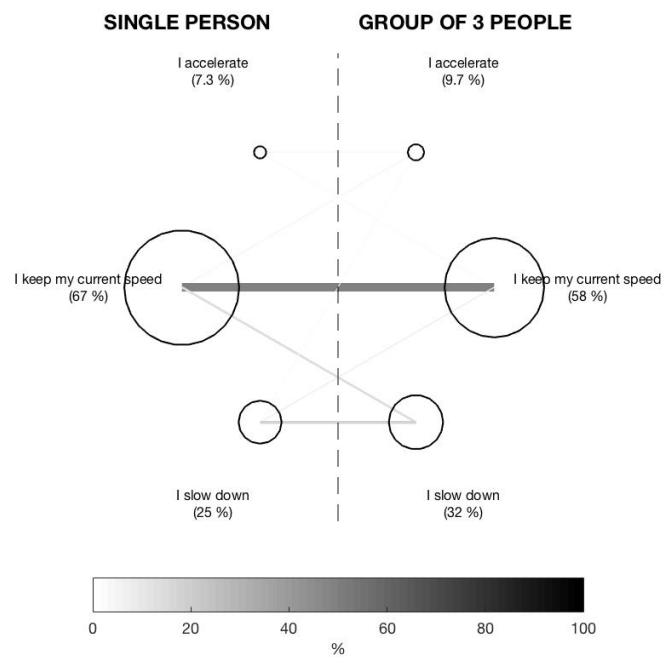


Figure 5.26: Pedestrians' speed choices and their changes with respect to conflicting group size (n=1556)

6

Discussion of findings

In this chapter, the findings from the survey results analysis are interpreted in an attempt to close the discussion on the extent to which situational and personal attributes impact collision avoidance behaviour of pedestrians and cyclists, described in terms of speed and position changes, in shared spaces.

First, the influence of the attributes most associated with speed and position choices are discussed (section 6.1). The survey method is then criticised in light of the panel effects found in the data (section 6.2). Finally, behavioural hypotheses are derived from the results (section 6.3), since no strong conclusions can be ascertained due to the panel effects.

6.1. Influence of attributes on collision avoidance behaviour

Visual cues and context, as depicted and specified in the survey images, do not seem to be more associated with choice than personal, experience, and opinion variables, with the notable exception of *direction and distance* for cyclists' position choice and *direction* for pedestrians' position choice. *Context* and *distance* are consistently the scenario variables the most associated with speed choice for both modes.

Eye contact and *group size*, which were attributes that played a major role during the field observation in Amsterdam, do not stand out as most influential situation attributes in determining choice through the survey. The first reason that could explain the discrepancy between observed behaviour and the survey results is that both *eye contact* and *group size* are attributes that are processed physiologically rather than rationally, meaning that the simple depiction of *eye contact* and *group size* in an image does not trigger the physiological processes that would affect behaviour effectively in real life. This would imply that those attributes are not analysed, rationalised in a similar way than conflicting trajectory *direction* or *distance* to conflict, while in the survey the respondents were forced to rationalise their behaviour.

Another, less plausible explanation is that the observed position and speed changes

that seemed to be caused by eye contact (or lack thereof) and the presence of a group of individuals could be due to other, unobserved attributes than those two. In other words, the assumption that eye contact and group size affect collision avoidance behaviour may simply be wrong – i.e a type II error, where the hypothesis that those two attributes had an effect on collision avoidance behaviour was falsely retained in the first place. As a result, those two attributes were tested in the survey, while they may in fact have little to no effect on behaviour in reality.

Personal, experience, and opinion attributes correlate with choice in similar ways to visual and contextual cues, confirming that the choices are not purely visual-based nor random, but rather subconscious and based on personal experience. *Cycling frequency* is even consistently more associated with any choice than *eye contact* or *group size*. Finally, *age* is the personal characteristics that stands out and that seems to play an important role – yet not significant for modelling purposes – in determining both position and speed choices for both modes.

All in all, few differences are observed between cyclists' and pedestrians' choices, especially in the case of speed choice. *Direction*, *distance*, and *context* to a lesser extent, are the most influential situational choice determinants. *Age*, on the other hand, is influential to the same degree over all choices, suggesting it may be used to explain the panel effect significance, and therefore as a nesting variable for further modelling efforts. Note that *gender*, which was found to introduce rather evident bias in the data, was found to be (one of) the personal variable least associated with any choice, indicating that gender bias seems not to impact collision avoidance manoeuvring.

6.2. Validity of the survey method

The observed choices are not random, otherwise all attributes would have had low and similar degrees of association with the choice variable, and follow a uniform distribution. Choices are not unanimous either, as the normal-like distribution of the random samples suggest. However, the behaviour of the population cannot be modelled using the response dataset as a whole, as the differences in means shown in the histograms are significantly different for all variables, as the t-test and the extremely low p-values proved. There are therefore strong panel effects. Because strong panel effects are at play, this means that estimating a log-linear model for each of the 4 choices – i.e. position and speed choices as a cyclist or pedestrian – is unfeasible. To attempt understanding the panel effect, it is worth examining the impact that the survey method itself may have had on the respondents' answers.

The survey was specifically designed to simplify statistical analysis yet yield accurate results, which means that only a few attributes were introduced in the survey images – to limit the number of questions – and their levels were clearly differentiated in the images. Each image in the survey was therefore lacking resemblance with reality, and missing complementary information – such as sound, physical contact with other people, temperature, respondent's height, etc. – that would typically be processed, be it consciously or subcon-

sciously, by an individual when trying to avoid a collision. Respondents may therefore have answered in two ways: by solely relying on the presented situation, meaning they gave an answer to a situation that is not fully realistic, or by imagining those attributes that were not presented, meaning they introduced a constant, personal bias in their answers. This last possibility may be an explanation to the strong panel effects observed via the t-tests.

6.3. Behavioural hypotheses

Although one cannot ascertain whether these are true because of statistically insignificant associations between the tested attributes and the respondents' choices, several behavioural hypotheses can be formulated, and may be worth investigating in future research.

Cycling frequency impacts pedestrian collision avoidance behaviour

It was indeed found that cycling frequency had a 50% chance of being moderately associated to both speed and position choices of pedestrians, a stronger degree of association than for cyclists' choices. This may therefore indicate that cycling experience affects the way individuals react to other cyclists. In other words, individuals who cycle may be better at reacting to cyclists than individuals who do not cycle, simply because they may be able to project themselves, and therefore the manoeuvres they would use, on cyclists whose trajectory conflicts with theirs.

Exposure to traffic impacts pedestrian collision avoidance behaviour

It was found that there is at least a 50% chance that mode choice for common destinations (work/school, shopping, reaching public transit) is moderately associated to pedestrian speed choice. This may indicate that mode choice for everyday transportation tasks has some impact on the walking experience. If one pushes the reasoning a bit further, it could be hypothesised that the differences in the selected mode of transportation for everyday tasks exposes individuals to different situations which, put together, builds knowledge (or lack thereof) on how to avoid collisions with other users.

Cyclists anticipate conflicts to keep their momentum

It was found that cyclists adjust their position more often than pedestrians when the conflict point is distant (90.4% of *far* conflicts). This seems to be a behaviour particularly specific to cyclists since, for comparison purposes, only 58% of pedestrians adjusted their position for distant conflict points. This corroborates the on-site observation in Amsterdam that keeping momentum is a priority to cyclists.

Subjecting cyclists to motorised traffic rules impacts their behaviour in shared spaces

It was mentioned that as the conflict gets closer, the common traffic rule of passing oncoming traffic to the right is applied by a majority of cyclists (56%), whereas pedestrians tend to have no clear rule. It was also found that for 60% of cyclists go right when *facing* a

(group of) pedestrian(s) (in comparison, 49% of pedestrians adopted that behaviour when faced with a (group of) cyclist(s)). Usually, in non-shared space environments, cyclists are required by law to follow the same traffic rules as motorised vehicles, such as keeping right, and yielding to traffic coming from the right. It therefore seems that cyclists develop habits under those traffic rules, and thus behave in similar ways in shared spaces.

