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# Abstract

This doctoral thesis investigated the socio-psychological dimensions influencing urban transport choices, with a specific focus on sustainable mobility, including active and integrated modes. Through a multidisciplinary approach combining systematic literature review and experimental studies, the work explored how individual perceptions, social norms, and environmental characteristics interact to shape behavioral intentions. The research is developed across four main phases:

- Literature Mapping: A scoping review was conducted to map the socio-psychological determinants of active mobility (walking and cycling). The findings highlighted a consistent trend where variables such as positive attitudes, perceived behavioral control, and habits serve as recurring predictors of transport intentions and behaviors.
- Experimental Studies on Cycling: Using video-based scenarios, two studies analyzed the impact of urban design and traffic conditions. The results suggested a general tendency for dedicated infrastructure to be associated with lower perceived danger and higher intentions to cycle, while the influence of social norms appears to vary depending on the perceived safety of the context, although this pattern should be interpreted with caution given its limited statistical robustness.
- Environmental Appraisals of Walkability: A video-based experiment examined the effects of seasonal variables, specifically snow and lighting, on pedestrian perceptions. The study observes how environmental conditions and visibility can influence the appraisal of urban spaces and walking intentions, particularly in low-light settings.
- Technology Acceptance in Integrated Mobility: The final phase applied the Technology Acceptance Model (TAM) to investigate the adoption of Mobility as a Service (MaaS) within a university population. The analysis indicated that perceived usefulness and ease of use were positively associated with the intention to adopt integrated mobility platforms, and the intention was positively associated with willingness to pay.

Overall, the findings suggested that sustainable mobility behaviors emerged from layered and interdependent processes. The observed trends indicated that while physical infrastructure provided a necessary foundation, individual mobility choices were significantly shaped by subjective perceptions and social-contextual factors. These results provided a nuanced perspective for urban planning, highlighting the importance of integrating psychological insights into the design of more sustainable transport systems.

# Chapter I. Understanding Sustainable Mobility: Systemic, Behavioral, and Experimental Approaches

## 1.1 Sustainability as a systemic and behavioral issue

Over the past decades, sustainability has emerged as one of the major challenges facing contemporary societies, assuming the role of a bridging concept between scientific domains and global policy agendas (Scoones, 2007). At the core of this debate lies the principle of sustainable development, defined as a model of growth capable of meeting the needs of the present generation without compromising the opportunities of future generations (World Commission on Environment and Development, 1987). This principle operates across deeply interconnected environmental, social, and economic dimensions (Sachs, 2012), which find some of their most evident and complex expressions in urban contexts.

Within cities, mobility systems represent a paradigmatic domain of this interdependence. They constitute an essential enabling condition for everyday life, while at the same time accounting for a substantial share of environmental impacts, energy consumption, and social inequalities (Hussain et al., 2022). In urban settings, therefore, sustainable mobility cannot be addressed solely as a technical or infrastructural issue but must instead be understood as a systemic problem involving spatial configurations, public policies, and individual behaviors. In the Italian context, this complexity is confirmed by recent analyses conducted by an institute called the Istituto Superiore di Formazione e Ricerca per i Trasporti (ISFORT, 2025), which has highlighted an increasingly fragmented mobility demand oriented toward “proximity”. This trend reflects a growing tendency for individuals to satisfy primary needs (e.g., work, education, shopping, health, leisure) within a reduced spatial and temporal range. Alongside persistent structural criticalities, such as the high rate of private motorization and disparities in access to services that fuel the phenomenon commonly referred to as “transport poverty”, a gradual but observable expansion of active mobility can nevertheless be observed.

The term active mobility refers to the set of travel modes based on human physical effort or the use of light, low-emission vehicles, primarily including walking, cycling, and forms of micromobility, such as electric scooters. Data from the first half of 2025 depict an evolving landscape: walking accounts for 20.6% of trips, a figure consistent with pre-pandemic levels recorded in 2019, while cycling and micromobility reach 5.2% for the first time, compared to 3.3% in 2019 (ISFORT, 2025).

Although these changes indicate a moderately positive trend toward more sustainable mobility patterns, their consolidation remains fragile and highly context dependent. This scenario highlights the need for integrated policies capable of reconciling decarbonization objectives with social justice, ensuring that the ecological transition does not result in new forms of exclusion. In this regard, scientific literature and public policies have long prioritized infrastructural interventions, focusing on modifications to transport supply and the built environment (e.g., Guo et al., 2023; Nazemi et al., 2021; Ullmann et al., 2022; Xu et al., 2017). However, it is now widely acknowledged that the transition toward sustainable mobility systems does not depend solely on the availability of technical solutions, but also, crucially, on individual and collective behaviors (Baeli et al., 2022; Eriksson & Forward, 2011; Frater et al., 2017a; Mosca et al., 2024a). Numerous articles have examined the relationships between individual factors and sustainable mobility behaviors, albeit often in a fragmented manner (e.g., Aranda-Balboa et al., 2020; Caballero et al., 2014; Ikeda et al., 2018; Meloni et al., 2025; Willis et al., 2015; Yang, 2015). These studies have shown that mobility choices, from the propensity to walk or cycle to the adoption of intermodal solutions, are not determined solely by the physical characteristics of the environment, but rather emerge from the interaction between personal attitudes, perceived safety, social influence, and established habits. From this perspective, sustainability cannot be conceived as an intrinsic property of transport systems, but rather as the outcome of everyday decisions that reflect subjective perceptions, social influence, and contextual constraints.

Within environmental psychology, this line of research focuses on so-called Pro-Environmental Behaviors (PEBs), defined as behaviors aimed at reducing negative impacts or generating beneficial effects on the natural environment in a broad sense (Lange, 2024). Although PEBs have been extensively studied in domains such as energy conservation (e.g., Pothitou et al., 2016), water consumption (e.g., Pereira-Doel et al., 2019), and waste management (e.g., Tonglet et al., 2004), their role within the transport sector has become increasingly central (e.g., Zavareh et al., 2020). The review by Pellegrini and Tagliabue (2024) has highlighted how different socio-psychological theoretical models contribute to explaining mobility choices, emphasizing the importance of subjective perceptions of the urban context in shaping not only individual behaviors but also the effectiveness of active mobility policies. Urban mobility thus represents an emblematic case of misalignment between sustainability goals and everyday practices. Despite the growing availability of alternatives to private motorized transport, car use continues to dominate in many contexts, particularly in Italy (Pellegrini & Tagliabue, 2024). In Europe, the transport sector is among the major contributors to greenhouse gas emissions and air pollution in urban areas (European Parliament, 2024; UNECE, 2024), while also significantly affecting quality of life, public health (Germanova &

Kernozhitskaya, 2017; International Energy Agency, 2022; World Health Organization, 2004), climate change (Creutzig et al., 2015; Pietzcker et al., 2014), and the use of urban space (Yigitcanlar & Kamruzzaman, 2014). In response to these impacts, numerous planning strategies promote a reduction in dependence on private cars and the adoption of more sustainable transport modes. However, empirical evidence has shown that the mere availability of infrastructure is not sufficient to ensure lasting behavioral change (Meloni et al., 2025).

Within this framework, active mobility, particularly walking and cycling, occupies a central role in urban sustainability strategies. The benefits associated with these modes are well documented and include improvements in physical health (Alexander & Schwandt, 2022) and mental well-being (Rojas-Rueda et al., 2016), reductions in emissions (Chapman, 2007; Creutzig et al., 2015), enhanced quality of urban life, and decreased traffic congestion (Koszowski et al., 2018). Nevertheless, adoption levels of active mobility as a daily transport mode often remain below stated targets (EUROSTAT, 2019), suggesting that awareness of the benefits alone is insufficient to trigger behavioral change. Choices to walk or cycle are also influenced by socio-psychological factors such as attitudes, emotions, and established habits (Caballero et al., 2019; Mandal et al., 2023). Existing literature, as will be discussed in Chapter II, also has highlighted relevant methodological limitations: many studies rely on self-reported measures, and cross-sectional designs, making it difficult to identify the causal mechanisms driving active mobility behaviors. These challenges underscore the need for research approaches capable of integrating environmental and psychological factors in a more controlled and systematic manner.

## **1.2 Studying mobility behavior: limitations of real-world contexts and the need for controlled methods**

Empirically investigating mobility behaviors in real-world contexts presents numerous methodological challenges. Environmental conditions are difficult to manipulate, exposure to potentially hazardous situations raises ethical concerns, and many relevant factors (e.g., traffic, seasonality, or alternative infrastructural configurations) cannot be modified for experimental purposes (Newman, 2025; van der Ham et al., 2015). In this context, the use of simulated environments and controlled scenarios represents a methodological response to the structural limitations of field research. Over time, various environmental simulation methods have been developed to approximate real-world experiences (e.g., Marans & Stokols, 1993; Nasar, 2008), ranging from static images (Huang, 2009) to videos (Parsons et al., 1998), and up to more advanced virtual environments (Rossetti & Hurtubia, 2020). These approaches allow the study of person–

environment interactions while maintaining a high level of experimental control, without entirely sacrificing perceptual realism.

Static images, for example, allow for controlled presentation of stimuli but lack the dynamic cues that are fundamental to human perception and behavior (Heft & Nasar, 2000). Video recordings, on the other hand, introduce a dynamic dimension that enables participants to simulate movement through the environment, increasing attentional engagement and exploration compared to photographs (Heft & Nasar, 2000; Kasraian et al., 2020; Parsons et al., 1998; Ulrich et al., 1991). Videos therefore represent an effective compromise between experimental control and realism (Rossetti & Hurtubia, 2020). However, this compromise also involves a trade-off between experimental control and ecological validity, as the increased standardization of stimuli may partially limit the extent to which simulated responses capture the complexity of real-world embodied behavior and contextual variability. In this sense, findings derived from video-based methodologies should be interpreted as approximations of real-world mobility decisions, reflecting a balance between internal validity and environmental realism rather than a full reproduction of naturalistic behavior. A further level of interactivity is offered by virtual environments and immersive virtual reality, which allow precise manipulation of environmental variables (Kort et al., 2003; Paljic, 2017). In particular, the use of 360° videos viewed through head-mounted displays (HMDs) has been shown to generate perceptions comparable to those experienced in real-world environments (Calogiuri et al., 2018; Dillon & Cai, 2022; Nukarinen et al., 2020). Overall, the literature has suggested that, while not fully replacing direct real-world experience, immersive virtual environments and video-based simulations constitute valid surrogates capable of producing meaningful effects (Gatersleben & Andrews, 2013; Yeo et al., 2020). The choice of simulation method therefore requires balancing realism, experimental control, and feasibility, making video-based simulations a particularly suitable solution for studying navigability and environmental perceptions (Kasraian et al., 2020; Liao et al., 2022).

### **1.3 From active mobility to integrated mobility: the role of MaaS**

Although active mobility represents a fundamental key component of urban sustainability (Alexander & Schwandt, 2022; Chapman, 2007; Creutzig et al., 2015; Koszowski et al., 2018; Rojas-Rueda et al., 2016), it alone cannot meet the full range of daily travel needs. In this regard, integrated mobility systems, and in particular the concept of Mobility as a Service (MaaS), have been proposed as solutions capable of reducing dependence on private cars by combining multiple transport modes within a single platform (Kamargianni et al., 2016). MaaS is configured as an ecosystem based on three key elements: (1) the centrality of user needs in service design, (2) the integration of Information and Communication Technologies (ICTs) with transport engineering models, and (3) the pursuit of

sustainability objectives. Its distinctiveness lies in the design of integrated services based on shared and connected mobility, accessible as a unified system (Cisterna et al., 2023; Hasselwander & Bigotte, 2023; Kamargianni et al., 2016; Smith & Hensher, 2020). Through digital platforms, users can plan, access, and pay for services, perceiving the system as an alternative to private car ownership, provided that the service offering is designed in alignment with actual demand (Meloni et al., 2025).

European policies and the introduction of innovative payment systems have facilitated the diffusion of MaaS in over 40 European cities (Meloni et al., 2025). Helsinki was among the first cities to implement structured solutions, introducing the concept of MaaS and launching the Whim standard (City of Helsinki, 2019; MaaS Global Whim, 2022). Subsequently, the model evolved through numerous international trials, including in London, Zurich, Sydney, Berlin, and Toronto, which helped explore different configurations of service integration, customization, and governance (Guidon et al., 2020; Hensher et al., 2021; Ho et al., 2021; Matyas & Kamargianni, 2019). Italy is notable for introducing a national coordination level, acting as an intermediary between MaaS operators and transport service providers (MITD, 2022; UITP, 2019). Through National and Regional Access Points (TTS Italia, 2021), initiatives have been launched such as OpenMove in Trentino, the Living Lab MaaS in Turin, BIPforMaaS in Piemonte, and the Nugo app by Ferrovie dello Stato, aiming to provide national coverage while coordinating multiple service providers and facilitating user access (Meloni et al., 2025).

However, as highlighted in the literature, technological availability alone does not automatically ensure service adoption. Acceptance of MaaS depends also on psychological processes that include perceived usefulness, perceived ease of use, system trust, and behavioral intention (e.g., Pellegrini et al., 2025a; Schikofsky et al., 2020; Vafaei-Zadeh et al., 2026). Analyzing these processes is essential to understand if and to what extent digital innovations can effectively support a transition toward more sustainable mobility behaviors.

#### **1.4 Objectives and structure of the thesis**

Considering the discussion above, this thesis aims to provide an integrated contribution to the understanding of sustainable mobility behaviors, with particular attention to socio-psychological determinants, environmental characteristics, and experimental methods that can overcome some of the limitations of research conducted in real-world contexts. The work is organized into five main chapters, in addition to this introduction, each addressing a specific dimension of the problem.

Chapter II presents a scoping review of the socio-psychological determinants of active mobility, mapping the variables associated with walking and cycling behaviors as everyday urban transport

modes. Chapter III reports two experimental studies on cycling based on video scenarios, designed to analyze the influence of urban environmental features and selected socio-psychological factors on the intention of using the bicycle. Chapter IV investigates walkability under seasonal conditions, examining the impact of snow and lighting on environmental perceptions and walking intentions in an urban forest context through a video-based experimental design. Chapter V analyzes the psychological mechanisms underlying MaaS adoption in a university population, applying the Technology Acceptance Model (TAM) to understand the role of perceived usefulness, perceived ease of use, behavioral intention, and willingness to pay. Finally, Chapter VI integrates the empirical results, discussing implications for research, urban planning, and the design of sustainable mobility services, while also outlining potential directions for future work.

In line with the considerations outlined above, it is important to clarify that this thesis does not rely on a single unifying theoretical framework. Rather, it adopts an integrative perspective that brings together multiple complementary dimensions to account for the complexity of sustainable mobility behaviors. Specifically, the research developed in this work can be interpreted across four interrelated levels. First, the environmental and infrastructural dimension concerns the physical characteristics of urban contexts and transport systems that enable or constrain mobility choices. Second, the socio-psychological dimension focuses on individual-level factors, such as attitudes, perceptions, habits, and social influences, which shape behavioral intentions. Third, the technological dimension addresses the role of digital and integrated mobility systems, such as MaaS, in transforming access to transport options. Finally, the methodological dimension reflects the use of controlled experimental approaches, particularly video-based simulations, to investigate person–environment interactions under conditions that are difficult to reproduce in real-world contexts.

# **Chapter II. Socio-Psychological Determinants of Active Mobility in Urban Environments: A Scoping Review of Walking and Cycling**

## **2.1. Introduction**

### **2.1.1. Background**

There has been a growing emphasis on policies promoting active mobility, which have become a key objective for numerous European cities (Wegener et al., 2017). Active mobility broadly refers to forms of transport that involve physical activity, most notably walking and cycling (Scotini et al., 2017; Zhou et al., 2020). While some studies extend this definition to other non-motorized modes, such as skateboarding (Scorrano & Danielis, 2021), for the purposes of this review and the present thesis, active mobility is operationalized specifically as walking and cycling.

Interest in active mobility has largely been driven by research highlighting its substantial impacts on both human health (Alexander & Schwandt, 2022) and environmental sustainability (Chapman, 2007; Creutzig et al., 2015). Active mobility behaviors contribute not only to the mitigation of traffic congestion (Koszowski et al., 2018) but also to physical and psychological well-being (Rojas-Rueda et al., 2016). For instance, Helbich et al. (2016) found that traffic exposure negatively affected children's likelihood to engage in walking or cycling, while a meta-analysis of 30 studies across Europe, the United States (US), Australia, and New Zealand indicated that the health benefits of walking and cycling outweigh risks associated with traffic accidents or air pollution (Mueller et al., 2015).

Despite the well-documented benefits, the adoption of walking and cycling remains limited in many contexts (EUROSTAT, 2019). This gap underscores the need to examine not only environmental conditions but also socio-psychological determinants that influence mobility decisions.

Socio-psychological variables are individual-level constructs influenced by social contexts and environmental perception, which in turn shape behavior. The Human–Environment Interaction (HEI) model (Küller, 1991) has provided a useful framework to understand these processes, proposing that behavior emerges from the continuous interaction between personal attributes and environmental features, mediated by subjective appraisal. In the field of active mobility, there have been examples of Ferreira et al. (2016), Johansson (2006), and Johansson et al. (2016). Complementing this

perspective, the Social Cognitive Theory (SCT; Schunk & Usher, 2012) highlighted how motivation, learning, and self-regulation develop within social and environmental contexts. In addition to these frameworks, the Theory of Planned Behavior (TPB) (Ajzen, 1991) provides another influential perspective for understanding active mobility behaviors. According to TPB, behavior is primarily driven by behavioral intentions, which are shaped by three key socio-psychological determinants: attitudes toward the behavior, subjective norms, and perceived behavioral control (PBC). These constructs closely align with the factors described above, illustrating how individual evaluations, social expectations, and perceived capabilities collectively influence decisions to walk (Mandal et al., 2023) or cycle (Caballero et al., 2019).

From this standpoint, socio-psychological variables operate as interpretive filters between environmental perception and behavior. Among these, attitudes, defined as the positive or negative evaluation of a behavior (Ajzen, 1991), have been widely studied (e.g., Duan et al., 2023; García et al., 2019), as well as social norms (e.g., Liu et al., 2023; Si et al., 2020; Zhang et al., 2019), which are described as implicit rules that influence behavior through perceptions of what most people do (descriptive norms), what others approve or disapprove of (prescriptive or injunctive norms), or through personal evaluations of one's own conduct (personal norms) (Cialdini et al., 1991). Perceived behavioral control (Caballero et al., 2019; Xu et al., 2020) reflects individuals' beliefs in their ability to overcome barriers and leverage facilitators, such as past experience or environmental supports (Hagger et al., 2022). Habit and self-efficacy, defined as the "belief in one's capabilities to organize and execute the course of action required to manage prospective situations" (Bandura, 1995, p. 2), also emerge as relevant constructs, mediating motivation and intention in walking and cycling behaviors (Rejeb et al., 2023; Silva et al., 2014).

Given the importance of socio-psychological variables, several literature reviews have synthesized existing findings. However, these reviews often differ in scope, methodology, or theoretical grounding. For example, Yang (2015) explored psychological and environmental influences on walking but limited the focus to walking behavior, highlighting the complex interactions between individual attitudes and neighborhood environments and proposing an integrated framework that combines competitive and synergistic mechanisms. Ikeda et al. (2018) investigated children's school travel, emphasizing safety, walkability, and social support, and highlighting the combined influence of perceived physical environments and social-sociodemographic factors on active school travel, while also underscoring the generally weak methodological quality of existing evidence. Caballero et al. (2014) focused on psychological predictors of cycling, highlighting the central role of habit, perceived behavioral control, and social support in determining both the initiation and regularity of

bicycle use, while also emphasizing that intentions become less influential once cycling becomes habitual. Willis et al. (2015) reviewed the literature on cycling for transportation, highlighting the central role of attitudes, perceptions, habits, and social-environment factors in shaping individuals' decisions to commute by bicycle, beyond the effects of the built environment alone. Similarly, Aranda-Balboa et al. (2020) reviewed parental barriers to children's active transport, identifying distance, traffic safety, crime-related safety, built environment, and social support as the main perceived obstacles, and highlighting how parental concerns are stronger for younger children, context-dependent, and shaped by environmental conditions and parental perceptions, underscoring the need for policy and educational interventions to improve safety and supportive environments. Collectively, these works have highlighted the role of socio-psychological determinants but reveal fragmented literature, often confined to specific populations, modes of travel, or variables.

A scoping review approach is therefore appropriate, as it enables a comprehensive mapping of diverse socio-psychological variables, and target populations, while also allowing for the identification of knowledge gaps, the clarification of conceptual ambiguities, and the examination of how research in this area has been conducted (Munn et al., 2018). In particular, the present review seeks to synthesize evidence relevant to walking and cycling in urban environments to provide a coherent foundation for the empirical studies presented in this thesis. This review also sets the stage for examining how environmental features interact with socio-psychological determinants to shape active mobility behavior.

### **2.1.2. Objective and research questions**

The present research aims to provide a comprehensive scoping review of socio-psychological variables associated with active mobility behaviors, with a specific focus on active travel from a transportation perspective. This focus reflects the interdisciplinary framework of the doctoral project, which is embedded within a broader research collaboration involving transportation engineers and urban planners. Accordingly, the review concentrates on studies addressing walking and cycling as modes of everyday transport, rather than as forms of leisure, sport, or recreational physical activity, to ensure conceptual and practical alignment with transport planning and urban design objectives. Within this framework, the review addresses the following Research Questions (RQs):

RQ1: What are the main bibliometric characteristics of the selected articles?

This question seeks to map publication trends and patterns, examining when the studies were published and in which countries. Sub-question RQ1.1 focuses on the temporal distribution of the selected articles, while RQ1.2 investigates the geographical coverage of the studies.

RQ2: What methodological features characterize the selected studies?

This question aims to explore the methodological approaches used in literature, including study designs. RQ2.1 examines the research designs employed, and RQ2.2 describes the characteristics of the participant samples involved.

RQ3: Which socio-psychological variables are linked to active mobility behaviors?

