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Travel time perception of active mode users

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Travel time perception of active mode users

By

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Cover image: Adapted from Salvador (1931). *The Persistence of Memory.*

Preface

This thesis is the final step before graduating from the master's in civil engineering, Transport and Planning track, at TU Delft. I would like to grab the opportunity given to me via this report, to thank the people who have assisted in this challenging yet exciting journey.

First of all, I would like to express my gratitude to my two main supervisors, Winnie Daamen and Florian Schneider. Thank you both for letting me work on a research area that I am passionate about and motivating me to face any challenges that the conduction of a master thesis involves.

Winnie, since I met you as a tutor of one of my classes, I have been impressed by your dedication to research and your work ethic. I am grateful that you allowed me to work close to you and to learn from you. I have benefited immensely from your detailed and extended feedback. You have challenged me to always be critical and pay attention to both the details and the bigger view of my project.

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I am deeply grateful to both of you, Winnie and Florian, for being there for me in my most and least productive periods. Over the last year, you have been supportive not only in terms of the thesis but also in the personal difficulties that I faced. In the aftermath, I couldn't be happier with my decision to work on my master thesis under your supervision.

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This thesis wouldn't have been possible without the tremendous contribution of Tim van Oijen. Tim, thank you for cooperating with me and including me in the design of the mobile app. It was exciting to work with you. You made the data collection period much less stressful and more enjoyable. I am delighted that our long and repetitive, over day and night meetings were not in vain and that this thesis demonstrates the potential of the mobile app.

Of course, I also want to thank my friends. Panos and Dimitris, thank you for the endless discussions both on my thesis and on any transport-related topic. Alexandra, thank you for all the fantastic moments we shared over the last year! I thank all three of you for our warm friendship. My lovely Paula, thank you for being the best study partner and for inspiring me since we met. Our chocolate breaks have been super powerful! To my friends from Greece, Natasa, Anna, Danai,

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Roxani Gkavra

Delft, December 2020

Executive Summary

Time is an integral part of all human activities. However, since there is not a dedicated sensory or brain region dedicated to the perception of time, the ability of people to estimate the duration of a stimulus is restricted and dependent on multiple factors (Grondin, 2010). The perception of time has attracted the attention of various fields of research, including among others transport planning. In the latter, the perception of travel time is investigated. Travel time is one of the most widely considered variables in the design of transport systems as well as in the investigation and the prediction of travel behavior and travel choices. However, up to date, there is limited knowledge on the perceived trip duration, its differentiation from the objectively measured travel time, and its impact on travel behavior.

Active modes, including walking and cycling, are prominent modes of transport in the daily life. Active modes have numerous advantages for both individuals and the society overall, such as health and environmental benefits. Thus, over the last few years, a lot of effort is put by both practitioners and researchers towards encouraging their usage and increasing their modal share. Nevertheless, the amount of research on the travel time perception of active mode trips is still disproportionate to their importance in the transport systems. Especially regarding the travel time perception of cycling trips, there is almost complete ignorance. Past research on car and public transport-based trips suggests that travelers overperceive the duration of their trips. However, cycling and walking trips differ from car and public transport trips in many aspects, including among others, the required physical effort, the interaction with the environment, the vulnerability to external conditions such as the weather, and the activities performed during these trips. Thus, the travel time misperception of active modes trips could differ from the one found for transit and car trips, and further research is required.

To fill in this research gap, this thesis aims at broadening the knowledge on the perception of travel time of active mode trips, by quantifying the deviation of the perceived from the actual trip duration. The thesis objective can be reached by answering the following main research question:

What is the relationship between perceived and actual travel time of pedestrians and cyclists, and which individual, trip-related, and external factors do influence it?

To identify the travel time misperception of active mode users, it is necessary to obtain information on objective and subjective travel time and the possible determinants of travel time misperception. Thus, data need to be collected. Previously used methods are either limited to a single mode e.g. GPS loggers, or have a low level of detail e.g. average travel time reports. To overcome these limitations, the present study proposes the gathering of data via a mobile

application. A mobile application developed in the Active Modes lab of Delft University of Technology (TU Delft), the UMO Research app, has been designed to serve the purpose of the present study. The app allows the simultaneous participation of multiple individuals in the collection of data, and, consequently, the recording of many travel time perception reports at the same time. In addition, it facilitates multiple data collection sources, including a location data (GPS) source and surveys.

The literature on both time perception and on travel time perception recommends that multiple factors could influence time misperception. The present pandemic circumstances during the period that this research is conducted, indicate that additional factors could affect the travel behavior and the emotional state of individuals. The selection of the factors that the present study considers is based on three criteria; the relevance to the characteristics of active mode trips, the extent of the documentation of their effect on travel time in the literature, and the ability to collect data on them, via a smartphone application. The selected factors are summarized in Table 1. Based on the expected impact of the selected factors, the research hypotheses are formulated. Among others, the return home effect and the influence of the actual travel time are tested.

Table 1. Selected factors

Subgroup	Factors
Individual characteristics and experience	Demographic Socioeconomic Emotional state Effort
Trip characteristics	Trip purpose Trip frequency Trip familiarity Trip flexibility Home inbound/outbound Duration Travel mode Peak/Off-peak
Context	Weather Nature

Individual level, Trip level

To collect data on all considered potential decisive factors of travel time misperception, two surveys have been structured and included in the app. The first survey is divided into two parts. The first part gathers information on the personal and the sociodemographic characteristics of each person. The second part captures the perception of trip duration of active mode trips via the presentation of three short cycling trip videos. The inclusion of the videos allows for testing the hypothesis on the effect of some factors in an experimental setup and provides the opportunity to test whether there is a significant relationship between the judgment of trips in the range of seconds (trip films) and of longer real-life trips which last some minutes or even hours. The second survey is on a trip level. In this survey, the perceived trip duration is reported. Respondent must complete the latter survey right after the completion of each of the trips that they conduct. A third additional evaluation survey has also been included in the app to capture the satisfaction of the individuals with their participation and their interaction with the app.

The data collection period lasted for two weeks in June 2020, in the Netherlands. In total, 76 people registered for the research. However, after processing the data and applying filters for invalid trip registrations, travel time reports of 44 people have been included. The descriptive statistics of the set of participants show that male, young, and highly educated people are overrepresented in the sample. The increased participation of these groups could be attributed to the fact that a large part of the respondents is a member of the TU Delft community. Furthermore, the stress level of the participants during the data collection period has been quite high, especially of the older participants. The pandemic circumstances, during the data collection period could have affected the stress level.

The filtered dataset contains 177 travel time perception reports of cycling and walking trips which account for almost 70% of the total trip observations. Unlike, the usual modal split in the Netherlands, in which more trips by bike than on foot are noticed, the ratio of walking to cycling trips is over 1 in the obtained dataset. A large variation is noticed in the objectively measured travel time (2.8- 1240 minutes), as well as in the perceived travel time (2- 200 minutes).

The descriptive statistics of the sample of participants and trip observations indicated that the collected data might not represent well the broader Dutch population, the common emotional state, and the usual mobility habits. However, the data collection effort has provided a rich data set of active modes trip records with a heterogenous set of actual and perceived trip durations which is sufficient for the analysis of the travel time misperception error under different trip circumstances. In addition, a set of observations (N= 70) of public transport and car trips are also included in the obtained dataset. Thus, the collected data allow the comparison of the travel time misperception among different modes of transport as well as to the findings of past research on car and transit travel time distortion.

The main dependent variable in the analysis of travel time misperception is the travel time distortion ratio (τ_{dist}), which is defined as the ratio of the subjective over the objective travel time. A value above and lower than 1 indicate an overestimation and underestimation of travel time, respectively. The determinants of the travel time misperception ratio have been examined via regression models. Ordinary least square linear regression models have been estimated for the total sample of cycling and walking trips, as well as for the underestimated and the overestimated trips separately. Furthermore, the misperception per mode of transport has been investigated.

The regression models managed to explain around 50% of the variance of travel time misperception. The model, which is estimated based on the overestimated active mode trips, has the highest explanation power (~65%). High physical exertion and poor weather conditions are significantly related to longer perceived travel time. The impact of the actual travel time is also found significant. With respect to the latter, the direction of the effect supports the hypothesis that the misperception error is larger for shorter than longer trips.

Apart from the linear regression model, a binary logistic regression model is estimated with the direction of the misperception error as the dichotomous variable (0: underestimation, 1: overestimation). The model estimation results indicate that the probability of overestimating a trip is lower for trips towards home, or when the traveler is very satisfied with the used infrastructure. A significant effect of gender has been found, showing that men tend to underestimate trip duration more than women. Moreover, the agreement between the expected trip duration before the initiation of a trip and the perceived travel time after its completion is related to a higher chance of underestimating the trip duration.

Although the dataset has been an unbalanced panel dataset, the estimation of random effects model has shown that the variance within individuals is higher than the variance between different people. This indicates that the perception of travel time of a person is not necessarily consistent across different trip conditions and under diverse circumstances. The variation in the experienced trip circumstances, individual state, and a possible learning effect could have contributed to this result.

From the findings of the present study, multiple conclusions are drawn. Firstly, the trip duration of cycling and walking trips is misperceived by travelers. Most people underestimate the travel time of trips conducted by active modes. This finding is relevant for both transport system designers and researchers since it could impact the mode choice behavior of travelers. From a societal point of view, the fact that cyclists and pedestrians perceive their trips as shorter than they are, indicates that perceived disutility introduced by time spent on travelling by these modes could be lower than the objectively measured. Thus, apart from the other benefits of active modes, an increase in their modal split could also reduce the discomfort that people experience due to travelling.

In addition, the underestimation of cycling and walking travel time contradicts the overestimation of travel time of trips conducted by car or public transport. The latter has been found both in the present study as well as in past research. The travel motives for which people choose to cycle or walk could have influenced the difference in travel time misperception direction.

Regarding the contribution of this research to the time perception literature, the results of the present study support the idea by a part of the research community that the exploration of the determinants of travel time perception provides deeper insight by splitting the time reports between those in which travel time is overperceived and underperceived.

Despite the interesting findings of the present research, the study has limitations. First of all, due to the fact that individuals responded to the same survey after each trip, they might have become aware of the travel time estimation task and could have paid more attention to the passage of travel time during their trips. In such a case, their trip duration reports belong to the prospective and not to the retrospective time estimation paradigm. Moreover, in terms of the research sample, the sample has not been representative of the study population. Thus, the findings only provide an indication of the actual travel time misperception of cycling and walking trips in the Netherlands and cannot be generalized to the corresponding population of active mode users. Besides, in the collected data points on perceived travel time, rounding of travel time has been very common. Due to rounding, it is possible that the reported travel time deviates from the trip duration that people perceive.

The present study has allowed for developing many recommendations for future research. Related to the limitation of the methodology of the present study, future research could ensure that travel time is always estimated retrospectively by alternating the travel time perception question or the type of task required e.g., temporal bisection task.

Further research could be conducted on the impact of the deviation between perceived and actual travel time on the travel behavior of cyclists and pedestrians. To the author's knowledge, no study has considered the misperception of travel time on travel choice behavior of pedestrians and cyclists. Moreover, factors which were not observed in detail in this study could be examined in further research such as the emotional state of the individuals.

Finally, this research is the first effort to exploit a mobile application for the collection of data for travel time perception research. Overall, the app has been proven suitable for the collection of data both on the perceived and the objective travel time, and on trip and individual characteristics. Based on this experience, some suggestions for future usage of the Umo Research app or of other similar apps are made. In future endeavors, the application of algorithms on the collected GPS points, which allow the automatic detection of the mode of transport used, and of the initiation and the termination of a trip, could decrease the task demand from the respondents. Furthermore, by requiring less interaction with the mobile application it is possible that individuals check less often the time. Thus, their time awareness could be reduced, and their reported travel times could be closer to those that they perceive.

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Glossary

Term	Definition
Active modes	Walking and cycling. Cycling includes trips by all types of bikes, including e-bikes
Actual travel time	The clock time elapsed between the start and the end of a trip. Alternative terms are objectively measured travel time, objective travel time
Travel time misperception	The deviation between the actual and the subjective travel time. Alternative terms which are used are: travel time distortion, travel time perception error
Perceived travel time	The amount of time that an individual considers that has elapsed between the start and the end of a trip. Alternative terms are subjective travel time and reported travel time
Travel time distortion ratio	The ratio of the perceived over the actual travel time

“Time is not something objective and real, it is not a substance, not an accident, neither an attitude, but a subjective condition”

Immanuel Kant

1 Introduction

Dissimilar to the rest of physical and emotional dimensions, time is omnipresent (Grondin, 2010; Matthews & Meck, 2016; Mione, Grondin, Bardi, & Stablum, 2020). Simultaneously, there is neither a sensory system nor a brain region dedicated to the processing of time (Matthews & Meck, 2016; Mione, Grondin, Bardi, & Stablum, 2020). Although many researchers in the fields of neuroscience and psychology have tried to develop models that describe the perception of time by humans, there is still a lack of consensus (Wittmann, 2009).

While neuroscientists and psychologists target to understand the process of time perception, the embedding of time in all of life's aspects attracts the attention of researchers in many other domains. A lot of research comes from the fields of marketing, consumer, and transportation research literature. Most of the studies in these three fields have been dedicated to the perception of the waiting time for the relevant service such as public transport service, hospitals, banking (Antonides, Verhoef, & van Aalst, 1996; Meng, Rau, & Mahardhika, 2018). However, regarding travel behavior, research has been conducted on understanding not only subjective waiting time but also perceived total travel time.

The implication of perceived travel time in travel behavior is multifold. Trip duration could be considered by travelers as smaller, equal or larger than the actual travel time. In the case of inequality, misperceived travel times could have explanatory power on travel decisions (Grondin, 2010). For example, time perception or time cognition capability of travelers has been identified as a possible root for their selection of routes that are longer than the shortest path (Tang & Levinson, 2018). For elderly pedestrians, the estimation of the time required to cross a road section in conjunction with the judgment of the traffic gap is crucial for their road safety (Naveteur, Delzenne, Sockeel, Watelain, & Dupuy, 2013). Perceived travel time of individuals also defines the subjective accessibility to various destinations, for example, hospitals, schools, gyms, parks, and shops (Dewulf, Neutens, Van Dyck, de Bourdeaudhuij, & Van de Weghe, 2012). The overestimation of walking time to such points of interest could decrease the willingness of people to travel on foot to these destinations, and could consequently deteriorate their level of physical activity (Dewulf, Neutens, Van Dyck, de Bourdeaudhuij, & Van de Weghe, 2012). Apart from the importance of time perception in decision making, perceived travel time affects the overall travel experience (Meng, Rau, & Mahardhika, 2018).

Travel time is widely considered as wasted time that should be minimized. However, a part of the scientific community supports that travel time can be thought to enhance the utility of a trip in case travelers are active, productive or travel time is quality time (Price & Matthews, 2013). In the case of active mode trips, the time spent in travel provides additional benefits such as physical activity and socializing and, consequently, an enhanced life satisfaction (De Vos, Schwanen, Van

Acker, & Witlox, 2019). The theory on time perception indicates that many factors impact the differentiation of the perceived from the actual time duration. Familiarity, predictability, attentional resource availability, arousal, and emotions have been proven to influence time perception. The mentioned added value of walking and cycling and other characteristics of active mobility, such as weather sensitivity and requirement for increased (physical) effort, could, as such, impact perceived travel time of active mode trips. Up-to-date, little research has been done to investigate the perceived travel time of pedestrians and cyclists (Meng, Rau, & Mahardhika, 2018).

Based on the topics introduced above, this thesis aims at generating knowledge on the judgment of the travel duration for trips conducted on foot or by bike and the deviation between the perceived and the actual travel time, as well as, at investigating the factors that influence it.

1.1 Research context

Most transport travel route and travel mode choice models are based on the concept of utility maximization. Therefore, it is important to understand the utility that people consider in their decision making. Regardless of the applied choice modelling technique (e.g., Logit model, Probit model, and Artificial neural networks), travel time is one of the most commonly considered utility parameters (Jing, Zhao, He, & Chen, 2018). A mismatch between actual and perceived travel time entails a deviation of the subjective travel utility from the objectively measured one. Before being able to evaluate the effect of including perceived instead of realized travel time in transport modelling, it is necessary to get knowledge on travel time misperception and its determinants.

Many researchers in the time perception field have already tried to identify factors that affect time perception. However, most of the research on time perception focuses on short time intervals, in the spectrum from milliseconds and up to hundreds of seconds (Block, Grondin, & Zakay, 2018). Common travel time exceeds this range and, thus, different aspects may affect travel time perception. It is necessary not only to identify these factors but also to understand the degree and direction of their influence. Considering the growing interest in the promotion of active modes and the limited research that has confronted the time perceptions of their users, this research aims at getting insight into travel time perception of cyclists and pedestrians.

1.2 Research objective and research questions

The objective of this research is to broaden the knowledge on travel time perception of both cyclists and pedestrians by quantifying the mismatch between their subjective and objective travel time and by defining the factors that contribute to it. The thesis also aims at determining the design requirements of a data collection tool which enables the acquisition of data on both the subjective and the objective travel time of active mode users, as well as on relevant factors. More specifically, as new opportunities arise from the fields of mobile communication and applications, the necessary functions of a mobile application are to be specified.

The main research question of the present study is formulated as follows:

What is the relationship between perceived and actual travel time of pedestrians and cyclists, and which individual, trip-related, and external factors do influence it?

Besides the main research question, other, supporting, questions are proposed. The sub-questions assist in revealing the various sub-topics that should be investigated and the knowledge that should be generated to achieve the research objective. The sub-questions are formulated as follows:

- *Which is the definition of time perception? (SQ1)*
- *How does the notion of time perception vary among studies on time and travel time perception? (SQ2)*
- *Which methods are suitable for the investigation of perceived time? (SQ3)*
- *Which indicators can be used to capture the relationship between perceived and actual travel time? (SQ4)*
- *Which are the data requirements to capture both perceived and realized travel time? (SQ5)*
- *Which methods can be applied to derive travel time information from empirical travel data? (SQ6)*
- *How suitable is a mobile application as the single data collection tool for travel time perception research? (SQ7)*
- *What is the deviation between subjective and objective travel time for different demographic and socioeconomic groups and trip characteristics? (SQ8)*
- *What is the influence of external factors, such as the weather, in the perceived trip duration? (SQ9)*

1.3 Research approach

To answer the research questions which were introduced in the previous section the research is divided into the literature body that is to be reviewed, the data collection approach, and the analysis that should be performed. In Figure 1.1, the research approach is visualized. The number(s) within the “speech bubbles” shows the corresponding number of research sub-question(s) that is answered in the indicated step.

The first three sub-questions aim at getting insight into the theory of time perception. Various terms and taxonomies have been used to describe perceived time. To specify the definition of perceived time in the context of this thesis, it is essential to study the relevant literature. The literature not only on time perception but also on travel time perception should be reviewed, since those address different time intervals and consider different factors.

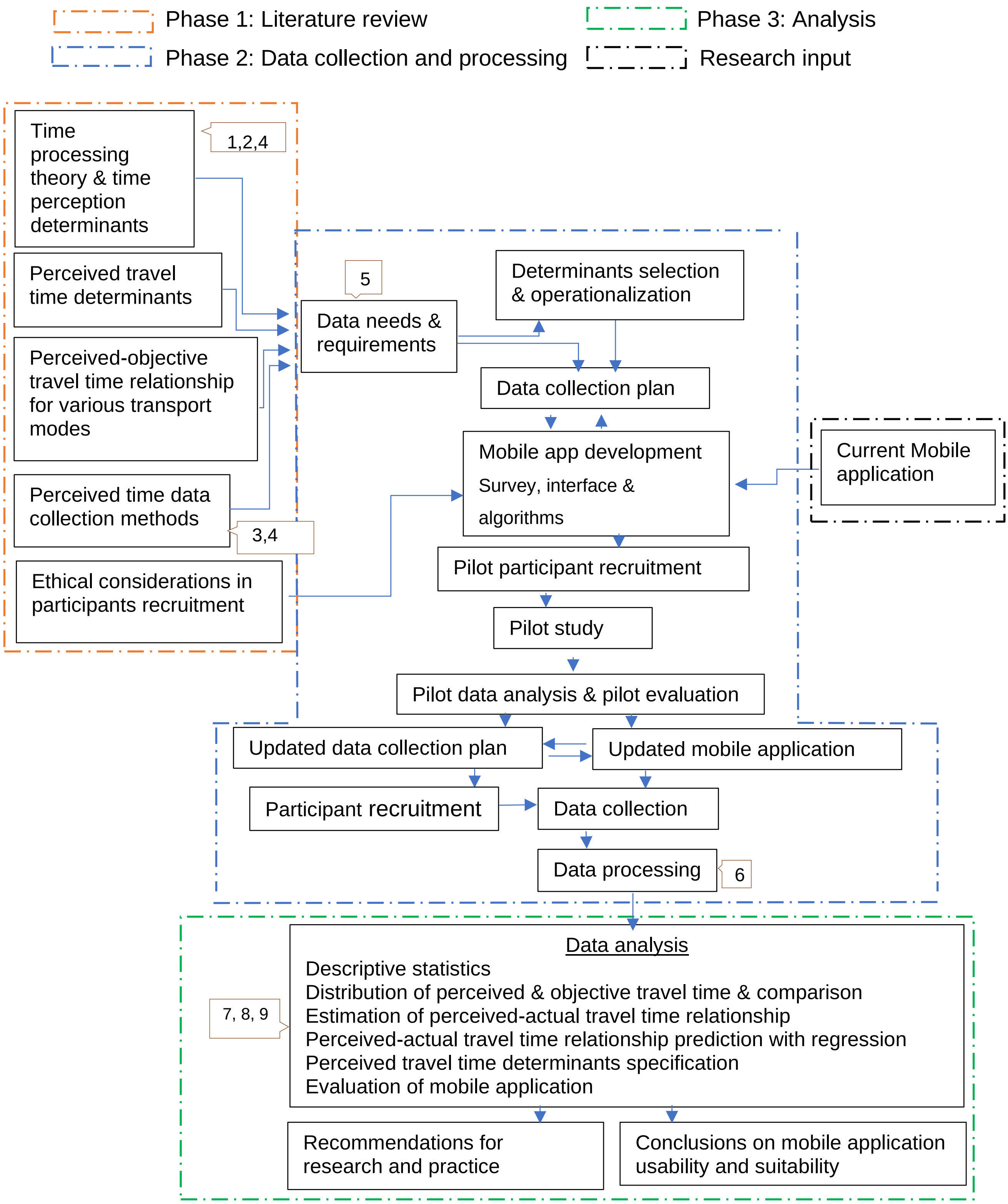

Figure 1.1. Research approach

The third and fourth sub-question triggers the investigation of the methods which can be used to capture people's time perception, calculate actual time and, subsequently, quantify travel time misperception. Reviewing the literature on travel time perception could reveal the available approaches for the estimation of perceived travel time duration

Besides, answering the fifth sub-question requires getting information on the factors that affect perceived time. Those factors, in conjunction with the applicable methods, will determine the design of the selected data collection method.

Sub-question number six (SQ6) reveals the extent to which the gathered data need to be processed before continuing to the analysis. The extraction of the objective and subjective travel time from raw travel data is essential.

Answering the seventh sub-question necessitates the collection of data on perceived and objective travel time via a mobile application. The analysis of the quality of the data and the assessment of the data collection tool from the participants will reveal its suitability for the research.

The last two sub-questions relate to the empirical analysis of the relationship between subjective and objective travel time. The comparison between different groups of participants will reveal the influence of socioeconomic, demographic, and trip characteristics in time perception. Similarly, the impact of other factors will be examined in terms of the significance and the direction of their effect.

1.4 Research contribution

Answering the research questions of this master thesis could contribute to both science and practice.

Practical implications: Identifying the factors that affect perceived travel duration could be useful for the design of transportation systems. The elements which contribute to diminished subjective travel time and, subsequently, to the discomfort introduced by travel, could be considered as crucial for the attractiveness and the usage of a system. Apart from its usefulness for system design, understanding the determinants of the travel time misperception, could be valuable for personalized trip information applications. To be more specific, knowledge of an individual's perceptions of travel time could assist route, activity location, and trip scheduling applications in offering recommendations that optimize individual subjective travel experience.

Research implications: A scientific contribution of this thesis is the quantification of the deviation between subjective and objective travel time for trip purposes, apart from commuting. So far, most research has focused on time perception of compulsory trips. Similarly, this thesis is one of the first attempts to investigate the subjective time of pedestrians and cyclists. Besides, quantifying the difference between perceived and objective travel time raises the question of which of the two durations should be applied in transport modelling and prediction. Research on the value of time could benefit too. This thesis also adds to the literature regarding the applicability of mobile applications as travel data collection tools. Moreover, considering the circumstances during which the current project takes place, the present research contributes to the knowledge on the mobility level and behavior in the era of the Covid-19 pandemic. Finally, the present study enriches the literature on retrospective time perception and, in specific, the perception of time intervals in the range of couple of minutes.

1.5 Thesis structure

After this introduction to the research context, scope, and approach the available relevant literature is reviewed, in the next chapter (Chapter 2). Based on the findings of Chapter 2, in Chapters 3 and 4, the conceptual and the experimental design of the present research are addressed. In Chapter 5, the process for the collection of data on both the objective and the subjective trip duration is described. In Chapter 6, the results of the study are presented, and travel time misperception is quantified. The last chapter is dedicated to the conclusions of the present study and the derived recommendations for future research on travel time perception (Chapter 7).

2 Literature review

The sense of time is pivotal in human life. Fundamental processes, such as control of body movement, rely on the ability of humans to keep track of time. However, distorted time perception is common and is noticed in a wide spectrum of time durations. Researchers from various fields have put effort to determine the extent and the reasons for misperception of time. This chapter provides an overview of the existing literature on time perception and of the current knowledge on the time perception of travelers. The literature review aims at providing insight into the process and stimulators of time perception. The available methods to collect relevant data and to quantify the deviation between actual and subjective travel time are studied alongside. The research sub-questions that are listed below, are those addressed in this chapter.

- *Which is the definition of time perception? (SQ1)*
- *How does time perception notion vary among studies on time and travel time perception? (SQ2)*
- *Which methods are suitable for capturing the perceived travel time? (SQ3)*
- *Which indicators can be used to capture the relationship between perceived and actual travel time? (SQ4)*

This review is divided into two parts. The first part is dedicated to the notion and the process of time perception. To understand the reasoning behind the selection of parameters that are included in travel time perception studies, it is essential to discuss the mechanisms and the factors which regulate time processing. The overview of the time perception literature answers two additional research questions. These questions support the above-mentioned question SQ1, and reveal key topics that need to be explored

- *What theories have been developed for the processing of time?*
- *Which factors influence subjective time?*

In the second sub-chapter, the focus is shifted to the perception of travel time. Past research on various modes of transport as well as the applied data collection methods are investigated. Similar to the previous part, two more research sub-questions direct the literature review on travel time perception.