Cyclists are expected to make the most effort to avoid a collision

It was already mentioned that cyclists seem to anticipate conflicts more often than pedestrians in an effort to keep their momentum. When those conflicts points are closer, however, cyclists slow down more often than pedestrians (56% of cyclists choose to slow down, 55% of pedestrians keep their current speed). Similarly, when conflicting trajectories are *crossing*, 87% of cyclists made a position change and 48% chose to slow down, while pedestrians chose to go straight (51%) and maintain their speed in the same situation (64%). This could be explained by the fact that pedestrians are typically considered the most vulnerable road users, and traffic rules usually enforce strict priority to pedestrians. Since cyclists are usually subjected to common motorised traffic rules (see above), pedestrians may expect cyclists to yield and give way.

7

Conclusion

This chapter aims to reflect on the survey results and discussion presented in Chapters 5 and 6. In an attempt to answer the research question – *What drives the collision avoidance behaviour of pedestrians and bicyclists in shared spaces?* –, key behavioural findings are summarised, and the methodology adopted in this study is criticised.

7.1. Behavioural findings

A set of situational and personal attributes were tested against pedestrians and cyclists' position and speed manoeuvre choices to avoid collision with one another in a survey using statistical analysis. It was found that panel effects were significant, which prevented continuing the modelling effort using log-linear analysis to unravel the extent to which the tested attributes impact collision avoidance behaviour (estimation of parameters).

Although none of the attributes were found to be significantly associated with collision avoidance manoeuvre choice for the entire population, it cannot be ascertained that all attributes tested are completely irrelevant to collision avoidance behaviour. The research hinted that this behaviour does not simply rely on visual and contextual cues, as originally observed in the field study, but also on personal characteristics, experience, and character, depending on the person, as the variance across sample suggests. This means that collision avoidance behaviour of each individual may be governed by a rather unique combination of the attributes studied in this thesis.

Nonetheless, attributes such as *distance* to conflict, conflicting trajectories *direction*, *context* of the situation, as well as the person's *age*, were found to be more associated with collision avoidance manoeuvre choice for both cyclists and pedestrians than other attributes. All in all, we can formulate the following behavioural hypotheses:

1. Cyclists anticipate conflicts to keep their momentum
2. Subjecting cyclists to motorised traffic rules impacts their behaviour in shared spaces
3. Cyclists are expected to make the most effort to avoid a collision
4. Cycling frequency amongst pedestrians impacts their collision avoidance behaviour
5. Exposure to traffic impacts pedestrian collision avoidance behaviour

Furthermore, descriptive analysis of the respondents' characteristics, personality, and transportation life outlined different habits (cycling frequency, main mode to reach certain destinations, etc.) and experiences (late cycling learner, traffic license ownership, etc.) found in different cultural backgrounds (European and North American). It was also found in the degree of association analysis that these background factors seem as significant as visual conflict attributes. This suggests that an individual's collision avoidance behaviour is the result of the use of a set of skills, rules, knowledge, and experiences acquired throughout their lifetime.

Finally, as explained in chapter 3, Rasmussen [Rasmussen, 1983] classifies behaviour as either skill-, rule-, or knowledge-based. It posits that walking and bicycling are skill-based behaviour, meaning it is rather automatic behaviour that cannot be self-reported. The somewhat mixed results from this research, where none of the attributes were found to be significantly associated with collision avoidance manoeuvre choice, tend to back up this theory. However, we found that some attributes were more associated with collision avoidance manoeuvring behaviour than others – i.e. *distance* and *direction* –, while some attributes that were believed to be strongly associated with that behaviour, such as *eye contact* and *group size*, were found to be amongst the least significant via the survey. This could indicate that while walking and cycling are skill-based behaviour, collision avoidance is a more complex behaviour resulting from a combination of skill-, rule-, and knowledge-based processes, as well as physiological processes that cannot be rationalised.

7.2. Recommendations...

In this section, the findings and the methods used in this thesis are reflected upon to draw recommendations for future research and practitioners.

7.2.1. ... for future research

Through the analysis of the survey results and its findings, this study highlighted the advantages and limitations of using an online stated-preference survey to assess the collision avoidance behaviour of cyclists and pedestrians in shared spaces. The choice between a stated-preference survey and other techniques depend on the eventual field of application of the findings.

Validity of using a stated-preference survey

Stated-preference surveys can help gain valuable insight on pedestrians and cyclists' identity and experience – which were found to be equally associated with collision avoidance behaviour than visual cues through the survey – from a large sample. It was indeed shown throughout this project that collision avoidance behaviour may be the result of subconscious, seemingly rational processes as well as physiological reactions. Such processes and reactions are difficult to capture and interpret in essence, however this online survey proved that an SP technique can be effective in doing so, to the extent we were able to confirm the validity of some hypotheses drawn from on-site observations of real conflicts. More practically speaking, distributing an online survey to reach out to cyclists is much easier than surveying cyclists in the field, simply because it is difficult to ask a cyclist to stop to fill out a survey.

The questionnaire could however be enhanced to create more realistic situations. This could take several forms, such as, for example, using videos instead of images, which would allow to control for sound, conflicting user speed, respondent speed, amongst other attributes that may have introduced bias in the results of this project.

Validity of using other techniques

First of all, as it was mentioned when selecting a stated preference technique for this project, collision avoidance behaviour may be the result of a combination of subconscious and physiological processes, hence asking survey respondents to rationalise the behaviour they would adopt facing certain conflicts may be an ill-defined way to assess the impact of sensory cues and other, more personal attributes.

Direct observations of behaviour by means of revealed-preference techniques would allow the researcher to effectively record actual behaviour. Revealed behaviour can be recorded, classified, and analysed using cameras, as shown for example by [Beitel et al. \[2017\]](#). Although such a technique may be valuable in assessing the occurrence of certain conflict types and quantifying position and speed changes (deflection from intended trajectory and acceleration), it is virtually impossible to acquire knowledge on the impact of personal, cultural characteristics and experience on behaviour using this technique.

A controlled experiment, in which conflict attributes and attribute levels are controlled for, would therefore be a good compromise and would enable the researcher to directly record and observe actual behaviour from participants, and to survey the participants on their personal background. In such an experimental design, participants would not be informed in advance of what situations they would be subject to (a research team would be in charge of generating specific conflict situations to test the desired attributes accordingly). The controlled experiment could potentially allow for more reliable testing of physiological attributes, such as *eye contact* and *group size*. Alternatively, such a controlled experiment could be carried out using a simulator or virtual reality, depending on the technology available.

7.2.2. ... for modellers

The most limiting factor in the analysis of the results was not so much the method employed to acquire data, but rather the number and nature of the attributes being tested. This research was rather exploratory, therefore many attributes and many levels (more than two for most attributes) were introduced in the survey for testing and, coupled with their categorical nature, they disqualified a number of statistical methods for the analysis from the get-go.

To maximise the number of statistical methods to be used for analysis, the survey designer should aim at limiting the number of attribute levels to two levels, and attempt to model these levels in a quantifiable manner (which is not the case for categorical attributes such as the ones used in this survey). Developing the survey in such a way that the response is linear could also maximise the number of statistical analysis techniques to choose from, and would allow for estimating a linear behaviour model in the end, without having to interpret interaction effects between 3 or more attributes (which is what the log-linear analysis would yield).

The lack of significantly different degrees of associations among the variables tested in this survey could be explained by the impossibility to depict extreme attribute levels in the survey images while keeping a simple, comprehensible survey design. It is indeed difficult to perfectly control the respondents' interpretation of the images, where some may have noticed a change in attribute levels while others did not, thus introducing a bias that cannot be measured and accounted for in the statistical analysis. An enhanced design would aim at presenting more extreme cases to the respondents, to significantly impact respondents' choices. This would generate more variance, and therefore more power in estimating parameters should a collision avoidance behaviour model be developed.

7.2.3. ... for practitioners

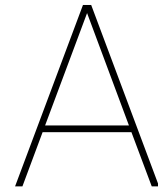
The premise of this thesis was that little is known on the ability of pedestrians and cyclists to share a unique space in a safe way. This lack of knowledge is often the reason advanced against the creation of shared spaces for pedestrians and cyclists, or the opening of pedestrian streets or malls to cyclists.