This question targets the identification of socio-psychological constructs that influence active mobility, as well as their specific effects on walking, cycling, or both. RQ3.1 addresses which variables have been investigated, while RQ3.2 considers how these variables are associated with behavioral outcomes.

## **2.2. Method**

This scoping review was conducted in accordance with the methodological framework outlined in the PRISMA Extension for Scoping Reviews (PRISMA-ScR; Tricco et al., 2018). Reference management during the review process was supported by the web-based software CADIMA (Kohl et al., 2018), a free online tool designed to facilitate the transparent conduct of systematic reviews, systematic maps, and other literature review types. In the present study, CADIMA was employed solely to identify and remove duplicate records from the initial search results, as too many results were obtained, which caused problems. All subsequent screening, selection, and organization of references were carried out manually using a customized Excel spreadsheet to ensure careful and consistent handling of the included studies.

### **2.2.1. Search strategy**

To identify studies examining socio-psychological variables in relation to active mobility behaviors, a systematic search was conducted between January and March 2024 across Web of Science, Scopus, and PsycInfo. The search strategy combined keywords covering three main dimensions:

Active mobility: “active mobility” OR “walkability” OR “cyclability” OR “bike”;

Socio-psychological variables: “psycho\*”;

Urban context: “environment\*” OR “road\* environment” OR “street\* environment”.

Boolean operators were used to combine these terms, ensuring a comprehensive and focused retrieval of relevant studies. This approach aimed to capture literature that addressed the interplay between individual psychological factors influencing walking and cycling behaviors.

### **2.2.2. Eligibility criteria and screening process**

A total of 1,294 records were initially retrieved from the systematic database searches using the predefined keywords. The screening process adhered to established inclusion and exclusion criteria, as summarized in the PRISMA-ScR flow diagram (see Figure 1).

In the first screening phase, duplicates, non-peer-reviewed documents, and records published in languages other than English, Italian, or Spanish were removed, resulting in 1,052 records. Title and abstract screening were then independently performed by me and another colleague with complementary disciplinary backgrounds (psychology and urban planning), ensuring a broader interpretative perspective. In cases of disagreement, a third reviewer was consulted to reach consensus. Records were excluded at this stage if they did not address socio-psychological variables or failed to consider active mobility (walking, cycling, or both).

After this phase, 96 articles were retained for full-text review. The relatively high number of records passing the initial screening reflects terminological inconsistencies across studies, particularly regarding the use of the term “physical activity”. In some abstracts, physical activity clearly referred to active mobility, whereas in others it remained ambiguous, encompassing recreational or structured exercise. To mitigate the risk of prematurely excluding relevant studies, the reviewers adopted a conservative approach: any abstract suggesting the possible presence of relevant information was retained for full-text evaluation.

Full-text screening was subsequently conducted by the same two reviewers (me and another colleague), with discrepancies resolved through discussion and consensus. Studies were included if active mobility was the only outcome, and socio-psychological variables were explicitly addressed and measured. The focus on active mobility from a transportation perspective was motivated by the interdisciplinary framework of the doctoral project, which is embedded in a broader collaboration with transportation engineers and urban planners. Accordingly, the review prioritised studies addressing walking and cycling as modes of everyday urban travel, excluding those primarily focused on recreational, sport, or exercise-related activities. Additional exclusion criteria eliminated studies that: (1) did not investigate active mobility from a transportation perspective, (2) lacked empirical data, or (3) considered forms of active mobility beyond walking and cycling (e.g., skateboarding).

Following this multi-stage screening process, 24 studies met all inclusion criteria. An additional 45 records were identified through reference chaining, all of which satisfied the same criteria. One of the articles initially included in this work was subsequently retracted by the journal (i.e., Yasir et al.,

2022); therefore, the scoping review ultimately incorporates 68 articles published between 2007 and 2023.

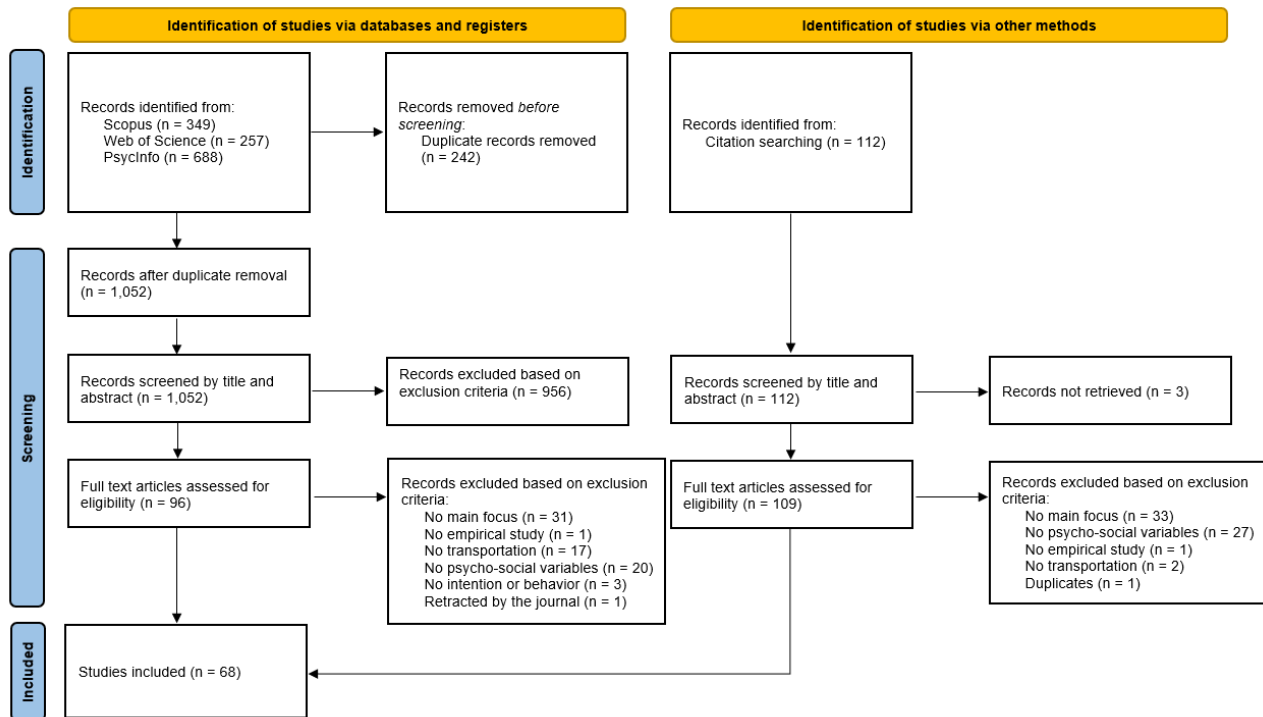


**Figure 1. Screening process for the selection of articles.**

### 2.2.3. Data extraction

All studies that met the inclusion criteria underwent full-text review, and relevant information was systematically extracted using a standardized template. Extracted data included: authorship, year of publication, journal, country of study, sample characteristics, and research design. In addition, details on the socio-psychological variables examined, the type of outcome measured (e.g., behavioral intention, self-reported behavior, or observed behavior), and the focus of the study (walking, cycling, or both) were recorded. Key findings were also documented, with particular emphasis on the reported influence of socio-psychological variables on active mobility behaviors.

## 2.3. Results and discussion

### 2.3.1. RQ 1.1. Distribution by year of publication

Figure 2 illustrates the annual distribution of articles included in the scoping review, covering the period from 2007 to 2023. Overall, the number of publications per year shows marked variability, with a notable peak in 2019, which recorded ten articles, representing the highest annual output across the entire period considered. Between 2009 and 2011, the publication output remained relatively stable, with a consistent number of five to six articles per year. This phase was followed by more pronounced fluctuations, with one of the lowest points observed in 2013, when only two articles were

published, followed by a partial recovery in 2014, with five publications. Similarly, 2018 recorded only one publication, immediately followed by a sharp increase in 2019. From 2020 to 2023, the number of articles has appeared to stabilize, ranging between two and five publications per year. Taken together, the temporal distribution does not reveal a clear linear growth trend, unlike what has been observed in other research domains, such as digital technologies for behavior change (Mosca et al., 2024b).

The pronounced peak observed in 2019 may be interpreted considering broader socio-political and cultural developments. In particular, the emergence in 2018 of a global movement aimed at raising public awareness of environmental sustainability and the climate crisis (Fridays for Future, 2026) may have contributed to increased scholarly attention toward sustainability-related topics, including active mobility. In this sense, fluctuations in publication volume appear to reflect periods of heightened academic interest triggered by external societal dynamics, followed by a phase of more regular and consolidated research output in recent years.

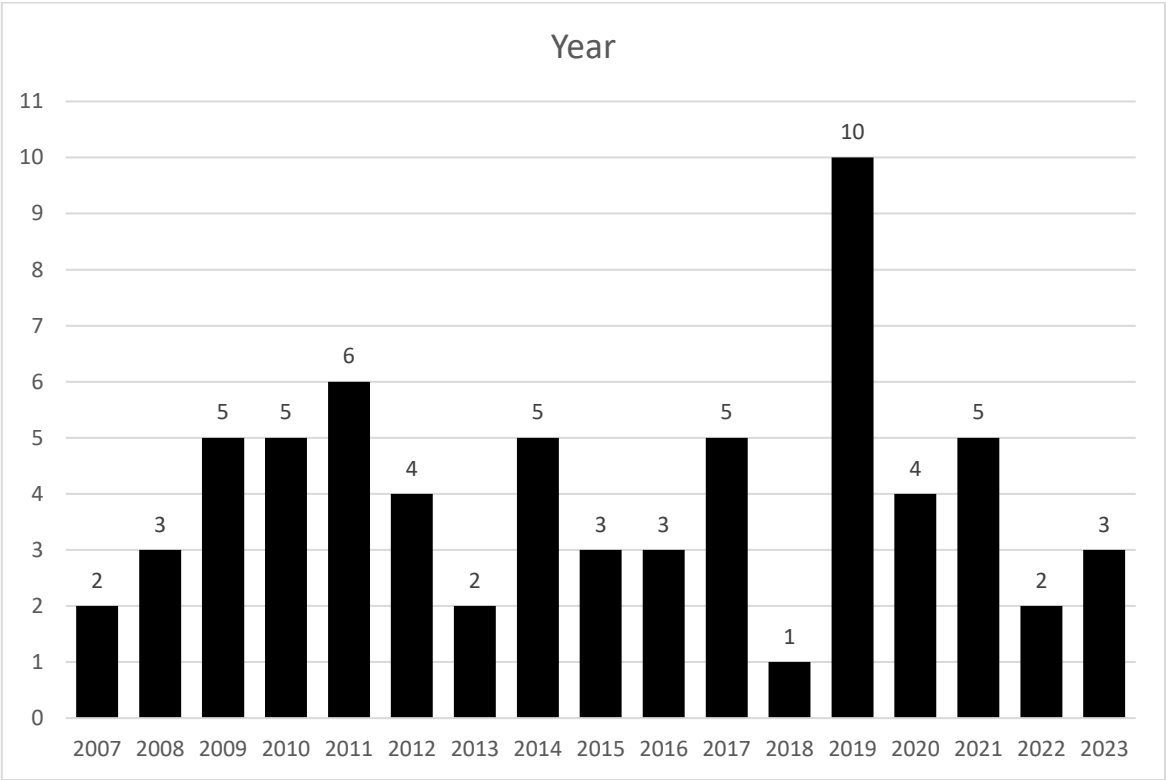


**Figure 2. Representation of distribution by year of publication.**

### **2.3.2. RQ 1.2. Distribution by geographical area**

Figure 3 presents the spatial distribution of studies included in the scoping review, based on the countries in which the research was conducted. Overall, the dataset includes contributions from nineteen countries, indicating a relatively wide, though uneven, international engagement with the topic. The US emerged as the leading contributor with fifteen studies, followed by China with nine and Spain with eight. A second cluster of countries shows substantial but more limited representation, including Belgium ( $n = 6$ ) and the United Kingdom ( $n = 5$ ). Moderate contributions were observed for Australia ( $n = 4$ ), The Netherlands ( $n = 4$ ), and New Zealand ( $n = 3$ ). In contrast, several countries were represented by only one or two studies, including Canada, Taiwan, Italy, Iran, Germany, Austria, Portugal, Argentina, Croatia, Ghana, Norway, and Hong Kong.

Despite evidence of scholarly interest, the geographical distribution of studies reveals marked imbalances. Entire regions, such as Africa, South America, Eastern Europe, and large parts of Asia, remain largely underrepresented, a pattern consistent with previous reviews on active mobility and related behaviors (e.g., Ikeda et al., 2018; Scrivano et al., 2024). This concentration of research in North America and Western Europe reflects a broader reliance on WEIRD populations (Western, Educated, Industrialized, Rich, and Democratic), which poses clear limitations to the external validity and cross-cultural generalizability of the findings (Henrich et al., 2010). Overall, while literature demonstrates an expanding international scope, the dominance of a relatively small number of countries suggests that current knowledge on the socio-psychological determinants of active mobility is shaped by context-specific evidence, underscoring the need for future studies conducted in more diverse socio-cultural and geographical settings, as also pointed out by Yang (2015).

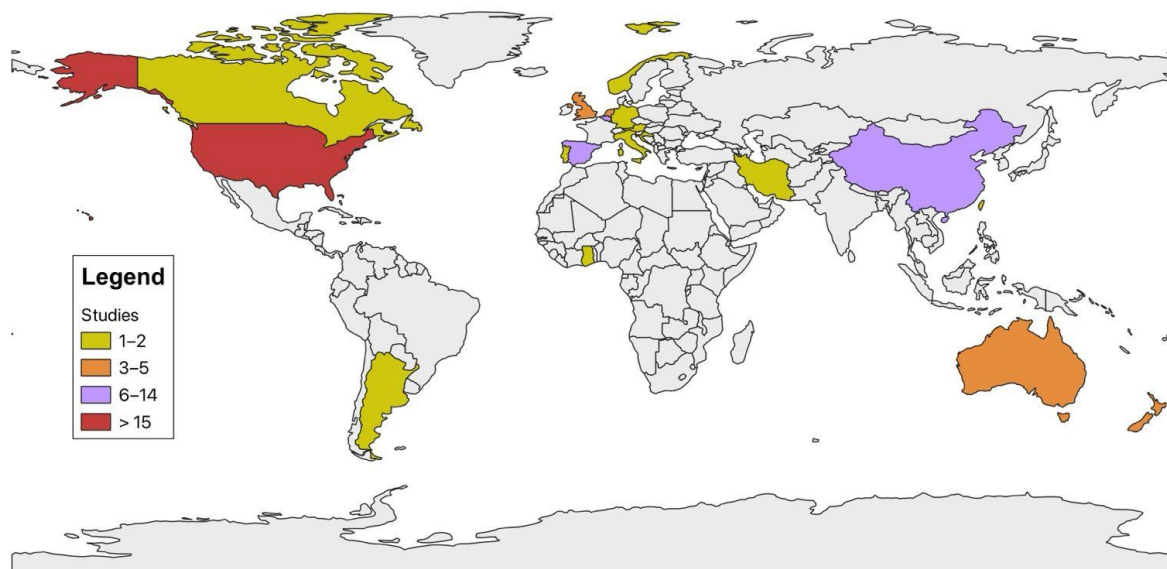


**Figure 3. Representation of distribution by geographical area.**

### **2.3.3. RQ 2.1. Distribution by research design**

Figure 4 presents the distribution of studies included in the scoping review according to research design, distinguishing between quantitative, qualitative, and mixed-method approaches. Quantitative studies were further classified according to temporal design (cross-sectional vs. longitudinal) and data collection instruments. Most of the included studies ( $n = 59$ ) adopted a quantitative, cross-sectional design, with questionnaires emerging as the most frequently used data collection tool. Within this group, considerable heterogeneity was observed in the mode of questionnaire administration: twenty-seven studies relied on general questionnaires, seventeen employed online questionnaires, and six combined online and offline formats. In addition, three studies conducted face-to-face interviews, while three relied on telephone interviews, either as a standalone method ( $n = 2$ ) or in combination with questionnaires ( $n = 1$ ). Two studies used Computer-Assisted Telephone Interviews (CATI), and only one study integrated self-report measures with objective behavioral data using an accelerometer. A smaller subset of studies ( $n = 5$ ) employed a quantitative, longitudinal design, again predominantly relying on questionnaires ( $n = 4$ ), with only one study using face-to-face interviews. Purely qualitative approaches were relatively rare, with only three studies conducting in-depth interviews, while a single mixed-method study combined online questionnaires, personal diaries, and interviews to triangulate data across multiple sources.

The strong predominance of cross-sectional, questionnaire-based studies likely reflects their practical advantages in terms of feasibility and cost. However, this methodological choice also entails notable limitations, particularly regarding the depth of insight into underlying processes and the ability to draw causal inferences. The fact that only one study (i.e., Murtagh et al., 2012) directly measured behavior using an accelerometer underscores a substantial gap between self-reported and objectively assessed active mobility behaviors, a discrepancy widely discussed in behavioral literature (Sheeran & Webb, 2016). Similarly, the limited number of qualitative studies may reflect a persistent marginalization of qualitative methodologies within environmental psychology, a tendency also highlighted in recent debates (Bercht et al., 2024; Ratcliffe et al., 2024). Nonetheless, qualitative research can meet high standards of rigor and transparency (Levitt et al., 2018) and offers unique potential for capturing meanings, motivations, and contextualized experiences of active mobility. Overall, while the field is currently dominated by quantitative, cross-sectional designs, longitudinal, qualitative, and mixed-method approaches provide valuable, yet underutilized, methodological contributions, pointing to important directions for future research.

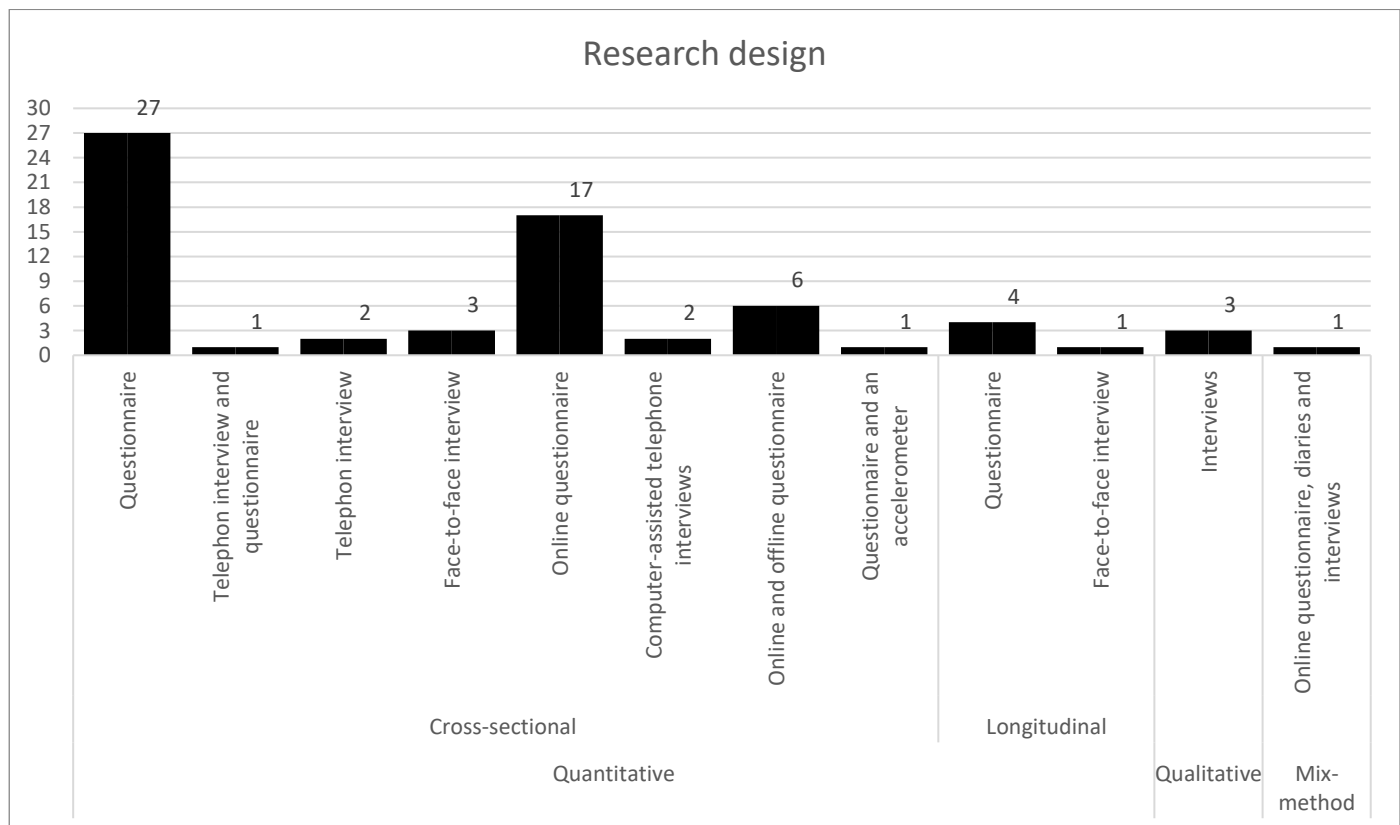


**Figure 4. Representation of distribution by research design.**

#### **2.3.4. RQ 2.2. Distribution by sample characteristics**

Figure 5 illustrates the distribution of studies included in the scoping review according to the population groups examined. A clear predominance of adult samples emerged, with adults accounting

for a total of 34,783 participants across the included studies. This finding reflects a strong and consistent research focus on the working-age population, which is often considered the primary target of active mobility policies from a transportation perspective. Children (11,561 participants) and adolescents (8,554 participants) were also substantially represented, indicating sustained scholarly attention to younger populations, particularly in relation to school travel and early habit formation. More specific sample compositions included child–parent dyads (1,258 participants) and studies jointly examining adolescents and adults (3,645 participants), suggesting an interest in intergenerational dynamics and shared decision-making processes related to active mobility. Research involving older adults accounted for 1,982 participants, showing that this population, although present in the literature, remains comparatively underrepresented.