- *Which data collection methods have been applied in the travel time perception literature?*

- *Which is the relationship between perceived and actual travel time based on empirical results?*

As it is revealed throughout this literature review, it is necessary to separately study time and travel time perception. Although studies of these two fields share the same core topic, there is variation regarding the data collection methods, the range of examined time intervals, and the operationalization of the considered variables.

The chapter closes by drawing conclusions on the reviewed literature and recognizing the existing research gaps.

2.1 Time perception

In this subchapter, the fundamental elements of time perception are discussed. First, classifications of the time perception notion are reported, followed by two models that have been developed to explain the process of time. Next, the approaches that are capable of capturing time perception are presented. The current subchapter closes with an overview of the factors that have been associated with time perception in the literature.

2.1.1 Time perception definition

Thones and Stocker (2020) define subjective time as “the conscious or unconscious mental representation of physical temporal information “.

Cognitive psychologists make a distinction between prospective and retrospective time estimation research (Eisler, Eisler, & Montgomery, 2007; Grondin, 2010; Matthews & Meck, 2016). In the prospective domain the subjects are aware beforehand that they are required to perform a time-related task. Conversely, in retrospective studies, participants are informed for the requirement to judge a time interval only after its completion. Most research within the prospective and retrospective spectrum examine time processing of brief (from milliseconds and up to some seconds) (Bisson, Tobin, & Grondin, 2008) and of longer periods (tens of seconds and more) (Matthews & Meck, 2016), respectively. Only very few studies address perception of time in the range of several minutes.

It is considered that dissimilar cognitive mechanisms are engaged in the prospective and the retrospective timing. Prospective time judgment is dominated by the availability of attentional resources whereas retrospective is guided by memory mechanisms (Grondin, 2010). There is some evidence on the independency of the two timing paradigms (e.g., Davydenko & Peetz, 2017), yet the oppossite is supported by other stydies too (Grondin & Laflamme, 2015).

In a different taxonomy, timing tasks are divided into implicit and explicit. In the case of explicit timing paradigm, research participants are specifically instructed to concentrate on the duration of an introduced stimulus or an action. In implicit timing tasks, subjects are not specifically requested to estimate a duration but are rather instructed to perform a task which implicitly activates timing mechanisms (Coull & Nobre, 2008).

In addition, time perception is divided into subjective and objective. Subjective time is defined as "the reported feeling or personal, private of psychic time" while the estimation of an individual regarding time refers to the objective time perception (Cappon & Banks, 1964).

2.1.2 Time processing models

Despite the ubiquity of time, there is neither a sensory system nor a brain area dedicated to time. Many research efforts have been undertaken to understand the process of time perception. Psychologists, as well as neuropsychologists, have come up with a series of models that try to structure the underlying process of time perception (Wittmann, 2009).

The basis for one of the most popular prospective timing models is the belief that there is an internal clock that is responsible for time perception (Church, 1984). Building on the internal clock theory, the Scalar Timing model supports that this clock is constituted of three distinguished processing stages: The clock stage, the memory stage, and the decision stage. The clock stage contains a pacemaker. The pacemaker begins to emit pulses every time a stimulus is activated. These pulses are aggregated in another component of the clock stage: The accumulator. In the memory process stage, the concentrated pulses are compared to the duration value of an equally long event that is stored in long-term memory. In the latter stage, the required time length is estimated based on the proximity of the saved timespan to the observed duration and a considered decision rule (Church, 1984; Gibbon, Church, & Meck, 1984). The rate of ticks' production is not stable and fluctuates depending on multiple factors (Matthews & Meck, 2016).

The attentional-gate model is a version of the "internal-clock" model. The differentiation between the two versions lies in the way that pulse generation is activated. As the name reveals, attention directed towards time is the element that triggers pulse emission (Zakay & Block, 1997). The more attention is paid to the elapse of time, the longer the perceived duration (Grondin, 2010).

In retrospective time estimation, people reconstruct the elapse timespan from memory. The number of changes that people face during the referred time length affects their ability to mentally reconstruct it and, subsequently, estimate its duration (Wittmann, 2009).

Literature on psychology and psychophysics support that subjective time follows a psychophysical law (Grondin, 2001). The psychophysical law is expressed as a power function, also referred to as Steven's law and is presented in Equation 1:

$$S = K * (\Phi)^b \quad \text{(Equation 1)}$$

Where:

S is perceived time

Φ is the actual (chronometric) duration

K, and b are model coefficients

The exponent parameter *b* shows the rate of change of the perceived time. If **b**<1 (or *b*>1) then subjective time increases less intense (or faster) than clock time (Grondin, 2010).

2.1.3 Perceived time data collection methods

Temporal bisection tasks have been applied to examine the perception of prospective timing. They are commonly used to investigate time distortion for durations that vary between milliseconds and seconds. Participants are asked, for instance, to characterize each presented stimulus as “shorter” or a “longer” than a reference timespan (Sowman & Wehrman, 2019).

Verbal estimation is an additional method to capture subjective time. Verbal estimation tasks demand from individuals to report the duration between two events e.g., two sound or auditory signals. Verbal estimation tasks are applicable for the judgment of duration in the spectrum of both seconds (Grondin & Laflamme, 2015) and minutes (Droit-Volet, Monceau, Berthon, Trahanias, & Maniadakis, 2018). The inclusion of term verbal should not mislead the reader to the assumption that time duration is reported exclusively verbally. Verbal estimations have also been recorded via mobile application.

Duration reproduction tasks inquire from individuals to replicate an interval that has been previously presented to them (Grondin & Laflamme, 2015). Duration reproduction and verbal estimation have been tested in prospective as well as in retrospective conditions.

Time estimation is often captured by requesting people to fill out questionnaires or surveys. Depending on the investigated time aspect, the formulation of the presented question varies. In Table 2.1, some alternative questions that are spotted in the literature are presented.

Psychophysical indicators could also reveal the subjective time perception. The activity of facial muscles such as Corrugator-supercilii (Fernandes & Garcia-Marques, 2019), and heart rate (Meissner & Wittmann, 2011) seem to provide some insight into how people experience time. However, as shown by the study of Otten’s team (Otten, et al., 2015), the power of these measures to reveal time perception is still indecisive. It seems, though, that they could offer interesting insight when used together with perception tasks, especially regarding the recognition of the arousal state (Wittmann, 2009).

Table 2.1. *Alternative questions on examining time perception*

Question Formulation	Response type	Time aspect	Study
How is time passing for you between the ... and... compared to the time of the clock, from "much slower" to "much faster?	Likert item	Time Passage	(Droit-Volet, Monceau, Berthon, Trahanias, & Maniadakis, 2018)
"It feels like it's taking forever to …"	5-point scale	Time passage	(Rankin, Sweeny, & Xu, 2019)
"It feels like I'll… before I know it"	5-point scale	Time passage	(Rankin, Sweeny, & Xu, 2019)
Estimate time between two signals, and a minimum and maximum	ss	Time Duration	(Grondin & Laflamme, 2015)
Intuitively (without thinking or counting), I have the impression that this … lasted … minutes and … seconds''.	mm and ss	Time Duration	(Bisson, Tobin, & Grondin, 2008)

2.1.4 Time experience determinants

Numerous variables appear to be connected to the distortion of temporal processing. In this section, an overview of the appointed factors and their influence on time perception is discussed. Subjective time determinants could be divided into five broad categories: Stimulus, activity, environment, individual state, and personal and sociodemographic characteristics (Table 2.2).

Table 2.2. *Time perception influencing factors*

Stimulus	Individual State	Individual characteristics	Environment	Activity
Temporal uncertainty Temporal relevance Duration Speed & direction of movement	Emotions Temperature	Gender Age Personal traits	Monotony	Effort Reward

Temporal uncertainty and temporal relevance are two variables linked to the amount of attention directed to time processing. The absence of certainty regarding the duration of a stimulus could grow the interest of people towards observing time. However, temporal uncertainty alone does not satisfy an enhanced timing accuracy. The importance of correctly speculating the elapsed duration is a prerequisite for increased attention paid at time processing (Clark-Foos, 2009).

The duration of the judged time duration affects the distortion of time. There is an inclination towards overestimating and underestimating short and long intervals, respectively. This trend, also referred to as Vierordt's law, appears in the judgment of timespans of (milli) seconds as well as of minutes (Droit-Volet, Monceau, Berthon, Trahanias, & Maniadakis, 2018). It is, therefore, not a time-interval characteristic, but it is relative to the temporal context.

The monotony of the surrounding environment, mentioned as sensory homogenization, has been named a determinant of time judgment and subjective experience. In the field of neuroscience, sensory homogenization is possible by creating a Ganzfeld; “homogenous perceptual field”. In the literature, a variation is found regarding the means to achieve a Ganzfeld in the lab, such as formulating a Whole-Body Perceptual Deprivation chamber and covering the eyes with ping-pong balls, all focus on reducing heterogeneity, stimulus, and pattern, and enhancing monotony (Glicksohn, Berkovich-Ohana, Mauro, & Ben-Soussan, 2017). The team of Glicksohn (Glicksohn, Berkovich-Ohana, Mauro, & Ben-Soussan, 2017) found that interaction with such an altered sensory environment prolongs time production tasks but also highlighted the existence of inter-personal differences. Furthermore, an effect of whether the time production takes places within the Ganzfeld environment or after exiting it, is mentioned.

Karsilar, Kisa and Balci (2018) examined how the speed and the direction of a moving object affect the time perception of its observers. Based on their analysis, they urge that the faster an object moves, the longer the subjective time of the person who observes its motion. The direction of movement (forward or backward) is used as a proxy for the degree of familiarity to the viewed biological motion and its effect is determined as insignificant (Karşılar, Kısa, & Balcı, 2018).

Reward has also been associated with time perception. The impact of the introduction of a monetary reward on the deviation of the prospective subjective time from the realized time has been examined in visual experiments. A significant positive relationship has been reported in case people are being informed of the existence of a reward by an unexpected, in terms of color and duration, rather than a standard signal (Failing & Theeuwes, 2016). The growth of perceived time is attributed to the increased importance of such a stimulus and the corresponding increase in the attention paid to it.

The effort required to achieve a final product is traditionally considered as a cost associated with it. However, putting effort can be thought of as a desirable or rewarding experience, and not only as a valuable means to the end but also in itself (Inzlicht, Shenhav, & Olivola, 2018). Under such circumstances, effort demand could be a time perception driver via the positive emotions it introduces.

A sense of fast passage of time could be explained. In contrast, if the difficulty of a task becomes frustrating or unbearable, sad feelings could be generated and a decrease in the speed that time passes would be expected. Empirical research supports that the more difficult a non-temporal task, the longer the estimated duration of an elapsed time interval (Droit-Volet, Monceau, Berthon, Trahanias, & Maniadakis, 2018). Droit-Volet’s team failed to find a significant relationship between the required effort and subjective time perception for relatively long time intervals (8-32 minutes).

Emotionally aroused people tend to report more distorted time judgments than people who interact with neutral stimuli. Time psychologists accumulate the effects of emotional state on time perception in the “time-emotion paradox” term (Droit-Volet & Gil, 2009). The influence of affect on time perception is compatible with both the dedicated clock and the attentional-gate model. Intense emotional experiences can increase the pulse rate as well as distract individuals from paying attention to the passage of time (Wittmann, 2009). Nevertheless, the impact of emotions on time judgment is not unequivocal. It varies based on the provoked emotions (e.g., negative vs. positive), the task duration (short vs. long), and the personal characteristics (e.g., age, test anxiety) (Rankin, Sweeny, & Xu, 2019). Among others, fear, anger, and stress have been proved to alter perceived duration.

The effect of temperature has been tested by various researchers (Alderson, 1974; Baddeley, 1966; Hancock, 1993; Tamm, et al., 2014; van Maanen, et al., 2019). Hoagland's early established chemical-clock hypothesis (Hoagland, 1933) indicates the existence of a causal relationship between increased body temperature and shortened time estimation whereas Baddeley (1966) suggests the reverse impact of colder than thermoneutral conditions. While the latter two studies examined the association between temperature and time processing by using intervals of 1 second, the team of Mioni (Mioni, Labonté, Cellini, & Grondin, 2016), which focused on the sub-second domain, found no significant influence of body temperature on time estimation of sub-second intervals.

The role of gender in time perception is undecisive. While the difference in the performance between men and women has not been significant in some studies (Droit-Volet, Monceau, Berthon, Trahanias, & Maniadakis, 2018), its relevance has been supported by others (Grondin & Laflamme, 2015). The effect of age is also not straightforward.

Apart from the demographics, other personal traits are also linked to the subjective judgment of how fast time elapses. People who manage to regulate their feelings tend to experience that time passes more slowly. Moreover, the individual time perspective; the degree of focus on past, present, or future and positive or negative experiences influences the subjective pace of the passage of time (Wittmann, Rudolph, Gutierrez, & Winkler, 2015). According to the Zimbardo Time Perspective Inventory (ZTPI), five different dimensions are recognized: past-negative, present-hedonistic, future, past-positive, and present-fatalistic (Zimbardo & Boyd, 2015). Future-oriented people appear to sense that time moves faster than the clock time (Wittmann, Rudolph, Gutierrez, & Winkler, 2015).

2.1.5 Conclusion time perception literature

The review demonstrates that there is a variety of categorizations and definitions for time perception. Thus, it is important to identify to which paradigm the present research belongs. The fact that alternative data collection methods are proposed by the literature, provides some flexibility towards the selection of the method which best serves the purpose of the present study and is, at the same time, feasible in its context. As far as the possible determinants are concerned, past studies suggest that context parameters such as the time uncertainty and importance as well as individual factors e.g., emotional state, could affect time misperception. Having established the basic notions, methods, and roots of subjective time, it is now possible to dive further into the travel time experience literature in the following subchapter 2.2.

2.2 Travel time experience

In the following three sections, the literature on subjective travel time is reviewed and the third sub-question (SQ3) is addressed. Travel time perception has been studied regarding various objectives. Travel time experience is investigated in studies dedicated to travel time distortion, to time perception effects on travel choice behavior and modelling, to travel satisfaction (Abenoza, Cats, & Susilo, 2019), and to the value of travel time (Karadimce, Lugano, & Cornet, 2018).

2.2.1 Subjective travel time empirical results

Research on the perception of travel time is less extensive than that on time perception. However, interesting empirical findings have been published.

First of all, while many time perception researchers have based their analysis on estimation of the power low function which was presented in Equation 1, travel time literature focuses mainly on the estimation of two indicators of time perception. Those are the travel time ratio (Equation 2) and the travel time perception error rate (Equation 3), with the former being much more widely used e.g., Parthasarathi, Levinson, & Hochmair (2013), Peer, Knockaert, Koster, & Verhoef, (2014). The travel time ratio is defined as follows:

$$\tau_{dist} = \frac{T_r}{T_a} \qquad \text{(Equation 2)}$$

Where:

τ_{dist} is the travel time distortion ratio

T_r is the reported perceived trip duration

T_a is the objective travel time

The time perception error rate has been used by Gonzalez's team (González, Martínez-Budría, Díaz-Hernández, & Esquivel, 2015) and is described below in Equation 3 :

$$per = \frac{pt - mt}{mt} \qquad \text{(Equation 3)}$$

Where:

per is the travel time perception error rate

pt is the perceived time

mt is the measured time

In one of the earliest studies on the discrepancy between objective and subjective travel time, it was found that people misperceive travel time to different extents for the various modes of transport (Clark, 1982). People seem to overestimate travel time spent on the bus more than in the car. Moreover, the perceived duration of a trip conducted by car increases faster than the length of one on a bus. To consider both the misperception of the travel time and its perceived rate of change, Steven's law can be applied (Clark, 1982).

Research on commute has shown that people overestimate travel time for further modes of transport, including motorcycles. Commuters who walk to their destination seem to have a better sense of the actual travel time and perform better in the time judgment task (Varotto, Glerum, Stathopoulos, & Bierlaire, 2014).

Apart from single mode trips, multimodal commuting trips have been examined. The misperception of travel time has been investigated in regards to the total travel time as well as to the duration of each trip stage (Meng, Rau, & Mahardhika, 2018). A variation among the factors that determine the travel time estimation per mode is also noticed.

Moreover, the notion of time perception has been applied as the estimation of the travel time required between an origin and destination, by the non-chosen modes of transport (Van Exel & Rietveld, 2009) (van Exel & Rietveld, 2010). While this approach is useful towards getting insight into the considered utility of the non-chosen alternatives, it disentangles time perception from time experience. Therefore, in the remainder of this literature overview, findings related to such studies are not analyzed further.

2.2.2 Data collection methods

Research on the deviation between perceived and actual travel time requires the collection of data on both subjective and objective travel time. The dominant method for the former is surveys, whereas for the latter, multiple alternative methods have been applied.

Two types of surveys are identified in the literature. On the one hand, surveys might request from each participant a single travel time estimation per origin destination pair, regardless of the number of trips conducted. Commonly examined trips are repetitive trips such as commuting trips. In this case, the research sample reports its perceived average or common travel duration between the considered origin and destination points (Peer, Knockaert, Koster, & Verhoef, 2014; Parthasarathi, Levinson, & Hochmair, 2013; Raghubir, Morwitz, & Chakravarti, 2011).

On the other hand, perceived travel time data can be collected per trip. Surveys on such subjective travel time have been conducted both on-site and online. To increase the reliability of perceived travel time data, it is preferable to ask immediately after the completion of a trip (Meng, Rau, & Mahardhika, 2018). Collecting data during a trip stage is also possible (Psarros, Kepaptsoglou, & Karlaftis, 2011). This method provides the opportunity to analyze the difference between subjective and objective travel time while assuring the absence of the end-episode effect

(Li, 2003). However, its applicability is higher for the investigation of waiting time due to time availability during this trip stage.

As far as the actual travel time data collection methods are considered, Global Positioning System (GPS) has been exploited in travel time perception studies. GPS provides location information by reporting the latitude and the longitude of a person's or a vehicle's position, accompanied by the exact date and time of the recording. Data is gathered either by installing GPS equipment to private vehicles (Parthasarathi, Levinson, & Hochmair, 2013) or via smartphone applications (Karadimce, Lugano, & Cornet, 2018).

Another used approach to satisfy the reliability of real travel time data is to follow research subjects and note the start and end trip time. This method enables to record not only the duration of the trip but also additional parameters as for example weather, mode, trip stages, and facilities visited (Meng, Rau, & Mahardhika, 2018).

In the absence of individual, actual travel time data, multiple other tools have been applied to retrieve actual travel duration. Clark, in his early research, repeated the trips conducted by the participants by driving the fastest route between the indicated origin and destination (Clark, 1982). Varotto's team (2015) used google maps and the combination of google maps with a transport assignment model, to compute travel time of trips made by private motorized vehicles and by the rest of transport modes, respectively (Varotto, Glerum, Stathopoulos, & Bierlaire, 2014). The last two methods prerequisite that trip origin and destination are reported by the traveler. Other network databases that are more detailed than google maps are also usable for extracting travel time. For example, walking time to various points of interest can be estimated by extracting the shortest distance to those based on a GIS street network and dividing this distance with common walking velocity (Dewulf, Neutens, Van Dyck, de Bourdeaudhuij, & Van de Weghe, 2012).

Lastly, experiments have been conducted to provide information on travel time distortion. Experimental setups are suitable for manipulating the environment and examining the influence of parameters whose appearance is rare, hazardous and/or not easily captured. In research on crossing time perception, an Ergo Timer Globus stopwatch, connected to photoelectric cells has been used to gather data on both the prospective estimation and the actual crossing time (Naveteur, Delzenne, Sockeel, Watelain, & Dupuy, 2013).

Virtual reality is an alternative means to study individual time judgment in an experimental set up (Shimokawa & Sugimori, 2019). In the VR environment, travel time perception is captured by requesting subjects to indicate when they believe that a specific amount of time is over while for example are watching a video of a trip e.g., walking through a city, a transit station (Shimokawa & Sugimori, 2019). Virtual reality videos such as those created by Shimokawa and Sugimori (2019) seem to be able to replicate findings from research in the physical environment. The virtual reality videos have been used by time perception reseracher's e.g. Chirico, et al., 2017. A shortcoming of VR data collection is that in case research subjects are unfamiliar with VR, they might get either excited or stressed during their interaction with the VR videos (Shimokawa & Sugimori, 2019). As discussed in section 2.1.4, emotions distort time estimation and, thus, the interpretation of the results of a VR experiment could be proved cumbersome.

The presentation of hypothetical driving trips between indicated start and origin points, and multiple available routes is another experimental setup that has been applied in travel time perception literature (Dixit, Jian, Hassan, & Robson, 2019).

2.2.3 Travel time duration determinants

Most studies on perceived travel time focus on the subjective waiting time (Meng, Rau, & Mahardhika, 2018). As seen in Table 2.3, the literature offers a vast number of possible regulators of waiting time for public transport services.

Table 2.3. *Public transport waiting time regulators*

Personal-Sociodemographic	Trip characteristics	Environment	Individual state	Public transport characteristics
Age Gender	Access time Time period	Weather conditions Surroundings Lighting Cleanliness Security	Stress	Service per hour Service headway
Travel experience	Trip purpose Actual waiting time	Information provision		

** Note: Adapted from Meng, Rau, and Mahardhika (2018)*

Regarding the perception of walking time, weather affects the perception of pedestrians in the context of multimodal trips (Meng, Rau, & Mahardhika, 2018). Reported walk time estimations are shorter when they are conducted in more dense or crowded areas (Shimokawa & Sugimori, 2019). While Shomokava and Sugimory (2019) provide proof over the effect of crowdedness in a VR setting, similar results are suggested from the investigation of real-life walking trips. More specifically, it has been found that pedestrians overestimate their time spent travelling in nature by almost a minute (Davydenko & Peetz, 2017).

The exposure to nature has been linked to multiple emotions, including relaxation, enjoyment, and diminished stress, to name a few. As explained in the time perception literature, intense (e.g., excitement) and low arousal (e.g., calmness) emotions are considered to have opposite impact on the perception of time. Therefore, despite the indication that time seems to pass slower while wandering in nature than across man-made surroundings, it is necessary to consider the effect of the change in the mood due to the contact with nature (Davydenko & Peetz, 2017).

Contrary to the results of Shimokawa and Sugimorey (2019), research on the relationship between perceived travel time and street density has found that by increasing the latter, commuters feel that driving time passes slower and as such overestimate their travel time (Parthasarathi, Levinson, & Hochmair, 2013). It should be mentioned, though, that these two studies investigate different modes and trip purposes (Table 2.4). Furthermore, in the latter research, street density, as well as intersection density, are considered obstructions towards increasing driving speed.

More network characteristics seem to influence the commuters' perceived driving time. Variation in the encountered road type, closeness and number of intersections, arterial treeness, and percentage of the roads with limited access, are important determinants of the difference between the objective and the subjective travel time (Parthasarathi, Levinson, & Hochmair, 2013).

Apart from the physical travel network, the mental representation of space influences how people process travel time. People perceive travel time to and from a location, relative to the location's importance and their familiarity with it (Raghubir, Morwitz, & Chakravarti, 2011). Familiar origin and destination locations trigger delayed start time and early end time, respectively. Thus, familiarity shortens the perceived duration of a trip. In this context, travelling towards home is perceived as faster than a trip that originates from it. This condition is described as the "return home effect". Carrion and Levinson (2019) doubt the return home effect. In their case study, the duration of homebound and work-bound commute trips is judged alike.

The return home effect could be thought a special case of the return trip effect. The latter arises in travels not only towards home but in more trips that are conducted in the reverse direction of an initial trip (van de Ven, van Rijswijk, & Roy, 2011). Although the return effect seems to be related with the increased familiarity of the second trip, Ozawa (2016) supports its elimination in very commonly performed trips such as commuting trips.

Strict arrival time is associated with a growing interest in time planning, and an increased significance of the adherence to the schedule. People who face higher flexibility regarding the time of reaching their work, tend to further underestimate travel time in comparison to those who underestimate travel time but face arrival time restrictions (Carrion & Levinson, 2019).

Similar to findings of time perception studies, people tend to perceive short trips as longer and trips that with bigger duration as shorter (Parthasarathi, Levinson, & Hochmair, 2013)

Table 2.4. *Summary of travel time perception studies*

Study	Setup	Time Data collection methods		Modes	Participants	Prospective (P)/ Retrospective (R)	Trip purposes	Time aspect	Main findings
		Subjective time	Objective time						
Shimokawa & Sugimori (2019)	Experimental	Time production task Verbal Estimation	VR	Walk	Students	P & R	NA	Passage	Cityscape and crowding increase perceive time
Davydenko & Peetz (2017)	Predetermined trips	Reported time duration	Handheld chronometer	Walk	Students	P & R (without travelling)	NA	Duration	Nature slows time
Parthasarathi, Levinson, & Hochmair, (2013)	Real life	Surveys -per trip -average OD time	-GPS loggers -Average OD time on fastest route	Car	Area residents	R	Commute	Duration	Network structure influence
Carrion & Levinson (2019)	Real life	Web-based survey	GPS device	Car	University stuff	R	Commute	Duration	Affective state and
Meng, Rau, & Mahardhika (2018)	Real life	Survey	Following participants	Walk (access/egress/transfer) PT (bus-rail)	PT users	R	Commute & non commute	Duration	Time Overestimation for all trip stages
Naveteur, Delzenne, Sockeel, Watelain, & Dupuy (2013)	Experimental	Time production task	Ergo Timer Globus stopwatch	(crossing) Walk	Young & elderly female	P	Commute	Duration	Age effect
Varotto, Glerum, Stathopoulos, & Bierlaire (2014)	Real life	Survey	Assignment model Google maps	Car Motorcycle Walk PT	University community	R	Commute	Duration	Underestimation of average walking time.
González, Martínez-Budría, Díaz-Hernández, & Esquivel (2015)	Real life	Survey	Vehicle realized timetable	Tram	Student population	P	Education	Duration	Effect of access travel time perception
Peer, Knockaert, Koster, & Verhoef (2014)	Real life	Questionnaire	Cameras	Car	Frequent travellers	R	Commute	Duration	Overestimation of travel time

2.2.4 Conclusions travel time perception literature

The review of travel time perception literature reveals that many different data sources and methods have been followed for the collection of data. These methods differ in the level of detail, and in the moment that the time report is requested, and in the set-up. Most research efforts have considered the perception of the waiting time for public transport services or the in-vehicle travel time by car or public transport for commuting trips. Despite, the limited research on active mode trips, the literature review reveals that characteristics of the travel network and surroundings such as the presence of nature, trip characteristics such as the mode of transport, as well as individual characteristics e.g., age, and the emotional state, are all possible determinants of travel time misperception.