This project showed that the collision avoidance behaviour of pedestrians and cyclists with one-another is rather complex, but not random. This very fact means that in shared spaces pedestrians and cyclists do follow logical reasoning, be it subconscious or conscious, as is the case in more standard traffic environments where traffic rules may apply. It would be a misconception to think of shared space behaviour as being of a completely different nature than in standard traffic environments, simply because shared spaces users are also users of standard traffic environments; they therefore carry their experience and training baggage, and use it to manoeuvre safely, everywhere.

Shared spaces would therefore not be a hazardous concept because people would not know how to behave in such places, but rather because of a lack of appropriate design

principles. What this research implies is that shared space users are not the direct cause of their unsafety, but are rather the vector of of an unsafe design. Designing shared spaces can effectively be tricky, for the research in this field is limited and our understanding of the human brain can only be achieved so much. However, in view of the results of this project, three basic design principles are recommended:

1. Get to know the users: identify who they are, where they come from, what their transport experience is, etc. to assess whether a shared space design is appropriate for a specific site.
2. Enhance the visibility of others: pedestrians, and more specifically cyclists, anticipate conflicts and adjust their trajectories as such to avoid conflicts. Increased visibility of the other users makes sure everyone can anticipate each other's trajectory and safely manoeuvre through the space.
3. Promote walking and cycling throughout: cycling frequency, but also exposure to conflicts between pedestrians and cyclists builds experience. Everyone learns from experience, be it good or bad, and uses the lessons learned to manoeuvre and avoid other conflicts later on. The more pedestrians and cyclists interact, the more experienced pedestrians and cyclists will be, and the safer they will interact with one another.



Pilot survey questionnaire

Collision avoidance behaviour - Pilot

Hello!

You received this link as part of my thesis research. Thank you for taking the time to answer this pilot survey, as it will tremendously help me to improve it for the final survey.

You will be prompted with 28 questions relating to situations involving cyclists and pedestrians. I know it's a lot but don't worry, they are very fast to answer. With your help, I am aiming at cutting down that number of questions for the final survey.

There will also be some general background questions and a feedback section at the end of the survey for me to know what I can do better.

Thank you!

**Required*



Instructions

In the questions that follow, you will have to pick a course of action from the perspective of a pedestrian or a cyclist (you will be given some context information at the beginning of each section of the survey). For all questions, your intended path is the following:

You are walking alone and...

... you are facing this cyclist: *



- ☐ I accelerate
- ☐ I slow down
- ☐ I stop
- ☐ I step aside
- ☐ I don't do anything

... you are facing these cyclists: *



- ☐ I accelerate
- ☐ I slow down
- ☐ I stop
- ☐ I step aside
- ☐ I don't do anything

... you are facing these cyclists: *



- ☐ I accelerate
- ☐ I slow down
- ☐ I stop
- ☐ I step aside
- ☐ I don't do anything

... you are facing these cyclists: *



- ☐ I accelerate
- ☐ I slow down
- ☐ I stop
- ☐ I step aside
- ☐ I don't do anything

You are shopping with friends walking and...

... you are facing this cyclist: *



- ☐ I accelerate
- ☐ I slow down
- ☐ I stop
- ☐ I step aside
- ☐ I don't do anything

... you are facing this cyclist: *



- ☐ I accelerate
- ☐ I slow down
- ☐ I stop
- ☐ I step aside
- ☐ I don't do anything

... you are facing these cyclists: *



- ☐ I accelerate
- ☐ I slow down
- ☐ I stop
- ☐ I step aside
- ☐ I don't do anything

... you are facing these cyclists: *



- ☐ I accelerate
- ☐ I slow down
- ☐ I stop
- ☐ I step aside
- ☐ I don't do anything

... you are facing these cyclists: *



- ☐ I accelerate
- ☐ I slow down
- ☐ I stop
- ☐ I step aside
- ☐ I don't do anything

... you are facing these cyclists: *



- ☐ I accelerate
- ☐ I slow down
- ☐ I stop
- ☐ I step aside
- ☐ I don't do anything

You are rushing to work walking and...

... you are facing this cyclist: *



- ☐ I accelerate
- ☐ I slow down
- ☐ I stop
- ☐ I step aside
- ☐ I don't do anything

... you are facing these cyclists: *



- ☐ I accelerate
- ☐ I slow down
- ☐ I stop
- ☐ I step aside
- ☐ I don't do anything

... you are facing these cyclists: *



- ☐ I accelerate
- ☐ I slow down
- ☐ I stop
- ☐ I step aside
- ☐ I don't do anything

... you are facing these cyclists: *



- ☐ I accelerate
- ☐ I slow down
- ☐ I stop
- ☐ I step aside
- ☐ I don't do anything

You are biking alone and...

... you are facing this pedestrian: *



- ☐ I accelerate
- ☐ I slow down
- ☐ I stop
- ☐ I swerve aside
- ☐ I don't do anything

... you are facing these pedestrians: *



- ☐ I accelerate
- ☐ I slow down
- ☐ I stop
- ☐ I swerve aside
- ☐ I don't do anything

... you are facing these pedestrians: *



- ☐ I accelerate
- ☐ I slow down
- ☐ I stop
- ☐ I swerve aside
- ☐ I don't do anything

... you are facing these pedestrians: *



- ☐ I accelerate
- ☐ I slow down
- ☐ I stop
- ☐ I swerve aside
- ☐ I don't do anything

You are biking with a friend and...

... you are facing this pedestrian: *



- ☐ I accelerate
- ☐ I slow down
- ☐ I stop
- ☐ I swerve aside
- ☐ I don't do anything

... you are facing this pedestrian: *



- ☐ I accelerate
- ☐ I slow down
- ☐ I stop
- ☐ I swerve aside
- ☐ I don't do anything

... you are facing these pedestrians: *



- ☐ I accelerate
- ☐ I slow down
- ☐ I stop
- ☐ I swerve aside
- ☐ I don't do anything

... you are facing these pedestrians: *



- ☐ I accelerate
- ☐ I slow down
- ☐ I stop
- ☐ I swerve aside
- ☐ I don't do anything

... you are facing these pedestrians: *



- ☐ I accelerate
- ☐ I slow down
- ☐ I stop
- ☐ I swerve aside
- ☐ I don't do anything

... you are facing these pedestrians: *



- ☐ I accelerate
- ☐ I slow down
- ☐ I stop
- ☐ I swerve aside
- ☐ I don't do anything

You are rushing to work biking and...

... you are facing this pedestrian: *




- ☐ I accelerate
- ☐ I slow down
- ☐ I stop
- ☐ I swerve aside
- ☐ I don't do anything

... you are facing these pedestrians: *



- ☐ I accelerate
- ☐ I slow down
- ☐ I stop
- ☐ I swerve aside
- ☐ I don't do anything

... you are facing these pedestrians: *



☐ I accelerate


☐ I slow down

☐ I stop

☐ I swerve aside

☐ I don't do anything

... you are facing these pedestrians: *



☐ I accelerate

☐ I slow down

☐ I stop

☐ I swerve aside

☐ I don't do anything

Personal information

Gender *

☐ Female

☐ Male

Age *

Your answer

Country of origin *

This helps me assess the impact of cultural background on your choices.

Your answer

City of residence *

This helps me assess the impact of your day-to-day experience on your choices.

Your answer

What situations do you find most challenging as a pedestrian/cyclist when facing a cyclist/pedestrian?

Your answer

Feedback

Tell me about your experience with answering this survey.

Clarity of the questions *

1

2

3

4

5

☐

☐

☐

☐

☐

Quality of the images *

1

2

3

4

5

☐

☐

☐

☐

☐

Relevance of proposed choices *

1

2

3

4

5

☐

☐

☐

☐

☐

Comments and suggestions *

How did you feel when answering this survey? Were you able to differentiate the images to some extent? What other choice would you have selected as a course of action that was missing in the proposed list? What is the main strength/weakness of the survey in your opinion? Please be as detailed as possible.

Your answer

Page 1 of 10

GET LINK

Never submit passwords through Google Forms.

B

Final survey questionnaire

*Required

Hello!

This survey is part of my final thesis project to obtain the degree of **MSc. Transport, Infrastructure & Logistics** from **TU Delft, The Netherlands**.

For several years now, I have been studying, researching, and developing solutions that **promote cycling and walking** through both my work and studies.

Your answers will help me - and hopefully academics and designers - to better understand and model interactions between pedestrians and cyclists, and improve streets design for all.

The survey should take about **9 minutes** of your time.