This uneven distribution, with adults dominating the research focus and older adults receiving limited attention, may be interpreted through Alfonzo's (2005) Hierarchy of Walking Needs, which conceptualizes feasibility as a foundational prerequisite for walking. Physical, health-related, and logistical barriers commonly experienced by older adults may constrain their engagement in active mobility, potentially contributing both to lower participation rates and to their reduced visibility in empirical research. Overall, while adults clearly constitute the primary population of interest, the substantial inclusion of children and adolescents, together with smaller but relevant subgroups, supports a partial life-course perspective on active mobility behaviors. Nevertheless, the limited focus on older adults highlights an important gap in literature, particularly considering aging urban populations and the growing relevance of inclusive and age-friendly mobility planning.

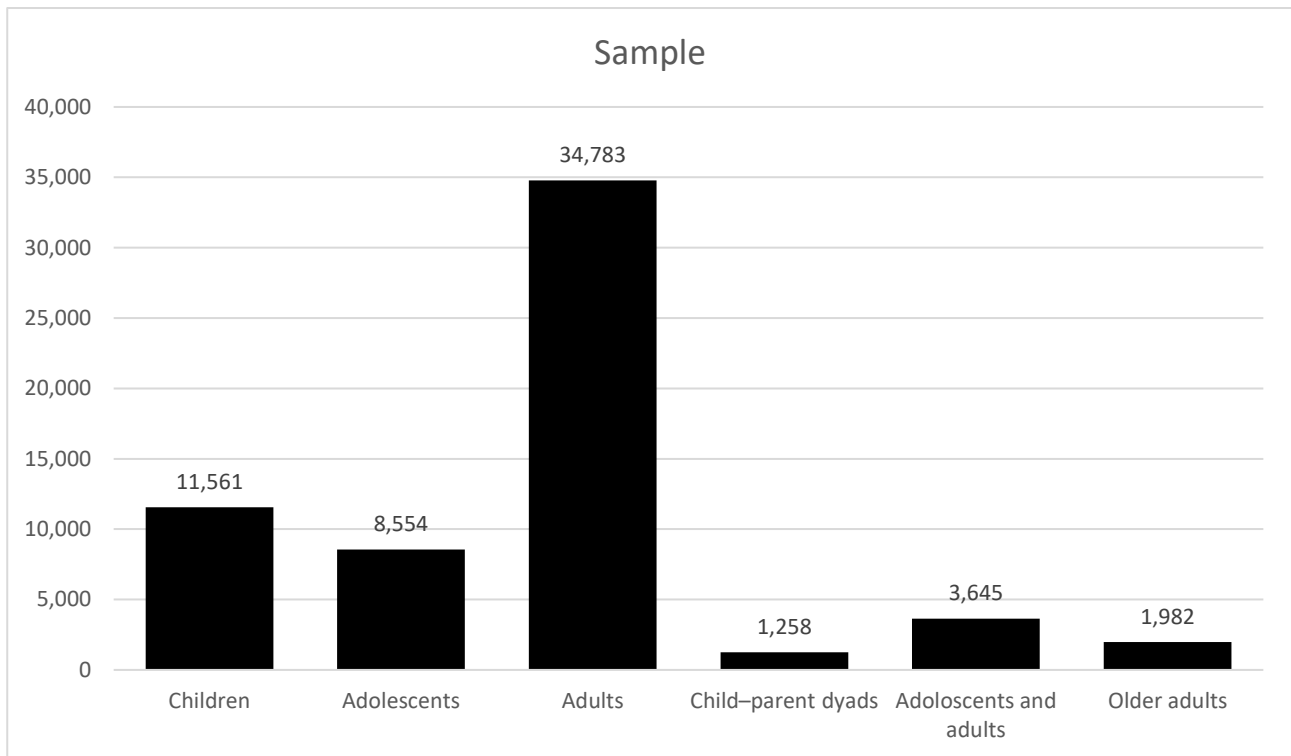


**Figure 5. Representation of distribution by sample characteristics.**

### **2.3.5. RQ 3.1. Socio-psychological variables in relation to active mobility**

Among the included studies, thirty-seven focused exclusively on cycling, twenty-one addressed both cycling and walking, and ten focused solely on walking. This distribution already suggests a stronger emphasis on cycling-related behaviors, which is reflected in the types and frequencies of socio-psychological variables examined across studies.

Across all categories, attitudes emerged as the most frequently analyzed variable. They were particularly prominent in relation to cycling ( $n = 28$ ; Acheampong, 2017; Baeli et al., 2022; Caballero et al., 2019; Cai et al., 2019; Chen & Lu, 2016; Chen, 2022; De Bruijn et al., 2009; Duan et al., 2023; Ducheyne et al., 2012; Fernández-Heredia et al., 2014; Frater et al., 2017a; Frater et al., 2017b; Gao et al., 2019; Gatersleben & Appleton, 2007; Heinen et al., 2011; Li et al., 2021; Liu et al., 2023; Lois et al., 2015; Lois et al., 2016; Milković & Štambuk, 2015; Muñoz et al., 2013; Muñoz et al., 2016; Si et al., 2020; Simsekoglu & Klöckner, 2019; Sottile et al., 2021; Trapp et al., 2011; Xu et al., 2020; Zhu et al., 2020), followed by studies examining cycling and walking combined ( $n = 11$ ; Barnett et al., 2019; Bopp et al., 2011; Bungum et al., 2009; Dill et al., 2014; García et al., 2019; Lemieux & Godin, 2009; Morckel & Terzano, 2014; Panter et al., 2011a; Panter et al., 2011b; Van Dyck et al., 2010; Zaragoza et al., 2020) and walking alone ( $n = 8$ ; Fallah Zavareh et al., 2023; McCormack et al., 2013; Murtagh et al., 2012; Rodriguez & Vogt, 2009; Yang & Diez-Roux, 2017; Zhang et al., 2019; Zhu & Lee, 2009; Zhu et al., 2008). This pattern highlights the central role of individual

evaluations of the behavior, particularly for cycling, and confirms that cognitive appraisals are key predictors of active mobility, in line with previous reviews (Willis et al., 2015). Subjective norms and perceived behavioral control were also frequently examined, especially in studies focusing on cycling (subjective norms:  $n = 19$ ; Acheampong, 2017; Baeli et al., 2022; Cai et al., 2019; Caballero et al., 2019; Chen, 2019; Chen, 2022; De Bruijn et al., 2009; Duan et al., 2023; Frater et al., 2017a; Frater et al., 2017b; Heinen et al., 2011; Li et al., 2021; Liu et al., 2023; Lois et al., 2015; Milković & Štambuk, 2015; Muñoz et al., 2013; Muñoz et al., 2016; Si et al., 2020; Xu et al., 2020; Zhu et al., 2020; PBC:  $n = 20$ ; Acheampong, 2017; Baeli et al., 2022; Cai et al., 2019; Caballero et al., 2019; Chen, 2022; De Bruijn et al., 2009; Duan et al., 2023; Ducheyne et al., 2012; Frater et al., 2017a; Frater et al., 2017b; Heinen et al., 2011; Li et al., 2021; Liu et al., 2023; Lois et al., 2016; Milković & Štambuk, 2015; Muñoz et al., 2013; Si et al., 2020; Wild & Woodward, 2019; Xu et al., 2020; Zhu et al., 2020). Their frequent inclusion reflects both the relevance of perceived social expectations and control beliefs for cycling and the widespread adoption of the TPB (Ajzen, 1991) as a guiding framework.

Variables related to self-efficacy appeared more frequently in studies addressing cycling and walking combined ( $n = 9$ ; Barnett et al., 2019; Bopp et al., 2011; Deforche et al., 2010; Lu et al., 2015; Mendoza et al., 2010; Mertens et al., 2019; Nguyen & Mertens, 2021; Silva et al., 2014; Van Dyck et al., 2010) and cycling alone ( $n = 4$ ; De Geus et al., 2008; Emond & Handy, 2012; Lois et al., 2015; Muñoz et al., 2016), while being comparatively less represented in walking-focused studies ( $n = 2$ ; Ball et al., 2007; Shimura et al., 2014). Social constructs such as social support were consistently reported across all modes (cycling and walking combined:  $n = 9$ ; Aranda-Balboa et al., 2021; Barnett et al., 2019; Deforche et al., 2010; Mertens et al., 2019; Nguyen & Mertens, 2021; Panter et al., 2010; Panter et al., 2011b; Silva et al., 2014; Van Dyck et al., 2010; cycling:  $n = 5$ ; De Geus et al., 2008; Ducheyne et al., 2012; Emond & Handy, 2012; Titze et al., 2008; Trapp et al., 2011; walking:  $n = 4$ ; Ball et al., 2007; McCormack et al., 2013; Shimura et al., 2014; Zhu et al., 2008), suggesting that interpersonal influences represent a cross-cutting dimension of active mobility behaviors. In contrast, social modeling was more prominently emphasized in studies examining combined cycling and walking behaviors, pointing to a stronger relational and contextual framing when multiple modes are considered simultaneously.

Affective variables, such as pleasure associated with cycling ( $n = 5$ ; Emond & Handy, 2012; Gatersleben & Appleton, 2007; Handy & Xing, 2011; Wild & Woodward, 2019; Xing et al., 2010), enjoyment related to cycling and walking combined ( $n = 3$ ; Barnett et al., 2019; Lee et al., 2017; Silva et al., 2014), and walking ( $n = 2$ ; Ball et al., 2007; Shimura et al., 2014), as well as emotional

satisfaction (n = 1; Titze et al., 2008), highlight the experiential and emotional components of active mobility, which remain less frequently investigated than cognitive determinants.

Other constructs, including personal norms, values, environmental concern, and habitual behavior, appeared sporadically across studies, contributing to a fragmented but multifaceted picture of the psychological underpinnings of active mobility. Notably, habit and past behavior were examined only once each in relation to walking, despite their well-established role in transport behavior research (Havlíčková & Zámečník, 2020).

Overall, the results indicate a strong predominance of individual-level cognitions and perceived control in cycling-related studies, whereas walking and combined-mode studies tend to incorporate a broader range of social and contextual variables. See Table 1 for the complete list of socio-psychological variables and their corresponding frequencies.

**Table 1. Frequencies of socio-psychological variables associated with cycling and walking behaviors.**

| Variables                    | Frequency |                   |         |
|------------------------------|-----------|-------------------|---------|
|                              | Cycling   | Cycling & Walking | Walking |
| Attitudes                    | 28        | 11                | 8       |
| Perceived Behavioral Control | 20        | 5                 | 2       |
| Subjective Norms             | 19        | 4                 | 3       |
| Habit                        | 7         | 2                 | 1       |
| Social Support               | 5         | 9                 | 4       |
| Descriptive Norms            | 5         | -                 | -       |
| Pleasure                     | 5         | -                 | -       |
| Self-efficacy                | 4         | 9                 | 2       |
| Social Norms                 | 3         | 4                 | -       |
| Environmental Concern        | 3         | -                 | -       |
| Social Modeling              | 2         | 5                 | 1       |
| Values                       | 2         | 1                 | -       |
| Discomfort                   | 2         | 1                 | -       |
| Personal Norms               | 2         | -                 | -       |
| Awareness                    | 2         | -                 | -       |
| Environmental Awareness      | 2         | -                 | -       |
| Social Disapproval           | 2         | -                 | -       |
| Comfort                      | 2         | -                 | -       |
| Prototype Similarity         | 2         | -                 | -       |
| Prototype Favorability       | 1         | -                 | -       |
| Prototype Imagined           | 1         | -                 | -       |
| Prototype Impression         | 1         | -                 | -       |
| Past Behavior                | 1         | 1                 | 1       |
| Moral Obligation             | 1         | -                 | -       |
| Awareness of Consequences    | 1         | -                 | -       |
| Beliefs                      | 1         | -                 | -       |
| Willingness                  | 1         | -                 | -       |
| Prescriptive Norms           | 1         | -                 | -       |
| Perceived Group Norm         | 1         | -                 | -       |
| Social Influence             | 1         | -                 | -       |
| Social Interaction           | 1         | -                 | 1       |
| Social Identity              | 1         | -                 | -       |
| Perceived Ease of Use        | 1         | -                 | -       |
| Perceived Usefulness         | 1         | -                 | -       |
| Emotional Satisfaction       | 1         | -                 | -       |

|                    |   |   |   |
|--------------------|---|---|---|
| Trust              | 1 | - | - |
| Enjoyment          | - | 3 | 2 |
| Companionship      | - | 1 | - |
| Volitional Control | - | 1 | - |
| Social Persuasion  | - | 1 | - |
| Emotional States   | - | 1 | - |
| Autonomy           | - | 1 | - |
| Competence         | - | 1 | - |
| Relatedness        | - | 1 | - |
| Sense of Community | - | - | 1 |
| Social Cohesion    | - | - | 1 |

### 2.3.6. RQ 3.2. Impact of socio-psychological variables in relation to the means of transport

Given the exploratory and descriptive nature of this scoping review, it is important to emphasize that the studies included do not permit definitive conclusions regarding causal or predictive relationships. Rather, the findings summarized below should be interpreted as associations reported in the literature and contextualized within each study.

#### 2.3.6.1. Predictors of intention to use the bicycle

Across the reviewed studies, a consistent set of socio-psychological variables emerged as significant predictors of the intention to use the bicycle for transportation. The most frequently examined factors included positive attitudes toward cycling, subjective norms, and PBC, in line with the TPB (Ajzen, 1991). Several studies further extended the TPB framework by incorporating constructs such as habits, social identity, and environmental concern.

Positive attitudes toward cycling were among the most consistent predictors of intention, as reported in Baeli et al. (2022), Cai et al. (2019), Chen & Lu (2016), Chen (2022), Frater et al. (2017a), Li et al. (2021), Lois et al. (2015), Lois et al. (2016), Milković & Štambuk (2015), and Zhu et al. (2020). Exceptions were noted in specific subgroups: Duan et al. (2023) found that positive attitudes did not significantly predict intention among college students, though they did among office workers; similarly, Acheampong (2017) reported non-significant effects.

Subjective norms were also robust predictors across multiple studies, including Cai et al. (2019), Chen (2019), Chen (2022), Duan et al. (2023), Frater et al. (2017a), Li et al. (2021), Lois et al. (2016), Milković & Štambuk (2015), and Zhu et al. (2020). Some studies, however, reported null effects for specific populations (Lois et al., 2015; Acheampong, 2017). Frater et al. (2017a) further differentiated sources of norms, showing that norms from friends and parents were positively associated with cycling intention, whereas descriptive norms from parents alone were not significant.

Perceived behavioral control consistently predicted cycling intention in Acheampong (2017), Baeli et al. (2022), Cai et al. (2019), Chen (2022), Duan et al. (2023), Li et al. (2021), Lois et al. (2016), Milković & Štambuk (2015), and Zhu et al. (2020). Frater et al. (2017a), however, reported non-significant associations, suggesting potential contextual or subgroup moderators.

Environmental motivations also played a role: general environmental concern positively predicted intention in Li et al. (2021), and Zhu et al. (2020); Chen (2019) found that both environmental values and trust in cycling positively influenced intention among current users. Duan et al. (2023) reported significant effects of environmental awareness for college students but not for office workers.

Habits and past behavior were highlighted as influential in Baeli et al. (2022), Cai et al. (2019), and Lois et al. (2015) indicating the importance of prior experience in shaping behavioral tendencies. Social identity as a cyclist was positively associated with intention in Lois et al. (2015), specifically among drivers, further supporting the notion that self-concept and role identification contribute to behavior.

Additional theoretical perspectives were occasionally employed to enrich understanding. Frater et al. (2017a) drew on the Prototype/Willingness Model (PWM; Gibbons et al., 1998) to explore risk-related and social-reactive pathways in adolescents, introducing constructs such as prototypes and behavioral willingness. Chen & Lu (2016) applied the Technology Acceptance Model (TAM; Davis, 1989), showing that perceived usefulness and ease of use of cycling-related systems positively influenced attitudes and intention.

In synthesis, these studies reinforce the centrality of positive attitudes, subjective norms, and PBC in shaping cycling intention, confirming the predictive relevance of the TPB. Extensions including environmental concern, habits, social identity, and prototype perceptions provide a more nuanced understanding of intention formation, though inconsistencies across subgroups and contexts suggest the presence of moderators that require further exploration. See Table 2 for a detailed description of variables, their associations, and study contexts.

**Table 2. Studies on the intention of bicycle use and its association with socio-psychological variables.**

| Authors                  | Journal Title                                                    | Country | Sample           | Research Design                                                                                  | Socio-psychological variables                                                               | Results                                                                                                                                                                          |
|--------------------------|------------------------------------------------------------------|---------|------------------|--------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Lois et al., 2015        | Transportation Research Part F: Traffic Psychology and Behaviour | Spain   | N = 595 (Adults) | Quantitative and cross-sectional study through the use of computer-assisted telephone interviews | 1. Attitudes<br>2. Subjective Norms<br>3. Self-efficacy<br>4. Social Identity<br>5. Habit   | 1. Positive attitudes toward cycling +<br>2. Subjective norms =<br>3. Self-efficacy for bicycle use =<br>4. Social identity + <sup>a</sup><br>5. Habit of cycling + <sup>a</sup> |
| Milković & Štambuk, 2015 | Psihologijske Teme                                               | Croatia | N = 712 (Adults) | Quantitative and cross-sectional study through the use of an online questionnaire                | 1. Subjective Norms<br>2. Perceived Behavioral Control<br>3. Attitudes<br>4. Personal Norms | 1. Subjective norms +<br>2. Perceived behavioral control +<br>3. Positive attitudes toward cycling +<br>4. Personal norms +                                                      |
| Chen & Lu, 2016          | Networks and Spatial Economics                                   | Taiwan  | N = 524 (Adults) | Quantitative and cross-sectional study through the use of a questionnaire                        | 1. Perceived Usefulness<br>2. Perceived Ease of Use<br>3. Attitudes                         | 1. Perceived Usefulness +<br>2. Perceived Ease of Use + <sup>b</sup><br>3. Positive attitudes toward cycling +                                                                   |

|                      |                                                                  |             |                       |                                                                                                       |                                                                                                                                                                                                     |                                                                                                                                                                                                                                                                                                                                                        |
|----------------------|------------------------------------------------------------------|-------------|-----------------------|-------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Lois et al., 2016    | Universitas Psychologica                                         | Spain       | N = 21 (Adults)       | Qualitative and cross-sectional study through the use of interviews                                   | 1. Attitudes<br>2. Social Norms<br>3. Perceived Behavioral Control                                                                                                                                  | 1. Positive attitudes toward cycling +<br>2. Social norms +<br>3. Perceived behavioral control +                                                                                                                                                                                                                                                       |
| Acheampong, 2017     | Transportation in Developing Economics                           | Ghana       | N = 348 (Adults)      | Quantitative and cross-sectional study through the use of a questionnaire or a face-to-face interview | 1. Attitudes<br>2. Subjective Norms<br>3. Perceived Behavioral Control                                                                                                                              | 1. Positive attitudes toward cycling =<br>2. Subjective norms =<br>3. Perceived behavioral control +                                                                                                                                                                                                                                                   |
| Frater et al., 2017a | Transportation Research Part F: Traffic Psychology and Behaviour | New Zealand | N = 331 (Adolescents) | Quantitative and cross-sectional study through the use of an online and offline questionnaire         | 1. Attitudes<br>2. Subjective Norms<br>3. Perceived Behavioral Control<br>4. Descriptive Norms<br>5. Prototype - Imagined<br>6. Prototype - Impression<br>7. Prototype Similarity<br>8. Willingness | 1. Positive attitudes toward cycling +<br>2a. Subjective norms from friends +<br>2b. Subjective norms from parents +<br>3. Perceived behavioral control =<br>4a. Descriptive norms from friends +<br>4b. Descriptive norms from parents =<br>5. Prototype - imagined =<br>6. Prototype - impression =<br>7. Prototype similarity =<br>8. Willingness + |
| Chen, 2019           | Transportation Letters                                           | Taiwan      | N = 255 (AA)          | Quantitative and cross-sectional study through the use of a questionnaire                             | 1. Values<br>2. Subjective Norms<br>3. Trust                                                                                                                                                        | <i>Users:</i><br>1. Environmental values +<br>2. Subjective norms +<br>3. Environmental trust on cycling +<br><i>Non-users:</i><br>1. Environmental values +<br>2. Subjective norms +<br>3. Environmental trust on cycling +                                                                                                                           |
| Cai et al., 2019     | Journal of Cleaner Production                                    | China       | N = 395 (Adults)      | Quantitative and cross-sectional study through the use of a questionnaire                             | 1. Values<br>2. Past Behavior<br>3. Attitudes<br>4. Subjective Norms<br>5. Perceived Behavioral Control                                                                                             | 1. Values =<br>2. Past behavior of cycling +<br>3. Positive attitudes toward bicycle +<br>4. Subjective norms +<br>5. Perceived behavioral control +                                                                                                                                                                                                   |
| Zhu et al., 2020     | Environmental Science and Pollution Research                     | China       | N = 988 (AA)          | Quantitative and cross-sectional study through the use of an online questionnaire                     | 1. Environmental concern<br>2. Attitudes<br>3. Subjective Norms<br>4. Perceived Behavioral Control                                                                                                  | 1. Environmental concern +<br>2. Positive attitudes toward cycling +<br>3. Subjective norms +<br>4. Perceived behavioral control +                                                                                                                                                                                                                     |
| Li et al., 2021      | Sustainability                                                   | China       | N = 751 (AA)          | Quantitative and cross-sectional study through the use of an online questionnaire                     | 1. Environmental Concern<br>2. Attitudes<br>3. Subjective Norms<br>4. Perceived Behavioral Control                                                                                                  | 1. Environmental concern + <sup>b</sup><br>2. Positive attitudes toward cycling +<br>3. Subjective norms +<br>4. Perceived behavioral control +                                                                                                                                                                                                        |
| Baeli et al., 2022   | Frontiers in Psychology                                          | Italy       | N = 294 (Adults)      | Quantitative and cross-sectional study through the use of an online questionnaire                     | 1. Descriptive Norms<br>2. Prescriptive Norms<br>3. Attitudes<br>4. Perceived Behavioral Control<br>5. Habit                                                                                        | 1. Descriptive norms +<br>2. Prescriptive norms +<br>3. Positive attitudes toward cycling +<br>4. Perceived behavioral control +<br>5. Habit of cycling +                                                                                                                                                                                              |
| Chen, 2022           | Frontiers in Psychology                                          | China       | N = 782 (Adults)      | Quantitative and cross-sectional study through the use of an online questionnaire                     | 1. Attitudes<br>2. Subjective Norms<br>3. Perceived Behavioral Control                                                                                                                              | 1. Positive attitudes toward cycling +<br>2. Subjective norms +<br>3. Perceived behavioral control +                                                                                                                                                                                                                                                   |
| Duan et al., 2023    | Behavioral Sciences                                              | China       | N = 676 (Adolescents) | Quantitative and cross-sectional study through the use of a questionnaire                             | 1. Attitudes<br>2. Subjective Norms<br>3. Perceived Behavioral Control<br>4. Environmental Awareness                                                                                                | <i>Office workers:</i><br>1. Positive attitudes toward cycling +<br>2. Subjective norms +<br>3. Perceived behavioral control +<br>4. Environmental awareness =<br><i>College students:</i><br>1. Positive attitudes toward cycling =<br>2. Subjective norms +<br>3. Perceived behavioral control +<br>4. Environmental awareness +                     |

**Note:** AA = Adolescents and adults; <sup>a</sup> = relationship only on the sample of drivers; <sup>b</sup> = indirect relations.