2.3 Conclusions

It is noticeable from section 2.1.1, that there is a lack of consensus regarding the terminology used in the time perception studies. This lack of standardization in combination with the need to efficiently communicate the results of this research, necessitate to explicitly specify the time perception terminology of the present study. In prospective timing conditions, people are informed about the need to judge time which might affect their focus on the observation of time and consequently, according to both the Internal clock (Church, 1984) and the Attentional gate model (Zakay & Block, 1997), their time perception. Contrary, retrospective timing does not affect the attention paid to time. Therefore, the examination of time in this thesis lies in the retrospective paradigm. In addition, the terms subjective time and perceived time are used interchangeably to indicate the retrospective time perception of individuals. Similarly, actual time and objective time mutually indicate the clock time.

As seen in the summary of travel time perception studies (Table 2.4), the perception of cyclists has been neglected. While trips by bike and on foot share some characteristics, e.g., vulnerability to weather conditions, they differentiate in many aspects, such as workload, speed, and interaction with other users. Speed has been identified as a determinant of time perception (Karşılar, Kısa, & Balcı, 2018). Workload and interaction could influence the attention towards time, and the temporal uncertainty of a trip and subsequently, the sense of trip duration. Therefore, it is expected that the time perception of cyclists deviates from the perception of pedestrians.

Besides, pedestrian travel time perception has been examined either in an experimental setting or as part of multimodal, public transport based trips. This thesis will try to contribute to the growth of the limited research on the time perception of active mode users, under real-life conditions.

Despite the power of the Google maps and GIS travel networks to provide information on trip duration, none of these is suitable for obtaining individual and trip specific travel times. These methods count on average travel behavior and/or walking speed to estimate trip duration. While it is possible to increase accuracy by considering multiple speed values to account for personal e.g., age, gender or trip e.g., trip purpose characteristics, it is expected that the resulting trip time deviates from the actual, individual, travel time.

GPS logging provides detailed information on the route of a trip and its duration after appropriate data processing. However, vehicle installed GPS systems generate data on a single mode of transport, and as such multimodal, and walking trips cannot be recorded. While portable handheld GPS sensors could overcome the issue of tracking trips of one mode, they are easily forgotten by participants (Vlassenroot, Gillis, Bellens, & Gautama, 2015).

Over the last years, various mobile applications have been developed to collect travel behavior data (Berger & Platzer, 2015; Vlassenroot, Gillis, Bellens, & Gautama, 2015; Cornet, Barradale, Bernardino, & Lugano, 2019). In a single mobile application multiple data sources which are appropriate for analysis of time perception such as surveys and GPS, can be embedded. Considering the widespread use of smartphones in the Netherlands, this thesis could exploit their possibilities and rely on the usage of a mobile application for the collection of data.

The literature reveals a plethora of factors and relationships that might be able to have an effect and explain the distortion of travel time. It is not possible to test all possible factors in a single research as this would require among other exhausting tasks for its participants. In the next chapter of the thesis, the selection of the considered parameters takes place.

3 Conceptual design

The above presented literature review on time, and especially on travel time perception, provides interesting findings on time distortion and its determinants. In this chapter, the factors which are examined in the present thesis are selected. Factor selection is based on multiple criteria, such as the relevance to the research objective and the documentation of their impact in the literature. In addition, research hypotheses which can be derived from the literature overview for the chosen potential determinants of travel time distortion are developed.

3.1 Factor selection process

In this section, the procedure towards choosing the factors which could impact the subjective travel time is presented. The selection is based on three criteria: The knowledge so far, the relevance to the research objective, and the feasibility of collecting data via the proposed data collection method. As far as the knowledge state is considered, factors are reviewed based on two sub-criteria. More specifically, the extent of knowledge, as well as the degree of consensus regarding the impact of a factor, are taken into account. In case a factor has been investigated in multiple studies and there is agreement over its influence on travel time perception, then it is labeled as “Extended knowledge”. Otherwise, it seems that there is only limited knowledge on its contribution to the perception of trip duration. The present study could provide insight into the impact of the factors which have not been examined extensively by considering them. Yet, the elements on which there is a lot of evidence on their impact, could also be part of this research in order to compare its findings with that of past studies.

Moreover, the present study focuses on revealing the travel time distortion of pedestrians and cyclists. Thus, the selection of parameters depends on their relevance with the characteristics of walk and bike trips. As seen in Table 3.1, variables are divided between highly and lowly relevant with the research objective. Some factors with low relevance to the research aim, could be part of this research due to their possible interaction with other elements. For instance, the distinction between peak/off-peak trips is judged as not very important for the cycling and walking trips. This is because past research has used the time period as a proxy for the experienced congestion and crowdedness, for the car and public transport trips, respectively. Nevertheless, for active mode travelers the peak/off-peak conditions might be of lower significance. However, under the circumstances that this study is conducted; the Covid-19 pandemic and the measures enforced against it, travelling on peak period is avoided against the spread of the virus, and is, thus, considered more stressful than normal. Thus, travelling during this period could influence the emotional state of cyclists and pedestrians. As such, in the present study, the peak/off-peak distinction is included, to check the effect of its interaction with the mood and the stress level on the travel time distortion.

Table 3.1. *Factor selection criteria*

	Knowledge status	
Relevance	Limited	Extended
High	Weather	Demographic characteristics
	Arrival time flexibility	Trip duration
	Distance	Socioeconomic
	Return/Home effect	Trip frequency/familiarity
	Speed	
	Complexity	
	Trip purpose	
	Information usage	
	Music	
	Emotional state (stress, enjoyment, mood)	
	Nature	
	Trip circuity	
	Intersection density	
Low	Read	Road congestion
	Peak/off-peak	
	Comfort	
	Proportion Limited access roads	
	P2A	
	Relative discontinuity	
	Arterial Treeness	
	Street Density	

Ability to be captured via mobile application: Yes , Yes, but with location data , No

The last criterion is the potential (Yes/ Yes, with location data/ No) of each factor to be captured via a mobile application within the time horizon of the present thesis. This criterion is decisive since factors that cannot be captured directly or indirectly via a mobile application, are automatically excluded from the pool of selected factors. As shown Table 3.1, only one factor is rejected as a result of this criterion.

Due to the possibility of extracting location information via a mobile application, the present research could follow an approach different from past studies in the consideration and estimation of some of the factors which are entailed in Table 3.1. For example, the impact of not only the subjective but also of the objective weather conditions could be examined. The former can be obtained directly via the surveys which are included in the data collection tool while the latter can be derived indirectly, by combining location data with historical meteorological measures.

In Table 3.1, only factors which are found in at least one of the reviewed studies on subjective travel time are included. The overview of the time perception literature suggests that there are more possible determinants of time perception (Table 2.2). The concepts which underline these factors need to be considered in the selection process. Most of the elements suggested by past time perception studies, such as the emotional state and the individual characteristics have already been directly assessed based on the selection criteria (Table 3.1).

Some of the rest of the proposed time perception determinants could be represented by a single or a group of factors listed in Table 3.1. Temporal relevance could be approached by travel time flexibility and trip purpose. Moreover, trip purpose could be used as a proxy for temporal uncertainty, but only for the distinction between frequent e.g., commuting and occasional e.g., leisure trips. Trip frequency/familiarity could maybe provide more insight to the uncertainly of trip duration. While not listed in Table 3.1, the expected travel time could also be used to capture the experienced travel time uncertainty of an ended trip.

The amount of effort that a person puts is the only potential time perception influencer (Table 2.2) which cannot be derived from any of the factors comprised in Table 3.1. Considering that the demand for physical effort is one of the main characteristics of active modes, it needs to be investigated in the present research.

The measures introduced by the Dutch government to fight the COVID-19 pandemic have affected the mobility and travel behavior of residents in the Netherlands. The timing of the present study provides an opportunity to evaluate the time perception of the remaining trips but also of how perceived travel time could be affected by aspects related to the pandemic. More specifically, the stress level during this period, is added to the examined agents of subjective travel time.

The evaluation of the possible influencers of travel time perception on the basis of the three defined criteria (Table 3.1) and the discussion on other factors which are either suggested by time perception theory or are very relevant to the active mode characteristics or to the current circumstances, have led to the formulation of the group of the examined factors. An overview is given in Table 3.2. Since it has already been decided that data is collected via a mobile application, information on these factors could be obtained via two ways: Either by processing of location data, or via travelers' reports. In Table 3.2, the information source is noted too. Besides, in the Table below, it is pointed out whether the factor should be observed on an individual or a trip level.

Table 3.2. *Selected factors*

Subgroup	Factors	Information source	
		Location data	Report
Individual characteristics and experience	Demographic		+
	Socioeconomic		+
	Emotional state		+
	Effort		+
Trip characteristics	Trip purpose		+
	Trip frequency		+
	Trip familiarity		+
	Trip flexibility		+

	Home inbound/outbound	+*	+
	Duration	+	
	Travel mode	+	+
	Peak/Off-peak	+	
Context	Weather	+	+
	Nature	+	

*Subject to report of home location

Individual level , Trip level

3.2 Research Hypotheses

Most of the travel time studies that were reviewed in the previous chapter have concluded that people report travel time as longer than it actually is. Although, these studies have mainly considered public transport or car trips of commuters, they are the basis for the formulation of the research hypothesis of the present study. Accordingly, the first hypothesis of this research is as follows:

The duration of walking and cycling trips is distorted (H1)

Although it is expected that people overall overestimate trip duration, some trips underestimated. Past research suggests that to identify the determinants of travel time distortion separate models should be estimated for the underestimated and the overestimated trips. Differences are expected regarding both the significant factors as well as the magnitude of their effect. Thus, the following is assumed:

A model that includes all time perception cases has less power in comparison to a model that considers only overestimated or underestimated trip durations (H2)

Overall, there is a lack of consensus across studies with respect to the influence of various variables. However, there is an agreement that the stimulus duration affects the perception error. This leads to the third (H3) hypothesis:

Travel time perception error is smaller in shorter trips than in trips which last more (H3)

In addition to the above-mentioned assumptions, more Hypotheses are formulated for individual factors that could affect travel time perception of walking and cycling trips.

- *Strict arrival time increases perceived travel time (H4)*
- *Dissatisfying weather increases perceived duration of cycling and walking trips (H5)*
- *Nature prolongs perceived duration of active mode trips (H6)*
- *A return home trip is perceived as shorter than it is (H7)*

- *High comfort or satisfaction leads to a shortened perceived travel time (H8)*
- *The usage of trip information reduces the travel time misperception (H9)*
- *Non-mandatory trips are perceived as shorter than mandatory trips (H10)*
- *Travelling during peak period prolongs perceived trip duration, when it is accompanied with high perceived stress (H11)*

It is worth recalling that in time perception studies, effort demand has been associated with both negative and positive emotions, depending on the content it takes place and, especially, on how much one seeks it. In terms of travelling by bike or car, high exertion could be desirable for trips which are conducted for leisure or for the trip itself. On the contrary, in compulsory trips, such as commuting trips, a low physical effort is preferred. Thus, the impact of effort on the present travel time perception study is examined in combination with the trip type and, more specifically, the trip purpose. Consequently, two additional hypotheses are formulated:

- *Mandatory trips with high effort demand provoke an increase of perceived travel time (H12)*
- *Non-mandatory trips which have a high effort demand are perceived as shorter than they are (H13)*

3.3 Conclusions

The pool of probable agents of travel time perception shows that to study the distortion of travel time individual, trip, context, and surrounding environment parameters, need to be contemplated. For the purpose of the present research, factors have been selected, taking into account the peculiarities of active mode trips such as the increased physical effort demand, as well as the prospect of capturing them via a mobile application.

To test the research hypotheses, information is needed on the parameters that underlie these hypotheses. As revealed in Table 3.2, it is essential that travelers report on their personal and trip characteristics and on many other aspects, such as their emotional state. Therefore, surveys need to be designed and embedded in the mobile app. In the next chapter, the development of a set of surveys which could provide the necessary data is described.

4 Experimental design

In the present chapter, the design of two different surveys which aim at capturing the perceived travel time of various time intervals and at collecting data on the selected factors is discussed. The first survey, called “Initial survey”, gathers data on personal characteristics, travel habits, and duration perception of intervals in the range of seconds. This survey has to be filled only once by each research participant. The second survey collects information on the travel time perception of real-life trips. In this survey, respondents are asked to report their subjective estimate of the trip duration. This ‘End trip’ survey is on a trip level and, thus, needs to be filled in every time a trip is concluded. In addition, an evaluation survey is designed. Finally, the architecture of a mobile application, which is designed to accommodate all surveys and is the single data collection source for this study, is described.

This chapter answers the fifth research sub-question (SQ5):

Which are the data requirements to capture both perceived and realized travel time?

4.1 Initial survey design

Data on the demographic and the personal characteristics of the research participants need to be collected in order to evaluate the representativeness of the sample. In addition, such information is necessary to investigate the influence of individual parameters on time distortion. Age, gender, education level, years of residency in the Netherlands, and employment status are questioned in the intake survey.

It is expected that a portion of the participants will be part of the institution to which the author of the present thesis is affiliated; the Delft University of Technology. The possible association with the TU Delft, as well as the role within it, if any, are questioned in the Initial survey.

Emotions should be measured on a trip level, as noted in Table 3.2. However, additional information is gathered for each person on his/her overall stress level, which could be attributed among other parameters to the pandemic circumstances. Stress experienced by people during their participation in the present research is evaluated based on the widely used Perceived Stress Scale (PSS) (Cohen, Kamarck, & Mermelstein, 1983). PSS is a validated psychological instrument which captures how stressful individuals’ life is in the current period. Similar to other studies on the stress of travelers (Avila-Palencia, et al., 2017) a shortened version of four elements (PSS-4) is applied. The content of PSS-4 is presented in Table 4.1.

Table 4.1. *Perceived Stress Scale Elements*

Question	Response type	Response description
In the last month, how often have you felt that you were unable to control important things in your life?	5-Likert item	Never Almost Sometimes Fairly often Very often
In the last month, how often have you felt confident about your ability to handle your personal problems?		
In the last month, how often have you felt that things were going your way?		
In the last month, how often have you felt that difficulties were piling up so high that you could not overcome them?		

For the first and last question of the PSS-4 scale, answers from never to very often are scored from 0 to 4, respectively. The rest of the questions are positively stated items. Therefore, they are scored in the reverse order. All four items scores are summed, and a single stress score is obtained which represents the stress state of an individual.

In the explanation of Table 3.2 it is mentioned that it is possible to identify if a trip is homebound via processing trip location data in combination with knowledge on the home location. Because of privacy concerns it is impossible to request the exact residence address. Therefore, information on the home location can be gathered by fusing data from two questions; the zip code on the detail level of the four numeric digits and the home address street name.

It is aimed that at least two trip reports are provided per individual. However, it is not possible to control whether an individual does so. In order to be able to test the third hypothesis (H3) even with a single real-life trip report, the judgment of short trips, is captured via the duration perception of trip films, in the Initial survey. As discussed in the literature review chapter (See section 2.2.2), videos, and even virtual reality videos have been applied in past studies on travel time perception (Shimokawa & Sugimori, 2019). Virtual reality is not only difficult to be embedded in mobile applications but also requires the provision of special equipment to the research sample. Thus, 2D screen videos are preferred in the present study.

The collection of time perception based on videos offers multiple further opportunities for the research. Firstly, it makes it possible to investigate intra-individual variability. The difference in the perception error rate between short and long time intervals could be analyzed. Furthermore, capturing the relationship between the trip duration distortion of video and real-life trips could provide insight into the suitability of using trip films for the quantification of the travel time misperception. Depending on the content of the presented videos the impact of various factors on time perception could also be evaluated. It is decided that the films resemble real-life trips. Considering the high share of cycling as a mode of transport in the Netherlands (Buehler, 2018), it is expected that the majority of the research sample is highly familiar with bike trips. As such, the research participants are presented with films of bike rides. The duration of the real-life cycling and walking trips is expected to be in the range of minutes or even hours. On the contrary, the presented films range between 21sec and 42 sec. The selection of the duration range is based on three aspects. First of all, the travel time of the cycling films is long enough to allow the participants' engagement with the presented cycling environment. Secondly, the videos' duration is similar to the duration of films used in other travel time perception studies. For instance, Shimokawa and Sugimori (2019) investigated the time passage of 30sec and 60sec whereas the people who took part in the research of Davydenko and Peetz (2017) watched walking films of 110 seconds. Finally, the videos' duration is restricted to under a minute, in order to not significantly increase the time required to fill in the survey and, accordingly, to not severely affect the response rate. The characteristics of each video can be seen in Table 4.2. In Figure 4.1, a screen shot of each video is also provided, showing the different travel environments. A link to the online version of the videos is available in Appendix C.

Table 4.2. *Video characteristics*

Video number	Description	Duration (ss)	Weather	Cycling facility	Interaction with other road users	Nature presence	Sound
Video 1	Cycling across TU Delft campus	21	Sunny	Bi-directional cycleway	None	Low	Off
Video 2	Cycling across nature	21	Sunny	Bi-directional cycleway	None	High	Off
Video 3	Cycling across urban, man-made environment	42	Sunny	Bi-directional cycle path with one interruption	Yes	None	Off

Figure 4.1. Screen shots of the three videos, Video1 across TU Delft campus (left), Video 2 in nature (middle), and Video3 across an urban environment (right)

The perception of trip duration is captured in alternative ways. The usage of differentiated time perception questions is preferred not only to reduce the attention paid to the exact estimation of elapsed time but also to investigate the effect of the question type on the misperception error. More specifically, for the first and the third video, verbal estimation is selected. Participants are requested to provide an estimation of the video duration in seconds. For Video3 the perceived elapsed time is reported via a multiple-choice question with one possible answer among the presented choices. The respondents are called to select which of the following five durations best describes the duration of the third cycling film: 20sec, 30 sec, 40sec, 50sec, 60sec. The perception of the second video is captured by encouraging individuals to judge its duration in comparison to the first video in a 5-points Likert item. The description of the five points is as follows: much shorter, shorter, equal, longer, much longer.

After each video, participants are asked to respond to a set of questions. Among others, the familiarity with the presented type of infrastructure and the pleasantness of the surrounding environment are investigated. Perception of these two factors is provided by an agreement 5- points Likert item. Satisfaction with some additional elements is questioned, to distract the respondent from paying attention to the time related tasks.

Finally, to evaluate the performance of the location data source of the data collection tool, in relationship to the android version of the devices, the latter information is also requested in the Initial survey.

In Figure 4.2, the summary of all the elements that the Initial survey captures is illustrated.

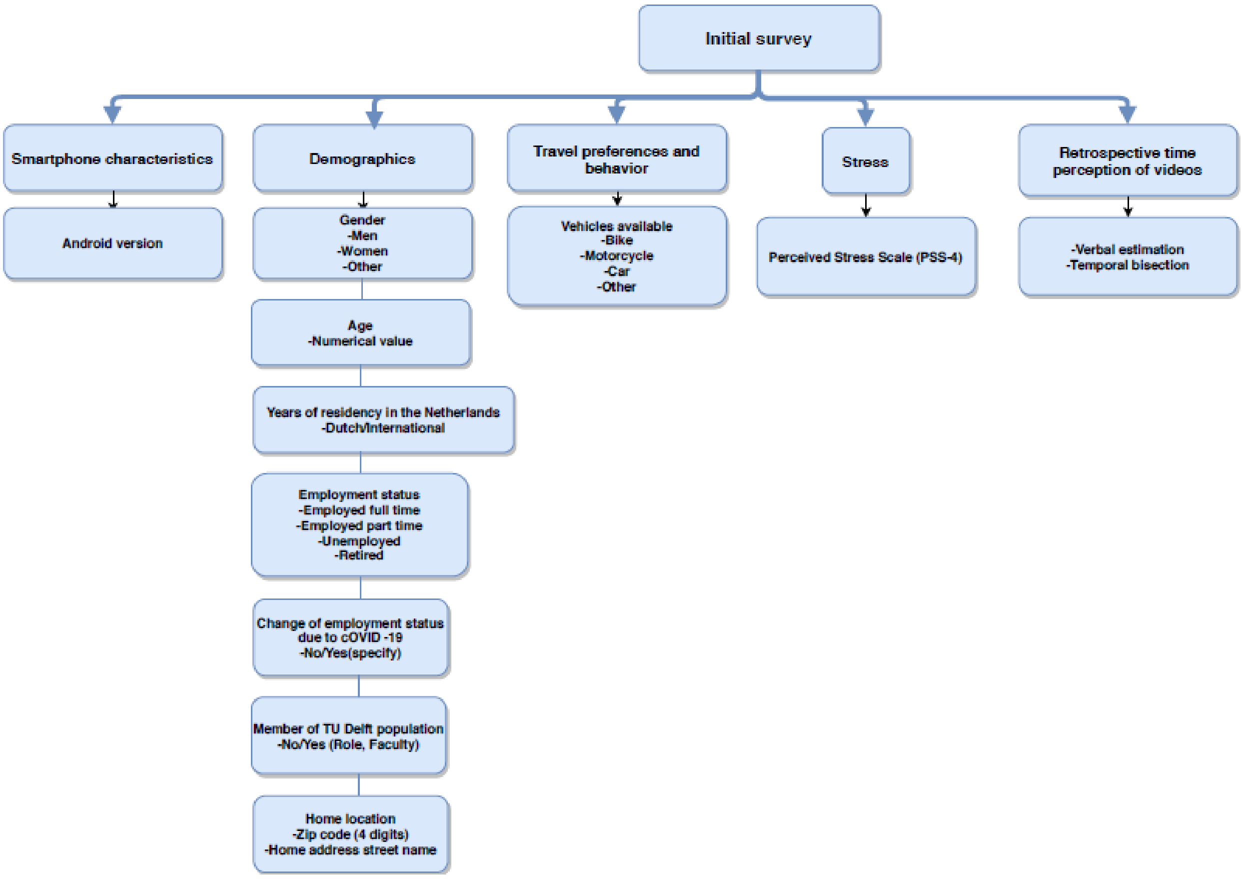

Figure 4.2. Initial survey elements

4.2 End trip survey

The trip level factors are examined in a survey which gathers information on the characteristics of the trip, the travel experience, and the individual state during the trip. First and foremost, via the End trip survey, the perceived travel time is captured. The perceived trip duration is the one reported by the respondent of the survey. Since rounding is common in time perception reports, it is crucial that survey participants are encouraged to avoid it. The exact formulation of the travel time perception question is as follows:

"How long was your trip?" Please indicate duration in minute intervals e.g.,11.

The mode of transport is included as a potential determinant factor in Table 3.2. Apart from the distinction between walking and cycling trips, more modes can be included in the survey. This allows for a comparison of the travel time distortion between active modes and the rest of the travel modes. Moreover, multimodal, public transport- based trips are also allowed to be registered. More precisely, the respondents select among bike, walk, car, public transport, motorcycle/mopped, and ferry as the main mode of their trip. For the public transport trips, the mode of transport can be further specified among bus, tram, train, and underground. The access and egress mode can also be reported.

Six different trip purposes are thought to be relevant to the present study, namely: Return home, Work/Education, Appointment, Shopping, Trip itself, Pick up/Drop-off.

Familiarity, deviation from expected trip duration, and stress level during the trip are inquired via 5-point Likert statements whereas the usage of trip planning information is indicated by a Yes/No statement. Apart from the stress level, the mood during the trip is approached by collecting information on the trip satisfaction. The formulation of the trip satisfaction question is based on a tool that has been developed in the context of the METPEX project in which satisfaction is declared via a five-points rating item which ranges from "Not at all satisfied" to "Completely satisfied" (Diana, et al., 2016). For active mode trips, the satisfaction with the infrastructure used during the trip is also investigated.

Weather perception is captured by a single question which measures the satisfaction with the prevailing weather conditions during the trip. The formulation of the question is identical to the one of a recent study on trip weather perception (Liu, Susilo, & Ahmad Termida, 2020).

The degree of effort required for active modes trips is evaluated with the usage of the OMNI Perceived Exertion Scale in which responses are provided in a 1-10 scale. The question is accompanied by an illustration of the scale for both cycling and walking trips (Figure 4.3).

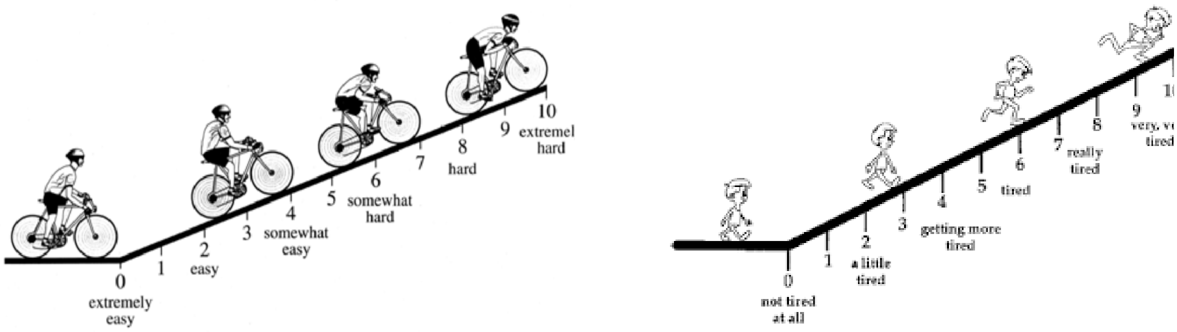

Figure 4.3. Exertion scale illustration for cycling (left) and walking (right) trips. From "Concurrent and construct validity of three alternative versions of the standard OMNI Cycle Scale of perceived exertion in young adult males", by Panzak, G (2012)

In Figure 4.4, an overview of the factors for which data is collected via the end trip survey is provided.