Thank you!

-Quentin Dumont-Freixo

Pre-fill responses, then click 'Get link'

INSTRUCTIONS

In the questions that follow, the people you see in the images are walking or cycling in front of you.

For each situation, your goal is to **avoid a potential collision** with them. You will therefore have to pick a course of action from the perspective of a pedestrian or a cyclist - you will be given some context information at the beginning of each section of the survey.

For all questions, you wish to follow **this path**:



Pre-fill responses, then click 'Get link'

you are cycling

The following people are in your way.
What would you do?



Pre-fill responses, then click 'Get link'

I would: *

- ☐ swerve left
- ☐ swerve right
- ☐ keep going straight

... and: *

- ☐ accelerate
- ☐ slow down
- ☐ keep my current speed



Pre-fill responses, then click 'Get link'

I would: *

- ☐ swerve left
- ☐ swerve right
- ☐ keep going straight

... and: *

- ☐ accelerate
- ☐ slow down
- ☐ keep my current speed



Pre-fill responses, then click 'Get link'

I would: *

- ☐ swerve left
- ☐ swerve right
- ☐ keep going straight

... and: *

- ☐ accelerate
- ☐ slow down
- ☐ keep my current speed



Pre-fill responses, then click 'Get link'

I would: *

- ☐ swerve left
- ☐ swerve right
- ☐ keep going straight

... and: *

- ☐ accelerate
- ☐ slow down
- ☐ keep my current speed



Pre-fill responses, then click 'Get link'

I would: *

- ☐ swerve left
- ☐ swerve right
- ☐ keep going straight

... and: *

- ☐ accelerate
- ☐ slow down
- ☐ keep my current speed



Pre-fill responses, then click 'Get link'

I would: *

- ☐ swerve left
- ☐ swerve right
- ☐ keep going straight

... and: *

- ☐ accelerate
- ☐ slow down
- ☐ keep my current speed



Pre-fill responses, then click 'Get link'

I would: *

- ☐ swerve left
- ☐ swerve right
- ☐ keep going straight

... and: *

- ☐ accelerate
- ☐ slow down
- ☐ keep my current speed



Pre-fill responses, then click 'Get link'

I would: *

- ☐ swerve left
- ☐ swerve right
- ☐ keep going straight

... and: *

- ☐ accelerate
- ☐ slow down
- ☐ keep my current speed



Pre-fill responses, then click 'Get link'

I would: *

- ☐ swerve left
- ☐ swerve right
- ☐ keep going straight

... and: *

- ☐ accelerate
- ☐ slow down
- ☐ keep my current speed



Pre-fill responses, then click 'Get link'

I would: *

- ☐ swerve left
- ☐ swerve right
- ☐ keep going straight

... and: *

- ☐ accelerate
- ☐ slow down
- ☐ keep my current speed



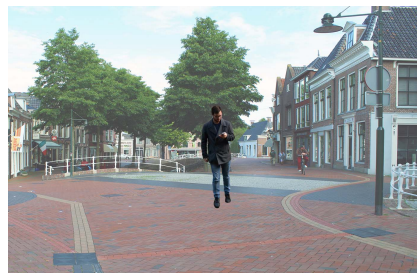
Pre-fill responses, then click 'Get link'

I would: *

- ☐ swerve left
- ☐ swerve right
- ☐ keep going straight

... and: *

- ☐ accelerate
- ☐ slow down
- ☐ keep my current speed



Pre-fill responses, then click 'Get link'

I would: *

- ☐ swerve left
- ☐ swerve right
- ☐ keep going straight

... and: *

- ☐ accelerate
- ☐ slow down
- ☐ keep my current speed

you are cycling
with a group of friends

Pre-fill responses, then click 'Get link'

The following people are in your way.
What would you do?



I would: *

- ☐ swerve left
- ☐ swerve right
- ☐ keep going straight

... and: *

- ☐ accelerate
- ☐ slow down
- ☐ keep my current speed

Pre-fill responses, then click 'Get link'



I would: *

- ☐ swerve left
- ☐ swerve right
- ☐ keep going straight

... and: *

- ☐ accelerate
- ☐ slow down
- ☐ keep my current speed

Pre-fill responses, then click 'Get link'



I would: *

- ☐ swerve left
- ☐ swerve right
- ☐ keep going straight

... and: *

- ☐ accelerate
- ☐ slow down
- ☐ keep my current speed

Pre-fill responses, then click 'Get link'



I would: *

- ☐ swerve left
- ☐ swerve right
- ☐ keep going straight

... and: *

- ☐ accelerate
- ☐ slow down
- ☐ keep my current speed

Pre-fill responses, then click 'Get link'

**you are cycling
and rushing
to catch a train**

The following people are in your way.
What would you do?



Pre-fill responses, then click 'Get link'

I would: *

- ☐ swerve left
- ☐ swerve right
- ☐ keep going straight

... and: *

- ☐ accelerate
- ☐ slow down
- ☐ keep my current speed



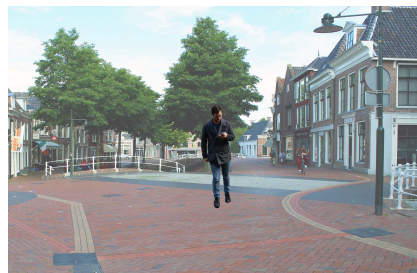
Pre-fill responses, then click 'Get link'

I would: *

- ☐ swerve left
- ☐ swerve right
- ☐ keep going straight

... and: *

- ☐ accelerate
- ☐ slow down
- ☐ keep my current speed



Pre-fill responses, then click 'Get link'

I would: *

- ☐ swerve left
- ☐ swerve right
- ☐ keep going straight

... and: *

- ☐ accelerate
- ☐ slow down
- ☐ keep my current speed



Pre-fill responses, then click 'Get link'

I would: *

- ☐ swerve left
- ☐ swerve right
- ☐ keep going straight

... and: *

- ☐ accelerate
- ☐ slow down
- ☐ keep my current speed

you are walking

Pre-fill responses, then click 'Get link'

The following people are in your way.
What would you do?



I would: *

- ☐ step to the left
- ☐ step to the right
- ☐ keep going straight

... and: *

- ☐ accelerate
- ☐ slow down
- ☐ keep my current speed

Pre-fill responses, then click 'Get link'



I would: *

- ☐ step to the left
- ☐ step to the right
- ☐ keep going straight

... and: *

- ☐ accelerate
- ☐ slow down
- ☐ keep my current speed

Pre-fill responses, then click 'Get link'



I would: *

- ☐ step to the left
- ☐ step to the right
- ☐ keep going straight

... and: *

- ☐ accelerate
- ☐ slow down
- ☐ keep my current speed

Pre-fill responses, then click 'Get link'



I would: *

- ☐ step to the left
- ☐ step to the right
- ☐ keep going straight

... and: *

- ☐ accelerate
- ☐ slow down
- ☐ keep my current speed

Pre-fill responses, then click 'Get link'



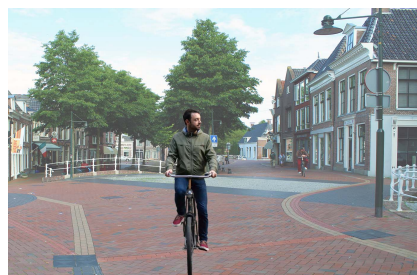
I would: *

- ☐ step to the left
- ☐ step to the right
- ☐ keep going straight

... and: *

- ☐ accelerate
- ☐ slow down
- ☐ keep my current speed

Pre-fill responses, then click 'Get link'



I would: *

- ☐ step to the left
- ☐ step to the right
- ☐ keep going straight

... and: *

- ☐ accelerate
- ☐ slow down
- ☐ keep my current speed

Pre-fill responses, then click 'Get link'



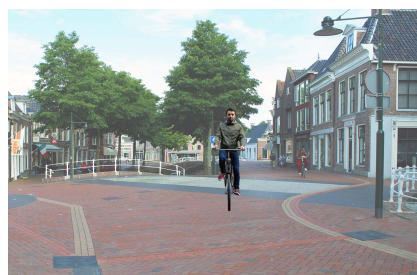
I would: *

- ☐ step to the left
- ☐ step to the right
- ☐ keep going straight

... and: *

- ☐ accelerate
- ☐ slow down
- ☐ keep my current speed

Pre-fill responses, then click 'Get link'