### 2.3.6.2. Predictors of self-reported cycling behavior

The studies examining self-reported cycling behavior consistently highlighted the influence of multiple socio-psychological determinants (see Table 3). Core constructs from the TPB complemented by habit, social support, affective evaluations, and environmental awareness, which were reported either as direct influences or as contextual factors.

Positive attitudes toward cycling were frequently associated with self-reported behavior, as shown in Frater et al. (2017b), Gao et al. (2019), Gatersleben & Appleton (2007), Heinen et al. (2011), Muñoz et al. (2013), Simsekoglu & Klöckner (2019), Sottile et al. (2021), and Trapp et al. (2011). However,

several studies reported null or negative associations, suggesting that favorable evaluations may not suffice when environmental or situational barriers are present. For instance, Caballero et al. (2019) and Si et al. (2020) found no significant link between attitudes and self-reported behavior, despite positive associations with intention. Ducheyne et al. (2012) reported a negative association between attitudes and non-use of cycling, while Fernández-Heredia et al. (2014) and Muñoz et al. (2016) highlighted differential effects for positive versus negative attitudes. Liu et al. (2023) and Xu et al. (2020) reported indirect effects of attitudes, emphasizing that cognitive evaluations may influence behavior primarily through mediating factors. Overall, these results indicate that attitudes are necessary but not sufficient to predict cycling behavior in the presence of contextual constraints.

Social influence constructs showed mixed results. Positive associations with self-reported behavior were found in Frater et al. (2017b), Heinen et al. (2011; only for short distances), Liu et al. (2023), Muñoz et al. (2016), and Xu et al. (2020), highlighting that perceived social approval may facilitate cycling under specific conditions. Conversely, Caballero et al. (2019), Muñoz et al. (2013), and Si et al. (2020) reported no significant effects, and Heinen & Handy (2012) observed contradictory results across samples. Broader social constructs, such as social support, consistently predicted cycling behavior: De Geus et al. (2008) and Emond & Handy (2012) found positive associations with support from friends and family, whereas Trapp et al. (2011) found no effect. Ducheyne et al. (2012) reported that social support negatively predicted never cycling but positively influenced actual cycling. Other dimensions of social influence, including descriptive norms (Bourke et al., 2018; Liu et al., 2023; Muñoz et al., 2013), perceived group norms (Bourke et al., 2018), and personal norms (Simsekoglu & Klöckner, 2019), were less consistent but suggest that social influence may reinforce existing habits rather than initiate new behavior.

PBC and self-efficacy were generally positive predictors. Significant associations were reported in Frater et al. (2017b), Heinen et al. (2011), Si et al. (2020), Wild & Woodward (2019), and Xu et al. (2020), whereas Caballero et al. (2019), De Bruijn et al. (2009), Ducheyne et al. (2012), Liu et al. (2023), and Muñoz et al. (2013) observed non-significant or negative effects among non-cyclists. This highlights a possible conceptual overlap between PBC and self-efficacy and underscores the importance of perceived personal capability in predicting self-reported behavior.

Habit emerged as a particularly strong and consistent predictor of self-reported cycling behavior, with positive associations reported in De Bruijn et al. (2009), Ducheyne et al. (2012), Heinen et al. (2011), and Muñoz et al. (2013). These findings reinforce the role of automaticity in maintaining active mobility, positioning habit as both a determinant and an indicator of behavioral consolidation.

Affective and experiential factors also influenced behavior. Pleasure associated with cycling was positively linked to self-reported cycling in Gatersleben & Appleton (2007), Handy & Xing (2011), Wild & Woodward (2019), and Xing et al. (2010) while pleasure related to car use negatively predicted self-reported cycling behavior. Comfort showed similar patterns, consistently facilitating self-reported cycling behavior (Handy & Xing, 2011; Xing et al., 2010).

Environmental concern and moral motivation played a more context-dependent role. Environmental awareness and concern were positively related to self-reported behavior in some studies (Handy & Xing, 2011) but not others (Gatersleben & Appleton, 2007), and effects were stronger for longer trips (Heinen et al., 2011). Moral obligation predicted intention but not self-reported behavior (Si et al., 2020), reflecting the distinction between motivational constructs and actual enactment.

In summary, self-reported cycling behavior is shaped by a complex interplay of socio-psychological variables. Positive attitudes, habits, PBC, and self-efficacy were among the most consistent predictors, while social support and affective experiences played pivotal, context-dependent roles. Discrepancies between intention and behavior across studies highlight the presence of intention-behavior gaps (Sheeran & Webb, 2016), suggesting that interventions should address both motivational and contextual barriers to effectively promote cycling.

**Table 3. Studies on self-reported cycling behavior and its association with socio-psychological variables.**

| Authors                      | Journal Title                                             | Country     | Sample             | Research Design                                                                                                       | Socio-psychological variables                                                                         | Results                                                                                                                                                                   |
|------------------------------|-----------------------------------------------------------|-------------|--------------------|-----------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Gatersleben & Appleton, 2007 | Transportation Research Part A: Policy and Practice       | UK          | N = 178 (Adults)   | Quantitative-qualitative and cross-sectional study through the use of an online questionnaire, diaries and interviews | 1. Attitudes<br>2. Discomfort<br>3. Pleasure<br>4. Environmental Awareness                            | 1. Positive attitudes toward cycling +<br>2. Discomfort -<br>3. Pleasure in cycling +<br>4. Environmental awareness +                                                     |
| Titze et al., 2008           | Preventive Medicine                                       | Austria     | N = 1,000 (Adults) | Quantitative and cross-sectional study through the use of computer-assisted telephone interviews                      | 1. Social Support<br>2. Emotional Satisfaction<br>3. Discomfort                                       | 1. Social support from friends/family +<br>2. Emotional satisfaction =<br>3. Discomfort -                                                                                 |
| De Geus et al., 2008         | Health Education Research                                 | Belgium     | N = 343 (Adults)   | Quantitative and cross-sectional study through the use of an online and offline questionnaire                         | 1. Social Norms<br>2. Social Support<br>3. Social Influence<br>4. Self-efficacy<br>5. Social Modeling | 1. Social norms =<br>2. Social support +<br>3. Social influence =<br>4. Self-efficacy +<br>5. Social modeling +                                                           |
| De Bruijn et al., 2009       | American Journal of Preventive Medicine                   | Netherlands | N = 317 (Adults)   | Quantitative and longitudinal study through the use of a questionnaire                                                | 1. Habit<br>2. Attitudes<br>3. Subjective Norms<br>4. Perceived Behavioral Control                    | 1. Habit of cycling +<br>2. Positive attitudes toward cycling =<br>3. Subjective norms =<br>4. Perceived behavioral control =                                             |
| Xing et al., 2010            | Transportation Research Part D: Transport and Environment | US          | N = 581 (Adults)   | Quantitative and cross-sectional study through the use of an online questionnaire                                     | 1. Comfort<br>2. Pleasure                                                                             | 1. Comfort +<br>2a. Pleasure in cycling +<br>2b. Pleasure in car use -                                                                                                    |
| Heinen et al., 2011          | Transportation Research Part D: Transport and Environment | Netherlands | N = 4,299 (Adults) | Quantitative and cross-sectional study through the use of a questionnaire                                             | 1. Attitudes<br>2. Subjective Norms<br>3. Perceived Behavioral Control<br>4. Habit<br>5. Awareness    | 1. Positive attitudes toward cycling +<br>2. Subjective norms + <sup>a</sup><br>3. Perceived behavioral control +<br>4. Habit of cycling +<br>5. Awareness + <sup>b</sup> |
| Handy & Xing, 2011           | International Journal of Sustainable Transportation       | US          | N = 965 (Adults)   | Quantitative and cross-sectional study through the use of an online and                                               | 1. Pleasure<br>2. Perception of Comfort<br>3. Environmental Concern                                   | 1a. Pleasure in cycling +<br>1b. Pleasure in walking =<br>1c. Pleasure in driving =<br>1d. Pleasure in public transport use -                                             |

|                                |                                                                     |                  |                         |                                                                                               |                                                                                                            |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
|--------------------------------|---------------------------------------------------------------------|------------------|-------------------------|-----------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                |                                                                     |                  |                         | offline questionnaire                                                                         | 4. Social Modeling<br>5. Social Disapproval                                                                | 2. Perception of comfort +<br>3. Environmental concern =<br>4. Social modeling from coworkers =<br>5. Social disapproval from supervisors -                                                                                                                                                                                                                                                                                                                                                 |
| Trapp et al., 2011             | International Journal of Behavioral Nutrition and Physical Activity | Australia        | N = 1,197 (Children)    | Quantitative and cross-sectional study through the use of a questionnaire                     | 1. Attitudes<br>2. Social Support<br>3. Social Disapproval                                                 | 1. Positive attitudes toward cycling +<br>2. Social support from friends =<br>3. Social disapproval =                                                                                                                                                                                                                                                                                                                                                                                       |
| Ducheyne et al., 2012          | International Journal of Behavioral Nutrition and Physical Activity | Belgium          | N = 850 (Children)      | Quantitative and cross-sectional study through the use of a questionnaire                     | 1. Attitudes<br>2. Social Support<br>3. Habit<br>4. Perceived Behavioral Control                           | <i>No Cycling:</i><br>1. Positive attitudes toward cycling -<br>2a. Social support from family -<br>2b. Social support from friends -<br>2c. Social support from neighborhood =<br>3. Habit of cycling =<br>4. Perceived behavioral control -<br><i>Cycling:</i><br>1. Positive attitudes toward cycling =<br>2a. Social support from family =<br>2b. Social support from friends +<br>2c. Social support from neighborhood =<br>3. Habit of cycling +<br>4. Perceived behavioral control = |
| Heinen & Handy, 2012           | International Journal of Sustainable Transportation                 | Netherlands & US | N = 31 (Adults)         | Qualitative and cross-sectional study through the use of interviews                           | 1. Beliefs<br>2. Social Norms                                                                              | <i>Case 1:</i><br>1. Beliefs about the use of bicycles +<br>2. Social norms +<br><i>Case 2:</i><br>1. Beliefs about the use of bicycles +<br>2. Social norms -                                                                                                                                                                                                                                                                                                                              |
| Emond & Handy, 2012            | Journal of Transport Geography                                      | US               | N = 1,357 (Adolescents) | Quantitative and cross-sectional study through the use of a questionnaire                     | 1. Social Support<br>2. Pleasure<br>3. Self-efficacy                                                       | 1a. Social support from friends =<br>1b. Social support from parents +<br>2. Pleasure +<br>3. Self-efficacy +                                                                                                                                                                                                                                                                                                                                                                               |
| Muñoz et al., 2013             | Transportation Research Record                                      | Spain            | N = 224 (Adults)        | Quantitative and cross-sectional study through the use of a face-to-face interview            | 1. Attitudes<br>2. Descriptive Norms<br>3. Subjective Norms<br>4. Perceived Behavioral Control<br>5. Habit | 1. Positive attitudes toward cycling +<br>2. Descriptive norms =<br>3. Subjective norms =<br>4. Perceived behavioral control =<br>5. Habit of cycling +                                                                                                                                                                                                                                                                                                                                     |
| Fernández-Heredia et al., 2014 | Transportation Research Part A: Policy and Practice                 | Spain            | N = 3,048 (Adults)      | Quantitative and cross-sectional study through the use of an online questionnaire             | 1. Attitudes                                                                                               | 1a. Positive attitudes toward cycling +<br>1b. Negative attitudes toward cycling -                                                                                                                                                                                                                                                                                                                                                                                                          |
| Muñoz et al., 2016             | Transportation Research Part A: Policy and Practice                 | Spain            | N = 654 (Adults)        | Quantitative and cross-sectional study through the use of a telephone interviews              | 1. Subjective Norms<br>2. Self-efficacy<br>3. Attitudes<br>4. Habit                                        | 1. Subjective Norms +<br>2. Self-efficacy for bicycle use =<br>3a. Positive attitudes toward cycling +<br>3b. Negative attitudes toward cycling -<br>4. Non-commuting cycling habit +                                                                                                                                                                                                                                                                                                       |
| Frater et al., 2017b           | Transportation Research Part F: Traffic Psychology and Behaviour    | New Zealand      | N = 803 (Adolescents)   | Quantitative and cross-sectional study through the use of an online and offline questionnaire | 1. Attitudes<br>2. Subjective Norms<br>3. Perceived Behavioral Control                                     | <i>Case 1:</i><br>1. Positive attitudes toward cycling +<br>2. Subjective norms +<br>3. Perceived behavioral control +<br><i>Case 2:</i><br>1. Positive attitudes toward cycling +<br>2. Subjective norms +<br>3. Perceived behavioral control =                                                                                                                                                                                                                                            |
| Bourke et al., 2018            | BMC Public Health                                                   | Australia        | N = 228 (Adults)        | Quantitative and cross-sectional study through the use of a questionnaire                     | 1. Descriptive Norms<br>2. Perceived Group Norm                                                            | 1. Descriptive norms =<br>2. Perceived group norms +                                                                                                                                                                                                                                                                                                                                                                                                                                        |
| Simsekoglu & Klöckner, 2019    | International Journal of Sustainable Transportation                 | Norway           | N = 910 (Adults)        | Quantitative and cross-sectional study through the use of an online questionnaire             | 1. Awareness<br>2. Personal Norms<br>3. Attitudes                                                          | 1a. Awareness of need + <sup>c</sup><br>1b. Awareness of consequences + <sup>c</sup><br>2. Personal Norms + <sup>c</sup><br>3. Attitudes toward cycling +                                                                                                                                                                                                                                                                                                                                   |
| Wild & Woodward, 2019          | Journal of Transport & Health                                       | New Zealand      | N = 24 (Adults)         | Qualitative and cross-sectional study through the use of interviews                           | 1. Perceived Behavioral Control<br>2. Pleasure<br>3. Social Interaction                                    | 1. Perceived behavioral control +<br>2. Pleasure +<br>3. Social Interaction +                                                                                                                                                                                                                                                                                                                                                                                                               |
| Gao et al., 2019               | Transportation                                                      | Netherlands      | N = 2,673 (Adults)      | Quantitative and cross-sectional study through the use of an online questionnaire             | 1. Attitudes                                                                                               | 1. Positive attitudes toward cycling +                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| Caballero et al., 2019         | Avances en Psicología Latinoamericana                               | Argentina        | N = 172 (Adults)        | Quantitative and cross-sectional study through the use of an online and offline questionnaire | 1. Attitudes<br>2. Subjective Norms<br>3. Perceived Behavioral Control                                     | <i>Behavior:</i><br>1. Positive attitudes toward cycling =<br>2. Subjective norms =<br>3. Perceived behavioral control =<br><i>Intention:</i><br>1. Positive attitudes toward cycling +<br>2. Subjective norms +<br>3. Perceived behavioral control +                                                                                                                                                                                                                                       |

|                      |                                       |       |                       |                                                                                   |                                                                                                                                                        |                                                                                                                                                                                                                                                                                                                                                                             |
|----------------------|---------------------------------------|-------|-----------------------|-----------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Xu et al., 2020      | Sustainability                        | China | N = 352 (AA)          | Quantitative and cross-sectional study through the use of an online questionnaire | 1. Attitudes<br>2. Subjective Norms<br>3. Perceived Behavioral Control                                                                                 | 1a. Positive attitudes toward cycling + <sup>c</sup><br>1b. Positive attitudes toward cars - <sup>c</sup><br>1c. Negative attitudes toward weather - <sup>c</sup><br>2. Subjective norms + <sup>c</sup><br>3. Perceived behavioral control +                                                                                                                                |
| Si et al., 2020      | Resources, Conservation and Recycling | China | N = 705 (Adults)      | Quantitative and cross-sectional study through the use of an online questionnaire | 1. Moral Obligation<br>2. Attitudes<br>3. Subjective Norms<br>4. Perceived Behavioral Control<br>5. Awareness of Consequences                          | <i>Behavior:</i><br>1. Moral obligation =<br>2. Positive attitudes toward cycling =<br>3. Subjective norms =<br>4. Perceived behavioral control +<br>5. Awareness of consequences =<br><i>Intention:</i><br>1. Moral obligation +<br>2. Positive attitudes toward cycling +<br>3. Subjective norms +<br>4. Perceived behavioral control +<br>5. Awareness of consequences = |
| Sottile et al., 2021 | Case Studies on Transport Policy      | Italy | N = 2,128 (Adults)    | Quantitative and cross-sectional study through the use of an online questionnaire | 1. Attitudes                                                                                                                                           | 1. Positive attitudes toward cycling +                                                                                                                                                                                                                                                                                                                                      |
| Liu et al., 2023     | Journal of Transport & Health         | China | N = 413 (Adolescents) | Quantitative and cross-sectional study through the use of an online questionnaire | 1. Attitudes<br>2. Subjective Norms<br>3. Perceived Behavioral Control<br>4. Descriptive Norms<br>5. Prototype Favorability<br>6. Prototype Similarity | 1. Positive attitudes toward cycling + <sup>c</sup><br>2. Subjective norms + <sup>c</sup><br>3. Perceived behavioral control =<br>4. Descriptive norms + <sup>c</sup><br>5. Prototype favorability =<br>6. Prototype similarity + <sup>c</sup>                                                                                                                              |

**Note:** AA = Adolescents and adults; <sup>a</sup> = significant relationship only over short distances, <sup>b</sup> = significant relationship only over long distances. <sup>c</sup> = indirect relations.

### 2.3.6.3. Predictors of self-reported walking behavior

Positive attitudes toward self-reported walking behavior emerged as one of the most consistently studied predictors (see Table 4). Several studies reported direct positive associations, including McCormack et al. (2013), Yang & Diez-Roux (2017), Zhu et al. (2008), and Zhu & Lee (2009). Similarly, Zhang et al. (2019) found a significant indirect effect of attitudes on self-reported walking behavior, whereas Rodriguez & Vogt (2009) reported a non-significant relationship. Fallah Zavareh et al. (2023) confirmed a positive link, reinforcing the central role of attitudes. These convergent findings suggest that cognitive evaluations are a robust predictor for initiating and maintaining self-reported walking behavior.

Subjective norms showed more variable results. McCormack et al. (2013) found no significant effect, while Zhang et al. (2019) reported a positive association. This indicates that perceived social expectations may exert a modest influence, potentially acting through mediating constructs.

PBC was a more consistent positive predictor, with both McCormack et al. (2013) and Zhang et al. (2019) reporting higher PBC levels associated with increased self-reported walking behavior.

Social support consistently emerged as an important determinant. Studies by Ball et al. (2007), McCormack et al. (2013), and Zhu et al. (2008) reported positive associations, typically distinguishing support from family versus friends. Ball et al. (2007) found that only family support significantly influenced self-reported walking, while Shimura et al. (2014) reported that social support from both family and friends protected against decline in self-reported walking behavior over

time. Social modeling also contributed, as shown by Zhu & Lee (2009), highlighting that observational learning from children and parents may facilitate self-reported walking engagement.

Self-efficacy appeared less influential in the walking domain, with Ball et al. (2007) and Shimura et al. (2014) reporting non-significant associations. Similarly, affective variables such as enjoyment or pleasure in walking did not consistently predict self-reported walking behavior, though Shimura et al. (2014) assessed their role in the context of behavioral decline, suggesting that affect may influence maintenance rather than initiation. Shimura et al. (2014) also examined broader social dimensions, including social interaction, sense of community, and social cohesion, finding positive effects for social interaction and community sense, but not for cohesion. Past behavior and habit were highlighted as key predictors. Zhang et al. (2019) identified previous walking behavior as a strong predictor of current self-reported walking, underscoring the role of habit in sustaining physical activity over time.

In summary, positive attitudes, PBC, and social support were the most consistent socio-psychological predictors of self-reported walking behavior, while subjective norms and affective evaluations showed more variable effects, often mediated or context-dependent. Several studies reported indirect effects, emphasizing the complexity of pathways from socio-psychological determinants to self-reported behavior. The findings of Shimura et al. (2014) provide complementary insight into behavioral maintenance, highlighting the importance of interventions that target both initiation and sustainability of walking habits.