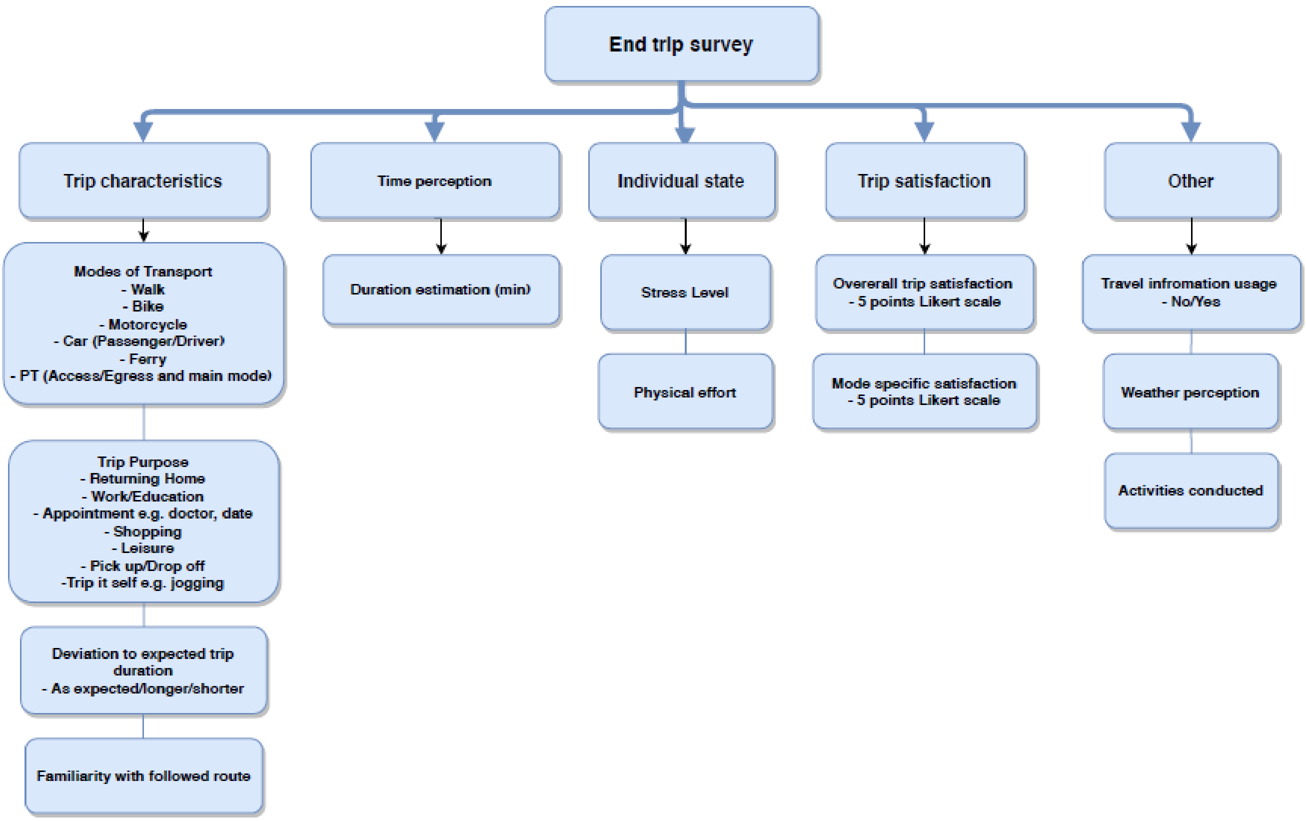

Figure 4.4. End trip survey summary

It is aimed that multiple trip reports are reported per individual. Since the research focuses on the retrospective time estimation, effort is put that the survey design does not reveal to the participants that the perception of time is the focus of the study. Thus, some questions which examine other trip satisfaction parameters are included in the end trip, in a separate section which is labelled as "Trip perception". Similar to previous studies e.g., Susilo & Cats (2014), additional questions are presented based on the chosen mode(s) of transport. In the case of travelling by public transport, participants are asked to report on the on-board space availability, and on the safety experience while waiting to board the public transport service. To car passengers and drivers, motorcycle and bike riders, and pedestrians, questions are posed on the perceived road safety.

4.3 Evaluation survey

The first two surveys have been developed to collect data necessary to test the research hypothesis in regard to travel time distortion and its determinants. In this section, an additional evaluation survey is introduced. The aim of this survey is multifold. First, the survey aims at receiving feedback from the individuals who take part in their research regarding their experience during their participation in the study. Identifying the aspects of the data collection which attract or discourage participation could be a valuable input for future research on travel time perception. Secondly, a set of questions targets to obtain information on the satisfaction with the mobile application. Since it is the first time that this mobile application is used, the participants' feedback could be considered for the further design of the Umo research app.

More specifically, research subjects are requested to reflect on their experience with the mobile application and on the required tasks. Finally, this survey examines whether the end trip survey respondents have used a time control mechanism to estimate their travel time and if so, in what frequency.

The evaluation survey is on the user level, and shall be completed only once, preferably before the termination of the participation. The survey can be found in Appendix C.

Having designed the three essential surveys for the collection of data, they need to be included to the single data collection tool: a mobile app. The app should also be able to gather location data. In the next section, the framework of the mobile app, and the functions of its design which are necessary in order to serve the purpose of the present research are discussed.

4.4 Data collection tool

The app which facilitates the End trip, the Initial, and the Evaluation survey has been developed based on the architecture that is illustrated in Figure 4.5. The app is android based and is named "Umo Research app". In this section the modules of the framework, as well as their role, are described.

The app has been developed with the scope to accommodate multiple future research efforts. The framework makes it possible that many researches work simultaneously on the same or different projects called experiments. Each experiment has a unique code, given by the researcher, and many users can simultaneously take part in the same experiment.

The app can be downloaded to any Android device. To distinguish between participants of different experiments, each new user is inquired to register to a single experiment in the welcome page of the app. Two alternative options have been developed to allow for registration. On the one hand, an “Active experiments” list has been created on the welcome screen, in which all publicly available experiments are shown. On the other hand, a user might be requested to manually type the code of the experiment in which he/she desires to participate. It is upon the researchers to decide whether their experiment is part of the above-mentioned list, or that the users need to enter the code by themselves. That latter is considered more suitable if it is essential to control who takes part in the research. In both cases the researcher needs to communicate the code to the potential participants beforehand.

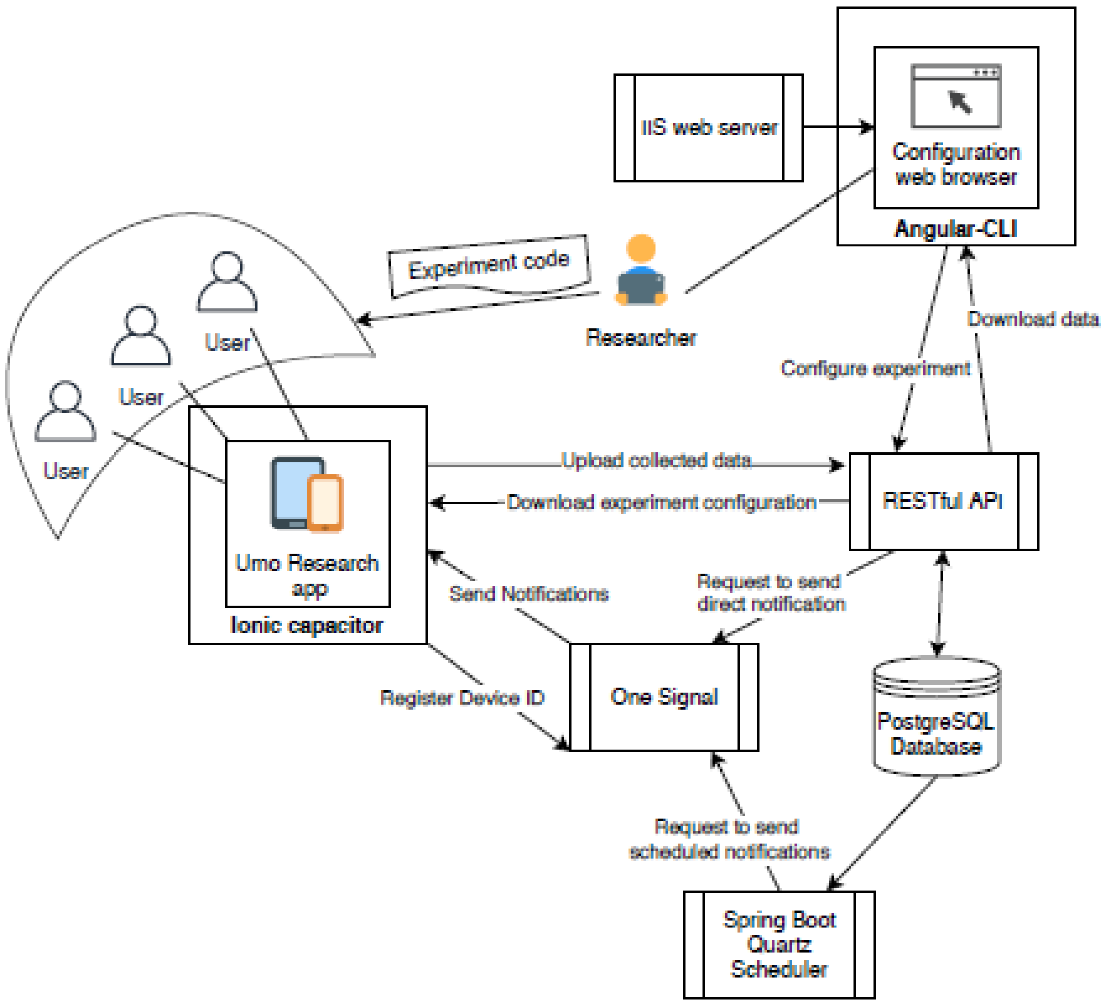

Figure 4.5. Data collection tool system architecture

The participant registration method as well as all experiment settings and content are configured by the researcher via the configuration web-browser which is developed on Angular-

CLI. Angular allows for testing the app locally while it is under development. Within this browser, the details of the experiment are specified. For the inclusion of surveys, the SurveyJS Builder has been integrated. SurveyJS offers a library of ready to use question and answer types. Furthermore, the format and the layout of a survey can be further manipulated via the JSON Editor tool.

Apart from the surveys, other data sources can also be arranged. In agreement with the data needs of the present thesis, a location data source is added. The location information is provided by the Global Positioning System (GPS). The source settings are adjusted via the web browser.

The data points are collected from the registered devices via an HTTPS-based API. The data are then saved in a SQL database. The obtained experiment data can be downloaded via the web browser. Survey data sets are in .csv format whereas the location data sets can be retrieved on both .csv and geojson format.

One Signal is an additional part of the data collection tool architecture. One Signal is a platform that enables sending notifications to the Android devices that have been registered to a specific experiment. It should be mentioned that the current state of the framework supports sending only text notifications. A researcher can choose between two alternative ways to send a notification. On the one hand, it is possible to schedule notifications at a specific time slot and/or frequency. To do so, a scheduler module has been added. More specifically, the open source Java based Spring boot is used together with Quartz Scheduler. On the other hand, notifications can be sent directly, without the mediation of a scheduler. These notifications appear as “Incoming messages” to the users. A particularity of the latter method is that it triggers an update of the experiment configuration on the devices that receive the notification. Thus, this type of notifications could also be sent in the case that the researcher wants to force such an update.

As far as the user interface design is concerned, the app has three tabs; a) the home tab, b) the help tab and c) the settings tab. On the home screen a ToDo List section is included. This includes the tasks-surveys which need to be completed (Figure 4.6). The moment that a survey appears in this list is defined by the researcher via the browser. A survey could be always present in the list or could either be generated based on predetermined moments or events. The start and the end of the data collection sources and of other surveys are the events which could trigger the appearance of a survey.

Besides the ToDo List, the home screen entails the Data Collection section. The purpose of this section is to allow the user to interact with the app both in the beginning and at the end of a trip. To report a single trip, a participant needs to press “Start collecting” and “Stop collecting” at the start and end of the trip, respectively. These actions allow for logging the trip start and termination events in the database.

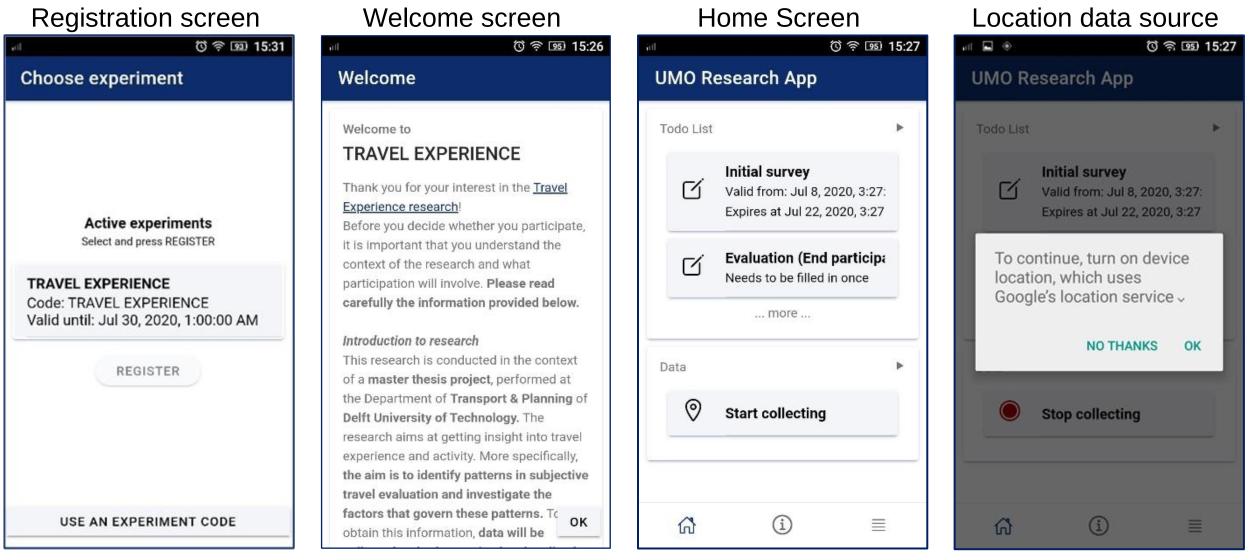

Figure 4.6. Umo Research app user interface screen examples

5 Data collection set up

To test the research hypothesis empirical data on travel time perception are essential. In this chapter the procedure of collecting such data is elaborated.

5.1 Data collection method

As mentioned earlier, the present thesis studies time retrospectively. This means that subjects become aware of the need to estimate a duration only after this is already complete. Starting from this requirement, it was decided that the name, the instructions, and the information provided to the public should not attract attention to the estimation of time. Thus, the study is titled “Travel Experience research”.

5.1.1 Safety and privacy of participants

It is aimed that the data collection of the present study poses to its participants risk no higher than the minimum risk (Human Research Ethics, 2020). Some of the measures that will be taken to satisfy participants’ safety, comfort and privacy are discussed here.

Before commencing the data collection, permission has been granted from the Human Research Ethics Committee (HREC) of TU Delft. Approval of the proposed data collection method by the committee directly indicates the compliance of the research with the General Data Protection Regulation (GDPR). In addition, the data management plan of the research has been approved by TU Delft.

Informed consent is asked from the subjects at the beginning of their involvement (Appendix C). Informed consent is remote and self-administrated. Before submitting their consent, prospective participants are informed about the research context as well as about the storage, sharing, preservation, and closure of their data. Besides, potential participants are encouraged to email the research team in case that they require further information before proceeding. The communication of this information to the potential participants is achieved via the Participant Information Sheet (Appendix A). The information sheet is presented to the participants right after their registration to the experiment.

To enhance the privacy of the users, precaution is taken that frequently visited locations cannot be extracted in detail from the data sets. To that end, the location data of each trip are trimmed for one minute at both the start and end of each trip.

It is recognized that the online mode of the proposed data collection method is less privacy-preserving than an offline collection, since it involves real-time information about participants’ locations (Wang, Wang, Wang, Zhang, & Kong, 2018). However, the anonymization of the users and the trimming of the location data ensure the privacy of the participants. To achieve anonymization, the system assigns a unique encrypted userID to each participant.

5.1.2 Experiment set-up

For the present study, alternative values were tested for the desired accuracy, the GPS signal frequency, and the type of location provider for the location data source. Three devices with different android version, namely; Android 7, Android 9, and Android 10, were used for tests. Based on the test results the default ionic values were indicated as most suitable towards achieving a balance between smartphone battery drainage and location data performance.

The present research aims at capturing the perceived travel time right after the completion of a trip. Thus, the End trip survey is generated by the time a user terminates the collection of trip data. To ensure that individuals report their travel time estimation close to the completion of their trip and consequently, that subjective travel time is not estimated based on memory, a time limit of half an hour is set for the completion of the End trip survey.

Notifications are scheduled to remind, as well as, to motivate individuals to report their travel experience. On average three notifications are sent daily. To lower the nuisance, the presented message is altered based on the day of the week and the prevalent conditions e.g., weather. Some of the used notifications can be seen in Table 5.1.

Table 5.1. *Examples of reminder notifications*

Notification text	Time/Frequency
Going for grocery shopping, for a walk/bike ride, or commuting? You can record all these trips!	9:00 a.m.
Remember to click “Stop collecting” at the end of your trip!	12:00 p.m.
Thank you for your contribution so far! Keep on reporting your travel experience and have a nice evening!	17:00 p.m.
We have just reached x number of trips! This is amazing!	Occasionally

The format of the datasets from the surveys, the user events, and the location data source events, is prepared in order to satisfy that information could be combined. The steps to extract information on the perceived and objective travel time, and the location of the trip are determined. The plan for combining the different data sets to estimate both the objective and the subjective travel time is illustrated in Figure 5.1.

1: unique TrackerID
2: End Trip survey creation= stop trip data collection event timestamp
3: reported travel time
4: start trip data collection event timestamp
5: location point timestamp

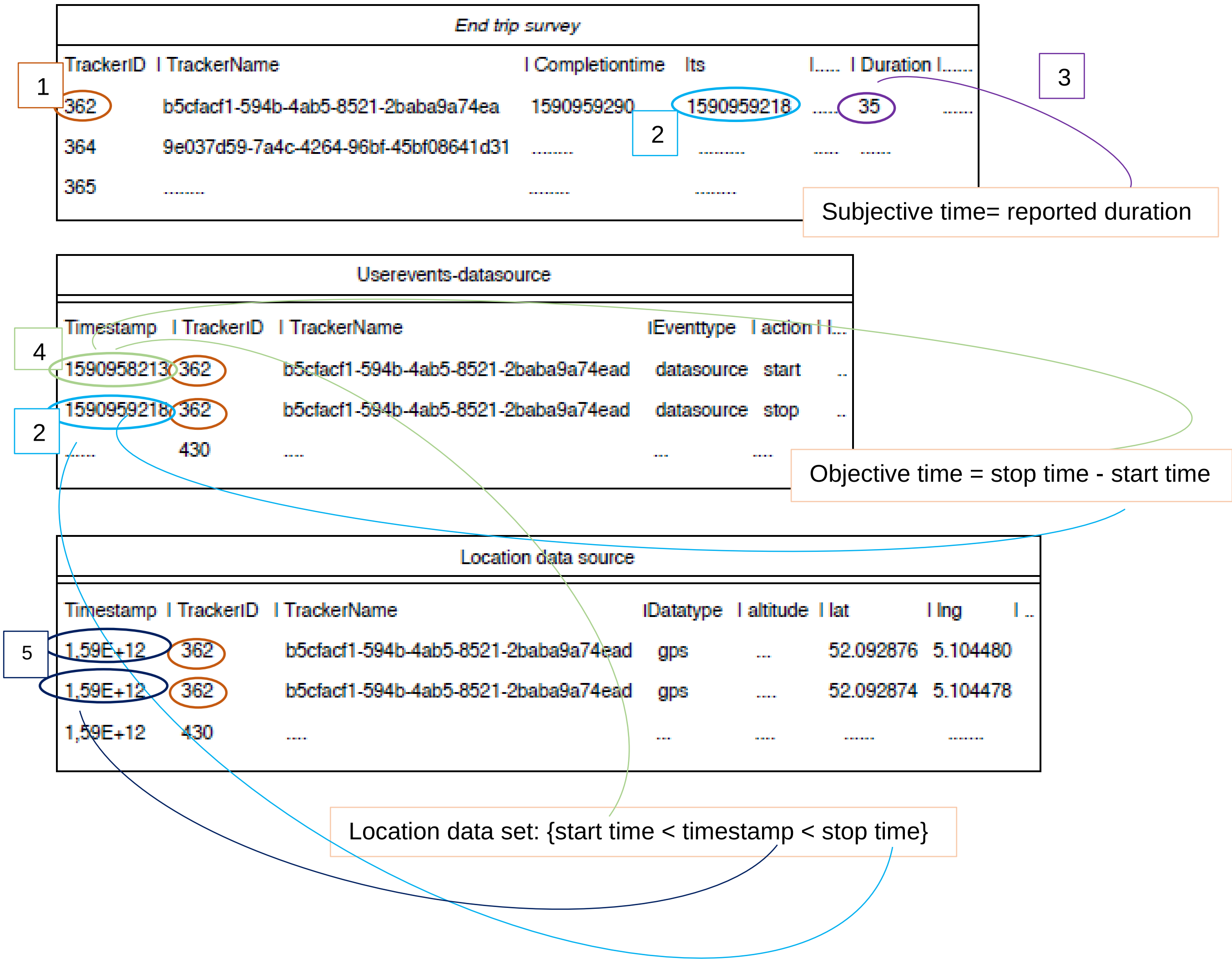

Figure 5.1. Information extraction from the combination of the obtained data set

5.1.3 Pilot study

It is important to test the proposed data collection method before proceeding to the actual data collection. To do so, a pilot study is performed. The pilot is useful towards obtaining valuable feedback for the time perception task, the overall task demand, as well as for the user interface of the mobile application.

For the pilot study a more extensive evaluation survey is designed. Usability, user acceptance, and technical performance are assessed in the evaluation survey of the pilot study. The parameters that are investigated are presented in Table 5.2.

In this sub-chapter the process, results, and evaluation of the pilot study of this research are presented. Finally, the researcher’s reflection on the pilot study and the proposed data collection method is discussed.

Table 5.2. *Pilot study evaluation parameters*

Usability	Task complexity	User acceptance	Quality and quantity of provided Information
Font size	Complexity of end trip survey questions	Willingness to participate again	On data privacy, storage, and handle
Text quality	Time required to fill in the End trip and the Initial survey	Participation enjoyment	Information and directions about the required tasks
Video quality in Initial survey		Battery drainage	
Navigation Ease of use		Trip report rate	

5.1.3.1 Procedure

The pilot study of this research took place from Wednesday 27thth of May until June 1st, 2020. Participants were recruited via direct communication, and they were mostly friends and colleagues of the researcher. In total 9 individuals (8 male and 1 female) accepted the invitation to take part. One respondent was above 60 years old whereas the age of the rest ranged from 25 to 35 years.

On the first day, the experiment code was provided to the individuals via email, and they were requested to fill in the informed consent, after reading thoroughly the information sheet. Trip recording initiated on the day after. Therefore, trip related data were collected for four days (Thursday-Sunday). Notifications were sent twice per day to remind the participants of reporting their travel experience.

5.1.3.2 Results

The performance of the pilot participants is analyzed not only to get an initial view on the travel time distortion and travel experience but also to estimate the necessary sample size.

In total 44 end trips surveys with a perceived trip duration report were collected. There is a variation in the sample in terms of the number of trips reported per individual, but all of them reported at least two trips. From the 44 observations, the vast majority, almost 80% correspond to active mode trips.

For the present research, the ratio of the perceived over the actual travel time is the main indicator of time misperception. The mean, minimum, and maximum values of the ratio are 0.84, 0.183, and 1.43, respectively. The mean value indicates that, on average, the pilot participants have underestimated their travel time.

The necessary sample size is estimated based on the variation of the variable of interest. In Figure 5.2, the travel time distortion ratio is tested for the normality of its distribution via a Q-Q plot. Since the pilot observations do not deviate a lot from the normal distribution line, the distribution is characterized as normal.

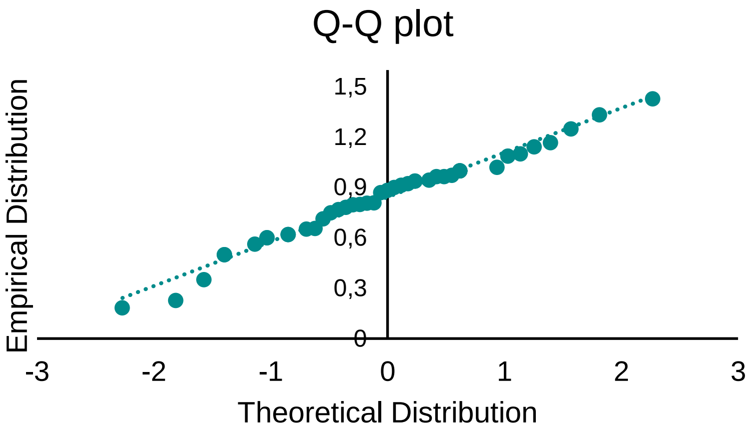

Figure 5.2. Distribution normality check

Assuming normality, the following equation (Equation 4) is applied to determine the necessary number of participants:

$$n \geq \frac{Z^2_{\alpha/2}}{d^2} \sigma^2 \qquad \text{(Equation 4)}$$

Where:

α is the significance level

d is the desired accuracy

σ^2 is the variance of the considered phenomenon

The mean value per participant is estimated as the average travel time perception ratio across all the trips that he/she has performed. As seen in Table 5.3, 8 out of 9 people underestimated their trips on average.

Table 5.3. *Pilot travel time distortion ratio*

Participant	Number of trips	Participant Mean
1	4	0.712
2	2	0.944
3	10	0.852
4	5	0.850
5	7	0.832
6	3	0.893
7	5	0.824
8	2	0.414
9	6	1.288
Mean	4.9	0.845
St.dev.	2.5	0.227

After processing the data points, it is found that the standard deviation of the travel time distortion ratio is 0.227. The confidence interval is set to 95% and the desired accuracy to 2% of the mean trip distortion ratio value. Based on the values presented in Table 5.3, minimum number of participants is estimate equal to 11.

5.1.3.3 Pilot study reflection

During the pilot study, both the weak and strong aspects of the tested data collection layout were revealed. The evaluation survey that was distributed to the participants as well as extended interviews which were conducted not only at the end but also during the study, provide important insight into the performance of the pilot.

In the interviews, it was pointed out from two respondents that they faced some difficulty in remembering to terminate the data collection right after their trips. Although they both rated the number of reminder notifications as adequate, they stated that they would desire more to be sent. Considering that the annoyance prompt by the notifications was judged as acceptable overall, it seems that more notifications need to be scheduled for the data collection daily.

The question on the perception of travel time "*How long was your trip? Please indicate in minute intervals."* seems to be confusing for some of the participants. It appears that they thought it asked for the objective trip duration. This made them to check their clock in order to answer. This deficiency was noticed in the first two days of the pilot and the question was reformulated for the remaining period as follows: "*How long do you think that your trip was? Please indicate in minute intervals."*

Since it is desired that the individuals report multiple trips, a major concern for the design of the experiment is whether some aspect of the "End trip" survey discourages the continuation of the participation after it is first experienced. All but one of the respondents who completed the evaluation survey, declared that the effort and the time required for this survey, is acceptable. The dissatisfied individual is the oldest participant (62 years). The analysis of the data from the specific user shows that on average he needed almost three times more seconds than the rest to complete the survey. It is worth mentioning that the mean value for the completion time was 1 min and 48 sec. These results indicate that individuals from different age groups might not be equally familiar with the required tasks or applied method. The same respondent reported almost 90% of the trips that he conducted within the period of interest. This is the second highest proportion among the whole group. Thus, fatigue could also have contributed to the expressed annoyance. To ensure that the sample experiences an as low discomfort as possible, the End trip study format was revised before commencing the actual data collection. The survey turned from a multiple page into a single page design, some questions were reformulated, and the expected time to complete the survey reduced from 2 to 1.5 minutes. The final version of the End trip survey is available in 0.

No complaints were made for the intake survey and the participants approved the usage and the quality of the cycling videos.