I would: *

- ☐ step to the left
- ☐ step to the right
- ☐ keep going straight

... and: *

- ☐ accelerate
- ☐ slow down
- ☐ keep my current speed

Pre-fill responses, then click 'Get link'



I would: *

- ☐ step to the left
- ☐ step to the right
- ☐ keep going straight

... and: *

- ☐ accelerate
- ☐ slow down
- ☐ keep my current speed

Pre-fill responses, then click 'Get link'



I would: *

- ☐ step to the left
- ☐ step to the right
- ☐ keep going straight

... and: *

- ☐ accelerate
- ☐ slow down
- ☐ keep my current speed

Pre-fill responses, then click 'Get link'



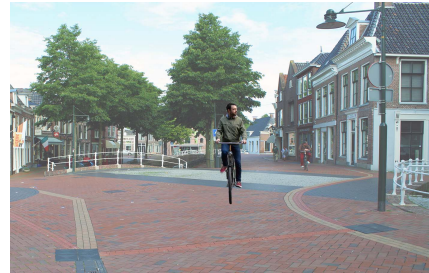
I would: *

- ☐ step to the left
- ☐ step to the right
- ☐ keep going straight

... and: *

- ☐ accelerate
- ☐ slow down
- ☐ keep my current speed

Pre-fill responses, then click 'Get link'



I would: *

- ☐ step to the left
- ☐ step to the right
- ☐ keep going straight

... and: *

- ☐ accelerate
- ☐ slow down
- ☐ keep my current speed

Pre-fill responses, then click 'Get link'

you are walking with a group of friends

The following people are in your way.
What would you do?



Pre-fill responses, then click 'Get link'

I would: *

- ☐ step to the left
- ☐ step to the right
- ☐ keep going straight

... and: *

- ☐ accelerate
- ☐ slow down
- ☐ keep my current speed



Pre-fill responses, then click 'Get link'

I would: *

- ☐ step to the left
- ☐ step to the right
- ☐ keep going straight

... and: *

- ☐ accelerate
- ☐ slow down
- ☐ keep my current speed



Pre-fill responses, then click 'Get link'

I would: *

- ☐ step to the left
- ☐ step to the right
- ☐ keep going straight

... and: *

- ☐ accelerate
- ☐ slow down
- ☐ keep my current speed



Pre-fill responses, then click 'Get link'

I would: *

- ☐ step to the left
- ☐ step to the right
- ☐ keep going straight

... and: *

- ☐ accelerate
- ☐ slow down
- ☐ keep my current speed

**you are walking
and rushing
to catch a train**

Pre-fill responses, then click 'Get link'

The following people are in your way.
What would you do?



I would: *

- ☐ step to the left
- ☐ step to the right
- ☐ keep going straight

... and: *

- ☐ accelerate
- ☐ slow down
- ☐ keep my current speed

Pre-fill responses, then click 'Get link'



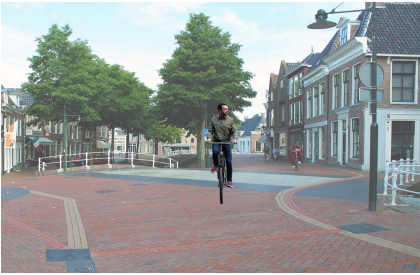
I would: *

- ☐ step to the left
- ☐ step to the right
- ☐ keep going straight

... and: *

- ☐ accelerate
- ☐ slow down
- ☐ keep my current speed

Pre-fill responses, then click 'Get link'



I would: *

- ☐ step to the left
- ☐ step to the right
- ☐ keep going straight

... and: *

- ☐ accelerate
- ☐ slow down
- ☐ keep my current speed

Pre-fill responses, then click 'Get link'



I would: *

- ☐ step to the left
- ☐ step to the right
- ☐ keep going straight

... and: *

- ☐ accelerate
- ☐ slow down
- ☐ keep my current speed

Pre-fill responses, then click 'Get link'

YOUR TRANSPORT LIFE

Generally speaking, do you agree with the following statements? *

	Not at all	Sometimes	Usually	Totally
"I tend to follow the rules"	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
"I am more risk-taking than the average person"	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
"The faster the better"	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
"Crowds make me feel nervous"	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
"I am confident in my bicycle riding skills"	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
"I am scared of bicycles"	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
"I believe cyclists should be allowed to bike in pedestrian areas"	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

At what age did you learn how to ride a bike? *

If you don't remember exactly when, an approximation is enough.

Your answer

Pre-fill responses, then click 'Get link'

As a child, did you receive any traffic education? *

Typically through school on topics such traffic rules, responsibility, safety, etc.

- ☐ Yes
- ☐ No

Do you own a driving license? *

- ☐ Yes
- ☐ No

What is your main mode of transportation to reach the following places? *

	Walking	Biking	Public transport	Car	Other
work/university	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
the supermarket	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
shopping area	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
the train station/bus terminal	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Do you have access to a bike? *

- ☐ I have my own bike(s).
- ☐ I have a subscription to a bike sharing system.
- ☐ I can easily borrow the bike of a friend or relative.
- ☐ Other:

Pre-fill responses, then click 'Get link'

On average, how often do you use a bike? *

- ☐ Daily
- ☐ A couple times a week
- ☐ A couple times a month
- ☐ Less than once a month
- ☐ Never

When did you last use a bicycle for the following purposes? *

	Today	< 1 week ago	< 1 month ago	< 3 months ago	> 3 months ago	I don't use the bike for this
Going to work/university	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Shopping/running errands	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Visiting friends/family	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Reaching public transportation	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Tourism	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Sports	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

What type of places or streets do you try to avoid when cycling?

Your answer

What type of places or streets do you try to avoid when walking?

Your answer

Pre-fill responses, then click 'Get link'

Final survey respondents' portrait

C.1. Sample characteristics

C.1.1. Age and gender distribution

The average respondent is 34.9 years old, 55.3% male (Figure C.1). The age distribution appears to be skewed towards young respondents, mostly due to the social network of this thesis' author, as expected.

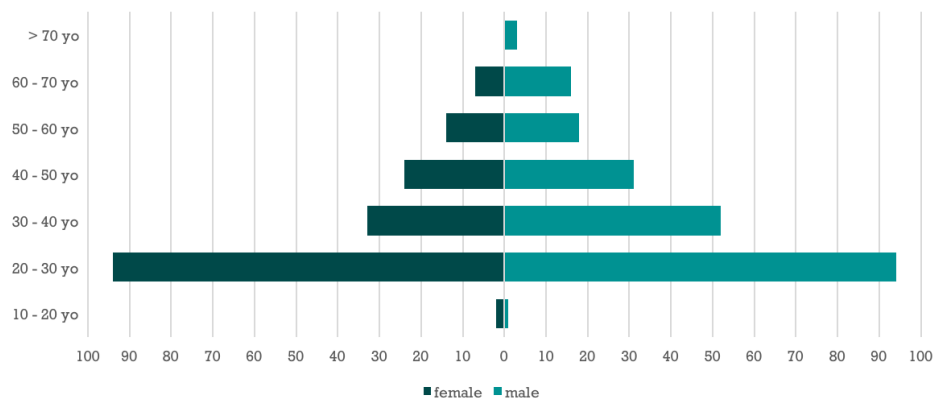


Figure C.1: Age and gender distribution of the survey respondents

C.1.2. Main mode of transportation

When asked about their main mode of transportation to reach very common destinations of everyday life, the survey respondents answered in over 60% of the cases that they use their bicycles, their feet, or public transportation (all categories). Figure C.2 more specifically shows the transportation habits of the respondents to go to work or university/school, to go shopping, to reach a public transportation stop or station, and to do groceries. An

overwhelming majority of respondents use the bicycle or walk for the former three destinations, most certainly due to the social network of this thesis' author, once again.