**Table 4. Studies on self-reported walking behavior and its association with socio-psychological variables.**

| Authors                           | Journal Title                              | Country   | Sample               | Research Design                                                                                   | Socio-psychological variables                                                               | Results                                                                                                                                                       |
|-----------------------------------|--------------------------------------------|-----------|----------------------|---------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Ball et al., 2007                 | Journal of Epidemiology & Community Health | Australia | N = 1,282 (Adults)   | Quantitative and cross-sectional study through the use of a questionnaire                         | 1. Self-efficacy<br>2. Enjoyment<br>3. Social Support                                       | 1. Self-efficacy in walking =<br>2. Enjoyment of walking =<br>3a. Social support from family +<br>3b. Social support from friends =                           |
| Zhu et al., 2008                  | The Scientific World Journal               | US        | N = 1,281 (Children) | Quantitative and cross-sectional study through the use of a questionnaire                         | 1. Attitudes<br>2. Social Support                                                           | 1. Positive attitudes toward walking +<br>2. Social support from children/parents +                                                                           |
| Rodriguez & Vogt, 2009            | Journal of School Health                   | US        | N = 1,897 (Children) | Quantitative and cross-sectional study through the use of an online and offline questionnaire     | 1. Attitudes                                                                                | 1. Positive attitudes toward walking =                                                                                                                        |
| Zhu & Lee, 2009                   | Journal of Public Health Policy            | US        | N = 2,695 (Children) | Quantitative and cross-sectional study through the use of a questionnaire                         | 1. Attitudes<br>2. Social modeling                                                          | 1. Positive attitudes toward walking +<br>2. Social modeling from children and parents +                                                                      |
| McCormack et al., 2013            | Journal of Physical Activity and Health    | Canada    | N = 1,967 (Adults)   | Quantitative and cross-sectional study through the use of a telephone interview and questionnaire | 1. Attitudes<br>2. Subjective Norms<br>3. Perceived Behavioral Control<br>4. Social Support | 1. Positive attitudes toward walking +<br>2. Subjective norms =<br>3. Perceived behavioral control +<br>4. Social support from friends and family +           |
| Shimura et al., 2014 <sup>a</sup> | Journal of Physical Activity and Health    | Australia | N = 445 (Adults)     | Quantitative and longitudinal study through the use of a questionnaire                            | 1. Self-efficacy<br>2. Enjoyment<br>3. Social Support<br>4. Social Interaction              | 1. Self-efficacy toward physical activity =<br>2. Enjoyment for physical activity =<br>3. Social support from family and friends +<br>4. Social interaction + |

|                             |                                           |       |                    |                                                                           |                                                                                            |                                                                                                                                                                              |
|-----------------------------|-------------------------------------------|-------|--------------------|---------------------------------------------------------------------------|--------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                             |                                           |       |                    |                                                                           | 5. Sense of community<br>6. Social Cohesion                                                | 5. Sense of community +<br>6. Social cohesion =                                                                                                                              |
| Yang & Diez-Roux, 2017      | American Journal of Health Promotion      | US    | N = 2,621 (Adults) | Quantitative and cross-sectional study through the use of a questionnaire | 1. Attitudes                                                                               | 1. Positive attitudes toward walking +                                                                                                                                       |
| Zhang et al., 2019          | Applied Psychology: Health and Well-Being | China | N = 157 (Adults)   | Quantitative and longitudinal study through the use of a questionnaire    | 1. Attitudes<br>2. Subjective Norms<br>3. Perceived Behavioral Control<br>4. Past Behavior | 1. Positive attitudes toward walking + <sup>b</sup><br>2. Subjective norms + <sup>b</sup><br>3. Perceived behavioral control + <sup>b</sup><br>4. Past behavior of walking + |
| Fallah Zavareh et al., 2023 | Transportation Research Record            | Iran  | N = 272 (Adults)   | Quantitative and cross-sectional study through the use of a questionnaire | 1. Attitudes                                                                               | 1. Attitudes toward walking +                                                                                                                                                |

**Note:** <sup>a</sup> = Decline in walking; <sup>b</sup> = indirect relations.

#### 2.3.6.4. Predictors of observed walking behavior

The study by Murtagh et al. (2012) represents the only investigation of walking behavior using direct observation. In contrast to findings from self-reported measures, none of the socio-psychological variables examined, positive attitudes toward walking, subjective norms, PBC, or walking habits, showed significant associations with observed walking. This discrepancy highlights the potential limitations of self-report data and the importance of context in translating intentions into actual behavior.

Notably, the habit of using motorized transport (car or bus) was significantly negatively associated with observed walking, indicating that reliance on vehicles may act as a structural barrier that overrides socio-psychological predispositions. This finding underscores the critical interplay between individual factors and contextual constraints, suggesting that interventions aiming to increase walking should not only target attitudes, social norms, or perceived control, but also consider the broader transportation environment (see Table 5).

**Table 5. Study on observed walking behavior and its association with socio-psychological variables.**

| Authors              | Journal Title                                                       | Country | Sample             | Research Design                                                                                | Socio-psychological variables                                                      | Results                                                                                                                                                                                                                                                                                                                                                               |
|----------------------|---------------------------------------------------------------------|---------|--------------------|------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Murtagh et al., 2012 | International Journal of Behavioral Nutrition and Physical Activity | UK      | N = 126 (Children) | Quantitative and cross-sectional study through the use of a questionnaire and an accelerometer | 1. Attitudes<br>2. Subjective Norms<br>3. Perceived Behavioral Control<br>4. Habit | <i>Intention:</i><br>1. Positive attitudes toward walking =<br>2. Subjective norms =<br>3. Perceived behavioral control +<br>4a. Habit of walking +<br>4b. Habit of car/bus use -<br><i>Behavior:</i><br>1. Positive attitudes toward walking =<br>2. Subjective norms =<br>3. Perceived behavioral control =<br>4a. Habit of walking =<br>4b. Habit of car/bus use - |

#### 2.3.6.5. Predictors of combined self-reported cycling and walking behavior

Across studies examining self-reported combined cycling and walking behavior, a wide range of socio-psychological variables were explored, with some constructs showing relatively consistent patterns (see Table 6). One of the most robust predictors was self-efficacy, which showed positive associations with active mobility behaviors in multiple studies, including Barnett et al. (2019; only

for destinations other than school travel), Bopp et al. (2011), Deforche et al. (2010), Lu et al. (2015), Mendoza et al. (2010; only parental self-efficacy), Mertens et al. (2019; only for walking), Nguyen & Mertens (2021), and Silva et al. (2014). Conversely, Van Dyck et al. (2010) reported non-significant effects, highlighting potential contextual or sample-specific variations. These findings reinforce the central role of confidence in one's ability to engage in self-reported active mobility, whether walking, cycling, or both.

Positive attitudes toward active mobility were also consistently associated with higher self-reported walking and cycling. This was evident in Barnett et al. (2019; excluding school travel), Dill et al. (2014), García et al. (2019), and Lemieux & Godin (2009; intention only). García et al. (2019) further explored value-based attitudes (e.g., universalism, self-direction, hedonism), finding mixed results depending on value orientation and travel mode, often mediated through indirect pathways. Conversely, Bungum et al. (2009), Morckel & Terzano (2014), Panter et al. (2011b), Van Dyck et al. (2010), and Zaragoza et al. (2020) found no significant effects, suggesting that the influence of attitudes may vary depending on context, measurement, or competing behaviors.

PBC was another important predictor, positively associated with self-reported behavior in Dill et al. (2014), Lemieux and Godin (2009; intention only), Panter et al. (2011b; not significant), and Zaragoza et al. (2020; intention only). Interestingly, Panter et al. (2011a) reported a negative association between PBC in car use and self-reported walking, illustrating how control beliefs can have opposite effects depending on the mode considered.

Social support, particularly from family, peers, or other relevant individuals, showed variable results. Positive associations were reported in Barnett et al. (2019), Deforche et al. (2010), Nguyen and Mertens (2021), Panter et al. (2010), and Silva et al. (2014) although effects often depended on the source (e.g., parental vs. peer support). For instance, parental support was significant in Silva et al. (2014), while peer support was not, and Panter et al. (2010) found peer support influenced self-reported cycling only over short distances. In contrast, Aranda-Balboa et al. (2021), Mertens et al. (2019), and Panter et al. (2011b) reported no significant associations.

Social modeling was examined in Deforche et al. (2010), Mertens et al. (2019), Nguyen and Mertens (2021), Silva et al. (2014), and Van Dyck et al. (2010) with mostly non-significant results, suggesting that observational learning may play a more indirect or limited role. Similarly, social norms were generally non-significant, with some exceptions such as Mertens et al. (2019), who found a negative effect on self-reported cycling behavior.

Affective constructs, including enjoyment and discomfort, were assessed in Barnett et al. (2019), Lee et al. (2017), Silva et al. (2014), and Teuber & Sudeck (2021). Discomfort was negatively associated with self-reported walking in Teuber & Sudeck (2021), highlighting the influence of experiential factors. Habitual behavior was positively associated with self-reported walking and cycling in Panter et al. (2011b) and Lemieux & Godin (2009), underscoring the importance of automaticity and behavioral consistency.

Some studies adopted broader theoretical perspectives. Zaragoza et al. (2020) included Self-Determination Theory (SDT; Ryan & Deci, 2000) variables, autonomy, competence, and relatedness, but none showed significant effects. Lu et al. (2015) reported indirect effects for emotional states and social modeling, highlighting the complexity of psychological mechanisms. Panter et al. (2011a) also examined competing automobile-related behaviors, finding that positive attitudes toward car use were associated with increased self-reported walking and decreased self-reported cycling, emphasizing the relevance of considering alternative transport modes when predicting active travel. García et al. (2019) examined value orientations, showing that some values positively influenced self-reported walking or cycling, whereas others had negative or indirect effects, suggesting that personal values shape transport preferences.

In summary, across the diverse studies reviewed, self-efficacy, positive attitudes toward active travel, and social support emerged as the most consistent predictors of self-reported combined walking and cycling behavior. Variables such as subjective norms, enjoyment, and social modeling were more variable, with effects often influenced by the type of self-reported behavior, target population, and presence of competing behaviors. These findings highlight the importance of addressing both facilitators and barriers in promoting active mobility.

**Table 6. Studies on self-reported cycling-and-walking behaviors and their association with socio-psychological variables.**

| Authors               | Journal Title                                                       | Country | Sample                  | Research Design                                                           | Socio-psychological variables                                                              | Results                                                                                                                                                                                                                                                                                                                                                     |
|-----------------------|---------------------------------------------------------------------|---------|-------------------------|---------------------------------------------------------------------------|--------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Bungum et al., 2009   | Journal of Community Health                                         | US      | N = 2,692 (Adolescents) | Quantitative and cross-sectional study through the use of a questionnaire | 1. Attitudes                                                                               | 1. Positive attitudes toward physical activity =                                                                                                                                                                                                                                                                                                            |
| Lemieux & Godin, 2009 | International Journal of Behavioral Nutrition and Physical Activity | Canada  | N = 130 (Adults)        | Quantitative and longitudinal study through the use of a questionnaire    | 1. Past Behavior<br>2. Perceived Behavioral Control<br>3. Attitudes<br>4. Subjective Norms | <i>Behavior:</i><br>1. Past behavior of active commuting +<br>2. Perceived behavioral control =<br>3. Positive attitudes toward active commuting =<br>4. Subjective norms =<br><i>Intention:</i><br>1. Past behavior of active commuting +<br>2. Perceived behavioral control +<br>3. Positive attitudes toward active commuting +<br>4. Subjective norms = |
| Panter et al., 2010   | Journal of Epidemiology & Community Health                          | UK      | N = 2,012 (Children)    | Quantitative and cross-sectional study through the use of a questionnaire | 1. Social Support                                                                          | <i>Walking:</i><br>1a. Social support from adults +<br>1b. Social support from friends =<br><i>Cycling:</i><br>1a. Social support from adults +<br>1b. Social support from friends + <sup>a</sup>                                                                                                                                                           |

|                                   |                                                                                    |           |                         |                                                                                   |                                                                                                         |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
|-----------------------------------|------------------------------------------------------------------------------------|-----------|-------------------------|-----------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Van Dyck et al., 2010             | International Journal of Behavioral Nutrition and Physical Activity                | Belgium   | N = 888 (Adolescents)   | Quantitative and cross-sectional study through the use of a questionnaire         | 1. Social Norms<br>2. Social Support<br>3. Self-efficacy<br>4. Attitudes<br>5. Social Modeling          | 1. Social norms =<br>2. Social support from family and friends =<br>3. Self-efficacy to be physically active =<br>4. Positive attitudes toward physical activity =<br>5. Social modeling from family and friends +                                                                                                                                                                                                                                                                                                        |
| Deforche et al., 2010             | Preventive Medicine                                                                | Belgium   | N = 1,445 (Adolescents) | Quantitative and cross-sectional study through the use of a questionnaire         | 1. Self-efficacy<br>2. Social Modeling<br>3. Social Support                                             | 1. Self-efficacy to be physically active +<br>2a. Social modeling from family +<br>2b. Social modeling from friends =<br>3a. Social support from family +<br>3b. Social support from friends +                                                                                                                                                                                                                                                                                                                            |
| Mendoza et al., 2010              | The Journal of Applied Research on Children: Informing Policy for Children at Risk | US        | N = 149 (Children)      | Quantitative and cross-sectional study through the use of a questionnaire         | 1. Self-efficacy                                                                                        | 1a. Self-efficacy for active commuting =<br>1b. Self-efficacy of parents +                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| Panter et al., 2011a <sup>c</sup> | International Journal of Behavioral Nutrition and Physical Activity                | UK        | N = 1,142 (Adults)      | Quantitative and cross-sectional study through the use of a questionnaire         | 1. Perceived Behavioral Control<br>2. Attitudes<br>3. Subjective Norms<br>4. Habit                      | <i>Walking:</i><br>1. Perceived behavioral control -<br>2. Positive attitudes toward car use +<br>3. Subjective norms =<br>4. Habit of car use =<br><i>Cycling:</i><br>1. Perceived behavioral control =<br>2. Positive attitudes toward car use -<br>3. Subjective norms =<br>4. Habit of car use =                                                                                                                                                                                                                      |
| Bopp et al., 2011                 | Journal of Public Health Management and Practice                                   | US        | N = 431 (Adults)        | Quantitative and cross-sectional study through the use of an online questionnaire | 1. Attitudes<br>2. Self-efficacy                                                                        | 1. Environmental attitudes +<br>2. Self-efficacy for active commuting +                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| Panter et al., 2011b              | Medicine and Science in Sports and Exercise                                        | UK        | N = 1,279 (OA)          | Quantitative and cross-sectional study through the use of a questionnaire         | 1. Habit<br>2. Attitudes<br>3. Subjective Norms<br>4. Perceived Behavioral Control<br>5. Social Support | 1. Habit for walking and cycling +<br>2. Positive attitudes toward active travel =<br>3. Subjective norms =<br>4. Perceived behavioral control =<br>5. Social support =                                                                                                                                                                                                                                                                                                                                                   |
| Dill et al., 2014                 | Journal of the American Planning Association                                       | US        | N = 1,159 (Adults)      | Quantitative and cross-sectional study through the use of a telephone interview   | 1. Attitudes<br>2. Social Norms<br>3. Perceived Behavioral Control                                      | <i>Walking:</i><br>1. Positive attitudes toward active mobility +<br>2. Social norms =<br>3. Perceived behavioral control +<br><i>Cycling:</i><br>1. Positive attitudes toward active mobility +<br>2. Social norms =<br>3. Perceived behavioral control +                                                                                                                                                                                                                                                                |
| Morckel & Terzano, 2014           | Journal of Physical Activity and Health                                            | US        | N = 99 (Adults)         | Quantitative and cross-sectional study through the use of an online questionnaire | 1. Attitudes                                                                                            | 1. Positive attitudes toward active mobility =                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| Silva et al., 2014                | Preventive Medicine                                                                | Portugal  | N = 625 (Adolescents)   | Quantitative and cross-sectional study through the use of a questionnaire         | 1. Enjoyment<br>2. Self-efficacy<br>3. Volitional Control<br>4. Social Support<br>5. Companionship      | 1. Enjoyment to walk/cycle =<br>2. Self-efficacy to walk/cycle +<br>3. Volitional control =<br>4a. Social support from parents +<br>4b. Social support from friends =<br>4c. Social support from teachers =<br>5a. Companionship from parents =<br>5b. Companionship from friends +                                                                                                                                                                                                                                       |
| Lu et al., 2015                   | International Journal of Behavioral Nutrition and Physical Activity                | US        | N = 857 (CPD)           | Quantitative and cross-sectional study through the use of a questionnaire         | 1. Self-efficacy<br>2. Social Persuasion<br>3. Social Modeling<br>4. Emotional States                   | 1a. Self-efficacy of children +<br>1b. Self-efficacy of parents +<br>2. Social persuasion =<br>3. Social modeling from friends/other people +<br>4. Emotional states + <sup>b</sup>                                                                                                                                                                                                                                                                                                                                       |
| Lee et al., 2017                  | Preventive Medicine                                                                | US        | N = 165 (Children)      | Quantitative and cross-sectional study through the use of a questionnaire         | 1. Enjoyment                                                                                            | 1. Enjoyment of walking +                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
| Barnett et al., 2019              | Journal of Transport & Health                                                      | Hong Kong | N = 1,299 (AA)          | Quantitative and cross-sectional study through the use of a questionnaire         | 1. Social Support<br>2. Self-efficacy<br>3. Enjoyment<br>4. Attitudes                                   | <i>Active travel to/from school:</i><br>1a. Social support from adults = -<br>1b. Social support from peers +<br>2. Self-efficacy for physical activity =<br>3. Enjoyment toward physical activity =<br>4. Positive attitudes toward physical activity =<br><i>Active travel to other destinations:</i><br>1a. Social support from adults +<br>1b. Social support from peers +<br>2. Self-efficacy for physical activity +<br>3. Enjoyment toward physical activity +<br>4. Positive attitudes toward physical activity + |
| García et al., 2019               | Sustainability                                                                     | Spain     | N = 1,254 (Adults)      | Quantitative and cross-sectional study through the use of an online questionnaire | 1. Values<br>2. Attitudes                                                                               | <i>Walking:</i><br>1a. Universalism =<br>1b. Self-direction +<br>1c. Stimulation - <sup>b</sup>                                                                                                                                                                                                                                                                                                                                                                                                                           |

|                            |                                                                   |         |                      |                                                                                    |                                                                                                                          |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
|----------------------------|-------------------------------------------------------------------|---------|----------------------|------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                            |                                                                   |         |                      |                                                                                    |                                                                                                                          | 1d. Hedonism -<br>1e. Achievement =<br>1f. Power - <sup>b</sup><br>1g. Security =<br>1h. Tradition -<br>1i. Conformity =<br>1l. Benevolence + <sup>b</sup><br>2. Positive attitudes toward walking +<br><i>Cycling:</i><br>1a. Universalism + <sup>b</sup><br>1b. Self-direction =<br>1c. Stimulation + <sup>b</sup><br>1d. Hedonism =<br>1e. Achievement =<br>1f. Power - <sup>b</sup><br>1g. Security - <sup>b</sup><br>1h. Tradition +<br>1i. Conformity =<br>1l. Benevolence -<br>2. Positive attitudes toward cycling + |
| Mertens et al., 2019       | Health & Place                                                    | Belgium | N = 200 (OA)         | Quantitative and longitudinal study through the use of a face-to-face interview    | 1. Self-efficacy<br>2. Social Norms<br>3. Social Support<br>4. Social Modeling                                           | <i>Walking:</i><br>1. Self-efficacy toward physical activity +<br>2. Social norms =<br>3. Social support =<br>4. Social modeling =<br><i>Cycling:</i><br>1. Self-efficacy toward physical activity =<br>2. Social norms -<br>3. Social support =<br>4. Social modeling =                                                                                                                                                                                                                                                     |
| Zaragoza et al., 2020      | Journal of Transport & Health                                     | Spain   | N = 1,189 (Children) | Quantitative and cross-sectional study through the use of a questionnaire          | 1. Attitudes<br>2. Subjective Norms<br>3. Perceived Behavioral Control<br>4. Autonomy<br>5. Competence<br>6. Relatedness | <i>Behavior:</i><br>1. Positive attitudes toward active mobility =<br>2. Subjective norms =<br>3. Perceived behavioral control =<br>4. Autonomy =<br>5. Competence =<br>6. Relatedness =<br><i>Intention:</i><br>1. Positive attitudes toward active mobility =<br>2. Subjective norms =<br>3. Perceived behavioral control +<br>4. Autonomy =<br>5. Competence =<br>6. Relatedness =                                                                                                                                        |
| Nguyen & Mertens, 2021     | International Journal of Environmental Research and Public Health | Belgium | N = 503 (OA)         | Quantitative and cross-sectional study through the use of a face-to-face interview | 1. Self-efficacy<br>2. Social Norms<br>3. Social Support<br>4. Social Modeling                                           | 1. Self-efficacy toward physical activity +<br>2. Social norms =<br>3. Social support from partner/friends +<br>4. Social modeling from partner/friends =                                                                                                                                                                                                                                                                                                                                                                    |
| Teuber & Sudeck, 2021      | International Journal of Environmental Research and Public Health | Germany | N = 997 (Adults)     | Quantitative and cross-sectional study through the use of a online questionnaire   | 1. Discomfort                                                                                                            | <i>Walking:</i><br>1. Discomfort -<br><i>Cycling:</i><br>1. Discomfort =                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| Aranda-Balboa et al., 2021 | International Journal of Environmental Research and Public Health | Spain   | N = 401 (CPD)        | Quantitative and cross-sectional study through the use of a questionnaire          | 1. Social Support                                                                                                        | <i>Walking:</i><br>1. Social support from children/parents =<br><i>Cycling:</i><br>1. Social support from children/parents =                                                                                                                                                                                                                                                                                                                                                                                                 |

**Note:** OA = Older adults; CPD = Child-parent dyads; AA = Adolescents and adults; <sup>a</sup> = significant relationship only over short distances; <sup>b</sup> = indirect relations; <sup>c</sup> = all socio-psychological variables are related to car use.

## 2.4. Practical implications

Given the exploratory nature of scoping reviews, which aim to map and describe the extent of existing evidence rather than to provide a critically appraised synthesis, the practical implications derived from the present review should be interpreted with appropriate caution (Munn et al., 2018). In this sense, the following considerations are not intended as prescriptive guidelines for policy or intervention design, but rather as indicative directions that emerge from recurrent patterns observed across the literature.