From the researcher's point of view, the pilot had a major contribution to the preparation of the data collection. The pilot study gave the chance to identify bugs in the app, especially, those related to different Android versions and smartphone brands. The information and instructions' sheet were updated after the pilot, to include and emphasize the smartphone settings that the users need to properly modify (Appendix B.).

Taking into account the prevalent measures against the COVID-19 and the reduced mobility in the Netherlands, the pilot was also important towards determining the current mobility level of the population and, subsequently, deciding whether the data collection can be successful. The number of trips conducted with active modes during the four days of the study, indicated that it is still justifiable to proceed to the collection of data under the prevalent circumstances. In subchapter 5.2, the actual data collection process is described.

5.2 Data collection procedure

Accounting for the reduced mobility due to the pandemic circumstances, people are encouraged to participate at least 4 days. Both workdays and weekends are considered.

5.2.1 Participant recruitment

The invitation to participate was disseminated online, mainly via social media. LinkedIn, Facebook and Instagram were the social media platforms that were exploited. Both a video and a poster were created to attract potential participants (Appendix A.). The video was uploaded on YouTube and was publicly accessible.

Communication was sought with multiple companies, organizations, and individuals. Those were asked to spread the invitation over their network. The selection of the contacts was based on the relativity of the thesis objective with their interests and work. Communication channels were established successfully with many actors, including the Dutch Cycling Embassy, Fietsersbond, Urban Cycling Institute, Polis|Platform for urbanism and Bicycles, and ITS-BITS. Most contacts shared the participation invitation via their social media accounts, while some also included it in their frequent newsletters.

In addition, four posters were put up around the researcher's home city; Delft, the Netherlands. The posters were exposed in central locations, on advertisement banners that the municipality of Delft indicated. Due to the travel restrictions that were applied to prevent the spread of COVID-19, it was not feasible to add posters in more cities.

5.2.2 Participants and observations

In total, 76 people registered for the research. Not all of them though, were active users of the mobile application. Trips were recorded from 56 users. As far as the participant recruitment process is concerned, Figure 5.3 indicates that despite the continuous dissemination of the participation invitation by various actors, most of the respondents were attracted on the first day of the invitation.

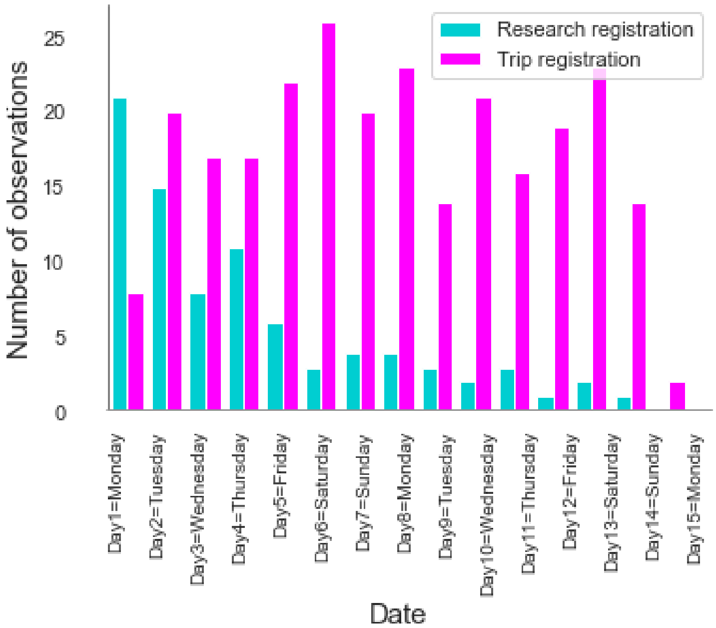

Figure 5.3. Number of reported trips and participation registrations per day (left), for the data collection period between 08/06/2020 and 22/06/2020

Since the recruitment of participants was conducted online, it is impossible to evaluate the non-response rate. However, based on comments and questions that the researcher received, at least three different reasons for not participating are recognized: a) possession of a non-Android smartphone, b) a high business, and c) almost no travelling due to the COVID-19 circumstances. During the last days of the data collection period an additional factor appeared quite often: “It seems to me that too much effort and time are required to install the app and get familiar with it, considering that I will be able to use it for such a short period of time”.

6 Results

In this chapter, the obtained data are processed and analyzed to answer the research questions. The chapter is divided into three sections. In the first section the obtained data points are exploited to extract information on perceived, actual, travel time and on the selected factors. Furthermore, the obtained data set is filtered to exclude non valid observations and are prepared for the analysis. In section 6.2, the characteristics of the participants and of the registered trips, as well as of the travel time reports, are discussed via descriptive statistics. Finally, the analysis of the travel time perception and the travel time perception model estimation results are presented.

6.1 Data pre-processing

Before proceeding to the analysis of the collected data, the different data sets are combined for the extraction of the information required to test the research hypotheses of the present study. Furthermore, based on some filters missing travel time reports, invalid registrations, and irrationally short and long trips are identified. These data points are removed from the data that is exploited for the analysis of travel time distortion.

6.1.1 Data preparation

First, the survey responses are checked for erroneous duration entries. Participants were encouraged to report trip duration and time since the completion of their trip in a numerical format. However, some submitted survey responses include a text answer for the trip travel time and/or the response delay. These responses are transformed into numerical values of minute intervals and kept in the database.

Secondly, the subjective and objective travel time of the research are estimated following the steps described in section 5.1.2, Figure 5.1. Moreover, the total subjective travel time is estimated with the inclusion of the reported delay between the completion of a trip and of the respond in the survey is estimated. Considering the response delay, the total reported travel time is estimated following equation 5:

$$TRtt = Rtt + Rd \qquad \text{Equation 5}$$

Where:

$TRtt$ is the total reported travel time

Rtt is the reported travel time

Rd is the reported number of minutes between the termination of the trip and the fill in of the survey, in case there is no Rd data available, its value is set to zero

6.1.2 Data filtering

The app is available on Google play, and there are no geographical restrictions for downloading it. Thus, it is necessary to check for the existence of trips in the end trip survey data set, which were conducted outside the Netherlands. The location test is performed by exploiting the trip GPS points which have been gathered via the smartphones. Not all trip registrations have been accompanied by the gathering of location points. Therefore, the test is only applied to the share of the trip observations which contains location information. In total, participants reported seven trips abroad. These seven trips and the four individuals who conducted them are excluded from the dataset.

Considering the aim of the present study, which is to quantify the deviation of the subjective, reported travel time from the objective one, only trips for which there is a reported travel time are valid. Among the 269 surveys submitted for trips within the Dutch borders, 14 do not contain a duration report and are ignored during the analysis.

Regarding the objective travel time, the obtained datasets are checked for the existence of both the start trip and the end trip events for each trip. The number of travel time reports is further reduced by two since for two reported travel time records it is impossible to estimate the objective duration of the respective trip. More specifically, for these two trips, there is no start-trip data collection event in the dataset.

From the remaining trip observations, those with unrealistically small objective duration need to be excluded. To find the travel time value which determines whether a trip duration is realistic or not, the distribution of objectively measured travel time is examined. At this filtering step, the focus is on the distribution of the shorter trip durations. In Figure 6.1, the distribution of the registered trips' duration, which are shorter than half an hour is illustrated. As seen in Figure 6.1, there is an isolated bar of very short trips on the far right of the x-axis. The three trips that this bar included, lasted less than one minute. Thus, the travel time of 2 minutes is set as the minimum acceptable travel time for the given dataset. The trips with a duration smaller than that value are removed from the dataset.

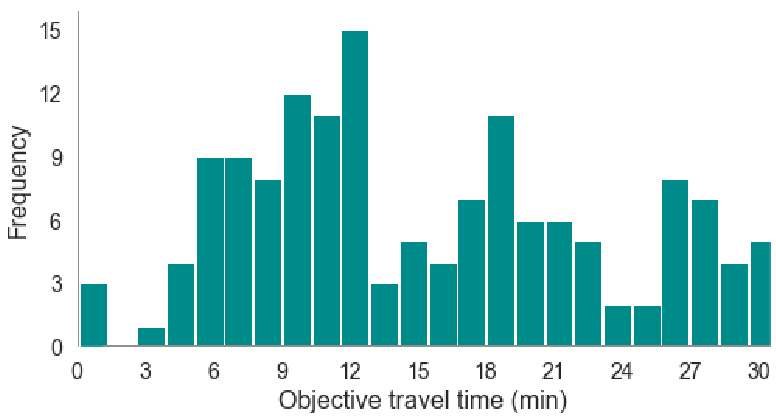

Figure 6.1. Objective travel time frequency distribution for trips less than 30 minutes

Apropos of the actual travel time, apart from the very short trips, the obtained data set is checked for very long travel time registrations. In Figure 6.2 the distribution of the actual travel time is illustrated in. Outliers are pointed in the distribution of the actual travel time, for all modes of transport. However, only two travel times by bike, are extremely different than the rest of the data points. Those two trips are 1246 minutes (~20 hours) and 582 minutes (~10 hours) long, whereas the next five longest cycling trips lasted between 130 and 200 minutes. These trips are extremely long, and it could be assumed that the individuals who reported them did not remember to indicate the completion of their trip on time. Furthermore, there are no similarly long trips by any other mode of transport and, as such, the number of observations in this duration range is very small. Thus, it is reasonable to exclude these two outliers from the analysis.

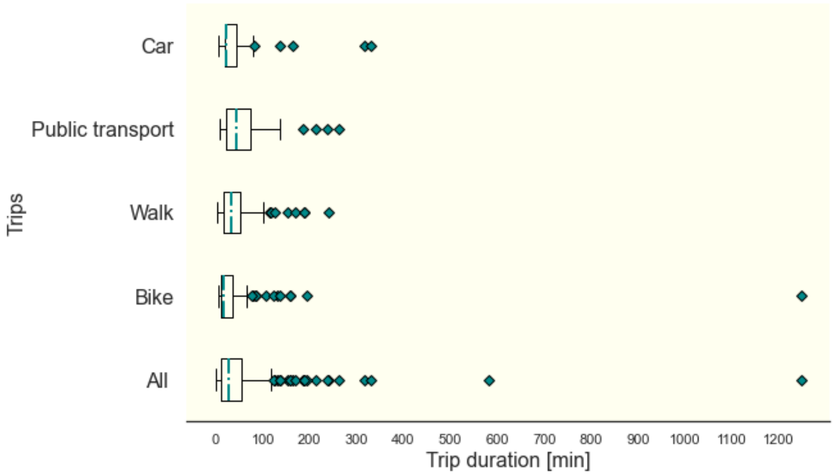

Figure 6.2. Actual trip duration distribution for all trips and per mode of transport

The updated data set contains 248 trip observations. The above-mentioned filter steps are illustrated in Figure 6.3.

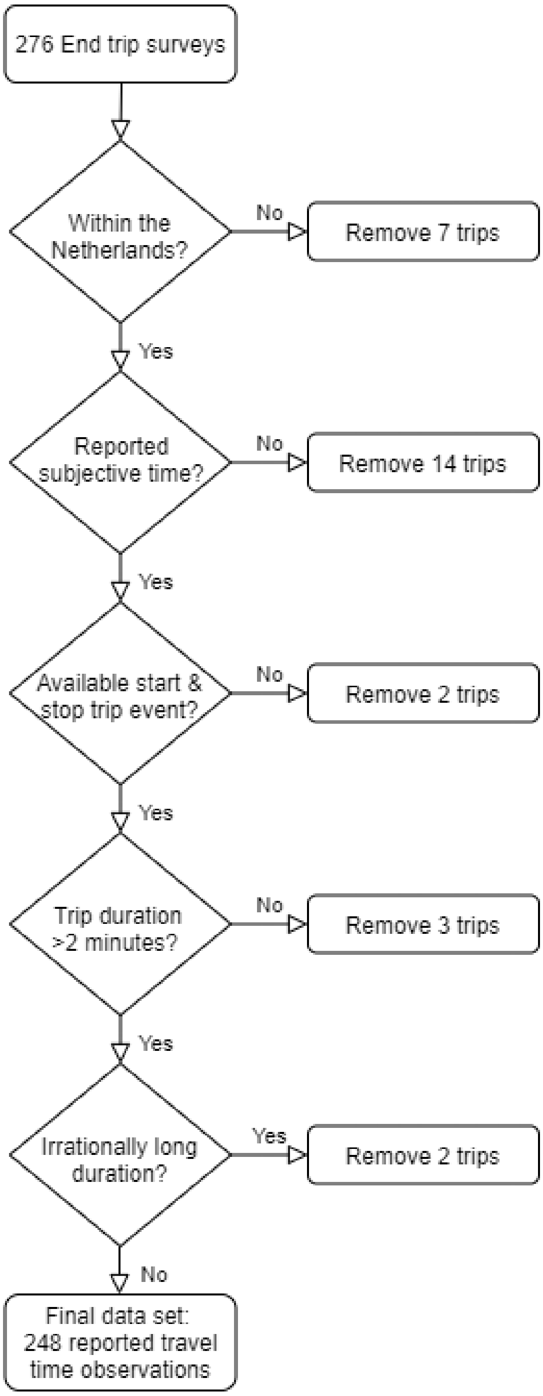

Figure 6.3. Data filtering process

6.2 Descriptive statistics

Before analyzing travel time misperception and its determinants, it is necessary to discuss the variance of the factors assumed to be possible determinants of travel time distortion (see section 3.1 and 3.2). The individual and trip characteristics of the obtained data points are discussed in the following three sections of this subchapter. The first section focuses on the presentation of the characteristics of the sample and of its reported trips. Then, in sub-section 6.2.3, the distribution of travel observations, both objective and subjective reports, is described. Travel time misperception of real-life trips and trips presented via videos is discussed in descriptive statistics.

6.2.1 Sample

In total, 76 people registered for the research. Not all of them, though, were active participants. Fifty-five individuals submitted at least one of the available surveys, which indicates that the dropout rate is 28%.

The sociodemographic and stress state characteristics of the sample are derived from the Initial Survey dataset. Out of the 55 active participants, all submitted the initial survey. After filtering the survey respondents who were outside of the Netherlands during the data collection period (see section 6.1.2), the sample of this survey includes responses from 53 individuals. An overview of all considered personal characteristics of the 53 participants is given in Table 6.1. In Table 6.1, different colors are used to emphasize the relative frequency of the various levels of each sociodemographic characteristic. More specifically, the darker the color, the more frequent the corresponding characteristic among the research participants. The “No response” level is excluded from the color scheme.

Table 6.1. *Participants sociodemographic characteristics*

Characteristic	Level	Frequency	Relative frequency
Gender	Female	21	0.40
	Male	31	0.58
	No response	1	0.02
Age	18-34	45	0.85
	35-49	3	0.06
	50-64	2	0.04
	No response	3	0.06
Education level	High school	2	0.04
	HBO/University	19	0.36
	MSc/PhD	31	0.58
	No response	1	0.02
Residency in the Netherlands	>6 months & <3 years	25	0.47
	>3 years	27	0.51
	No response	1	0.02
Employment status before Covid-19	Full-time	20	0.38
	Part-time	12	0.23
	Unemployed	14	0.26
	Other	6	0.11
	No response	1	0.02
Employment status change due to Covid-19	Yes	2	0.04
	No	50	0.94
	No response	1	0.02
Employment status after Covid-19	Full-time	20	0.38
	Part-time	10	0.19
	Unemployed	15	0.28

	Other	7	0.13
	No response	1	0.02
TU Delft community member	No	19	0.36
	BSc/MSc student	28	0.53
	PhD student/Researcher/Academic stuff	5	0.09
	No response	1	0.02
TU Delft faculty (N=33)	Civil Engineering and Geosciences (Department of Transport & Planning)	18	0.54
	Civil Engineering and Geosciences (other)	7	0.13
	Architecture and the Built Environment	2	0.06
	Mechanical, Maritime, and Materials Engineering	1	0.06
	Technology, Policy, and Management	1	0.09
	Electrical Engineering, Mathematics, and Computer Science	3	0.09
	No-response	1	0.03
Mode ownership/subscription	Bike	48	0.91
	Bike sharing system subscription	7	0.13
	Private Car	10	0.19
	Motorcycle/Moped/Scooter	1	0.02
	Other	1	0.02

← More common, Less common →

As seen in Table 6.1, more men (~58%) than women (~40%) participated in the research. The share of men and women in the dataset differs from that in the population. In the latter, the ratio is almost 50-50 (Central Bureau for Statistics, 2020). The overrepresentation of male participants in the sample could be attributed to the fact that 6 out of 10 participants are members of the Delft University of Technology (TU Delft) community. Among TU Delft staff and students, the ratio of women and men is approximately equal to 0.36 (Delft University of Technology, 2019).

The vast majority of the survey respondents are between 18 and 34 years old, and there is no representation of the elderly (>65 years old) people in the sample. The usage of a smartphone application as the data collection tool and the reduced mobility of vulnerable groups due to the Covid-19 pandemic could have led to the bias towards the younger groups of the society.

Regarding the education level, 95% of the participants are highly educated and have at least a University or HBO degree. Due to the over-representation of TU Delft members in the sample, this finding is not surprising.

Regarding the employment status of the survey respondents, 57% is employed during the data collection period. Only two individuals (~6%) reported a shift in their employment status due to the Dutch government's measures against the coronavirus pandemic. Job loss has been related to increased anxiety and stress and, as such, could potentially affect travel time misperception. However, since in the present study, only a small portion of the sample has recently lost its job, its effect on time perception is not examined further.

None of the participants has been living in the Netherlands for less than six months. As such, it is expected that the whole sample is at least somewhat familiar with the Dutch active modes infrastructure and with the environment depicted in the short duration cycling films, which are presented in the second part of the Initial survey. Besides, almost all respondents, 50 out of 53, reported that they own a bike or a subscription to a bike-sharing scheme. Thus, it is expected that the majority of the sample also has some cycling experience.

The stress level of the participants has also been captured, based on the PSS-4 scale, which was described in detail earlier in section 4.1. In Appendix E. a detailed presentation of the score at each scale item is provided. The internal consistency of the PSS-4 scale is tested to examine whether the scale is suitable for capturing how stressed the research sample is. Following the example of past studies, in which the same version of the Perceived Stress Scale has been applied, Cronbach's a is used. Although there is no strict rule regarding the Cronbach's a value, over which the scale is considered consistent, 0.70 is a widely accepted minimum rate (Lee, 2012). The estimated value of Cronbach's a is 0.897. This value indicates a high consistency among the items of the scale. Therefore, the PSS-4 is appropriate for obtaining information on the stress level of the people who participated in the present study.

The distribution of the overall PSS-4 score across the respondents of the survey is illustrated in the histogram below (Figure 6.4). In the frequency histogram, it can be recognized that most of the participants seem to be quite stressed, scoring between 8 and 11, a little bit above the mean value of the sample. Nevertheless, no one in the sample reaches an extreme maximum stress value (13-16). On the contrary, one person reported very low stress, of value 2, on the PSS-4 scale. The negative value of the skewness (-0.497) also supports these observations. A significant correlation is found between the age and the stress level of the individuals via Spearman's correlation coefficient estimation, r_s =.388, p(two-tailed) <0.01. The latter indicates that in the sample, older people appear to be more stressed than younger ones.

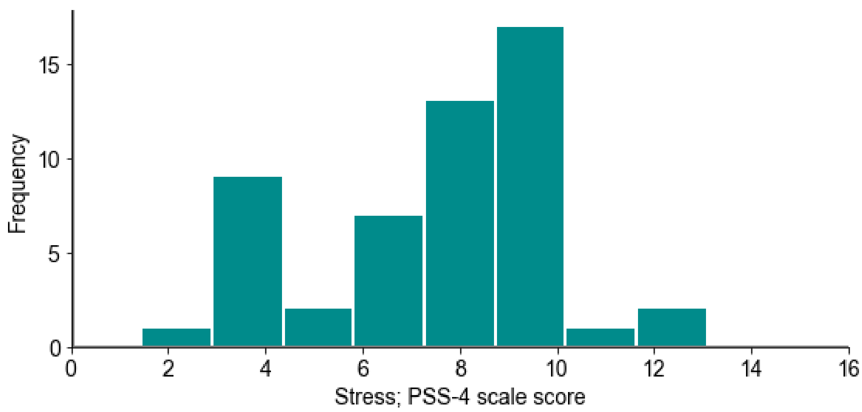

Figure 6.4. Reported stress histogram, N=53

6.2.2 Trip characteristics

Although 53 individuals submitted the initial survey, only 44 reported at least one subjective travel time in the filtered dataset. It is noticed that there is a variety in the number of trips reported by those 44 participants. The average number of trips recorded per respondent is 5.57, and the standard deviation is 6.11. Nevertheless, four very active users have reported considerably more trips than the rest of the participants and the mean value. Each of these participants has provided at least 15 observations, and altogether they have reported 84 trips. As mentioned above, the total dataset consists of 248 perceived travel time records. Therefore, these four individuals account for around one third of the total number of observations. This means that the data collection has resulted in an unbalanced, panel data set of trip observations.

Unbalanced data sets could result in producing biased models. Furthermore, the unbalanced distribution of trips per user poses an additional risk to the present study as it indicates an unequal learning effect among the participants. As some users have responded to the end trip survey many times, they might have changed their behavior in two different ways. On the one hand, their trip duration reports may have turned from retrospective to prospective, which means that they could have paid more attention to time passage. On the other hand, the repetitiveness of the task could have increased either their familiarity with the survey questions (practice effect) or their tiredness (boredom effect). In the latter case, individuals could have paid less attention to the questions posed and appear almost a guessing behavior in their duration reports. The unbalanced and the panel character of the data is considered in selecting the travel time misperception model in section 6.3.1. It is worth mentioning that by excluding the above-mentioned highly active, the average number of trips reported drops to 4 per person and the standard deviation to 3.2.

Regarding the reported trip characteristics, an overview is given in Table 6.2. Considering all trip purposes, 57% of all trips begin from home. Furthermore, one out of five trips are a return home trip. Thus, in total, most of the trips are homebound. The percentage of homebound trips (78%) is a bit lower than the one found in the Netherlands Mobility Panel (~81%) (Hoogendoorn-Lanser, Schaap, & OldeKalter, 2015).

Regarding the trip purpose distribution, in Table 6.2, it is noticed that the commuting trips, which are either for Work or Education purposes, account for only 10% of the total trips reported. On the contrary, the trip itself purpose is the second most common. These findings are contradictory to the normal trip purpose distribution in the Netherlands. More specifically, trips for work and education purpose occurred less often, whereas the trip itself purpose is four times more frequent than the national travel survey in the Netherlands suggests (Centraal Bureau voor de Statistiek, 2020). However, the present trip purpose complies with the circumstances in the Netherlands during the data collection period, such as the increased rate of remote working and studying. Since the current research considers both commuting and non-compulsory trips, the distribution of trip purposes as presented in Table 6.2, indeed allows for the estimation of travel time misperception for various trip purposes.

In Figure 6.5, the distribution of the various travel motives for trips by bike or on foot is illustrated. It is noticed that almost half of the pedestrian trips and one fifth of bike trips were made for the shake of walking or cycling. For these trips, it is possible that individuals seek a higher physical effort demand than for the rest of their trips. This could affect the impact and direction of physical exertion variable on travel time misperception.

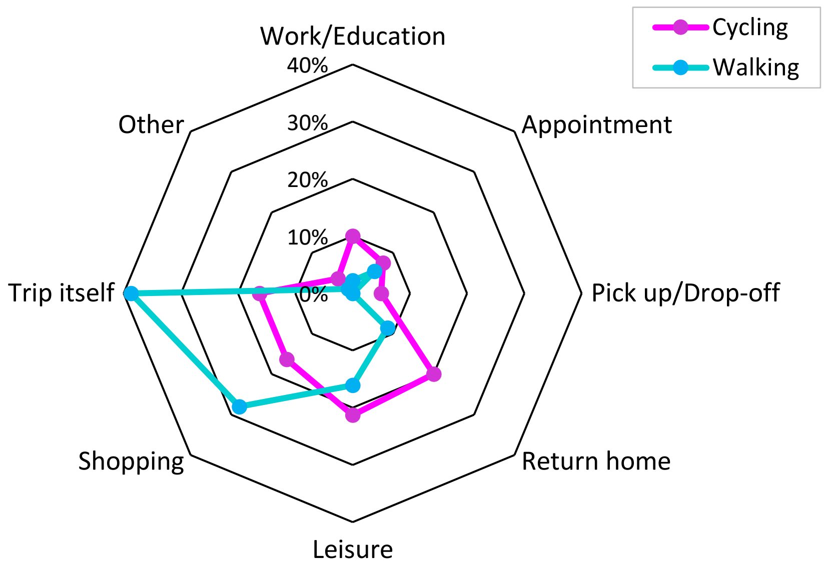

Figure 6.5. Trip purpose division for cycling and walking trips

The share of active mode trips in the total number of reported trips is high. More specifically, 177 trips have been conducted either by bike or on foot. The overrepresentation of active mode trips in the sample is not problematic for the present study as its focus is the time perception of travelers by these modes. The ratio of walking to cycling trips is above 1. Although this is dissimilar to the ratio estimated by the MPN data, it complies with the emerged travel behavior patterns due to the Covid-19 pandemic, as described by de Haas's team (de Haas, Hamersma, & Faber, 2020).

In total, only three trips have been conducted by Ferry or Motorcycle/Mopped. Therefore, these modes are not included in the analysis. It is pointed out, though, that the duration of the ferry and motorcycle trips was underperceived. The observations of car and public transport trips are kept in the dataset to compare the travel time distortion for these trips with those by active modes.

Table 6.2. *Trip Characteristics overview, N= 248*

Characteristic	Levels		Frequency		Relative frequency	
	Return home		54		0.21	
	Work/Education		25		0.10	
	Appointment		19		0.08	
	Pick up/Drop off someone	Home Origin	5	143	0.02	0.57
	Shopping	Home based*	52	195	0.21	0.78
	Leisure		41		0.17	
	Trip itself		49		0.20	
	Other		3		0.01	
Transport mode	Bicycle	Active Modes	81	177	0.33	0.69
	Walk		96		0.36	
	Car		40		0.16	
	Motorcycle/Mopped		2		0.008	
	Public Transport		30		0.12	
	Ferry		1		0.004	
	No-response		1		0.004	
Day of the week	Monday		31		0.13	
	Tuesday		27		0.11	
	Wednesday	Weekdays	39	170	0.15	0.68
	Thursday		32		0.13	
	Friday		41		0.16	
	Saturday	Weekend	46	78	0.19	0.31
	Sunday		32		0.12	

*Home bound trips include both trips originating from home and returning at home trips

An analysis of the obtained location data shows that the registered trips are spatially unequally distributed. Although most of the trips have been conducted in the Randstad, especially in and around Delft city, some trips have also been reported in the provinces of Noord Brabant, Overijssel, and Drenthe (Appendix D.). The concentration of the trip registrations on a few areas of the Netherlands indicates that there might be local unobserved parameters such as the modal split and the overall walkability and cyclability of these areas, which affect the overall travel experience and, consequently, the travel time perception of the participants.