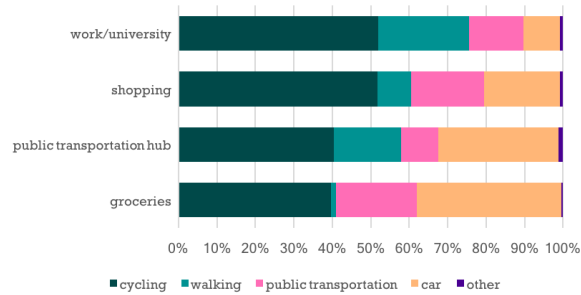


Figure C.2: Main mode of transportation used by the survey respondents to reach common destinations

C.1.3. Access to bicycling

Overall, 90% of the survey respondents owns a bicycle, 18% have a bicycle sharing programme subscription, and 12% can easily borrow the bicycle of a friend, relative, or neighbour. While 2.6% of respondents fell into all three categories, 4.1% stated that they have virtually no access to a bicycle.

C.1.4. Cycling frequency

Figure C.3 depicts how often the respondents stated that they cycle, with a majority stating that they cycle on a daily basis (55.5%).

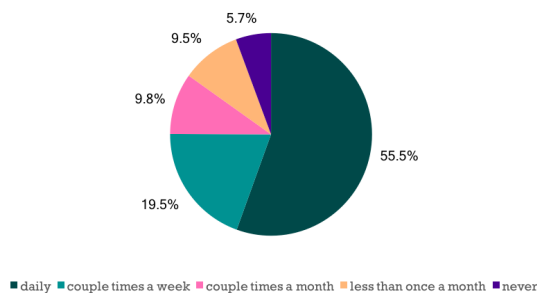


Figure C.3: Cycling frequency of survey respondents

C.2. Traffic experience

C.2.1. Learning how to cycle

More than 90% of respondents learned to ride a bicycle before 10 years old, of which about 35% have acquired that skill before age 5 (Figure C.4)

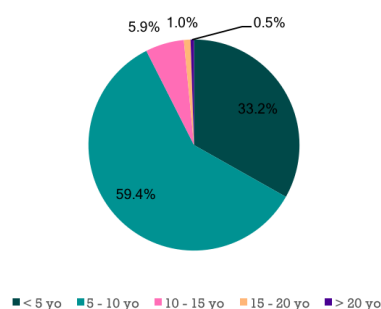


Figure C.4: Distribution of how early the survey respondents have acquired cycling skills

Interestingly enough, those who ride their bicycle frequently have learned how to ride a bicycle at a younger age than those who do not use that mode of transportation often (Figure C.5).

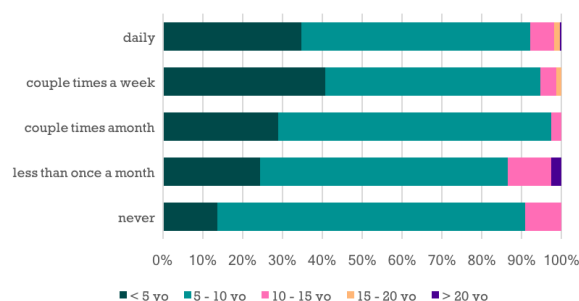


Figure C.5: Impact of acquiring cycling skills at an early age on cycling frequency

C.2.2. Driving license ownership

91.5% of respondents have a driving license. License ownership seems to be positively correlated to cycling frequency (Figure C.6). This may be an indication that cycling frequency relies on knowing the rules of the road. For example, one may be more prone to cycle if they know about and are trained and experienced with signage, way-finding, yielding rules, making eye contact, etc.

C.2.3. Traffic education

77.1% of respondents have received traffic education as part of their school curriculum (Figure C.7).

C.3. Opinion

Figure C.8 shows the level of agreement of the respondents with several statements regarding crowd density, speed, risk-taking behaviour, shared space, etc. The majority of the re-

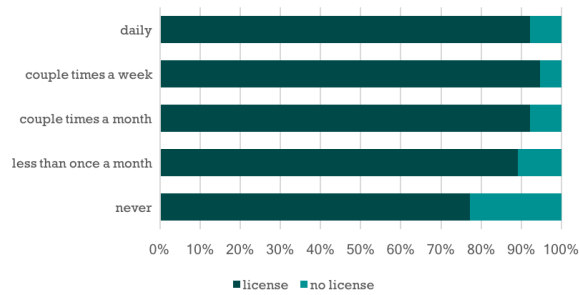


Figure C.6: Relation between driving license ownership and cycling frequency

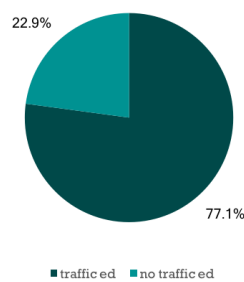


Figure C.7: Share of respondents who have received traffic education

spondents tends to be rather cautious, respectful of rules, self-confident, and not intimidated by bicycles as a pedestrian. The sample is however split on the question regarding mixing bicycles and pedestrians.

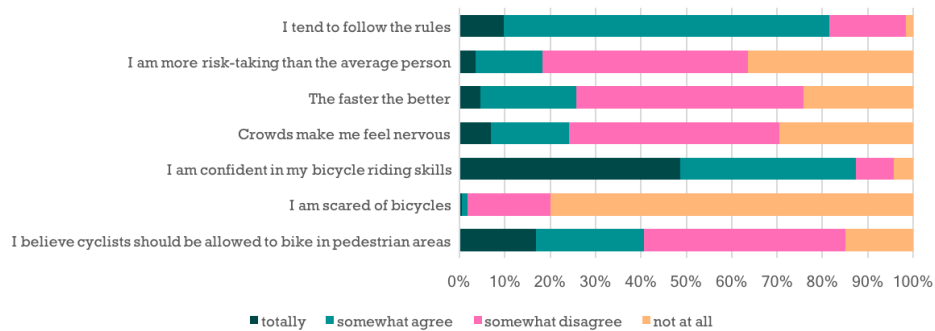


Figure C.8: Level of agreement with various statements

Interestingly enough, self-confidence in cycling skills is greater when cycling skills are learned at an earlier age (Figure C.9).

Self-confidence in cycling skills seems to boost the average cycling frequency of respondents (Figure C.10), although cycling frequency may also help gaining confidence.

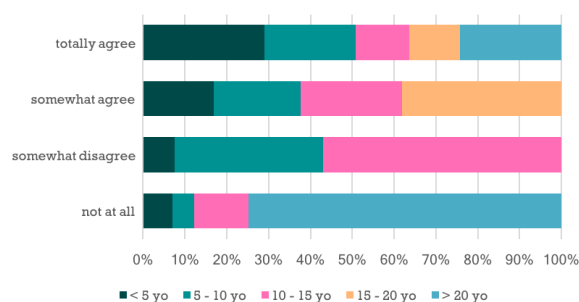


Figure C.9: Impact of acquiring cycling skills at an early age on the level of agreement with the statement "I am confident in my cycling skills"

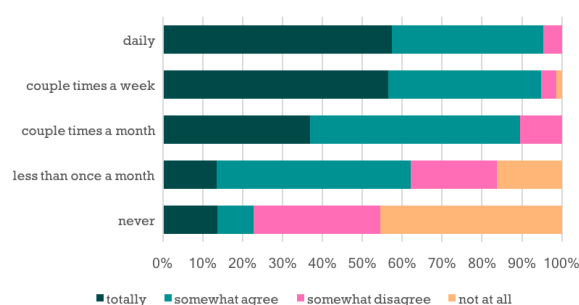


Figure C.10: Relation between cycling frequency and the level of agreement with the statement "I am confident in my cycling skills"

C.4. Bias

As for every stated-preference survey, there exists a response bias, i.e. a discrepancy between what respondents self-report and what their actions would be in reality. In theory, this type of bias could be explored and measured using both stated and revealed preference information from the same sample of respondents, however this is not the case here.

Bias in the answers can also be due to the survey questions formulation, which was addressed here by developing a balanced survey design in the first place (i.e. each respondent is confronted an equal amount of times with all attribute levels).

Finally, social and cultural backgrounds, age, and experience may also affect one's answers. This is in fact part of the research carried out here, aiming at unravelling the factors, be they visual, personal, social, etc., that influence collision avoidance behaviour. More specifically, it is often found in the scientific literature that age, gender, and country of origin – and subsequent intersectional associations – significantly explain the variance in answers. This section therefore aims at identifying the extent of three typical biases in the sample population.