The results of the scoping review highlight several potential practical and policy-relevant insights for promoting active mobility in urban contexts. A consistent finding across numerous studies was the strong predictive influence of socio-psychological variables, including positive attitudes, subjective norms, perceived behavioral control, self-efficacy, and habit, on both the intention to engage in active mobility and self-reported behavior (e.g., De Bruijn et al., 2009; Duan et al., 2023; Lois et al., 2015). These findings indicate that interventions aimed at increasing active mobility should go beyond infrastructural improvements and incorporate strategies that target psychological and social determinants of behavior. For instance, public campaigns could foster attitude change by highlighting the health and environmental benefits of walking and cycling, while also leveraging social norms by emphasizing community engagement and widespread participation (Chen, 2019; Frater et al., 2017a). Programs designed to enhance perceived behavioral control and self-efficacy, such as guided walking or cycling groups, skill-building workshops, and confidence-boosting initiatives, can help individuals overcome perceived barriers and increase their engagement in active mobility (Silva et al., 2014; Xu et al., 2020). Moreover, this review provides a comprehensive overview of socio-psychological predictors, serving as a valuable resource for researchers and practitioners seeking to design empirically informed interventions. Given the observed role of habit and past behavior in sustaining active mobility (Heinen et al., 2011; Muñoz et al., 2013), urban planners and policymakers should aim to make active mobility the default and convenient choice. This can be achieved through consistent infrastructure, safe environments, and routine reinforcement strategies that embed walking and cycling into daily routines. Tailoring interventions to specific populations, such as children, adolescents, and older adults, is essential, as the relevance and strength of socio-psychological predictors may vary across age groups and contexts. Overall, integrating insights from behavioral science with urban policy and planning can create comprehensive, effective strategies that encourage sustainable transportation choices and foster long-term behavioral change.

## **2.5. Limits and future developments**

The present scoping review advances understanding of the socio-psychological determinants of active mobility; however, several limitations warrant attention. First, search-scope constraints, such as the exclusion of books, book chapters, and publications in languages other than English, Italian, and Spanish, may have resulted in the omission of relevant empirical evidence, potentially underrepresenting findings from diverse cultural contexts. Future research could broaden evidence gathering to include multilingual sources and grey literature, enhancing comprehensiveness and cross-cultural representation. Second, methodological imbalances are evident: literature is dominated by cross-sectional, self-report designs, which limit causal inference and are prone to social-

desirability and recall bias (De Bruijn et al., 2009; Lois et al., 2015). Longitudinal, experimental, and mixed-method approaches remain scarce, reducing the ability to track behavioral change over time. Addressing this limitation through longitudinal and experimental designs would allow researchers to better capture the dynamics of active mobility behavior and strengthen causal inferences. Third, the literature shows considerable conceptual ambiguity regarding the status of perceived safety. In several studies, perceived safety is operationalized as an environmental or infrastructural attribute rather than as an individual-level psychological perception (e.g., Corseuil Giehl et al., 2017; de Paiva Neto et al., 2021). Nonetheless, there is consistent evidence that perceived safety plays an important role in shaping cycling and walking behaviors (e.g., Heinen et al., 2010; Ikeda et al., 2018; Piras et al., 2021a). This lack of conceptual clarity complicates its integration within a socio-psychological framework and may obscure how perceived safety operates as a determinant of active mobility behavior and as a target for behavioral interventions. For this reason, and in line with the specific focus of the present scoping review on socio-psychological variables, perceived safety was not included among the core constructs. However, this conceptual gap also highlights the need for further empirical investigation aimed at clarifying the psychological role of perceived safety in active mobility contexts, an issue that is addressed in the subsequent empirical studies. Fourth, contextual gaps are pronounced: most evidence originates from high-income countries, leaving populations in the Global South largely unexamined and raising questions about the generalizability of findings. Expanding research into under-studied regions, and considering potential moderators such as age, gender, or urban density, could improve external validity and provide a more globally representative understanding of socio-psychological determinants.

## **2.6. Conclusion**

In summary, this scoping review provides a comprehensive mapping of socio-psychological determinants of active mobility, highlighting the central role of attitudes, perceived behavioral control, self-efficacy, social norms, and habit in shaping both intentions and self-reported behaviors related to walking and cycling, and observed walking. The review also underscores important gaps in the literature, including methodological limitations, conceptual ambiguity around perceived safety, and geographical biases toward high-income, WEIRD populations. While these limitations constrain the generalizability of findings, they simultaneously point to clear avenues for future research.

Specifically, the gaps identified in this review directly informed the design of the subsequent empirical studies included in this thesis. First, the conceptual ambiguity surrounding perceived safety motivated its explicit investigation as a socio-psychological construct in active mobility contexts. Second, the predominance of cross-sectional and self-report designs led to the adoption of

experimental and scenario-based methodologies, allowing for a more controlled examination of causal mechanisms underlying mobility choices. Third, the integration of environmental and social factors within existing research prompted a focus on how these dimensions interact in shaping individuals' decisions to engage in active mobility.

In this way, the present review does not only provide a descriptive overview of literature but also establishes a clear rationale for the research program developed in this thesis. Building on these considerations, the empirical part of the work is structured into Studies 1 and 2 on cycling and Study 3 on walking, offering a coherent and evidence-based investigation of active mobility behaviors in urban contexts.

# Chapter III. Socio-psychological and Environmental Determinants of Cycling Intentions: A Scenario-based Approach (Study 1 & Study 2)

*This chapter is based on a manuscript currently under review: Manunza, A., Mosca, O., Sottile, E., Piras, F., Muroli, E., Meloni, I., Fornara, F. (under review). Psychological and Environmental Factors Influencing Urban Cycling: Insights from a Pilot Study.*

## 3.1. Introduction

In recent decades, the environmental and health externalities associated with road traffic have become a central concern in the development of urban and transport policies worldwide. In the European Union, the transport sector remains one of the main contributors to energy-related greenhouse gas emissions, accounting for 23.8% of total emissions in 2022 (European Parliament, 2024). Inland transport is responsible for most of this share, with road transport alone contributing nearly 70% (UNECE, 2024). This dominance is largely attributable to the widespread reliance on private and commercial vehicles powered by fossil fuels, the slow diffusion of low-emission alternatives, and the continued growth of road freight transport (European Parliament, 2024; EUROSTAT, 2024). Beyond their impact on climate change (Creutzig et al., 2015; Pietzcker et al., 2014), transport-related emissions pose serious risks to human health, particularly in urban environments, as noted by the International Energy Agency (IEA, 2022), where they have been associated with respiratory, cardiovascular, and oncological diseases (Germanova & Kernozhitskaya, 2017; World Health Organization, 2004).

Considering this situation, active mobility has gained increasing attention as a key component of sustainable urban transport strategies, both at the policy level (European Parliament, 2024) and within the scientific literature (Chandia-Poblete et al., 2022; Scrivano et al., 2024; Zougheibe et al., 2021). Active modes of transport are widely recognized for their potential to reduce emissions, improve public health, and enhance the livability of urban spaces. Nevertheless, their contribution to overall mobility demand remains limited in several European contexts. In Italy, for instance, walking and cycling currently account for just over 20% of daily travel, a figure that has declined slightly since the early 2000s (ISFORT, 2023). Although the COVID-19 pandemic temporarily altered travel behaviors, leading to a peak in active mobility in 2020, this increase was short-lived. However,

looking at more recent trends, there are early signs of recovery: in the first half of 2025, walking accounted for 20.6% of trips, slightly below the same period in 2024 but consistent with 2019 levels, while cycling, including micromobility, showed the most significant growth, reaching 5.2% for the first time and increasing from 3.3% in 2019, suggesting a modest but positive upward trend (ISFORT, 2025).

This scenario underscores the need to better understand the factors that facilitate or hinder the adoption of cycling as a regular mode of transport, especially in the context of post-pandemic mobility patterns. A substantial body of research has identified cycling infrastructure as one of the most influential determinants of bicycle use. Among infrastructural factors, the presence and design of cycling facilities consistently emerge as key determinants of cyclists' subjective safety. Experimental studies using simulated or virtual environments have shown that separated or protected bicycle lanes are perceived as significantly safer than painted lanes (Nazemi et al., 2021) or mixed-traffic conditions (Guo et al., 2023; Ullmann et al., 2022; Xu et al., 2017). Participants typically report higher perceived safety and comfort, as well as greater willingness to cycle, when physical or visual separation from motorized traffic is provided, particularly through segregated infrastructure (Bogacz et al., 2021; Huemer et al., 2022). These findings align with earlier research indicating that the existence of cycling infrastructure is one of the most important criteria in route choice and perceived safety (e.g., Heinen et al., 2010; Parker et al., 2013), even if it is not always sufficient to ensure an adequate sense of safety when cycling (Hopkins & Mandi, 2017). Design details such as lane coloration have also been shown to matter, with red-colored bicycle lanes increasing perceived safety compared to uncolored markings (Ullmann et al., 2022; van Goeverden & Godefrooij, 2011).

Traffic conditions represent another critical environmental factor. A large body of literature reports a negative association between motorized traffic volume and both perceived safety and cycling uptake, with higher traffic levels generally discouraging cycling and increasing perceived risk (e.g., Foster et al., 2011; Fraser & Lock, 2011; Pucher et al., 2010; Winters et al., 2011). Experimental studies in virtual environments have largely confirmed these patterns, showing that scenarios with higher traffic density led to increased risk perception and reduced willingness to cycle (Bialkova et al., 2022; Bogacz et al., 2021). At the same time, some simulation-based studies suggest that moderate variations in traffic volume may not always be salient enough to produce significant perceptual differences, particularly when cyclists are already protected by dedicated infrastructure (Nazemi et al., 2021; Ullmann et al., 2022). This points to a nuanced interaction between traffic intensity and infrastructural design, whereby the presence of physical separation can have attenuated the perceived impact of traffic volume.

Beyond infrastructure and traffic, visual and environmental qualities of the streetscape, especially urban greenery, have been shown to influence cycling-related perceptions and intentions. Several studies indicate that the presence of trees, vegetation, and green elements enhances the attractiveness of cycling environments and increases both comfort and willingness to cycle (e.g., Bialkova et al., 2022; Wahlgren & Schantz, 2012; Wendel-Vos et al., 2004). Experimental manipulations using images, videos, or virtual reality have suggested that greener streetscapes are perceived as more pleasant and inviting for cycling, sometimes even leading cyclists to accept longer routes to avoid “grey” environments (Krenn et al., 2014, 2015; Nawrath et al., 2019). However, evidence is not entirely consistent, as some studies have failed to find a direct association between proximity to green spaces and cycling behavior (e.g., Moudon et al., 2005; Winters et al., 2010), suggesting that greenery may interact with other functional attributes rather than acting as a standalone determinant. Similarly, elements of street furniture, such as bicycle racks or bus shelters, have been associated with improved perceived safety and ease of movement, particularly in shared or redesigned street spaces (Kaparias et al., 2013).

While these physical and perceptual characteristics are crucial, cycling behavior cannot be fully understood without considering socio-psychological factors. Social norms have been repeatedly shown to influence transport-related intentions and behaviors, in line with the TPB (Ajzen, 1991). Social norms, as mentioned in the previous Chapter, operate through perceptions of what others approve or disapprove of (injunctive norms), what others typically do (descriptive norms), and personal moral standards (Cialdini et al., 1991). Research has demonstrated that both injunctive and descriptive norms are associated with cycling adoption, as shown in the results of the previous Chapter, shaping individuals’ perceptions of social acceptability, legitimacy, and typicality of cycling within a given context (Baeli et al., 2022; Eriksson & Forward, 2011; Frater et al., 2017a). Observing, or believing, that cycling is common among peers or within one’s community can normalize the behavior and strengthen intentions to cycle (Heinen & Handy, 2012; Wang et al., 2015). However, not all empirical evidence has shown the same results; in fact, there are examples in which no significant relationship has been found between injunctive norms and intention to use bicycles (Acheampong, 2017; Lois et al., 2015) and between descriptive norms and intention to use bicycles (Frater et al., 2017a). For this reason, it is useful to continue investigating the role played by these variables in the field of bicycle use.

Despite the growing literature on infrastructural and socio-psychological determinants of cycling, most studies rely exclusively on self-report questionnaires, with limited ability to experimentally manipulate environmental conditions (e.g., Bourke et al., 2018; Duan et al., 2023; Gabrhel, 2019).

Studying cyclists' perceptions and intentions directly in real-world settings poses practical and ethical challenges, as traffic levels, infrastructure configurations, and environmental features cannot easily be controlled or modified in situ (Newman, 2025; van der Ham et al., 2015). In this context, video-based simulations and virtual environments offer a valuable methodological alternative. By presenting participants with dynamic and realistic representations of urban cycling scenarios, videos preserve movement cues and temporal continuity that are critical for assessing perceived safety, comfort, and navigability (Heft & Nasar, 2000; Kasraian et al., 2020; Liao et al., 2022). Previous research has shown that such simulations can elicit meaningful perceptual and behavioral responses, closely approximating real-world experiences (Bhagavathula et al., 2018; Chamilothori et al., 2019; Parsons et al., 1998).

Building on this approach, recent studies have increasingly used digitally manipulated videos or virtual reality setups to examine how specific infrastructural, traffic, and environmental features shape cyclists' perceptions and behavioral intentions (e.g., Guo et al., 2023; Rossetti & Hurtubia, 2020). However, relatively few investigations have integrated these environmental manipulations with socio-psychological variables, such as social norms, within a unified, scenario-based framework. In particular, the role of social norms as a potential mediator between environmental characteristics and cycling intentions remains underexplored when norms are assessed in relation to concrete, visually presented urban scenarios.

Taken together, existing evidence highlights the importance of infrastructural design, perceived safety, environmental quality, and social-contextual factors in shaping cycling intentions. At the same time, it points to the need for experimental approaches that allow these elements to be examined jointly, under controlled yet realistic conditions. The studies presented in the following sections attempted to address this gap by combining video-based representations of urban cycling environments with measures of perceived safety, comfort, and social norms, variables taken into consideration based on the results of the previous scoping review, with a specific focus on individuals' intention to use the bicycle in distinct infrastructural scenarios. Through this integrated and interdisciplinary approach, developed in collaboration with engineers, urban planners, and computer scientists, the research aimed to provide a more nuanced understanding of how physical and social features of the urban environment jointly contribute to the promotion of cycling as a sustainable mode of transport.

## **3.2. Study 1**

### **3.2.1 Objectives and hypotheses**

Study 1 investigated how socio-psychological factors and perceptions of urban street design interact in shaping individuals' intention to cycle in an urban context. Using an immersive desktop-based reproduction of a street in Cagliari, the study examined the effects of different street configurations on perceived danger, discomfort, and negative interactions with traffic, and how these perceptions relate to cycling intention. Moreover, the study explored whether perceived social approval of cycling could mitigate the negative influence of perceived danger on individuals' intention to use a bicycle.

By combining controlled visual manipulations of urban environments with the assessment of key socio-psychological variables, Study 1 offers an integrated examination of physical and social determinants of cycling intention. Based on the existing literature outlined above, the following hypotheses were formulated:

Hypothesis 1 (H1). Higher perceptions of danger, discomfort, and negative vehicular interactions were expected to be associated with lower intention to use the bicycle:

H1a: Participants reporting higher perceived danger were expected to show lower intention to cycle;

H1b: Participants reporting higher perceived discomfort were expected to show lower intention to cycle;

H1c: Participants experiencing more negative vehicular interactions were expected to show lower intention to cycle.

Hypothesis 2 (H2). Perceptions of danger, discomfort, and negative vehicular interactions were expected to vary across immersive cycling scenarios:

H2a: Perceived danger was expected to differ between scenarios;

H2b: Perceived discomfort was expected to differ between scenarios;

H2c: Negative vehicular interactions were expected to differ between scenarios.

Hypothesis 3 (H3). Intention to use the bicycle was expected to differ across immersive cycling scenarios.

Hypothesis 4 (H4). Scenarios with high traffic, compared to low traffic, were expected to be associated with:

H4a: Higher perceived danger;

H4b: Higher perceived discomfort;

H4c: More negative vehicular interactions;

H4d: Lower intention to cycle.

Hypothesis 5 (H5). Injunctive norms were expected to be positively associated with the intention of using the bicycle.

Furthermore, to explore the role of injunctive norms more specifically, the present study proposed the following research question: did injunctive norms moderate the relationship between perceived danger and intention to use the bicycle across different cycling scenarios?

### **3.2.2. Method**

#### **3.2.2.1 Sample**

Participants were recruited online via LimeSurvey through personal networks using a snowball sampling approach. The data collection was conducted between May and June 2024. Because this is a non-probability sampling method, the sample cannot be considered representative of the broader population, and the results should therefore be interpreted with caution.

A total of 128 responses were initially collected. After data cleaning (see Section 3.2.2.4), the final sample comprised 109 participants living in the metropolitan area of Cagliari. The gender distribution was balanced, with 58 women (53.2%) and 51 men (46.8%). The average age of participants was 37.06 years ( $SD = 14.40$ ), with an age range from 21 to 73 years. Regarding employment status, the distribution across categories was as follows: 27.5% of the sample consisted of university students ( $n = 30$ ), while 12.8% were postgraduate and PhD students, ( $n = 14$ ). Retirees accounted for 4.6% of the sample ( $n = 5$ ), 35.8% were employees ( $n = 39$ ), and 13.8% were self-employed workers ( $n = 15$ ). The categories of unemployed, homemakers, and “other” are equally represented, each comprising 1.8% of the sample ( $n = 2$  for each category). Finally, bicycle usage frequency (Ma et al., 2014) was investigated with the question: “Recently, how often have you used a bicycle for your commuting?” The results indicate that most participants, 79.8% ( $n = 87$ ), never used a bicycle, while 6.4% ( $n = 7$ ) used it less than once a month. Only 0.9% ( $n = 1$ ) reported using a bicycle one to three times a month, and 12.8% ( $n = 14$ ) stated they used it once a week. No participants reported using a bicycle more than once a week.

#### **3.2.2.2. Research design**

The present study adopts a  $2 \times 5$  experimental design, in which four independent variables were manipulated. The between-subjects variable was traffic condition, divided into two levels: high traffic

vs. low traffic. The within-subjects variables included the presence or absence of a bicycle lane, urban greenery, and street furniture (i.e., bus shelters and bicycle racks). These variables were combined to create five distinct scenarios, all implemented in a virtual environment using Unity software (Unity Technologies, 2024). The use of multiple scenarios was intended to allow a detailed and exploratory examination of the individual and combined effects of key infrastructural elements on cyclists' perceptions and intentions. Specifically, the scenarios were designed to disentangle the contribution of each element, as well as their joint presence, in shaping perceived safety, comfort, and intention to cycle.

The scenarios were characterized as follows:

Baseline Scenario (BS): represented a real street in the city of Cagliari without a bicycle lane, urban greenery, or street furniture;

Scenario 1 (S1): car parking was removed, sidewalks were widened, and a raised shared pedestrian and red bicycle path was built on the eastern side of the corridor;

Scenario 2 (S2): urban greenery was introduced into Scenario 1;

Scenario 3 (S3): street furniture was introduced into Scenario 1;

Scenario 4 (S4): both urban greenery and street furniture were introduced into Scenario 1.

Participants were randomly assigned to one of the two traffic conditions (high traffic or low traffic). The presentation order of the scenarios was randomized, except for the Baseline Scenario, which was always presented first to provide a common reference point. Figure 6 illustrates the structure according to which the manipulated scenarios were presented.

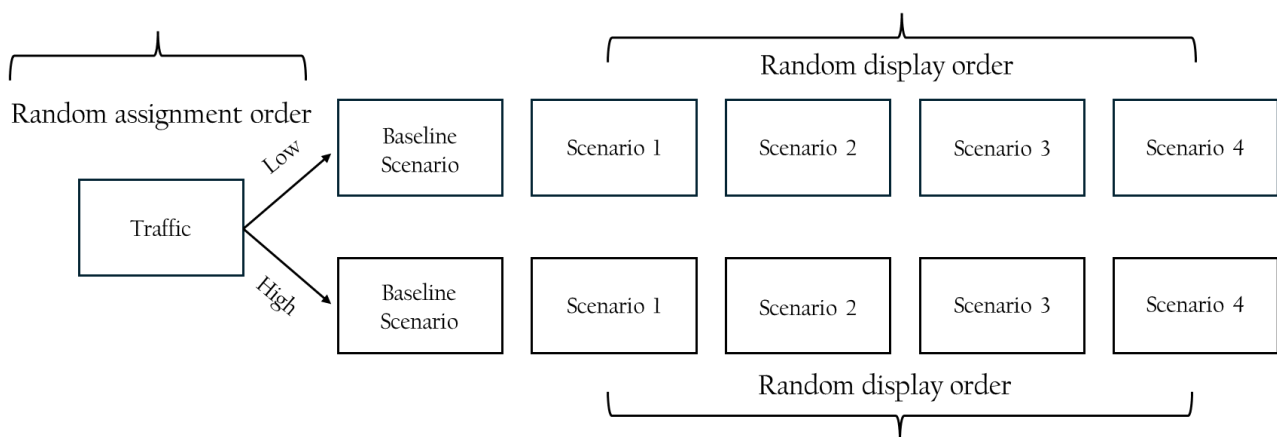


**Figure 6. Order of assignment to the two traffic conditions (high vs low) and order in which scenarios are displayed.**

For each scenario, participants viewed a video (with an average duration of 1 minute and 22 seconds) accompanied by a representative still image (Figures 7–16). Because sensory fidelity is known to affect the perceived realism of virtual environmental stimuli, particularly through auditory cues (Kort et al., 2003), the videos included real traffic sound to enhance immersion and ecological validity.

The experimental protocol followed a fixed sequence. Initially, participants answered questions regarding socio-demographic characteristics, frequency of bicycle use, and injunctive norms concerning bicycle use, referring specifically to close social contacts such as family members, friends, and partners. Injunctive norms were assessed before the experimental scenarios, as this study adopted an exploratory perspective aimed at capturing participants' general perceptions of social approval or disapproval toward cycling, rather than context-specific normative cues. This approach was consistent with previous research showing that injunctive norms provide a broad indicator of perceived social expectations and are particularly suitable in early-stage investigations of social influences on mobility-related intentions (e.g., Chen, 2022; Heinen et al., 2011). Subsequently, participants viewed the five scenarios one at a time and, for each scenario, reported their perceptions of danger, discomfort, vehicular interaction, and their intention to cycle.