6.2.3 Travel time observations

In this section, the data on the perceived and the actual travel time are analyzed in terms of descriptive statistics. First, in section 6.2.3.1, the distribution of both the objectively measured and the subjective travel time of real-life trips is discussed. Moreover, the travel time misperception is examined in terms of the average value. Next, in section 6.2.3.2, the data on the judgment of travel time for short cycling films are analyzed in terms of summary statistics. Finally, the relation between the travel time perception ratio of short trips and the corresponding ratio of longer, real-life active modes trips is determined.

6.2.3.1 Objective and subjective travel time empirical observations

Regarding the duration of the recorded trips, objective and the reported travel time are plotted in Figure 6.6 separately for each mode of transport as well as for all trips combined.

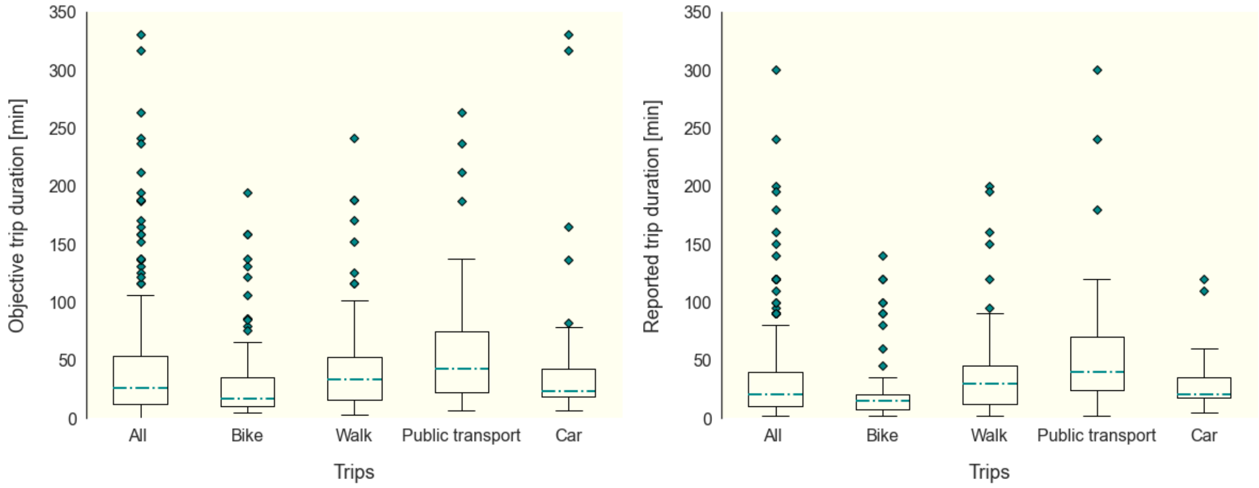

Figure 6.6. Objective (left), and reported (right) trip duration distribution for all trips, and per mode of transport

As discussed in the literature review, the misperception error might differ in shorter and longer time intervals. Thus, the actual travel time is also of interest. In the boxplots of Figure 6.6, multiple upper outliers are spotted in all actual travel time data sets. There is no solid reason to exclude these outliers from the analysis, but their differentiation from the rest of the data points should be taken into account. In the model estimation, the effect of including these observations will be examined.

The objective duration boxplots (Figure 6.6) provide information about the differences in the distribution of trip duration across the four modes of transport. Surprisingly, it is noticed that the mean value of walking trip duration is higher than the average travel time by bike. Although this is not common for daily trips, the high share (~40%) of walking trips for the trip itself as the travel motive (see Figure 6.5) could explain this increased duration of the trips conducted on foot.

Comparing the two sets of boxplots (Figure 6.6), a greater variability is observed in the objective trip duration for all modes, but especially for cycling trips. The higher dispersion of the actual travel times is also indicated by the Interquartile range (IQR) values (Table 6.3).

In Table 6.3, it is noticeable that the minimum and maximum reported trip duration for all modes of transport are rounded to 0 intervals. Rounding is very common in the whole subjective travel time dataset. Around 70% of the reported values are intervals of 5 minutes. As discussed in the literature review, rounding is, in general, not sparse in travel time reports.

Table 6.3 *Distribution measures of actual and subjective travel time*

Mode	Measures of central tendency				Measures of dispersion							
	Median		Mean		IQR		Min		Max		№ outliers	
	Actual	Reported	Actual	Reported	Actual	Reported	Actual	Reported	Actual	Reported	Actual	Reported
Bike	16.4	15	35.6	24	25.8	12	4.5	2	194.6	140	13	10
Walk	34.2	30	44.5	38.3	39.4	38	2.8	2	240.8	200	8	5
Public Transport	36.7	40	60.6	54.9	53.1	45	5.6	2	262.9	300	3	2
Car	23.1	20	48.9	28.1	23.9	17	6.6	5	330.9	120	5	2

In the above table (Table 6.3), apart from the IQR, the values of various central tendency and dispersion measures are presented for both the reported and the observed trip duration.

For all modes of transport, the mean value of the reported travel time is lower than the observed one. In order to evaluate the deviation of the subjective from the objective trip duration for all trips, as well as per mode of transport, five dependent one tail t-tests are applied. The null hypothesis (H_o) is that there is no difference between the two travel time values. The alternative hypothesis (H_1) is that the reported trip duration is smaller than the actual one. The paired t-tests results are summarized in Table 6.4.

For the estimation of the effect size the following equation is used:

$$r = \sqrt{\frac{t^2}{t^2 + df}}$$

Equation 6 (Rosnow & Rosenthal, 2013)

The null hypothesis is rejected for cycling, walking, and car trips since the t-tests indicate a significant difference (p<.05) between the mean values. Cyclists and pedestrians have underestimated travel time in a similar way based on the t value. However, the effect size is bigger for the bike (*r= .31*) than the walking (*r= .26*) trips. For car users, the perceived trip duration is on average smaller than the objectively measured travel time by 2 minutes (*t(40)= -2.050, p< .05, r= .31*).

Table 6.4. *Paired t-tests for mean comparison of actual and reported travel time*

	t	df	Significance (1-tailed)	Effect size (r)
All trips	-3.985	245	.000**	.27
Bike	-2.888	79	.002**	.31
Walk	-2.578	92	.006**	.26
Public Transport	-0.610	30	.275	.11
Car	-2.050	40	.024*	.31

*Significant at 95% significance level (p<.05) **Significant at 99% significance level (p<.01)

For public transport passengers, the null hypothesis is not rejected (p> .05). A possible explanation for the insignificant misperception of the duration of public transport trips, is the usage of a time/duration information source. The research respondents declared that they checked some information source for more than half of the public transport trips to plan their trip.

The comparison of the means could have been affected by the existence of both overestimated and underestimated travel durations. Therefore, the dependent t-tests are repeated for the underestimated and the overestimated trips separately. The small sample sizes of the car and the public transport trips, after the split of the dataset, do not allow to assume normality. Thus, the normality of the distribution of the difference between the subjective and the objective travel time is checked a priori. Because the car and public transport trip distributions fail the normality tests, the t-test is applied only for the active mode trips.

Table 6.5. *Paired t-tests for mean comparison of actual and reported travel time, for underestimated and overestimated trips*

	Underestimated trips (N=101)				Overestimated trips (N=143)			
	t	df	Significance (1-tailed)	Effect size (r)	t	df	Significance (1-tailed)	Effect size (r)
All trips	-5.341	143	.000**	.41	7.382	101	.000**	.59
Bike	-3.608	47	.000**	.47	6.665	31	.000**	.76
Walk	-4.177	56	.002**	.49	5.589	35	.000**	.69
Public Transport	-	9	-	-	-	20	-	-
Car	-	27	-	-	-	12	-	-

*Significant at 95% significance level (p<.05) **Significant at 99% significance level (p<.01)

The t-tests revealed a significant difference for all examined pairs at the 95% significance interval (Table 6.5). Although for both overestimated and underestimated trips, the difference between the subjective and the observed travel time is significant (p< .05), the average misperception error is bigger for the overestimated trips (*t(101)= 7.382, r= .59*) than for the underestimated trips (*t(143)= -5.341, r= .41*).

The comparison of the means provides some information on the average degree and significance of travel time misperception. However, it is necessary to look deeper and check for extreme observations that might severely affect the mean. To achieve this, the reported travel time is plotted over the objectively measured trip duration in Figure 6.7. The scatter plots enable the pairwise comparison of the actual with the perceived travel time. In the plots, the y=x line has been included. The points which are located above this line represent the trips for which the reported trip duration is longer than the objectively measured travel time.

Most of the points are close to the line, demonstrating a small inequality between the two travel time values. Nevertheless, for the underestimated bike, walk, and car trips, it is noticed that there are points that are very distant from the line. According to the estimated objective travel time of these trips, those are quite long trips which lasted more than one hour. Reviewing these observations' characteristics in the data set, no pattern is found which could justify the irregular difference between the actual and perceived travel time. The trip purpose, the activities performed during these trips, the response time to the survey, the trip duration expectancy, and the reported delay between the actual and the indicated completion of the trip, via the app, have been examined. However, none of them was consistent among these widely misperceived trip durations. Thus, no factor could be directly characterized as the cause of the large deviation between the subjective and objective travel time.

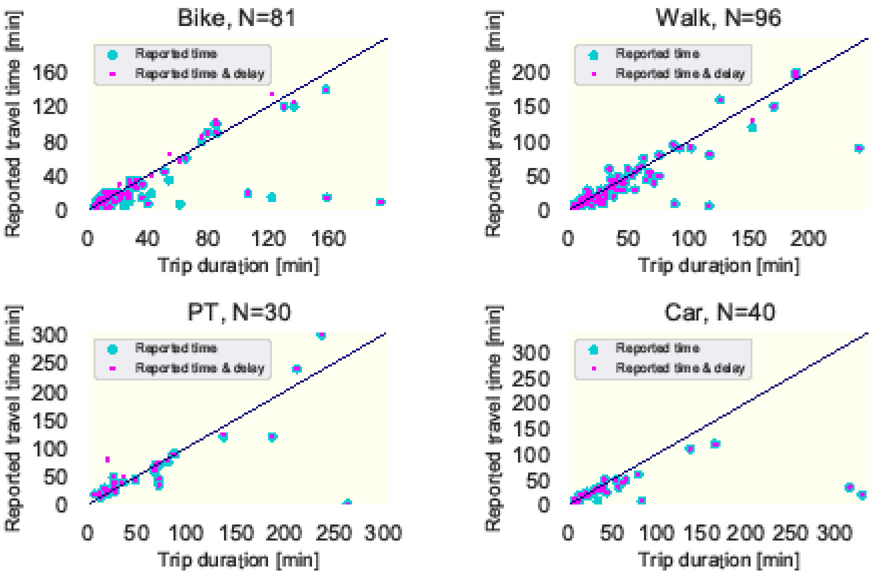

Figure 6.7. Reported over actual travel time, per mode of transport

The effect of including the reported response delay in the estimation of the subjective travel time can be seen in Figure 6.7. It is worthwhile to recall that the reported trip response delay is the time that a respondent indicates that has elapsed from the completion of the trip until the moment that he/she responds to the End Trip delay. From the 244 observation, around one third is accompanied by a delay report.

As seen in Figure 6.7, with the inclusion of the delay, overall, the distance from the y= x line is reduced. In addition, some underestimated trips jump to the spectrum of overestimated trips. However, there are still 14 points that show extreme positive difference, above one hour, between the objective and the subjective travel time. The huge misperception error for these trips could be thought of as irrational. Consequently, the consideration of these observations could not add value to the analysis of travel time perception. As such, these outliers are excluded from the travel time misperception analysis.

Despite considering the abovementioned data points as invalid for the analysis of trip duration perception, the existence of such outliers in the dataset indicates that non-observed and uncontrolled factors could have influenced the estimation of either the subjective or the objective travel time. Among the potential roots are the belated indication of the trip completion from the user in the app and the delayed log of the end trip event in the database.

6.2.3.2 Travel time misperception of short trips

In this section, the gathered travel time perception reports of the cycling films are discussed. The analysis of the misperception of the videos' duration provides insight into the distortion ratio for very short trips and its relationship with the duration misperception of real-life trips.

The three videos' duration has been judged by almost 75% of the participants who submitted the Initial Survey and performed at least one trip. The three different videos' response rate is quite uniform, with 31, 33, and 34 responses to Video 1, Video 2, and Video 3, respectively. For a detailed description of the video characteristics the reader is referred to section 4.1.

The respondents' performance in both the verbal estimation tasks (Video1 and Video3) and the temporal bisection task (Video2) is summarized in Table 6.6. Most of the individuals have misperceived the duration of all videos. Regarding the split of the travel time distortion direction among the misperceived time reports, the majority of people have underestimated the duration of both the first and the last cycling film. On the contrary, most people overestimated the difference between the duration of the cycling film across nature and the trip across the TU Delft campus. It is reminded that the first two videos last the same number of seconds (21sec), and the last video is twice as long.

The accurate estimation of the presented trip duration is most common for the last video (~38%). In contrast, all individuals have misperceived the duration of the trip film across the TU Delft campus. The question type could have influenced the high rate of correct travel time reports for Video3. As described in section 4.1, the verbal estimation of the perceived duration was provided via a multiple choice question with five predetermined values, whereas the perceived duration of the first cycling film was reported in the detail level of seconds.

Table 6.6. *Short interval travel time perception via videos*

	Video1 (N= 31)	Video2* (N= 31)	Video3 (N= 34)
No misperception	0%	21.2%	38.2 %
Overestimation	29%	45.5%	17.7 %
Underestimation	71%	33.3%	44.1 %

*While 33 people reported a duration estimation of Video2, only those who also judged the duration of Video1 are considered

Regarding the perception of the first presented travel time (Video1), the reported duration ranges from 5 seconds to 60 seconds and is normally distributed around the average reported value ($t_{Vid1\_reported}$= 20.2 sec), which is almost equal to the actual duration (T_{vid1}= 21 sec). The performance of a t-test proves that the mean perceived duration is not significantly different than the true value, $t(30)= -.292$, $p= .772$. The influence of the familiarity with the environment across which the video has been filmed is also tested via a t-test. The null hypothesis is that there is no difference in the perceived duration between those who are familiar with the surroundings and those who are not. The inclusion or not of an individual to the TU Delft community has been used as a proxy for the level of familiarity. No significant effect of the familiarity is found, $t(30)= 0.034$, $p= .97$, and the null hypothesis is not rejected.

In the comparison between the duration of the cycling video across the TU Delft campus to the duration of the cycling trip across nature, around one out of five individuals have made no error and have reported that the first two videos have equal duration. In Figure 6.8, the distribution of the comparison report is illustrated. Most of the individuals felt that Video2 lasted more than the Video1. This indicates that the presence of nature has on average prolonged the perceived elapsed time. Thus, the hypothesis regarding the impact of nature on travel time perception is supported (*Nature prolongs perceived duration of active mode trips (H6)*).

In Figure 6.8, the perception of the travel time of the second cycling trip across nature is also examined in relation to the misperception direction of the first video. It is observed that overall, the respondents tried to compensate for their misperception error of the duration of the first video. The majority of the individuals who reported a duration smaller than the actual one for the first video stated that the second one is longer than the former. In contrast, most of those who overestimated the first trip indicated that the second last fewer seconds than the first one. The effect of the time misperception on the video across the TU Delft campus to the estimation of the cycling trip across the nature is examined via a Mann-Whitney test. The test is chosen due to the ordinal character of the duration comparison variable. Based on the observations made for Figure 6.8, the hypothesis is that those who have underestimated the duration of the first video have indicated a longer duration for Video2 than those who overperceived Video1. Indeed, the estimation of the duration of the second video is significantly affected by the perception direction for the first video; $U = 35$, $p<.05$. This finding suggests that the subjective duration of Video2 could have been reported as longer than the travel time of the first video due to the underestimation of the latter rather than because of the effect of the cycling environment. Thus, the confirmation of the nature impact hypothesis is not straightforward.

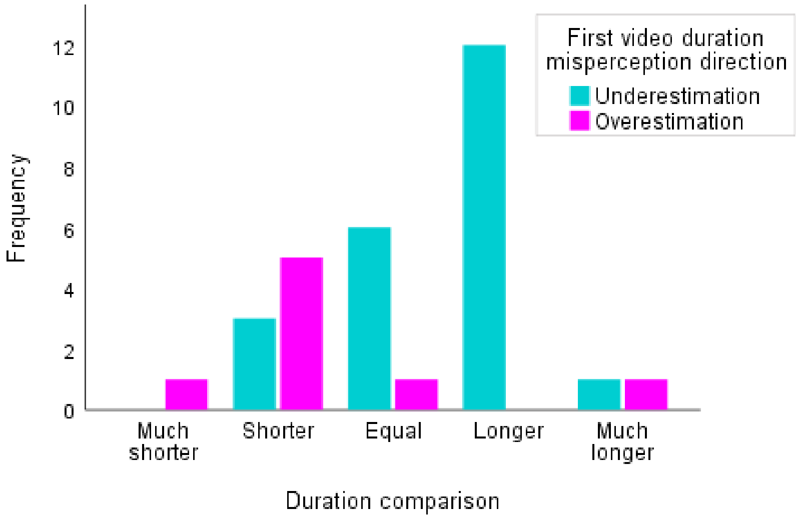

Figure 6.8. Duration comparison distribution between the two equally long cycling trip videos, per group of perception performance in the first video (TU Delft campus), N= 30

As mentioned above, most of the survey respondents have underperceived the duration of the film, which resembles a cycling trip across a busy, urban environment (Video3). Since this video lasts twice as long as the Video1, the intra-individual variability in the time distortion ratio is examined by combining the data collected for both videos. In Figure 6.9, the trip duration ratio is plotted for the two video reports. It is observed that the people who underestimated the trip duration of the first cycling film consistently did the same for the duration of the last film. The consistency in the misperception error direction indicates that each person might be biased towards receiving a trip as longer or shorter than it is, regardless of the judged duration. To assess whether individual characteristics explain the time distortion, group comparisons were performed. More specifically, the impact of age, gender, stress level, and the interaction between age and stress on the estimation of the short trips' duration were tested. However, no significant relationship was found.

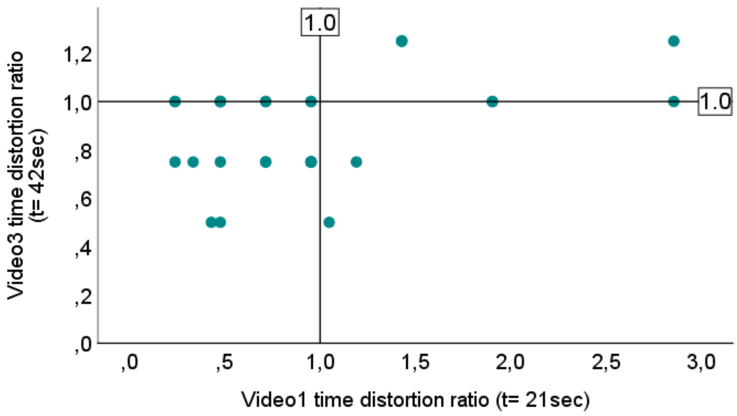

Figure 6.9. Travel time distortion ratio of Video3 over Video1

6.2.3.3 Travel time perception of trip videos and real-life trips

In the last two sections, the travel time misperception error was analyzed for the participants' trips and the trips presented to them via videos. In this section, the relationship between the travel time distortion between these two different conditions is investigated.

To examine whether the duration misperception of real-life active mode trips is related to the misperception of short trip films' travel time, their correlation is estimated. The survey respondents provided a detailed travel time report only for the first cycling film (Video1). Therefore, the time perception ratio of Video1 is included in the performance of the association test. From the dataset of trips conducted by active modes, a single observation per individual is exploited. More specifically, the first trip (cycling or walking) of each research participant is considered.

The estimation of Pearson correlation results in an insignificant correlation value (r= 0.149, n= 31, p= .424). This value implies no significant relationship between travel time misperception of the short trips presented via videos and the trips that people experience in real-life. This finding indicates that the examination of travel time misperception via trip videos does not manage to approximate the travel time distortion of real-life trips. However, the trip, which was presented in the considered film, was across a calm, traffic interaction-free environment, under sunny weather, and no specific trip purpose was indicated. Thus, the absence of a significant correlation might be due to the deviation of the trip characteristics and the individuals' emotional state during their real-life trips to those presented and experienced while watching the trip film.

6.3 Travel time perception regression analysis

In this section, the main analysis on the travel time misperception of active mode users takes place. The analysis aims at testing the remaining research hypotheses by capturing the influence of the factors which underlie the hypothesis, via regression models. The estimation of regression models with the travel time distortion ratio as the dependent variable enables the determination of both the magnitude and the significance of the effect of considered factors. In the first subsection, the analysis approach is explained, whereas, in section 6.3.2, the selection and coding of the independent variables are discussed. In the third part, the results of the estimation of two types of regression models are presented. Finally, the results of the chapter are summarized in sub-section

6.3.1 Analysis approach

To identify the determinants of travel time misperception as well as the size and direction of effect, regression models are used. The dependent variable is the travel time distortion ratio (τ_{dist}) (Equation 2). The travel time ratio is preferred over the time misperception error rate (see Section 2.2.1) since it controls for the actual travel time level, and at the same time is widely used in the travel time distortion literature. The latter enables the comparison of the results of the current research with those of previous studies. For the estimation of the travel time misperception ratio, an ordinary least squares (OLS) model is applied (Lin_Model). Lin_Model is also estimated for the underperceived and overperceived trips separately to check the differentiation on the factor effect under the two conditions.

Apart from the travel time distortion ratio, the determinants of the direction of the duration misperception are also investigated. The estimation of models with the dichotomous underestimation vs. overestimation variable as the dependent variable could reveal the factors which tend to provoke the sense of a prolonged or shortened trip duration. The binary character of this variable necessitates the estimation of a logistic regression model (Log_Model).

Before estimating Lin_Model and Log_Model, it is necessary to decide whether one or more observations per individual are considered. Not all participants have reported multiple trips. Thus, in case multiple observations are considered, the model could be biased towards those with more travel time perception registrations. Alternatively, if a balanced data set is targeted, the analysis would consider only people with more than one trip registration. However, in this case, not only the variance in the individual related travel time perception is reduced, but also a survival bias could be introduced. The survival bias would be included since the analysis would be based on people who travelled more during the data collection period or were more enthusiastic about the research. To reduce the introduced bias without losing variance information, two alternative paths are designed for the travel time misperception modelling.

The full approach towards the exploration of the active mode trip duration perception agents and the estimation of the regression models for the dependent variables is illustrated in Figure 6.10.

On the one hand, the two models are estimated based on a single observation per person. Since a learning effect might have affected travel duration misperception in trips apart from the initial one, Lin_Model is estimated twice. The first time, only the initial trip registration of each participant is kept in the dataset, and as such, the learning effect is completely omitted. In the second estimation, a random observation is selected per participant. To check the presence and potential impact of a learning effect, the trip number is included in the regression as an independent variable (0: first trip, 1: later trip).

A drawback of performing the analysis based on a single observation per person is that the sample size of travel time reports is reduced, from 166 trip registrations to 36, and, consequently, does not allow for the estimation of separate models for under- and overperceived trip durations. Moreover, hypothesis H3 (H3: *People who report multiple trips appear a smaller travel time perception error in their longer trips than in their shorter ones)* cannot be tested by using only one travel time perception report per individual. To overcome these limitations of the first approach, the second one allows for multiple observations per person. Thus, the abovementioned two types of models are estimated based on the unbalanced panel data set of active mode trips. The sample size of this panel data set (N= 166) allows for applying Lin_Model for the total as well as for the overperceived (N= 72) and underperceived (N= 82) trips separately.

In addition, using the panel data set, an analysis per mode of transport is performed. This analysis enables the comparison of the determinants of travel time distortion between different modes of transport. Apart from cycling and walking trips, the agents of duration misperception of non-active modes trips (public transport and car trips combined) are specified based on the corresponding data set (Figure 6.10).

The estimation of a model based on the panel data set could be biased due to unobserved heterogeneity among the different individuals. The bias in the model for the estimation of travel time misperception could be introduced due to individual-specific characteristics that consistently affect the perception of travel time over different time duration reports. In addition, these individual effects could also be correlated to the rest of the considered variables in the model, such as the actual trip duration, the trip purpose, etc. Fixed effects models are regression models that enable to control for unobserved heterogeneity between entities in panel data. More specifically, these models allow for the intercept to differ among the considered cases, which in the present study are the research participants. Fixed effects panel regressions models handle the unbalanced number of data entries per individual, since, in their estimation the individual heterogeneity is controlled over the complete sequence of data observations. The sample size of the active mode observations (N= 166) allows the application of an entity fixed effect model, with the trackerID number as the control variables. However, before applying them, it should be checked whether there is indeed a correlation between the individual effects and the independent variables. In case there is no significant correlation, random effects models should be used instead. To test whether a random effects regression or a fixed effects regression model needs to be applied, the Hausman test is used. The null hypothesis is that the random effects model is suitable, whereas the alternative hypothesis is that the fixed effect model is more appropriate. FE_Model and RE_Model represent the fixed effects and the random effects model, for linear regression (Figure 6.10).

The final step of the analysis approach design is to decide the regression method. In past studies on travel time perception, which applied regression models in their analysis, both standard and stepwise multiple regressions have been used. Therefore, there is no strong theoretical background on which of the methods is preferable for the objective of the present research. It is decided that the default Force enter method is followed for all models (Lin_Model, Log_Model, FE_Model, and RE_Model).

The OSL and the logistic regression models are estimated in SPSS. The fixed and random effect model and the Hausman test are performed using the STATA software. The results of the model estimation are presented in section 6.3.3. However, before proceeding to the results, the considered set of predictors and applied coding scheme is shown in the next section.