C.4.1. Age bias

At least 80% of people aged between 30 and 50 years old stated that they use their bicycle several times a week (Figure C.11). This group is the most active, with 64.7% of the respondents in the 30-40 age group stating that they bike on a daily basis. The younger and older generations tend to cycle less often, although the bicycle is used several times a week by at least 60% of all respondents.

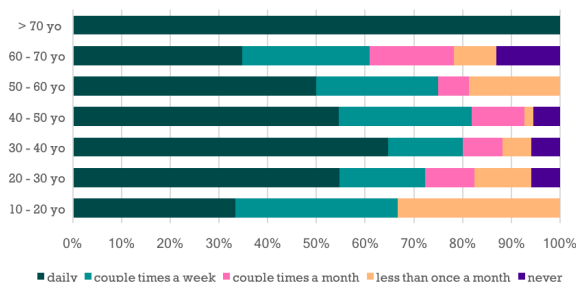


Figure C.11: Ageing impact on cycling frequency

There also seems to be no clear trend in contrasting the respondents' age with the age at which they stated they learned how to ride a bicycle. This goes against the belief that older generations have learned how to cycle at an earlier age than the younger generations.

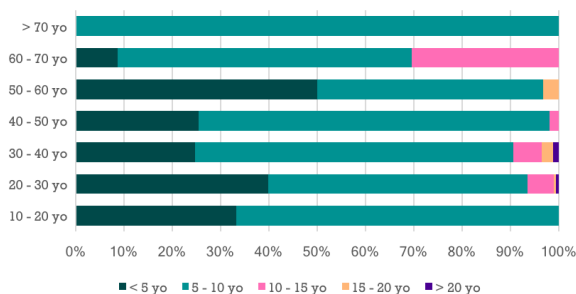


Figure C.12: Generational impact on acquiring cycling skills

As a result of the step-wise implementation of traffic education and road safety programmes in schools since the mid-1950s, a growing share of children and teenagers are learning about traffic rules and best behaviour. This is well illustrated in Figure C.13.

C.4.2. Gender bias

Gender is often researched in behavioural and sociological studies; it is not regarded as a determinant for behaviour, but rather as an indicator of how culture and education shapes the perception, behaviour and beliefs of and towards men and women in society.

Figure C.14 shows the structure of bicycle access for both female and male respondents. Overall, 85.1% of women stated that they own a bicycle (with or without an extra possibility

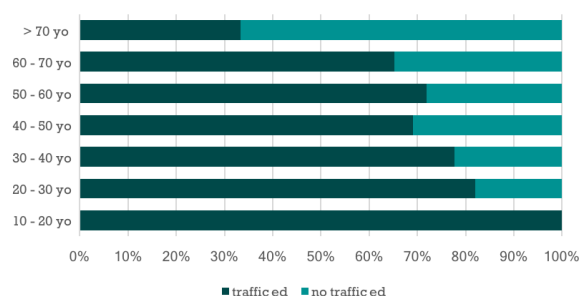


Figure C.13: Traffic education efforts through generations of children

to share and/or borrow one), to be contrasted with 94.4% of men. Interestingly enough, men tend to subscribe to bicycle sharing programmes more than women (23.3% vs. 11.5%, respectively). On the other hand, women borrow a bicycle from a friend or relative more than men (13.2% vs. 10.7%, respectively). Finally, 4.2% of male respondents own, have a subscription to a bicycle sharing programme, and can easily borrow a bicycle from a friend or relative (vs. 0.6% of female respondents), while 5.7% of female respondents have none of these options available (vs. 2.8% of male respondents).

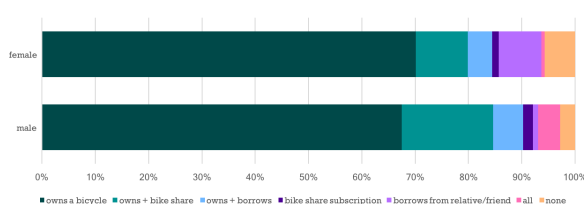


Figure C.14: Gender bias in bicycle accessibility

We saw in subsection C.2 that 91.5% of the respondents own a driving license, however only 87.4% of the female respondents own one, while 94.9% of the male respondents do.

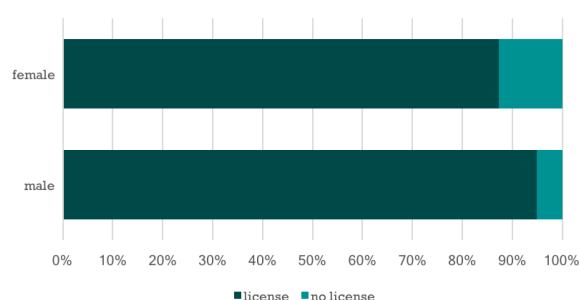


Figure C.15: Gender bias in driving license ownership

In light of the bicycle access structure highlighted above, Figure C.16 shows strong differences in cycling frequency between men and women, although the differences in bicycle access among genders are not significant enough to explain all of the variance.

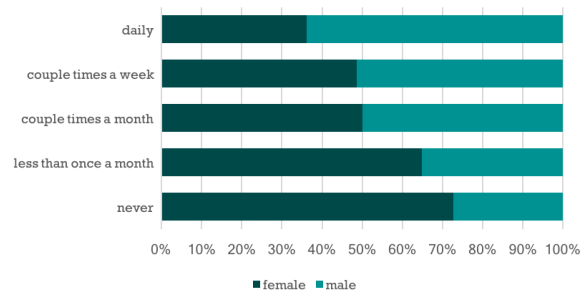


Figure C.16: Gender effect on cycling frequency

Figure C.17 highlights another interesting insight in the data: male respondents learned how to cycle at a younger age than women. However, one can see that the gender bias fades out for those who learned how to cycle at an age of 10 or more (although the number of respondents on those age groups are relatively low compared to the younger age groups).

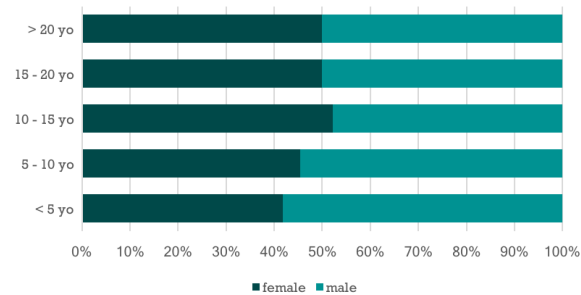


Figure C.17: Gender bias on acquiring cycling skills

C.4.3. Cultural context

Figure C.18 shows the country of origin and the country of residence of the survey respondents, respectively. The Netherlands, France, and Canada are, without surprise, over-represented due to the personal, educational, and professional history of the author of this thesis. These three countries, as well as the United States (fourth largest contingent of respondents) are further analysed below to give insights on potential cultural bias that may exist in the data.

The Netherlands is a country famous for its cycling culture, which arose in the 1970s and has since never stopped to progress. Conversely, the American cycling culture is still in its infancy. It is therefore logical that children living in a country where cycling is essential to daily life learn how to cycle at an early age. Figure C.19 confirms this premise, and tells us that 66.0% of Dutch respondents have learned how to cycle before 5 years old, while this number plummets dramatically to 25.7%, 21.5%, and 4.8% for French, Canadian, and American respondents, respectively.