After viewing all scenarios, participants were asked to indicate which scenario they considered the best and worst, and to report their intention to cycle in those two scenarios. The intention to cycle was therefore measured twice in two different ways. This decision was primarily dictated by the interdisciplinary nature of the research project, which required the assessment of behavioral intention using two complementary formats to meet different analytical objectives. Specifically, the two measurements were designed to support distinct data analyses conducted within the broader framework of the project, while also allowing for the examination of intention both at the individual scenario assessment level and in a comparative context. All questionnaire items were presented in Italian, and all participants took part in the study voluntarily and did not receive any compensation.



**Figure 7. Baseline Scenario with low traffic condition, the absence of the bicycle lane, urban greenery and street furniture.**



**Figure 8. Scenario 1 with low traffic condition, the presence of the bicycle lane, the absence of urban greenery and street furniture.**



**Figure 9. Scenario 2 with low traffic condition, the presence of the bicycle lane and urban greenery and the absence of street furniture.**



**Figure 10. Scenario 3 with low traffic condition, the presence of the bicycle lane and street furniture and the absence of urban greenery.**



**Figure 11. Scenario 4 with low traffic condition, the presence of the bicycle lane, street furniture and urban greenery.**



**Figure 12. Baseline Scenario with high traffic condition, the absence of the bicycle lane, urban greenery and street furniture.**



**Figure 13. Scenario 1 with high traffic condition, the presence of the bicycle lane, the absence of urban greenery and street furniture.**



**Figure 14. Scenario 2 with high traffic condition, the presence of the bicycle lane and urban greenery and the absence of street furniture.**



**Figure 15. Scenario 3 with high traffic condition, the presence of the bicycle lane and street furniture and the absence of urban greenery.**



**Figure 16. Scenario 4 with high traffic condition, the presence of the bicycle lane, street furniture, and urban greenery.**

### **3.2.2.3. Measures**

The measuring instruments employed in the study were as follows.

*Injunctive norm:* It was measured using four items: “Imagine you decide to travel to your place of work/study by bicycle. Indicate, on a scale from 1 to 7, to what extent the following groups of people would approve: My family, My friends, My colleagues, My fellow citizens” The items were measured using a 7-point Likert scale (1 = Totally disagree; 7 = Totally agree). The reliability of the measure was  $\alpha = 0.89$ .

*Perception of danger:* for each scenario, it was measured using three items: “Dangers present”, “Unsafe crossings”, and “Unsafe intersections”. The items were measured with a 7-point Likert scale (1 = Completely disagree; 7 = Completely agree). The reliability of the measure was as follows:  $\alpha = 0.85$  (Baseline Scenario), 0.89 (Scenario 1), 0.93 (Scenario 2), 0.92 (Scenario 3), 0.96 (Scenario 4).

*Perception of discomfort:* for each scenario, it was measured using three items: “Sense of discomfort”, “Unpleasant visual elements”, and “Unpleasant sound elements”. The items were measured with a 7-point Likert scale (1 = Completely disagree; 7 = Completely agree). The reliability of the measure was as follows:  $\alpha = 0.83$  (Baseline Scenario), 0.84 (Scenario 1), 0.82 (Scenario 2), 0.86 (Scenario 3), 0.89 (Scenario 4).

*Perception of vehicular interaction:* for each scenario, it was measured using two items: “Negative car interaction” and “Negative cyclist interaction”. The items were measured with a 7-point Likert scale (1 = Completely disagree; 7 = Completely agree). The two items were positively correlated as follows:  $r = 0.41$  (Baseline Scenario,  $p < 0.01$ ), 0.60 (Scenario 1,  $p < 0.01$ ), 0.74 (Scenario 2,  $p < 0.01$ ), 0.67 (Scenario 3,  $p < 0.01$ ), 0.83 (Scenario 4,  $p < 0.01$ ).

*Intention to use a bicycle (a)*: The intention to use the bicycle in the specific scenarios was measured with a single dichotomous item with a “Yes” (= 1) and “No” (= 0) response: “If you had to ride on Viale Ciusa in the current conditions shown in the scenario displayed, would you use a bicycle?”.

*Ranking scenarios*: Participants were asked to rank the scenarios from best to worst through a response ranking, where all scenarios had to be selected and placed in positions from first to fifth: “We kindly ask you to rank the scenarios from best to worst”.

*Intention to use the bicycle (b)*: The intention to use the bicycle in the best and worst-case scenarios was assessed using three items for each scenario: “I would gladly use the bicycle in this scenario”, “In this scenario, it would increase the likelihood that I would use the bicycle” and “In this scenario, it would increase my frequency of bicycle use.” The items were measured using a 7-point Likert scale (1 = Totally disagree; 7 = Totally agree). The reliability of the measure was as follows:  $\alpha = 0.94$  (best scenario), 0.98 (worst scenario).

All variables were assessed using ad hoc items. Main socio-demographic indicators (i.e., gender, age, employment status, and bicycle usage frequency) were also collected for each participant.

#### **3.2.2.4. Data analysis**

Before data processing, a data cleaning procedure was applied, resulting in the removal of 19 responses deemed anomalous in terms of overall duration. Specifically, questionnaires completed in less than 10 minutes or more than 40 minutes were excluded. This criterion was adopted because the questionnaire included five videos, with a total duration of approximately 7 minutes, making it unlikely to provide accurate feedback in less than 10 minutes. Similarly, an upper time limit of 40 minutes was established, which was considered adequate given the number of pre- and post-viewing questions, as well as the entire study structure, including scenarios, images, and associated questions.

Prior to hypothesis testing, internal consistency was assessed for all multi-item scales containing at least three items. As reported in the previous Section, Cronbach’s alpha coefficients met the minimum acceptable thresholds, indicating satisfactory reliability across all measures (Kilic, 2016; Tavakol & Dennick, 2011). Composite scores were subsequently computed for each construct.

All analyses were conducted using SPSS statistical software (Version 25.0; IBM Corp., 2017). Descriptive and inferential statistical tests were performed. Specifically, given that the sample data did not follow a normal distribution, the following non-parametric tests were used:

Friedman's test (Friedman, 1940): A non-parametric test used to analyze differences between more than two related samples or repeated measures on a single sample. In other words, it serves as a non-parametric alternative to repeated measures ANOVA for ordinal or non-normally distributed data;

Wilcoxon's test (Wilcoxon, 1992): A non-parametric statistical test used to compare two related or dependent samples;

Cochran's test (Cochran, 1950): A statistical test used to compare the proportions of successes (or positive events) between several groups or conditions when the data are binary. It determines whether there are significant differences between these proportions;

McNemar's test (McNemar, 1947): A non-parametric statistical test used to compare the proportions of paired or dependent data when the data are binary.

In addition, moderation analyses were performed using the PROCESS model macro (Hayes, 2017). A moderation regression analysis (Model 1) was performed to investigate whether the relationship between the independent variable (IV; perception of danger) and the dependent variable (DV; intention to use the bicycle) was influenced by the moderator, injunctive norms. Finally, to interpret and discuss the results of the traffic manipulation in relation to the sample used, a post-hoc power analysis was conducted using G\*Power 3.1 (Faul et al., 2009).

### **3.2.3. Results**

Descriptive statistics for all measured variables, including injunctive norm, perception of danger, perception of discomfort, vehicular interaction, and intention to cycle (a), intention to cycle in the best scenario and the worst scenario are reported in Table 7, with means, medians, and standard deviations presented for each scenario as well as across the entire sample. Subsequently, the results are presented in two Sections.

Table 7. Descriptive statistics (mean, median, and standard deviation) for the variables included in the analysis.

|                       | Baseline Scenario |        |      | Scenario 1 |        |      | Scenario 2 |        |      | Scenario 3 |        |      | Scenario 4 |        |      | Total |        |      |
|-----------------------|-------------------|--------|------|------------|--------|------|------------|--------|------|------------|--------|------|------------|--------|------|-------|--------|------|
|                       | Mean              | Median | SD   | Mean       | Median | SD   | Mean       | Median | SD   | Mean       | Median | SD   | Mean       | Median | SD   | Mean  | Median | SD   |
| Injunctive norm       | -                 | -      | -    | -          | -      | -    | -          | -      | -    | -          | -      | -    | -          | -      | -    | 4.50  | 4.50   | 1.89 |
| Danger                | 6.05              | 6.67   | 1.28 | 2.29       | 2.00   | 1.37 | 2.22       | 2.00   | 1.50 | 2.09       | 1.67   | 1.36 | 2.10       | 2.00   | 1.40 | 2.95  | 2.00   | 2.08 |
| Discomfort            | 5.52              | 5.67   | 1.39 | 2.48       | 2.33   | 1.37 | 2.31       | 2.00   | 1.32 | 2.26       | 2.00   | 1.38 | 2.45       | 2.00   | 1.48 | 3.00  | 2.33   | 1.87 |
| Vehicular interaction | 5.60              | 6.00   | 1.43 | 1.99       | 1.50   | 1.30 | 1.94       | 1.50   | 1.37 | 2.02       | 1.50   | 1.40 | 1.99       | 1.50   | 1.42 | 2.71  | 2.00   | 2.00 |
| Intention to cycle(a) | 0.10              | 0.00   | 0.30 | 0.88       | 1.00   | 0.33 | 0.86       | 1.00   | 0.35 | 0.88       | 1.00   | 0.33 | 0.86       | 1.00   | 0.35 | 0.72  | 1.00   | 0.45 |
| Best scenario         | -                 | -      | -    | -          | -      | -    | -          | -      | -    | -          | -      | -    | -          | -      | -    | 5.69  | 6.33   | 1.61 |
| Worst scenario        | -                 | -      | -    | -          | -      | -    | -          | -      | -    | -          | -      | -    | -          | -      | -    | 1.97  | 1.00   | 1.82 |

Note: *SD* = Standard Deviation.

### 3.2.3.1. Impact of perceived danger, discomfort, and vehicular interaction on cycling intention

First, a correlation analysis was conducted to examine the overall relationship between perceived danger, discomfort, vehicular interaction, and intention to use the bicycle, to test H1a, H1b, and H1c. To this end, for each participant, scores for danger, discomfort, vehicular interaction, and intention to use the bicycle were averaged across the five scenarios, yielding aggregated indices that captured general perceptions and intentions rather than scenario-specific responses.

The aggregated intention to use the bicycle was negatively correlated with all aggregated perceptual variables. Specifically, the strongest association emerged with perceived discomfort ( $r = -0.43, p < 0.01$ ), followed by perceived danger ( $r = -0.41, p < 0.01$ ), and perceived vehicular interaction ( $r = -0.33, p < 0.01$ ). These results indicate a negative relationship between perceived discomfort, perceived danger, and perceived vehicular interaction and intention to use the bicycle.

To test H2a, potential differences between the various scenarios regarding the perception of danger, a Friedman test was performed. The results were significant ( $\chi^2 = 248.77; df = 4; p < 0.001$ ), which allowed for further investigation to identify the specific scenarios showing significant variations. A subsequent Wilcoxon test revealed significant differences between different conditions, as shown in Table 8:

Scenario 1 vs. Baseline Scenario ( $Z = -8.68, p < 0.001, r = -0.83$ );

Scenario 2 vs. Baseline Scenario ( $Z = -8.60, p < 0.001, r = -0.82$ );

Scenario 3 vs. Baseline Scenario ( $Z = -8.67, p < 0.001, r = -0.83$ );

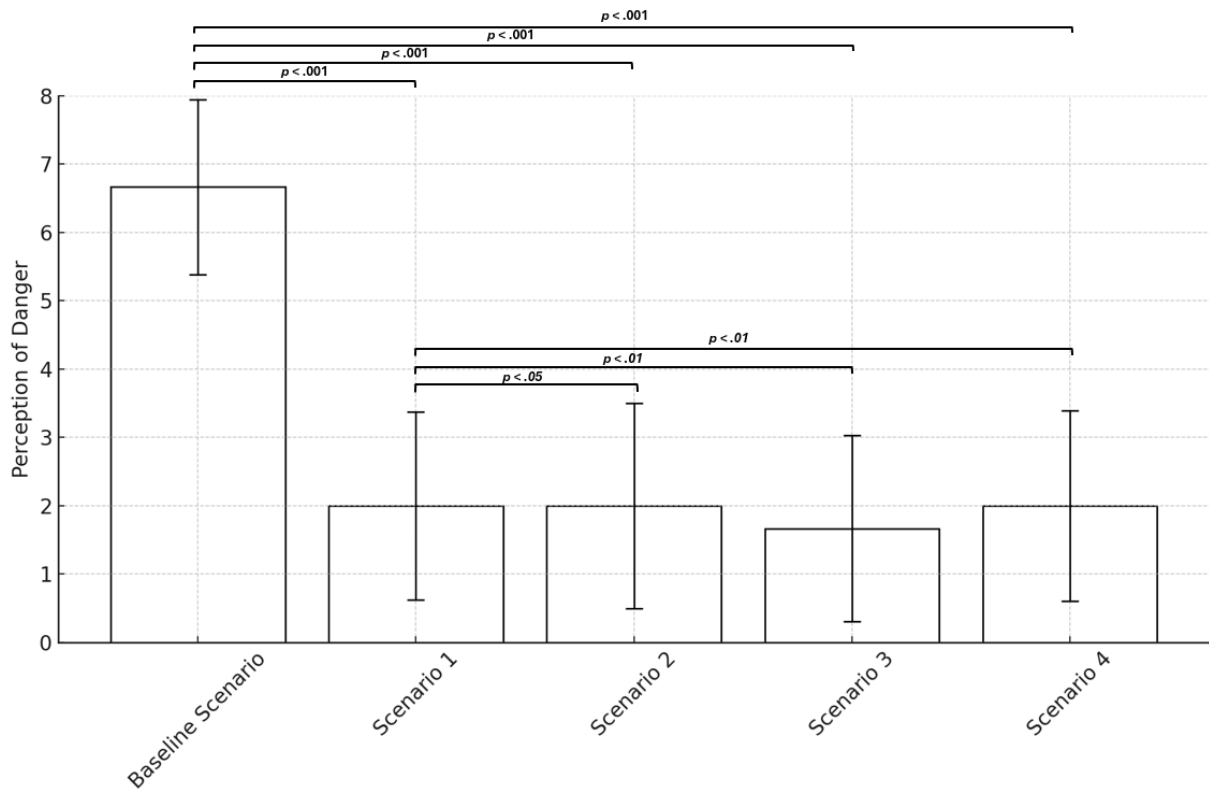
Scenario 4 vs. Baseline Scenario ( $Z = -8.66, p < 0.001, r = -0.83$ ).

Additionally, Scenario 2 differed significantly from Scenario 1 ( $Z = -2.01, p < 0.05, r = -0.19$ ), as did Scenario 3 ( $Z = -2.89, p < 0.01, r = -0.28$ ) and Scenario 4 ( $Z = -2.84, p < 0.01, r = -0.27$ ) compared to Scenario 1. All other comparisons not shown in the text did not yield significant differences. This suggests that the absence of a bicycle lane is perceived as the most adverse condition. Moreover, the presence of additional infrastructural elements, such as urban greenery (Scenario 2), street furniture (Scenario 3), or both (Scenario 4), in combination with a bicycle lane is perceived as a less dangerous condition. These results are also displayed in Figure 17.

**Table 8. Results of Wilcoxon's test of perception of danger.**

|             | S1 - BS  | S2 - BS  | S3 - BS  | S4 - BS  | S2 - S1 | S3 - S1 | S4 - S1 | S3 - S2 | S4 - S2 | S4 - S3 |
|-------------|----------|----------|----------|----------|---------|---------|---------|---------|---------|---------|
| Z           | -8.68*** | -8.60*** | -8.67*** | -8.66*** | -2.01*  | -2.89** | -2.84** | -1.09   | -0.70   | -0.43   |
| Effect size | -.83     | -.82     | -.83     | -.83     | -.19    | -.28    | -.27    | -       | -       | -       |

Note: \*\*\* =  $p < .001$ ; \*\* =  $p < .01$ ; \* =  $p < .05$ .

**Figure 17. Perception of danger: representation of the differences between scenarios.**

Similarly, to test H2b, differences in perception of discomfort across the scenarios were examined using a Friedman test, which yielded significant results ( $\chi^2 = 220.74$ ;  $df = 4$ ;  $p < 0.001$ ). This prompted further analysis to identify specific differences between the scenarios. A Wilcoxon test confirmed several significant differences, as detailed in Table 9:

Scenario 1 vs. Baseline Scenario ( $Z = -8.61$ ,  $p < 0.001$ ,  $r = -0.83$ );

Scenario 2 vs. Baseline Scenario ( $Z = -8.63$ ,  $p < 0.001$ ,  $r = -0.83$ );

Scenario 3 vs. Baseline Scenario ( $Z = -8.60$ ,  $p < 0.001$ ,  $r = -0.82$ );

Scenario 4 vs. Baseline Scenario ( $Z = -8.51$ ,  $p < 0.001$ ,  $r = -0.82$ ).

Additionally, Scenario 3 showed a significant difference when compared to Scenario 1 ( $Z = -2.41$ ,  $p < 0.05$ ,  $r = -0.23$ ). All other comparisons not shown in the text did not yield significant differences. This suggests that the absence of a bicycle lane represents the most discomforting condition for participants. Furthermore, among scenarios that include a bicycle lane and additional infrastructural elements, a difference in perceived discomfort emerges between the condition with a bicycle lane alone (Scenario 1) and the condition combining a bicycle lane with street furniture (Scenario 3), suggesting that street furniture may play a role in reducing feelings of discomfort. These results are illustrated in Figure 18.

**Table 9. Results of Wilcoxon's test of perception of discomfort.**

|             | S1 - BS  | S2 - BS  | S3 - BS  | S4 - BS  | S2 - S1 | S3 - S1 | S4 - S1 | S3 - S2 | S4 - S2 | S4 - S3 |
|-------------|----------|----------|----------|----------|---------|---------|---------|---------|---------|---------|
| Z           | -8.61*** | -8.63*** | -8.60*** | -8.51*** | -1.46   | -2.41*  | -0.73   | -0.41   | -0.74   | -1.75   |
| Effect size | -.83     | -.83     | -.82     | -.82     | -       | -.23    | -       | -       | -       | -       |

**Note:** \*\*\* =  $p < .001$ ; \* =  $p < .05$ .

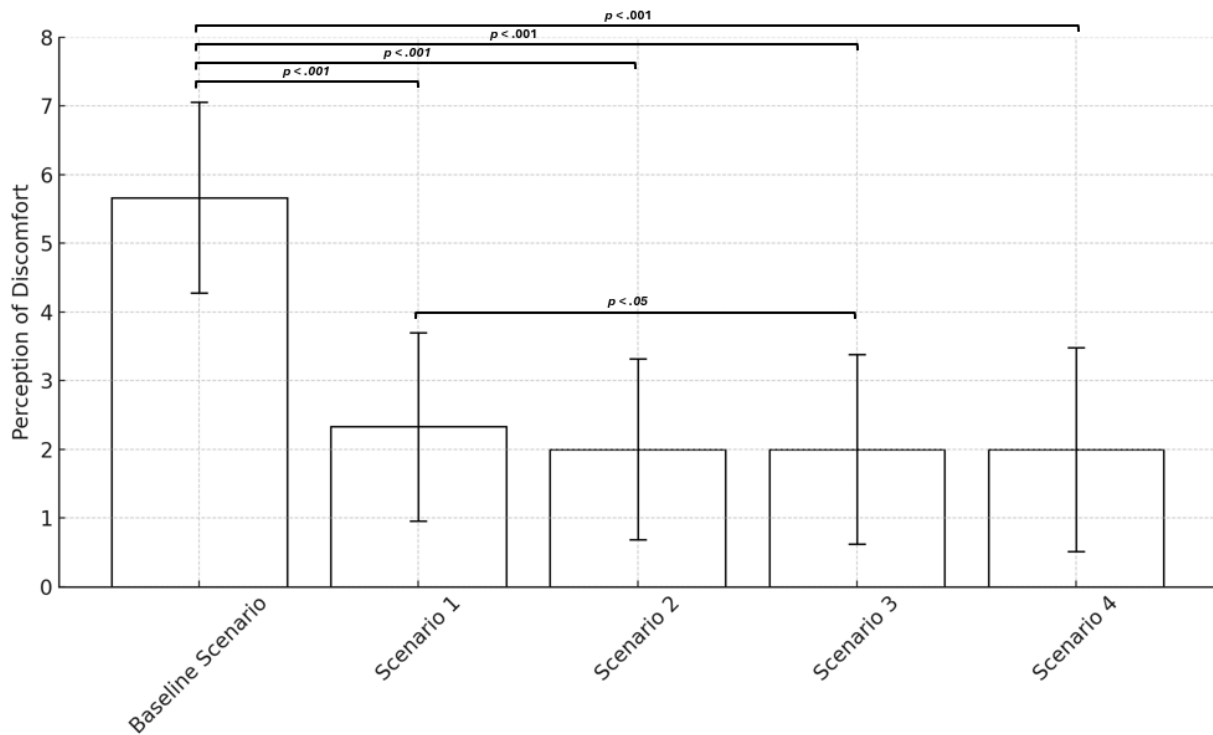


**Figure 18. Perception of discomfort: representation of the differences between scenarios.**

To test H2c, the analysis of perception of vehicular interaction across the scenarios was conducted using the same Friedman test, which yielded significant results ( $\chi^2 = 247.38$ ;  $df = 4$ ;  $p < 0.001$ ). This prompted further investigation through a Wilcoxon test, which once again indicated significant differences between the following scenarios, as shown in Table 10:

Scenario 1 vs. Baseline Scenario ( $Z = -8.67, p < 0.001, r = -0.83$ );

Scenario 2 vs. Baseline Scenario ( $Z = -8.63, p < 0.001, r = -0.83$ );

Scenario 3 vs. Baseline Scenario ( $Z = -8.56, p < 0.001, r = -0.82$ );

Scenario 4 vs. Baseline Scenario ( $Z = -8.56, p < 0.001, r = -0.82$ ).