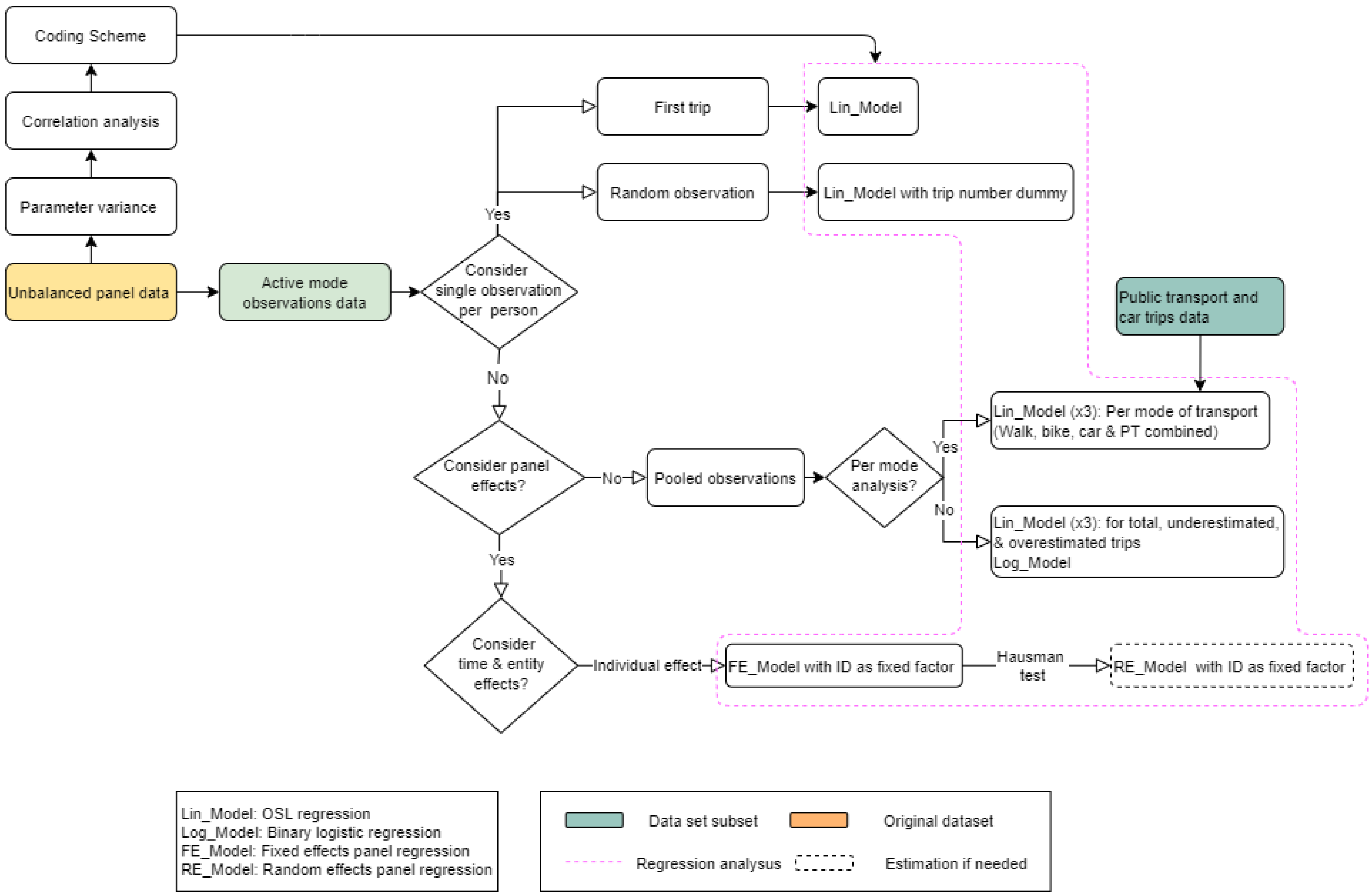

Figure 6.10. Travel time perception analysis approach

6.3.2 Predictor variable selection and coding

The variables of interest are those which are related to the formulated research hypotheses. Before proceeding to the model estimation, the possibility of testing the research hypothesis based on the collected data needs to be evaluated. In order to add the possible determinant of travel time misperception to the set of the regression model predictors, their variance is examined. For the present study, the variation is explored based on the total data set of active mode trips observations. The descriptive statics analysis already provided inside into the variance of some factors, including on some trip (trip mode, trip purpose, actual and perceived travel time) and individual (age, gender) characteristics. Thus, this section focuses on the variance of the rest of the variables, which are directly related to one or more of the research hypotheses. In Table 6.7, the relative frequency of the variables' levels is presented. The hypothesis that each factor underlie is also noted.

Table 6.7. Variance of ordinal variables

Factor	Relevant hypothesis	Relative frequency across levels (%)	Hypothesis
Physical exertion	0 (No exertion)	60.8	*Mandatory trips with high effort demand provoke an increase of perceived travel time (H12)*
	2	21.1	
	4	11.4	
	6	6.1	*Non-mandatory trips which have a high effort demand are perceived as shorter than they are (H13)*
	8	0	
	10 (Extreme)	0	
Trip satisfaction	Very disappointing	1.1	*High comfort or satisfaction leads to a shortened perceived travel time (H8)*
	Disappointing	3.5	
	Neutral	16.9	
	Satisfying	56.5	
	Very satisfying	22.0	
Weather satisfaction	Very disappointing	1.2	*Dissatisfying weather increases perceived duration of cycling and walking trips (H5)*
	Disappointing	10.3	
	Neutral	27.2	
	Satisfying	26.0	
	Very satisfying	24.3	
Infrastructure quality	Poor	2.4	*High comfort or satisfaction leads to a shortened perceived travel time (H8)*
	Fair	9.6	
	Good	27.1	
	Very good	42.2	
	Excellent	17.5	
Duration expectancy	Much shorter	0.6	*Strict arrival time reduces the misperception error (H4)*
	Shorter	10.8	
	As expected	63.3	
	Longer	15.7	
	Much longer	1.8	
	No expectation	6.0	

Due to the limited sample size and the type of trips performed by the research participants, the variance is very low for some ordinal variables. Regarding the overall trip satisfaction and the satisfaction with the infrastructure, almost all participants answered similarly. More specifically, the vast majority of the participants were very satisfied with both their overall travel experience and the used infrastructure. To test the hypothesis related to perceived trip satisfaction and comfort, the levels of each variable are grouped into two categories. Trips observations are divided into those with high satisfaction, and those with medium or low satisfaction (Table 6.9).

Besides, testing the H12 *Mandatory trips with high effort demand are overestimated*) and H13 (*Non-mandatory trips which have a high effort demand are underestimated*) research hypothesis is not possible. These hypotheses refer to the impact of the interaction between the trip purpose type and the level of physical effort demand. In terms of collected data points, the physical effort is quantified as the reported physical exertion (0(Low)- 10(High) scale). The perceived physical effort demand ranges between 0 and 6, which means that none of the participants felt that a conducted trip required very high physical exertion. Thus, the obtained data set does not allow to test the two hypotheses.

Since these hypotheses cannot be tested via regression analysis, the relationship between the level of exertion and trip type in terms of trip purpose is explored based on crosstabulation (Table 6.8). The mandatory trips include the trips which are conducted for Work/Education as well as for Appointment trip purpose. As assumed in the conceptual design chapter, travelers try to minimize the physical effort demand for mandatory trips. This is indicated by the small number of compulsory trips with average to high (4-6) physical exertion. While there are no observations of non-compulsory trips with very high exertion, the effort demand is more distributed across the reported values (Table 6.8). However, no pattern is found between the combination of trip type with exertion level and the time misperception level. The majority of both the compulsory and the non-compulsory trips is underestimated, regardless of the perceived physical effort demand.

Table 6.8. *Physical exertion, trip purpose, and time misperception direction crosstabulation*

			Physical effort demand				
Misperception direction			0.0	2.0	4.0	6.0	Total
Underestimated	Trip purpose	Non-mandatory	51	20	8	6	85
		Mandatory	4	0	1	1	6
	Total		55	20	9	7	91
Overestimated	Trip purpose	Non-mandatory	42	15	9	4	70
		Mandatory	4	0	1	0	5
	Total		46	15	10	4	75
Total	Trip purpose	Non-mandatory	93	35	17	10	155
		Mandatory	8	0	2	1	11
		Total	101	35	19	11	166

Medium physical effort demand   Quite high physical effort demand

To overcome the absence of data points in all categories of the level of physical demand, the physical exertion observations are divided into two groups of low (0-2) and average to high (4-6) exertion. Similarly, where possible, the classes of the rest of the considered ordinal variables are grouped. In Table 6.9, the variables that are included in the regression analysis are presented, together with their coding scheme.

Table 6.9. *Considered variables in regression, and coding scheme*

Trip duration estimation direction(1: if τ_{dist} >1, 0: if τ_{dist}<1)*
Travel time misperception ratio, τ_{dist} (continuous)*
First trip (1: first trip ,0: later trip)
Duration (continuous, [min])
Travel period (1: peak, 0: off-peak)
Trip purpose Compulsory trips (1: Work/Education, Appointment ,0: non-compulsory) Return home (1: return home, 0: rest)
Mode-active modes trips Walk (1: walking trips, 0: bike) Mode-public transport and car trips PT (1: Public transport, 0: car)
Activity (1: at least one activity, 0: none)**
Information usage (1: yes ,0: no)
Route Familiarity (1: unfamiliar route, 0: familiar,)
Trip satisfaction (1: high ,0: low)
Duration Expectancy; shorter or much shorter is the reference category Expectancy-met (1:as expected) Expectancy-longer (1: longer or much longer than expected)
Trip stress (1: high ,0: low)
Physical exertion (1: high, 0: low)[a]
Infrastructure satisfaction (1: high 0: low)[a]
Weather satisfaction, neutral is the reference (-1: dissatisfying, 0: neutral, 1: satisfying) Disappointing weather (1: disappointing or very disappointing, 0: rest) Satisfying weather (1: satisfying or very satisfying weather, 0: rest)
Gender (1: Female, 0: Male)
Age (0: <49, >50 years old)
Stress level, low stress [3-5 score PPS4] is the reference category 1: Medium [6-8 score PSS40] 2: High [9-12 score PSS4]

*Dependent variable, ** Where the sample size allows, different activities (listening to music, browsing internet, enjoying the view, texting) are introduced, with no activity as the reference value, [a]Active modes specific variables,

In the above table (Table 6.9) the entire set of variables that are considered in the regression models is listed. However, before inserting them in the various regression models, their correlation should be determined. Not all models are estimated for the same sample of travel time observations Thus, a correlation analysis is performed for each different dataset. Significantly correlated parameters are excluded before the estimation of each model. In the next section, the results of the regression analysis are presented.

6.3.3 Regression results

In this section, the findings of the regression analysis are discussed.

In Table 6.10, the predictors with a significant effect on the travel time distortion ratio for the first reported trip are listed. From the total trips considered in this dataset (N=33), 71% have been underestimated. The model captures 40% (R^2=.405) of the variance in the duration misperception via two significant variables: the familiarity with the route and the type of trip. More specifically, when travelling along an unfamiliar route or for a non-mandatory trip purpose, the travel time distortion ratio decreases in comparison to familiar routes and mandatory trips, respectively. The effect of mandatory trips on travel time misperception is as expected based on the theory (*Non-mandatory trips are perceived as shorter than mandatory trips (H10*)). Furthermore, compulsory trips usually have a less flexible arrival time. Therefore, this finding supports the hypothesis (H4) that a stricter arrival time window results in an increased perception of travel time. Carrion and Levinson (2019) have also found that more flexible arrival times tend to shorten the subjective trip duration and result in underestimation of travel time in their research on travel time distortion by car.

Regarding the influence of familiarity, it seems that cycling or walking across familiar routes increases subjective travel time. Cyclists and pedestrians constantly interact with the surrounding environment of their trips. However, even for trips by bike or on feet, it is possible that travelling across a familiar route induces boredom and a loss of interest. These could lead to a slower perceived passage of travel time (Danckert & Allman, 2005).

The return home effect could not be tested with this dataset because none of the trips was towards home. Almost all trips were homebound. This means that most participants decided to use the app for the first time from for a trip departing from home.

The estimation of Lin_Model, based on a single random observation per individual, shows that different parameters impact travel time perception. This model (N=36) explains a smaller part of the variance in the travel time perception ratio, in comparison to the first model. The satisfaction with the trip and the usage of information significantly affect the trip duration misperception at a 95% significance level. However, their impact is in a reversed direction. Similar to the findings of Meng's team (Meng, Rau, & Mahardhika, 2018) on waiting travel time, the usage of information leads to a smaller ratio than without exploiting an information source. This finding corroborates the H9 hypothesis of the study (*The usage of trip information reduces the travel time misperception (H9).* However, in the descriptive statistics of this dataset, in none of the overestimated trips, the travelers indicated the usage of information to plan their trip or select their route. Thus, it is possible that the model results are biased towards those who underestimated travel time.

It is worth mentioning that the dummy indicating whether a trip is the first reported or not is insignificant (p= .418), and its standardized coefficient has a positive sign and is equal to 0.163. The insignificance of the trip number implies that there is not an important learning effect.

Table 6.10. *Model estimation results for one observation per person*

Model					Coefficients				
	r	R^2	Sig	Darbin-Watson	Variable	B	Stand. Beta	t	Sig
Lin_Model_1	.637	.405	.040	2.542					
Data set: Only the first active modes trip of every individual is considered, N= 33					constant familiarity compulsory	.951 -0.344 .442	 -.476 .384	19.878 -2.605 2.158	.000 .017 .043
Lin_Model_2	.509	.259	.015	1.967					
Data set: One random observation of every individual is considered, N= 36					constant satisfaction information	.626 	 .398 -.354	6.747 2.437 -2.167	.000 .021 .039

The effect of sociodemographic characteristics has not been tested in the single observation model due to the already large number of independent variables for the given sample size (N=36). Furthermore, the logistic regression model, Log_Model, could not be estimated due to the fact that its assumptions regarding the minimum number of observations per variable were not met.

To overcome the limitations of the models presented above, the panel data set of all active mode trips is exploited. In Table 6.11, the regression results for the estimation of Lin_Model are presented. The larger data set has allowed the exploration of the impact of more variables. Many significant correlations have been found among the considered variables, which has led to the exclusion of some parameters. The decision on which one of the significantly correlated parameters to keep in the model has been determined by the magnitude and the significance of the correlation with the dependent variable.

The first model, which considers all observations (Lin_Model_3), explains one-fifth of the variance of the dependent variable which is lower than both models which used a single observation. Despite its decreased power, the pooled regression model provides explanatory insight into the potential effect of various determinants of travel time misperception. The models which are dedicated only to the underestimated (Lin_Model_4) and the overestimated (Lin_Model_5) trips have a higher R^2 value. The latter captures around 65% of the variation in the travel time misperception ratio, based on the included variables.

Different significant variables are found by the estimated models (Table 6.11). The results of the regression corroborate the hypotheses on the impact of poor weather (*Dissatisfying weather increases the perceived duration of cycling and walking trips (H5)).* Disappointing weather prolongs the perceived travel time of overestimated trips. The effect of adverse weather is also significant for trips conducted by car or public transport. It should be mentioned that the weather conditions were not considered in the estimation of the pooled regression models due to the fact that it is highly correlated ($r= -0.328$, $p< .01$) with the perceived satisfaction from the used infrastructure. This correlation indicates that under adverse weather conditions tend to judge the infrastructure across which they travel as worse than they do so under good weather conditions. Of course, a reverse relation is also possible; lower quality of infrastructure provokes a stronger discomfort under disappointing weather conditions.

Except for the model on the underperceived trip durations, the effect of returning home is significant ($p< .05$) in all cycling and walking trips datasets. In contrast to what was expected based on the literature (van de Ven, van Rijswijk, & Roy, (2011), Raghubir, Morwitz, & Chakravarti, (2011)), the variable is positively related to the travel time distortion ratio. Thus, the seventh research hypothesis is rejected (*A return home trip is perceived as shorter than it is (H7)*). However, the return home effect has also been pointed insignificant in past studies, e.g., Carrion & Levinson (2019).

The only model in which familiarity is not significant is the one estimated solely for the overperceived trips. Furthermore, in agreement with the findings presented in Table 6.10, low familiarity with the followed route leads to a further underestimation of the duration of a trip conducted by bike or on foot. On the contrary, for trips conducted by car or public transport, travelling across unfamiliar routes increases perceived travel time. The reason for this difference in sign could be the fact that travelling across not familiar routes might be desirable for active mode trips and undesirable for car or public transport travelers. Considering the high rate of active modes trips with the trip itself as the main trip purpose (see Table 6.2), it could be that cyclists and pedestrians have actually sought and enjoyed exploring new routes or routes that they do not cross frequently.

The conducted trips' objective duration is negatively related to the travel time misperception ratio, indicating that for longer trips, that ratio becomes smaller. This finding is consistent for both active modes and non-active modes trips and adheres to Vierordt's law. Furthermore, it corroborates the H3 hypotheses (*Travel time perception error is smaller in shorter trips than in trips which last more (H3*) on the effect of actual travel time on travel distortion.

The level of physical effort demand increases perceived travel time of underestimated cycling and walking trips. Since for the underestimated trips, the value of the travel time distortion ratio ranges between 0 and 1 (no misperception), an increase in the dependent value indicates a smaller perception error. Thus, it seems that people are more aware of the elapsed time for trips with higher exertion.

Table 6.11. *Linear regression estimation results for the panel data set*

Model					Coefficients				
	r	R^2	Sig	Darbin-Watson	Variable	B	Stand. Beta	t	Sig
Lin_Model_3	.448	.201	.001	1.898					
Data set: All active mode trips, N= 154					constant	.775	.775	6.760	.000
					duration	-.004	-.216	-2.283	.024
					return home	.376	.382	4.440	.000
					infrastructure satisfaction	.183	.175	2.071	.040
					Interaction: duration*activity	.004	.188	1.9770	0.50
Lin_Model_4	.499	.249	.044	1.883					
Dataset: Underestimated active modes trips N= 83					constant	.730		8.592	.000
					familiarity	-.094	-.231	-2.005	.049
					exertion	.211	.403	3.267	.002
					gender	.097	.248	2.143	.036
					interaction: compulsory trip *exertion	-.491	-.385	-2.758	.007
Lin_Model_5	.655	.429	.000	1.980					
Dataset: Overestimated active modes trips N= 70					constant	1.418		13.424	.000
					duration	-0.003	-.290	-2.480	.016
					return home	.180	.284	2.311	.024
					as expected	-.241	-.436	-3.036	.004
					longer than expected	-.298	-.429	-2.947	.005
					disappointing weather	.187	.221	2.082	.042
Lin_Model_6	.588	.346	.000	1.828					
Dataset: Bike trips N= 72					constant	0.995		11.547	.000
					return home	0.279	.310	2.998	.004
					familiarity	-0.316	-.389	-3.744	.000
					interaction: high stress*peak time	0.248	.297	2.808	.007
Lin_Model_7	.478	.228	.003	2.149					
Dataset: Walk trips N= 81					constant	0.951		12.687	.000
					familiarity	0.187	.300	2.697	.009
					music	0.259	.361	3.282	.002
					interaction: high stress*peak time	-0.140	-.199	-1.866	.066
Lin_Model_8	.722	.522	.000	1.870					
Dataset: Car and public transport trips N= 56					constant	1.070		25.229	.000
					duration	-0.005	-.557	-4.273	.000
					familiarity	0.152	.379	3.287	.002
					compulsory trips	0.178	.237	2.078	.043
					first trip	-0.191	-.254	-2.195	.033
					information	0.118	.0288	2.306	.024
					disappointing weather	0.203	.269	2.330	.024
					enjoying the view	-.221	-.326	-2.760	.008
					internet	0.210	.379	3.200	.003

The effect of age is not tested in the analysis of the walking trips since none of the participants over 50 years old reported a trip conducted on foot. In addition, in most of the derived datasets which were used for the estimation of the regression models, there was a strong correlation between gender and age and the objectively measured travel time. It seems that female and older participants have cycled and walked for more time than male and young ones, respectively.

The logistic regression model, which is estimated for the pooled observations, is predicting whether the duration of a trip is over or under perceived, at a 68.4% accuracy (Table 6.12). The chance of overestimating a trip is lower for return home trips. The probability of perceiving travel time as more prolonged than it is higher for women than men. The logistic regression analysis results in a significant effect of the agreement between the expected and the experienced travel time. More specifically, the model estimation results show that when people perceive the trip duration close to the travel time that they expected before the initiation of their trips, it is more probable that they feel that their trip lasted less than it did. This means that in case people encounter unexpected deviation from their expected travel time, then the chance of overestimating the duration of their trip is higher. The importance of satisfying the minimization of the unexpected events during walking and cycling trips could be concluded from this finding.

Table 6.12. *Logistic regression estimation results; underestimation vs. overestimation*

Model					Coefficients				
	-2LL	Sig	Nagelkerke R Square	Percentage correct (%)	Variable	B	Exp(B)	Wald	Sig.
Log_Model	178.168	.003	.251	68.4					
Dataset: All active mode trips, N= 153					constant	3.525	33.942	3.703	.054
					return home	-1.320	0.267	5.510	.019
					duration as expected	-1.087	0.337	4.406	.036
N_{under}= 82					infrastructure satisfaction	-1.589	0.204	5.302	.021
Nover= 70					interaction: duration*activity	0.054	1.056	7.915	.005
					first trip	-0.982	.374	3.545	.06
					gender	1.101	3.007	7.304	.007

The influence of the overall stress level has not been included in any of the models, due to its strong correlation with the trip purpose and the travel time of the reported trips. It has been found that the participants with the higher stress, travel longer and for compulsory trips. The collinearity of the predictors has been assessed in all models by running a Variance Inflation Factor (VIF) test and no multicollinearity has been found.

The last model is an effects model, either fixed effects or random effects model. The Hausman test is performed to identify whether a fixed or a random effects models is more suitable for the present panel data set.

The result of the Hausman specification test estimation is as follows:

$$chi2(11) = 17.91$$
$$Prob > chi2 = 0.0837$$

The p value of the test is larger than 0.05. Thus, the test indicates that the null hypothesis should be accepted and consequently, that the random effects model is more appropriate for the given panel data set. This means that RE_Model needs to be estimated instead of FE_Model (Figure 6.10). The estimation of a random effects model better suits the sample of the study too, since it does not exhaust the population and is not representative of it. The random effects model estimation results in a rho=0, indicating that the within the trips reported by the same individual the variability is much higher than the variability between the different people. Thus, the estimation of the OLS Lin_Model is sufficient for the present panel dataset.

Apart from the sufficiency of the simple linear model, the random effects model results indicate that in the considered sample, the travel time misperception might not be an intrinsic individual characteristic or at least not consistent for all trip durations and under diverse travel conditions.

6.3.4 Conclusions

The last three sections have focused on identifying the factors which influence travel time distortion. Via the estimation of multiple linear and one logistic regression models, various determinants of travel time misperception have been identified. In Table 6.13, an overview of the effect of the factors involved in the research hypotheses is given. However, the analysis has been conducted in multiple data sets. Therefore, the findings presented in the table below only provide an insight into the potential decisive factors of perceived travel time and cannot be generalized directly to the set of active mode trips.

Table 6.13. *Travel time perception determinants and direction of effect*

	Travel time distortion ratio	
	Increase	Decrease
Trip actual Duration		+
Compulsory trips	+	
Agreement with expected travel time	+	
Route unfamiliarity		+
Gender	+	
Usage of information source		+
Trip satisfaction	+	
Infrastructure satisfaction	+	
Return home	+	
Physical effort demand	+	
Disappointing weather	+	

7 Conclusions and Recommendations

This chapter focuses on the discussion of the conclusions and the recommendations of the present study, In the first section, conclusions are drawn from the findings and the methodology of the that are drawn from the present research. In the second sub-chapter, recommendations are made to practice, future research, and future usage of the UMO Research app.

7.1 Conclusions

The present research has aimed at broadening the knowledge on travel time perception of cycling and walking trips. In this sub-chapter, the main research question is answered based on the knowledge gained from the present study.

7.1.1 Addressing the research questions

Before the main research question, the formulated research sub-questions are answered based on the conducted research. The literature review has revealed that the perceived time and travel time are used to indicate the perception of time under different paradigms, prospective and retrospective, and different time notions; time passage and time duration (*Which is the definition of time perception? (SQ1), How does the notion of time perception vary among studies on time and travel time perception? (SQ2)).* While most time perception studies focus on the judgment of short time intervals, travel time perception research is concerned with the estimation of trip durations which are usually in the range of minutes or hours. The present study has focused on the retrospective estimation of time duration of completed trips.

Furthermore, the conducted literature overview allowed the identification of various methods which are appropriate for capturing subjective time (*Which methods are suitable for the investigation of perceived time? (SQ3)).* For research on travel time perception, the verbal estimation of the elapsed duration while travelling is preferred, as it provides a direct comparison with the actual trip duration.

The fourth sub-question (*Which indicators can be used to capture the relationship between perceived and actual travel time? (SQ4)*), has also been addressed in the study of past studies. Travel time distortion ratio, travel time misperception error rate, and the deviation between perceived and objective travel time are the used indicators for travel time perception research. The first two offer the advantage of controlling the effect of the actual duration.

Sub-question SQ5 (*Which are the data requirements to capture both perceived and realized travel time?*) has been addressed by summarizing the potential determinants of trip duration judgment and defining criteria for the selection of the factors which need to be considered in the present research. The relevance with the characteristics of the considered modes of transport, the ability of the selected data collection source to collect data points, and the documentation of the factors' effect on past studies are capable of defining the factors on which data are necessary.

To derive information on travel time misperception, different data sets need to be combined (*Which methods can be applied to derive travel time information from empirical travel data? (SQ6*)). The objective and subjective travel time need to be extracted. The former is estimated as the difference between the stop and the start of a trip, whereas the latter needs to be reported by people . Furthermore, the analysis of the collected data has resulted in a set of predictors of travel time misperception. In terms of individual characteristics, men tend to underestimate travel time more than men. No other effect of sociodemographic characteristics is found (*What is the deviation between subjective and objective travel time for different demographic and socioeconomic groups and trip characteristics? (SQ8)).* Moreover, in terms of trip characteristics, mandatory trips are perceived as longer than trips for other travel motives. This could also be attributed to the stricter travel time arrival requirement that compulsory trips have. The actual duration of a trip affects the travel time distortion as for longer trips the misperception error is smaller. This is in line with the theory. However, it could also be attributed to rounding. Rounding to intervals of 5 minutes is very common in the obtained travel time reports. For shorter trips, this rounding might have affected the estimation of the travel time distortion ratio more than for longer trips.

The findings of the present study do not support the return home effect. However, other studies have also found an insignificant effect. For the present study, considering the pandemic circumstances under which the present research was conducted, during which people spent a lot of time at home, it is possible that returning home trips were associated with negative emotions due to the long lockdown period. Negative emotions increase the subjective duration and, as such, they might have affected the return home effect value in the present study (Rankin, Sweeny, & Xu, 2019).

The impact of nature on perceived travel time has been explored for a trip presented via a video. The effect of the presence of nature in increasing subjective travel time has been confirmed. However, since the impact of nature has been captured via a duration comparison task, it is possible that the finding is due to individuals' effort to compensate for their misperception of the other trip film. Furthermore, the immersion in the presented environment is limited in short videos. Thus, longer videos might be essential for capturing the impact of nature on travel time perception via films.

Disappointing weather increases perceived trip duration (*What is the influence of external factors, such as the weather, in the perceived trip duration? (SQ9).* However, satisfaction with the weather might also be related to the emotional state of the traveler. While emotions are one of the most important determinants of time perception, their effect has not been fully faced in this research. Although trip stress and overall stress have been considered, their correlation with other considered variables necessitated their exclusion from the analysis.