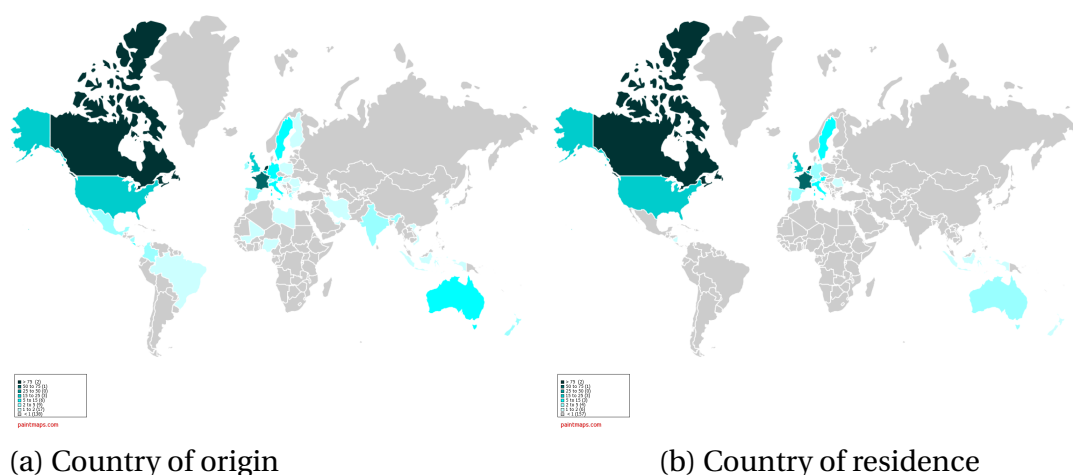


Figure C.18: Country of origin and residence of the survey respondents

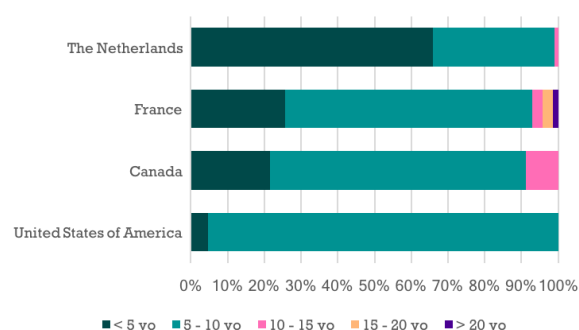


Figure C.19: Age at which cycling skills were acquired in four countries

Interestingly enough, more French respondents stated that they cycle daily than the Dutch (Figure C.20). Again, caution must be taken in interpreting cycling frequency results, as survey respondents are not likely to be representative of habits in their respective countries. Still, it is interesting to see that the European context - dense town centres, mixed used zoning, traffic calming measures, etc. - is encouraging people to cycle more often than the North American one - low density, single use zoning, wide boulevards, etc.

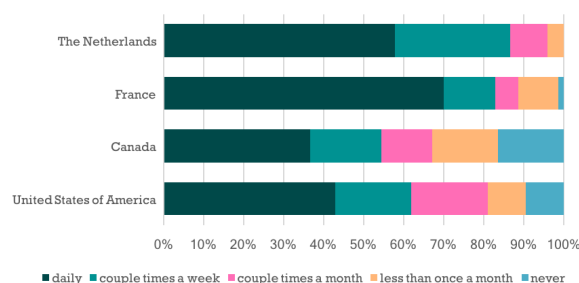


Figure C.20: Cycling frequency in four countries

Figure C.21 shows the main mode of transportation chosen by Dutch, French, Canadian and American respondents, respectively. In all four countries, the bicycle is chosen as the main mode to go to work/university. While Dutch and French respondents choose to cycle or drive to other destinations, Canadians and Americans make much greater use of the public transportation system.

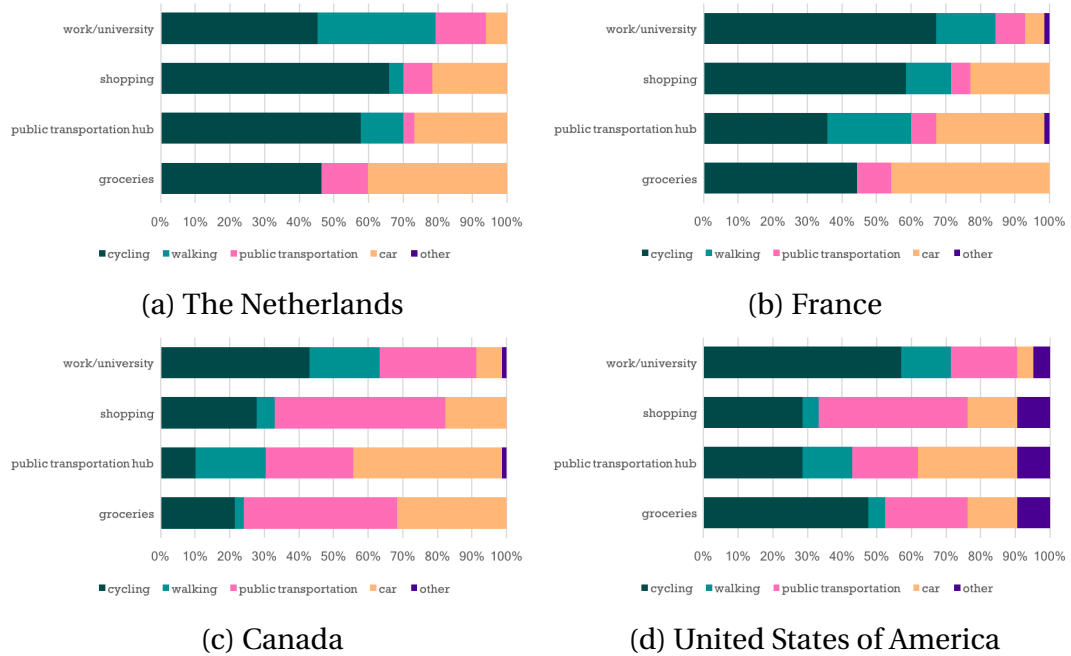
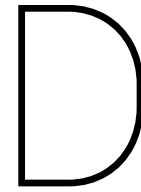


Figure C.21: Main mode of transportation used by respondents of four countries to reach common destinations



Final survey respondents' choices

In this appendix, each picture corresponds to a question of the online survey, and a heat map shows the combination of the respondents' speed (A = accelerating, C = constant speed, S = slowing down) and position (L = left, T = through, R = right) manoeuvring choices. The first 20 questions are answered from the perspective of a cyclist, while the last 20 questions are answered from the perspective of a pedestrian. The two sets follow the design shown in Table [D.1](#).

Table D.1: Final survey choice sets

Question	<i>distance</i>	<i>direction</i>	<i>eye contact</i>	<i>group size</i>	<i>context</i>
1	close	facing	yes	1 person	none
2	far	crossing	yes	3 people	none
3	close	crossing	no	1 person	none
4	far	facing	no	3 people	none
5	close	crossing	yes	3 people	none
6	close	facing	no	1 person	none
7	close	facing	yes	3 people	none
8	far	facing	yes	1 person	none
9	far	crossing	yes	1 person	none
10	far	crossing	no	1 person	none
11	close	crossing	no	3 people	none
12	far	facing	no	1 person	none
13	close	facing	yes	1 person	with friends
14	close	crossing	no	1 person	with friends
15	far	facing	no	3 people	with friends
16	far	crossing	yes	3 people	with friends
17	close	facing	yes	3 people	rushing to train
18	close	crossing	no	3 people	rushing to train
19	far	facing	no	1 person	rushing to train
20	far	crossing	yes	1 person	rushing to train



(1) Image

A			
C			
S			
	L	T	R

(1) Manoeuvres



(2) Image

A			
C			
S			
	L	T	R

(2) Manoeuvres



(3) Image

A			
C			
S			
	L	T	R

(3) Manoeuvres



(4) Image

A			
C			
S			
	L	T	R

(4) Manoeuvres



(5) Image

A			
C			
S			
	L	T	R

(5) Manoeuvres



(6) Image

A			
C			
S			
	L	T	R

(6) Manoeuvres



(7) Image

A			
C			
S			
	L	T	R

(7) Manoeuvres



(8) Image

A			
C			
S			
	L	T	R

(8) Manoeuvres



(9) Image

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(9) Manoeuvres



(10) Image

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(11) Image

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(11) Manoeuvres



(12) Image

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(12) Manoeuvres



(13) Image

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(13) Manoeuvres



(14) Image

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	L	T	R

(14) Manoeuvres



(15) Image

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	L	T	R

(15) Manoeuvres



(16) Image

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	L	T	R

(16) Manoeuvres



(17) Image

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(17) Manoeuvres



(18) Image

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	L	T	R

(18) Manoeuvres



(19) Image

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	L	T	R

(19) Manoeuvres



(20) Image

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(20) Manoeuvres



(1) Image

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(1) Manoeuvres



(2) Image

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(2) Manoeuvres



(3) Image

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(3) Manoeuvres



(4) Image

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(4) Manoeuvres



(5) Image

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(5) Manoeuvres



(6) Image

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(6) Manoeuvres



(7) Image

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(7) Manoeuvres



(8) Image

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(8) Manoeuvres



(9) Image

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(19) Manoeuvres



(20) Image

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(20) Manoeuvres

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