The current research has proven that a mobile application is a suitable tool for the collection of data on travel time perception (*How suitable is a mobile application as the single data collection tool for travel time perception research? (SQ7)).* The UMO Research app has enabled the collection of data on a trip level, right after the completion of the trip. Thus, it has enhanced the chances of capturing the perceived trip duration rather than the one recalled from memory. In addition, the app has offered the possibility of collecting data on various travelers simultaneously. Finally, by using a mobile application, apart from the misperception of long real-life trips, the judgment of short trip films has been captured via the inclusion of trip films. While no significant relationship has been found between the travel time distortion ratio of trips presented via videos and real-life trips, the direction of the misperception error is the same.

This aim of this study was to answer the following main research question:

What is the relationship between perceived and actual travel time of pedestrians and cyclists, and which individual, trip-related, and external factors do influence it?

Based on the insights provided by the present study and the answer to the research sub-questions, the main research question has been addressed. Overall, it has been found that both for real life trips and trip films, the ability of individuals to assess the time elapsed is limited. This study has pointed out that, on average, travel time of active mode trips is underestimated. The underestimation of travel time has been confirmed both in an experimental setup and for real-life trips. The underestimation of travel time of trips conducted by bike or on foot, the perception of the travel time disutility could be lower than the objectively measured one for walking and cycling trips. A shorter perceived travel time implies a lower discomfort due to time spent travelling and a reduced disutility of travelling.

In addition, the underestimation of cycling and walking travel time contradicts the overestimation of travel time of trips conducted by car or public transport. The latter has been found both in the present study as well as in past research. The travel motives for which people choose to cycle or walk could have influenced the difference in travel time misperception direction. The high ratio of trips for the trip itself as the travel purpose could have influenced the findings of the present study.

The estimation of regression models has revealed that both the direction of the duration misperception, overestimation vs. underestimation, and the extent of the distortion are affected by trip characteristics such as the trip purpose (compulsory vs. non-compulsory trips), the objective travel time, the familiarity with the route. The deviation of the experienced travel time from the one expected before the initiation of the trip results in an increased perceived trip duration. Furthermore, a significant effect of gender has been found. The impact of external conditions, such as adverse weather, is supported by the results of this thesis. Finally, the usage of an information source for the planning of a trip has also been identified as a determinant of travel time distortion.

The estimation of models separately for underestimated and overestimated trips has resulted in a richer set of determinants of travel time perception. This suggests that the present research agrees with the literature on travel time perception, which supports that in order to explain the determinants of travel time misperception, separate models should be applied for the underestimated and overestimated trips.

7.2 Recommendations

In the first and the second subsection, recommendations are formulated for practical applications and future research, respectively. Finally, a few points are discussed regarding the usage the UMO research app in future studies on travel time perception research. The recommendations for the UMO research app could be relevant for other mobile applications which collect data on travel perceptions and experience, too.

7.2.1 Recommendations to practice

The fact that the duration of trips made by active modes is perceived as shorter than it is indicates that travelling by these modes reduces the perceived time loss due to travelling in the society. Transport experts could benefit from this finding by adding it to the list of benefits from increasing the modal split of cycling and walking trips.

The exploration of the factors that affect the perceived trip duration also provides insight into the aspects that affect cyclists' and pedestrians' traveling experience. The quality of the infrastructure seems to be of high importance, especially under adverse weather conditions. Thus, towards encouraging the share of trips by bike and on foot, the provision of a satisfying infrastructure shall be considered.

Furthermore, this study has found that a deviation from the expected travel time could lead to an increased subjective duration. Therefore, transport planners and traffic managers are recommended to try to minimize the appearance of unexpected events. The provision of information to cyclists and pedestrians for planned disturbances could enhance the agreement between the expected and experienced travel time.

During this study, the applicability of using a mobile application to collect data on travel experience has been proven. Apart from obtaining information on travel time misperception, this study suggests that mobile applications are a suitable tool for collecting data on individuals' subjective evaluation of their trips. Transport experts could benefit from the widespread of smartphones to apply similar apps and obtain information on factors that cannot be objectively measured, including trip satisfaction, sense of safety, etc.

7.2.2 Recommendations for future research

Multiple recommendations for future research are made. Recommendations are made regarding the enhancement of the present study's methodology and data collection, further research on potential determinants of travel time misperception, and the estimation of the impact of travel time misperception on travel behavior.

First of all, future research could ensure the retrospective character of the duration estimation by alternating the time perception question. The time perception literature suggests differences in time estimation for retrospective and prospective estimations. Thus, in order to accurately capture the perceived trip duration, it is necessary to always collect retrospective time judgment data.

This study is one of the first which capture travel time perception for multiple trips purposed. A significant effect of the trip purpose has been found in terms of a distinction between mandatory and non-mandatory trips. However, the small data set has not allowed testing the impact of all trip purposes separately. Future research efforts could try to obtain a richer data set and evaluate the effect of trip purpose on travel time perception.

Regarding the research sample, in the present study, there was no representation of the elderly. The interviews during the pilot study and the analysis of the time required to complete the surveys revealed that older people perform well at the required tasks in terms of the time needed to complete them. Thus, the reason behind the absence of the elderly participants could be the participant recruitment approach. While this study disseminated the participation invitation mostly via social media, different participant requirement channels and methods might be necessary to attract older people.

The present study has used videos to capture travel time perception of cycling films. The analysis of the videos' subjective time has revealed an underestimation of cycling trips, similarly to the misperception error of the duration of real-life trips by active modes. Videos offer the opportunity of capturing the perception on the same trip for many people, and as such, estimating better the impact of the considered factors. However, the present study has used very short films that might not have allowed the immersion with the video's environment. Future studies could further investigate the suitability of the usage of videos for travel time perception research by also including videos with a duration similar to that of real-life trips.

Further analysis could be performed on the obtained dataset to evaluate the influence of network characteristics as well as of other objectively measured variables such as the actual weather conditions. The effect of the presence of nature has been determined in the present study only for trip films. Thus, future research could provide more information on its impact by capturing the presence of nature in real-life trips. The exploitation of the collected GPS points could already offer in-depth insight into this direction.

Furthermore, the present study has not addressed the travel time perception of cycling and walking trips as access or egress modes. The main reason was to avoid increasing respondent fatigue. However, considering the high share of such active mode trips in the Netherlands, future research could include these trips. The application of algorithms to automatically detect some characteristics such as the mode of transport, the trip start time, and the weather conditions could decrease the current number of questions asked. The automatic detection of such characteristics and variables could allow adding questions on different trip stages or perceived elements without increasing the task demand.

Apart from either exploring more determinants of travel time misperception of trips conducted by active modes or investigating the duration distortion for various trip stages, future studies could examine the impact of the deviation between perceived and actual travel time on travel behavior. To the author's knowledge, no study has considered the misperception of travel time on the travel choice behavior of pedestrians and cyclists.

7.2.3 Recommendations for the UMO Research app

Regarding the mobile app that has been tested in this study, it has been proven that it can already be used to collect different travel data from various data sources. Yet, some proposals for further development and usage can be made.

The usage of a mobile app has provided the opportunity to request user input right after the completion of a trip. To further extend the effectiveness of this request, push notifications could be applied. For example, pushed notifications could be triggered by entering a geofence around a person's home, work location, or other points of interest, such as a train station bike parking. The usage of geofences and push notifications could reduce the delay between the actual arrival at the destination and the indication of the trip termination. Moreover, push notifications could be sent in the absence of movement for at least some seconds or minutes. Of course, the generation of such push notifications requires the collection of location data real-time. For the present study, there was a log of 2 minutes for privacy concerns. Thus, before exploiting the generation of push notifications, further algorithms need to be applied to ensure the app users' privacy.

A limitation of the present version of the app is that the included survey generation module does not allow for random generation of alternative questions and tasks. The inclusion of different questions for the same factor of interest is important to ensure the retrospective character of travel time reports as well as to reduce the fatigue of the users from the repetitiveness of the tasks.

Regarding some other functionalities of the app, the termination of participation is not yet fully effective as there is no way to force unregistering from the experiment. For experiments in which it is necessary to control either the participation period or the number of reported trips, this function should be added. In future applications, this function could ensure that all individuals either participate for an equal number of days or register the same number of trips. Thus, a more balanced data set could be obtained.

Moreover, the log of all start and end source events in the database should be satisfied. In the present research, the absence of such events has been encountered in less than 1% of the trips. However, in a bigger sample its impact could be proven significant.

In addition, the fact that the app is not yet available for iOS devices excluded an increasing group of the population from participation. So, it is suggested that the architecture of the application is adapted to facilitate iOS devices too.

Finally, the first try of using the app for a research purpose has proven that there are burdens towards increasing the willingness of people to participate. To motivate participants, it would be beneficial to add a feedback section for the participants. Feedback could be provided on the trips conducted, such as the travelled distance or calories burnt. It could also assist in providing some statistics on the whole sample’s activity to encourage more active participation.

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Appendix A. Invitation Poster and certificate of participation

In this appendix the poster which was used for the recruitment of participants in the data collection of the present study is presented (Figure A.1).The poster was disseminated online and was also advertised around the city of Delft.

Figure A.1. Participant recruitment- Invitation poster

The video that served as the introduction to the research and was included both in the participant information sheet and in the online promotion of the data collection effort is available via the following link https://youtu.be/Wlrq1iFa0EQ. Some shots of the video are illustrated in Figure A.2.

Apart from the introductory video, an explainer video was used to instruct on the steps required for the registration of a trip via the UMO Research app. The video is available online https://youtu.be/4qIdOO6GYhc.

Figure A.2. Participant recruitment- introduction to research and invitation video

At the moment of the termination of their participation, all participants received a thank you note via the app (Figure A.3).

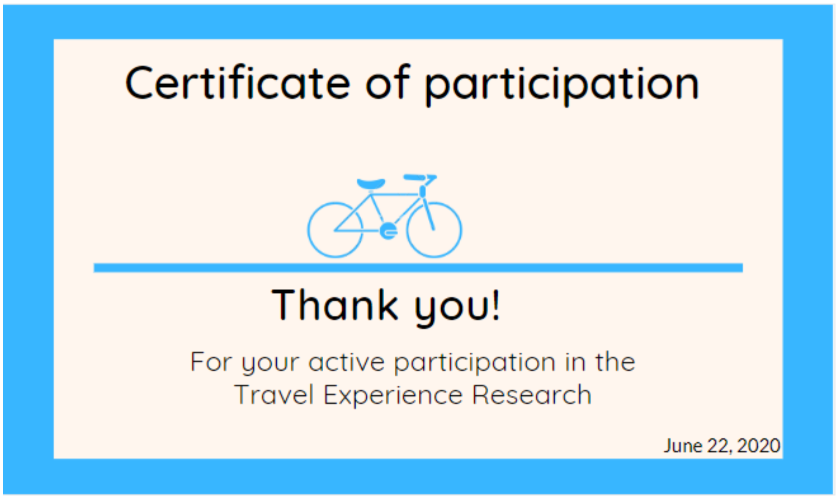


Figure A.3. Participation thank you note

Appendix B. Participant Information sheet

The participant information sheet which is presented after registering for the data collection of the present study is present below. The information sheet was embedded in the welcome page of the travel experience experiment in the UMO Research app. Since the information sheet was on mobile phone view, bold font was used to emphasize its most important points.

Participant information Sheet

Thank you for your interest in the Travel Experience research!

Before you decide whether you participate, it is important that you understand the context of the research and what participation will involve. **Please read carefully the information provided below.**

Introduction to research

This research is conducted in the context of a **master thesis project**, performed at the Department of **Transport & Planning** of **Delft University of Technology.** The research aims at getting insight into travel experience and activity. More specifically, **the aim is to identify patterns in subjective travel evaluation and investigate the factors that govern these patterns.** To obtain this information, **data will be collected on both perceived and realized travel activities**, via the UMO Research app. You are invited to participate in this study because **you live in the Netherlands**, you travel at least once per week by bike or on foot, you possess an Android smartphone, **and you are above 18 years old.**

Requested actions during participation

Your **participation will initiate after you sign an informed consent,** via the app. **After signing, a survey will be presented, named “Initial survey”.** This survey includes questions on demographic and socioeconomic characteristics, travel preferences, and travel habits. In addition, it entails three short trip films, each with its corresponding set of questions. It is expected that **the “Initial survey” can be completed in less than 5 minutes.** The "Initial survey" **remains available in your “Todo List” until the end of the data collection period.** This allows you to **complete it at a time of your convenience.** Then, **you will be requested to report on your travel experience and to allow tracking your trips. It is desirable that you record trips over 5 different days, which are not necessarily successive. Both workdays and weekends are considered.** You have full control over which trips are being recorded. Every time you desire **to allow recording a trip you need to perform two actions.** You can check the Trip Recording Explainer video for an overview. **First**, it is necessary that you **activate data collection at the beginning or shortly before your trip, via the app.** This enables the collection of location data, and more specifically, GPS data, via the app. **The application runs in the background**

on your device and, thus, it does not restrict the usage of your mobile phone. **Make sure that you allow the function of the UMO Research app in the background**. Depending on your phone you could control this either in the phone power saving/optimization/usage settings or in the permissions list of the specific app's settings. **Second, by the time you finish the trip** e.g., reach your destination, you need to **indicate the completion of your trip by selecting the “Stop collecting” function.** This action automatically disables the collection of location data. Furthermore, **after the completion of each of your trips, a short questionnaire, the “End Trip” survey, will be presented to you.** This survey **examines your travel experience on the conducted trip.** No action will be required while traveling. Before concluding your participation in the experiment, you are encouraged to complete the "Evaluation survey" in which you can express your satisfaction with both the mobile app and your participation in the research. **You are free to decline to complete any of the questionnaires or surveys presented to you.**

Participation and withdrawal

Participation in this research project is voluntary. If at any moment, after the initialization of your involvement, you wish to withdraw from the study, you may do so. You could either uninstall the app or unregister from the experiment. The latter option is available in the options section, ☰, of the app. There will be no obligation to explain the reasons behind your decision to discontinue your participation in the study, and there will be no penalties for you.

Data privacy

The research is compliant with the General Data Protection Regulation and has also been approved by the Human Research Ethics Committee of TU Delft. **All data will be anonymous** and will be shared only among the researchers who are involved in the study. Data will be processed to serve the aim of the study. Data on both travel activity and experience will be associated with demographic data, not with individuals. **Data will be used in the report of the master thesis project and in scientific publications.**

Contact possibilities

In the case that you want further information related to the research or your involvement in it, please Email Us. The researchers listed below will respond to your questions:

Gkavra Roxani	MSc student	Department of Transport & Planning TU Delft	R.Gkavra@student.tudelft.nl
Schneider Florian	PhD student	Department of Transport & Planning TU Delft	F.Schneider@tudelft.nl
Daamen Winnie	Associate professor	Department of Transport & Planning TU Delft	W.Daamen@tudelft.nl

You are also encouraged to contact the above-mentioned researchers if you want to express a complaint or a problem during your participation. **You can anytime revisit the above and additional information via the help button** ⓘ

You can also check our Research introduction/promo video.

Your interest and participation in our study is very much appreciated!

Date: 26/05/2020

Appendix C. Surveys

In this appendix the surveys which were used for the collection of information on travel time perception are listed. For the interested reader, a link is also provided for the online version of each of the surveys (Table C.7.1).

Table C.7.1. *Surveys*

Survey Name	Survey Link
Informed consent	https://surveyjs.io/published?id=c2249fd7-8104-411c-b29e-b0f2beda2280
Initial survey	https://surveyjs.io/published?id=7a4fc621-77dc-49fa-87fc-9c1cd277c7e2
End trip survey	https://surveyjs.io/published?id=d801b37c-4e70-4b54-a038-06bda5e1d3c6
Evaluation survey	https://surveyjs.io/published?id=24e85736-b5e4-4f73-853a-c6f095dbd994

Informed consent survey

Informed consent form for Travel Experience research

Taking part in the study

☐ * I have read and understood the study information dated 26-05-2020, or it has been read to me. I have been able to ask any questions that I had about the study and these questions have been answered to my satisfaction.

☐ * I consent voluntarily to be a participant in this study and understand that I can refuse to answer questions and I can withdraw from the study at any time, without having to give a reason.

☐ * I understand that taking part in the study involves filling in an intake survey, indicating start and end of my trips, while the route is recorded by an the UMO Research app that I installed on my mobile phone and has been developed by the Transport & Planning Department of TU Delft, and responding to short questionnaires at the destinations of my trips through the app.

☐ * I understand that taking part in the study involves that my routes are tracked using the app and the areas of commonly visited locations and time spent for my activities as well.

Use of the information in the study

☐ * I understand that the information I provide will be used for analyzing high-resolution activity travel behaviour in space and time. The results will be used in the report of the master thesis and in related scientific publications.

☐ * I understand that personal information collected about me which could identify me will not be shared beyond the study team.

Future use and reuse of the information by others

☐ * I give permission for the anonymous data on mobility habits, socioeconomic and trip characteristics, and locations visited, that I provide to be archived in the UMO repository (an Urban Observatory Mobility facility with the aim to store and archive data, and make it accessible for researchers) so it can be used for future research and learning

Digital Signature

Date format dd/mm/yyyy

* Date

Initial survey. Part 1

Android version

- Android 5.0-5.1.1.
- Android 6.0-6.0.1
- Android 7.0-7.1.2
- Android 8.0-8.1
- Android 9.0
- Android 10.0
- Other/ Do not know

Age

Gender

- Female
- Male
- Other

Highest Level of completed education

Choose...

Are you part of the Delft University of Technology community?

- No
- Yes

Years of residency in the Netherlands

- <6 months
- >6 months and <3 years
- >3 years

Employment status before COVID19

- ◯ Employed Full time
- ◯ Employed part time
- ◯ Unemployed
- ◯ Retired
- ◯ Other

Did your employment status change due to the COVID-19 pandemic?

- ◯ No
- ◯ Yes (Indicate new status)

In the last month, how often have you felt that you were unable to control important things in your life?

Never	Almost never	Sometimes	Fairly often	Very often

In the last month, how often have you felt confident about your ability to handle your personal problems?

Never	Almost never	Sometimes	Fairly often	Very often

In the last month, how often have you felt that things were going your way?

Never	Almost never	Sometimes	Fairly often	Very often

In the last month, how often have you felt that difficulties were piling up so high that you could not overcome them?

Never	Almost never	Sometimes	Fairly often	Very often

Which of the following modes do you possess?

Select all that apply

- ☐ Bike
- ☐ Bike sharing system subscription
- ☐ Car
- ☐ Motorcycle/Moped/Scooter
- ☐ Other (Describe)

Initial survey. Part 2

Trip films

Welcome to the second part of this survey! In this section you are requested to watch three short videos. After each video some follow-up questions are presented. Answering these questions is important for two reasons. First, it provides input for the examination of the factors that might affect your travel experience. Second, it helps researchers evaluate the usage of video for the collection of data on travel experience. So please keep on and complete this survey section. Thank you for your contribution!

First video

How confident would you feel to cycle over this cycling infrastructure?

Not at all confident	Slightly confident	Somewhat confident	Moderately confident	Extremely confident

How many seconds do you think that this first trip film last?

Only a single view of the video is allowed

Second video

How confident would you be to cycle in this environment during night?

Not at all confident	Slightly confident	Somewhat confident	Moderately confident	Extremely confident

How would you describe the duration of the second film trip in comparison to that of the previous film?

Much shorter	Shorter	Equal	Longer	Much longer

Third video

How often do you cycle across such a cycling environment for your everyday trips?

Never	Almost Never	Occasionally/Sometimes	Almost every time	Every time

How confident would you feel to overtake the mobility scooter in front of you?

Not at all confident	Slightly confident	Somewhat confident	Moderately confident	Extremely confident

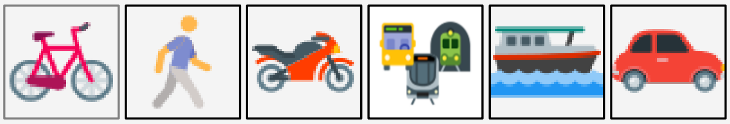
Which of the following best describes the duration of the last film trip?

- ○ 20 seconds
- ○ 30 seconds
- ○ 40 seconds
- ○ 50 seconds
- ○ 60 seconds

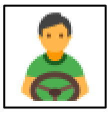
End Trip Survey

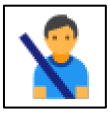
Mode of Transport

In case you used many modes, indicate the one by which you travelled for most time



Car occupant type

 Car driver

 Car passenger

In the case you started recording your trip before boarding and/or after alighting the public transport vehicle(s), by which mode did you reach the public transport stop/station (Access mode) and which mode did you use after exiting the public transport vehicle (Egress mode)?

Access mode

Egress mode

Which of the following best describes the purpose of your trip?

- ○ Returning Home
- ○ Work/Education
- ○ Appointment e.g. doctor, date,
- ○ Shopping
- ○ The trip itself e.g. jogging, walk a dog
- ○ Pick up/Drop-off somebody
- ○ Leisure
- ○ Other

Intuitively and without checking your clock, how many minutes do you think your trip lasted?
Respond in minute intervals e.g. 1

How many minutes ago did your trip end?

Did this trip last as long as you expected?

Much shorter	Shorter	As expected	Longer	Much longer	No expectation

How familiar are you with the route that you followed?

Not at all	Slightly	Somewhat	Moderately	Extremely

How much stress did you feel during your trip?

Not stress	Little stress	Neutral	Much stress	Extreme stress

How was the weather during your trip?

Very disappointing	Disappointing	Neutral	Satisfying	Very satisfying

How satisfied are you from your trip overall?

Very dissatisfied	Dissatisfied	Neutral/Unsure	Satisfied	Very satisfied

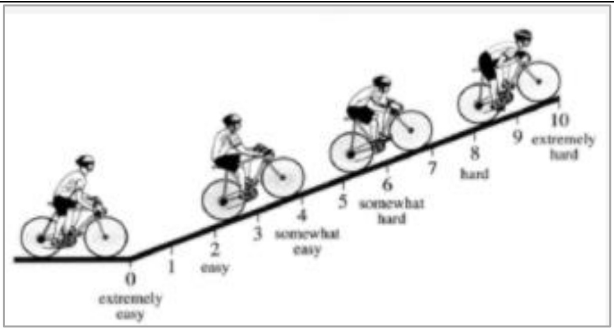
Did you use any type of information to plan your trip? e.g. route planner, public transport website or mobile application

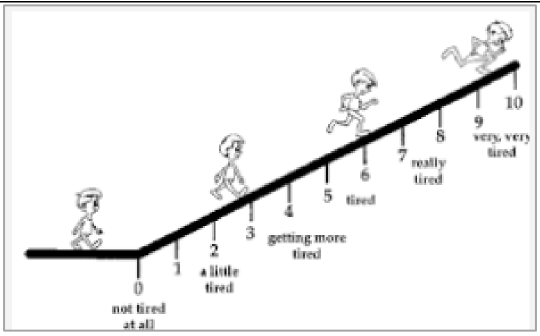
○ No ○ Yes

How difficult, in terms of physical effort, was it for you to complete this trip? Rate from 0-10.

You can use the figures below if you need help in estimating trip difficulty

Extremely easy 0	2	4	4	6	8	10 Extremely difficult





During your trip you might have conducted some activities. Select all that apply.

- ◯ Listening to music/radio/podcast
- ◯ Chatting with co-travellers
- ◯ Taking photos/Filming
- ◯ Enjoying the view
- ◯ Texting/Making phone call(s)
- ◯ Browsing the internet
- ◯ Shopping
- ◯ Working on laptop/notebook or reading
- ◯ Playing with dog
- ◯ Other activity

Walking/cycling travel experience statements

I was concerned about crashes/conflicts with other road users

Strongly disagree	Disagree	Neither agree or disagree	Agree	Strongly agree

The quality of the infrastructure e.g. walk pavement, bike path was

Poor	Fair	Good	Very good	Excellent

Public transport trip satisfaction

I am satisfied with the available personal space on-board

Strongly disagree	Disagree	Neither agree or disagree	Agree	Strongly agree

I felt comfortable while on board

Strongly disagree	Disagree	Neither agree or disagree	Agree	Strongly agree

I felt safe while waiting for the public transport service

Strongly disagree	Disagree	Neither agree or disagree	Agree	Strongly agree

Car/motorcycle travel experience statements

I was concerned about crashes/conflicts with other road users

Strongly disagree	Disagree	Neither agree or disagree	Agree	Strongly agree

I am satisfied with the car parking availability

Strongly disagree	Disagree	Neither agree or disagree	Agree	Strongly agree

Evaluation survey

Please complete this survey only before you terminate your participation in the research. This survey aims at capturing your satisfaction with the mobile application and the research participation required tasks.

Mobile Application ease of use

○ Inadequate ○ Poor ○ Acceptable ○ Good ○ Excellent

Information/instructions provided

○ Inadequate ○ Poor ○ Acceptable ○ Good ○ Excellent

How much did your participation in the research influence the battery drainage of your phone?

○ No effect ○ Minor effect ○ Neutral ○ Moderate effect ○ Major effect

How much did your participation in the research affect your normal phone usage?

○ No effect ○ Minor effect ○ Neutral ○ Moderate effect ○ Major effect

How adequate was the number of notifications that you received as a reminder to report your trips?

○ Did not receive notifications ○ Inadequate ○ Slightly inadequate ○ Neutral

○ Quite Adequate ○ Adequate

How would you rate the time required to complete the Initial survey?

○ Unacceptable ○ Slightly unacceptable ○ Neutral ○ Slightly acceptable ○ Acceptable

How would you rate the time required to complete the End trip survey?

○ Unacceptable ○ Slightly unacceptable ○ Neutral ○ Slightly acceptable ◉ Acceptable

In the End trip survey, the following question was listed "Intuitively and without checking you clock, how many minutes do you think that your trip lasted?". How often did you use a clock or another time control mechanism to

estimate the duration of your trip?

Never Rarely, in less than 10% of my trips Occasionally, in about 30% of my trips Sometimes, in about 50% of my trips Frequently, in about 70% of my trips Usually, in about 90% of my trips In every trip

Did you pay more attention to the duration of your trips after completing the End trip survey for the first time?

No Yes I completed the survey only once

From the total number of trips that you conducted in the period of your participation in the research, how many did you report via the app?

None About 10% About 30% About 50% About 70% About 90% Every trip, 100%

Overall participation enjoyment

Here you can provide additional comments to the research team!

Appendix D. Spatial distribution of reported trips

Figure D.1. Spatial distribution of collected trip location points

Appendix E. PSS-4 stress level

Table F.1. Reported stress on the Perceived Stress Scale items, N= 53

Stress Item	Mean	Standard Deviation
Item 1	2.153	0.894
Item 2	1.557	0.802
Item 3	1.769	0.831
Item 4	1.942	0.777
PSS-4 score	7.423	2.577