All other comparisons not shown in the text did not yield significant differences. This suggests that the absence of a bicycle lane constitutes a critical factor in the perception of vehicular interaction. These findings are graphically represented in Figure 19.

**Table 10. Results of Wilcoxon's test of perception of vehicular interaction.**

|             | S1 - BS  | S2 - BS  | S3 - BS  | S4 - BS  | S2 - S1 | S3 - S1 | S4 - S1 | S3 - S2 | S4 - S2 | S4 - S3 |
|-------------|----------|----------|----------|----------|---------|---------|---------|---------|---------|---------|
| <i>Z</i>    | -8.67*** | -8.63*** | -8.56*** | -8.56*** | -0.86   | -0.36   | -0.22   | -0.61   | -0.08   | -0.01   |
| Effect size | -.83     | -.83     | -.82     | -.82     | -       | -       | -       | -       | -       | -       |

**Note:** \*\*\* =  $p < .001$ .

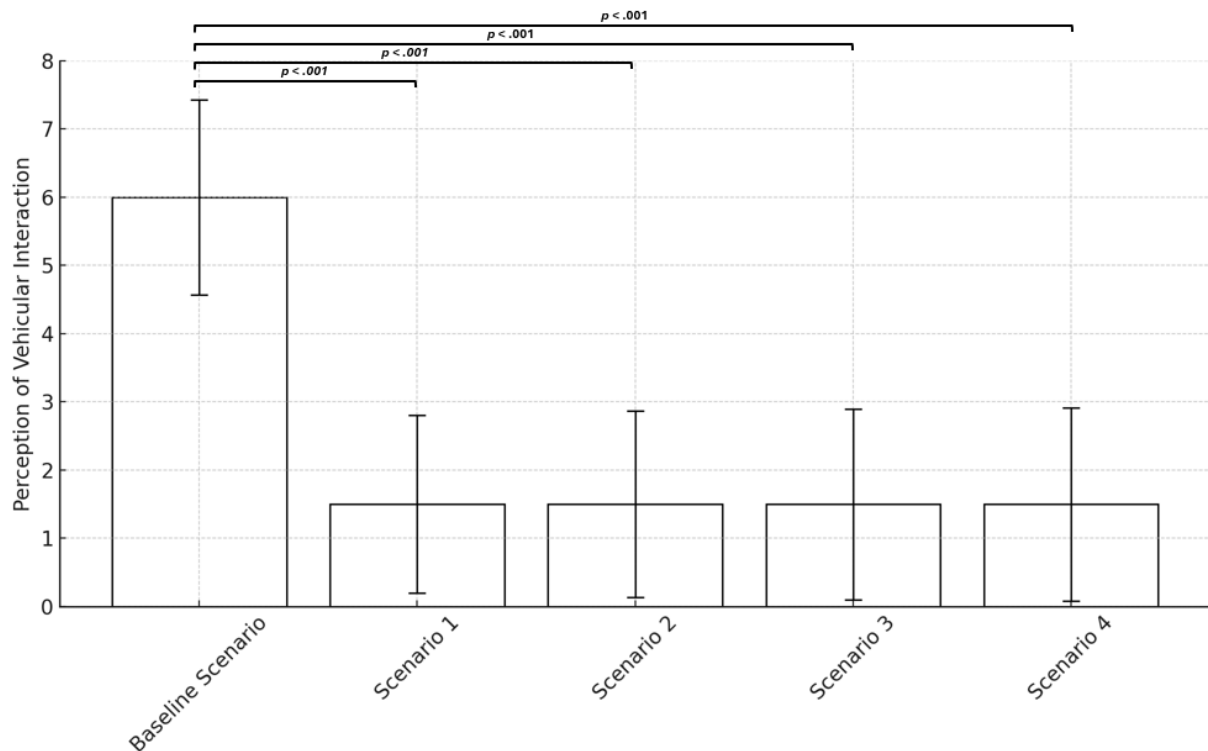


**Figure 19. Perception of vehicular interaction: representation of the differences between scenarios.**

To conclude the first part of the results, and to test H3, the findings related to intention to use the bicycle (a) (“If you had to ride on Viale Ciusa in the current conditions shown in the scenario displayed, would you use a bicycle?”) were presented. In line with the analysis conducted for

perception of danger, perception of discomfort, and perception of vehicular interaction, it was first investigated whether significant differences existed across the scenarios for intention to use the bicycle. Following the significant results of Cochran's test ( $Q = 278.27$ ;  $df = 4$ ;  $p < 0.001$ ), specific differences between scenarios were identified using McNemar's test. The outcomes, as summarized in Table 11, are as follows:

Scenario 1 vs. Baseline Scenario ( $\chi^2 = 79.28$ ,  $p < 0.01$ );

Scenario 2 vs. Baseline Scenario ( $\chi^2 = 79.11$ ,  $p < 0.01$ );

Scenario 3 vs. Baseline Scenario ( $\chi^2 = 81.10$ ,  $p < 0.01$ );

Scenario 4 vs. Baseline Scenario ( $\chi^2 = 79.11$ ,  $p < 0.01$ ).

All other comparisons not shown in the text did not yield significant differences. This suggests that the absence of a bicycle lane may play a crucial role in the decision to use a bicycle or not.

**Table 11. Results of McNemar's test of intention to use the bicycle.**

|          | S1 - BS | S2 - BS | S3 - BS | S4 - BS | S2 - S1 | S3 - S1 | S4 - S1 | S3 - S2 | S4 - S2 | S4 - S3 |
|----------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|
| $\chi^2$ | 79.28   | 79.11   | 81.10   | 79.11   | -       | -       | -       | -       | -       | -       |
| $p$      | .00     | .00     | .00     | .00     | .75     | 1.00    | .75     | .77     | 1.00    | .73     |

Finally, to test H4a, H4b, H4c, and H4d, the manipulation of traffic (high traffic condition vs. low traffic condition), analyzed using the Mann-Whitney U-test (Mann & Whitney, 1947; Wilcoxon, 1945), did not yield significant results.

### **3.2.3.2. Influence of social norms and individual perceptions on cycling intention**

To analyze the intention to use the bicycle (b) and correlate it with other variables, we first asked participants to identify both the best and worst scenarios according to their perceptions. Following this, participants were asked about their intention to use the bicycle in both the best and worst scenarios. Participants were initially asked to rank the presented scenarios in order of preference ("We kindly ask you to rank the scenarios from best to worst"). As illustrated in Figure 20, Baseline Scenario was consistently ranked as the worst, while Scenario 4 was identified as the best.

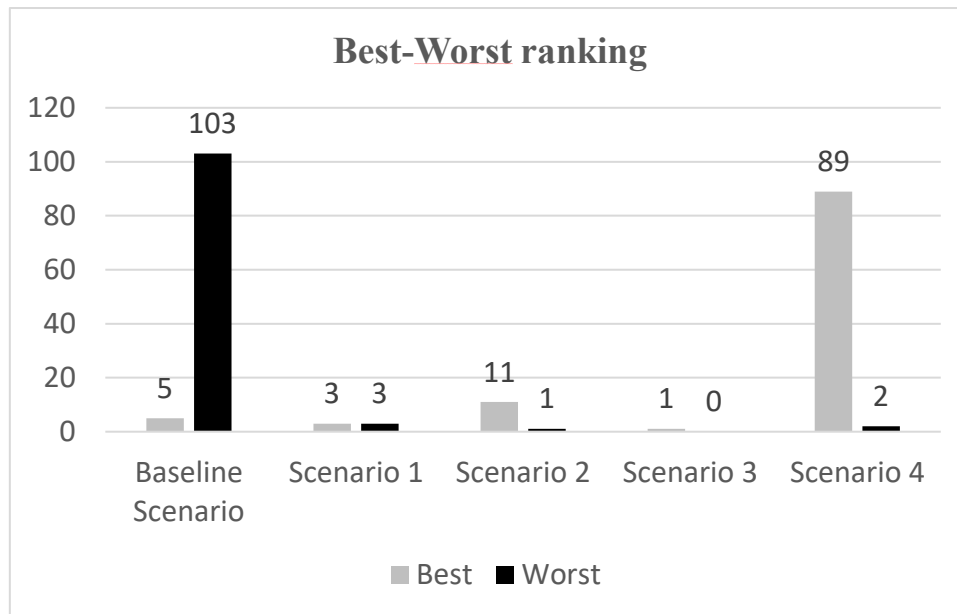


**Figure 20. Ranking for the choice of the best and the worst scenarios.**

Based on these rankings, we calculated the average of participants' intention to use the bicycle across both the best and worst scenarios, allowing us to assess bicycle usage intentions independently of the specific scenario. Subsequently, to test H5 and to further explore the research question concerning the potential moderating role of injunctive norms, a moderation analysis was conducted. Injunctive norms were specified as the moderating variable in the relationship between perceived danger (independent variable) and intention to use the bicycle (dependent variable). The overall model was statistically significant ( $R^2 = 0.16$ ,  $F(4, 104) = 5.87$ ,  $p < 0.001$ ) and was designed to address the following research question: do injunctive norms moderate the relationship between perceived danger and intention to use the bicycle across different cycling scenarios? The results indicated that both injunctive norms ( $p < .05$ ) and perceived danger ( $p < .05$ ) emerged as significant predictors of intention to use the bicycle. In contrast, the interaction term between perceived danger and injunctive norms was negative and marginally non-significant ( $p = 0.06$ ). Although the interaction effect was not statistically significant, the results may suggest a tendency whereby, under comparable levels of perceived danger, individuals with higher levels of injunctive norms could report a greater intention to use the bicycle. This relationship can also be illustrated using graphical representation. As depicted in Figure 21, under conditions of high perception of danger (+1), the intention to use the bicycle remains low, regardless of whether the injunctive norm is above or below average. Conversely, when the perception of danger is low (-1), the intention to use the bicycle increases as the value of the injunctive norm rises. In this analysis, additional covariates related to socio-demographic characteristics and current behavior, were included: age, sex, and frequency of bicycle use. Upon

realizing that age and frequency of bicycle use had no significant effect ( $p = 0.90$ ;  $p = 0.14$ , respectively), they were removed from the analysis, leaving sex as the only covariate (as shown in Table 12).

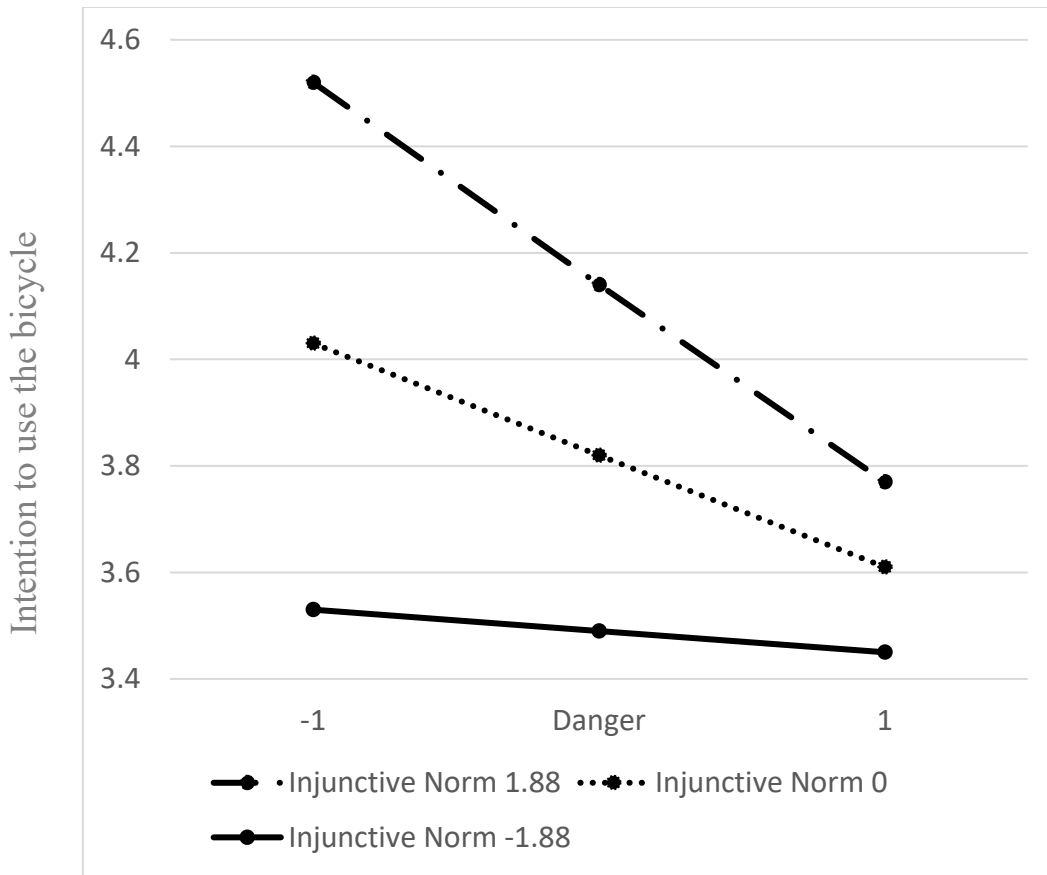


Figure 21. Moderation analysis with intention to use the bicycle (b) as DV, perception of danger as IV and injunctive norm as moderator.

Table 12. Results of moderation analysis.

|                          | B    | se  | t     | p   | LLCI | ULCI |
|--------------------------|------|-----|-------|-----|------|------|
| Danger                   | -.21 | .10 | -2.12 | .04 | -.41 | -.01 |
| Injunctive norm          | .17  | .06 | 2.69  | .01 | .05  | .30  |
| Danger * Injunctive norm | -.09 | .05 | -1.91 | .06 | -.18 | .00  |
| Sex                      | .42  | .21 | 2.03  | .05 | .01  | .83  |

Note: LLCI = Lower Level of the Confidence Interval; ULCI = Upper Level of the Confidence Interval.

### 3.2.4. Discussion

The results highlighted the role of perceptions of danger, discomfort, vehicle interactions, and social norms in shaping individuals' intentions to use bicycles as a means of transportation. Although these findings provide useful insights into how different road configurations and psychological variables

may influence cycling mobility, they should be interpreted with caution, as the participants were recruited through a non-probability snowball sampling method, which limits the generalizability of the results. Not all findings were fully consistent with the initial hypotheses.

The findings from the first part of the analysis revealed a negative correlation between the intention to use a bicycle and perceptions of discomfort, danger, and negative interactions with vehicles, supporting H1 and more specifically H1a, H1b, and H1c. These results align with prior studies, such as Piras et al. (2021a; 2021b), which highlighted the strong relationship between the intention to cycle and perceived comfort. Similarly, the work of Esteban-Cornejo and colleagues (2016) underscores the link between active mobility and the perception of danger, with a particular emphasis on traffic safety as a key component of perceived security.

The analysis also revealed significant differences across the various scenarios, supporting H2, and more specifically H2a, H2b, and H2c. The Baseline Scenario consistently showed higher levels of perceived danger, discomfort, and negative vehicular interactions, further emphasizing the importance of cycling infrastructure, such as dedicated bicycle lanes, in enhancing the perceived safety and comfort of cycling. A consistent result emerged from the significant differences observed between the various scenarios and the intention to use a bicycle, supporting H3. In this case, the only statistically significant differences were those between the Baseline Scenario and all the other scenarios, reinforcing the idea that the bicycle lane, which is a common feature in all modified scenarios, is an essential element in promoting cycling mobility. This result is consistent with other research that has emphasized the fundamental importance of urban infrastructure, and in particular bike lanes, in promoting the use of bicycles for transportation (e.g., Bagloee et al., 2016; Bogacz et al., 2021; Chen et al., 2018; Heinen et al., 2010; Huemer et al., 2022; Parker et al., 2013).

Regarding the perception of danger, the results revealed a statistically significant difference between Scenario 1 vs. Scenario 2, Scenario 3, and Scenario 4. This finding can be explained as follows: from a road safety perspective, the presence of elements that separate the participant (immersed in the simulation as a cyclist) from cars and general traffic appears to play a crucial role in shaping perceived safety, confirming the results of various studies (e.g., Bogacz et al., 2021; Guo et al., 2023; Huemer et al., 2022; Nazemi et al., 2021; Ullmann et al., 2022; Xu et al., 2017). This interpretation is partially supported by the present results. Scenarios including a bicycle lane combined with either urban greenery (Scenario 2) or urban furniture (Scenario 3) elicited significantly lower perceptions of danger compared to the scenario featuring a bicycle lane alone, suggesting that the addition of a further separating element enhances perceived safety.

However, this cumulative interpretation is not fully supported when considering Scenario 4. Despite including both urban greenery and street furniture in addition to the bicycle lane, Scenario 4 did not produce significantly lower perceptions of danger compared to scenarios combining the bicycle lane with only one additional infrastructural element. This pattern suggests the presence of a threshold effect rather than a linear increase in perceived safety. In other words, the results indicate that the inclusion of at least one additional infrastructural element beyond the bicycle lane may be sufficient to substantially improve perceived safety, while further additions do not appear to yield proportional gains. This finding aligns with previous work by Hopkins and Mandic (2017), which emphasizes that the mere presence of a bicycle lane is not always sufficient to provide an adequate sense of safety for cycling.

Regarding the perception of discomfort, a small yet statistically significant difference was observed between Scenario 1 and Scenario 3. This discrepancy can be attributed to the composition of the scenarios. Scenario 1 consists solely of a dedicated bicycle lane, whereas Scenario 3 integrates the bicycle lane with urban infrastructure elements, specifically bus shelters and bicycle racks. Notably, bicycle racks may play a crucial role in cyclists' perceived comfort. In other words, the availability of bicycle racks along the route could enhance the cycling experience compared to a scenario where only the bicycle lane is present, in line with Heinen and Buehler (2019). The opportunity to securely park one's bicycle may be an important factor contributing to this increased comfort, corroborating results of Piras et al. (2023). Although the study by Piras et al. (2023) does not explicitly address comfort but rather intention to cycle, it can be inferred that well-designed infrastructure elements such as bicycle racks may enhance the overall cycling experience, potentially improving both perceived comfort and intention to cycle.

At the same time, the absence of significant differences involving Scenario 4 suggests that perceived comfort may not increase cumulatively with the addition of multiple infrastructural elements. In this respect, differences in comfort appear to emerge primarily when the added element is clearly interpretable and functionally meaningful for cyclists, as in the comparison between Scenario 3 and Scenario 1. Conversely, more complex combinations of elements, such as the joint presence of urban greenery and street furniture, may be less easily discriminable at a perceptual level, resulting in comparable comfort evaluations across scenarios. This pattern can be explained by principles of cognitive load: as the number of elements and their interactions increases, so does the cognitive effort required to process them (Tremblay et al., 2023; Van Merriënboer et al., 2010). In other words, when multiple infrastructural components are presented simultaneously, the perceptual and cognitive system may reach a threshold beyond which additional features do not translate into further perceived

comfort, supporting the notion that clear, interpretable elements have the strongest impact on cyclists' subjective experience.

Furthermore, the role of bus stops in relation to cyclists' comfort perception has been examined in previous research. For instance, the study conducted by Li et al. (2012) yielded contrasting findings. They found that the presence of bus stops negatively affects cyclists' perceived comfort when the bicycle lane is physically separated from vehicular traffic. Conversely, and rather unexpectedly, bus stops were associated with increased comfort when the bicycle lane was integrated into the roadway.

Regarding the perception of vehicular interaction, the only significant difference observed was between the Baseline Scenario and all other scenarios. This finding reflects the design of the scenarios presented to participants. Specifically, in scenarios including a bicycle lane, the videos depicted a cyclist separated from motorized traffic, leading participants to perceive minimal interaction with vehicles. Consequently, no significant differences were observed between the scenarios featuring a bicycle lane, while the Baseline Scenario, which lacked any cycling infrastructure, elicited a higher perception of vehicular interaction.

Notably, traffic conditions (high vs. low) did not show a significant difference; therefore, H4 must be rejected, and consequently also H4a, H4b, H4c, and H4d. The lack of significance may be due to the small and unbalanced sample size. The sample imbalance occurred during the initial data cleaning process, where responses from participants who completed the task either too quickly or too slowly were removed. This process disproportionately affected the two conditions, resulting in a sample size of  $n = 64$  for the low-traffic condition and  $n = 45$  for the high-traffic condition. Power analysis indicated that with a larger and more balanced sample ( $n = 101$  for both the low-traffic and high-traffic conditions), the result would likely have been significant, with a power of 0.80.

The second part of the analysis focused on examining how social norms interact with perceptions of danger, and the intention to use the bicycle. A significant positive relation was found between injunctive norms and the intention to use the bicycle, supporting H5. This result supports the idea that social influence plays a pivotal role in transportation choices, with individuals being more likely to adopt cycling if they perceive it to be socially accepted and valued (Baeli et al., 2022; Liu et al., 2023; Xu et al., 2020). This finding is particularly relevant when considering the potential for promoting cycling as a socially endorsed behavior, which could be facilitated by public campaigns or policy initiatives aimed at normalizing cycling and creating a culture of sustainable mobility.

Finally, the moderation analysis suggested a potential variation in the relationship between injunctive norms and cycling intentions depending on perceived danger. However, this result should be

interpreted with caution, as it emerged from an exploratory research question (“Do injunctive norms moderate the relationship between perceived danger and intention to use the bicycle across different cycling scenarios?”) and the observed  $p$ -value (0.06) did not reach conventional thresholds for statistical significance ( $p < 0.05$ ). In particular, the pattern of results indicated that when participants perceived low levels of danger, their intention to use the bicycle tended to increase as perceived social approval for cycling increased. By contrast, when perceived danger was high, the association between injunctive norms and cycling intention appeared substantially attenuated. Overall, this pattern may tentatively suggest that social approval could play a more relevant role under safer perceived conditions, whereas perceived danger may represent a stronger constraint that limits the influence of social norms. Nevertheless, given the borderline statistical evidence, these interpretations should be considered exploratory and not definitive.

The central role of perceived safety is further consistent with Alfonzo’s (2005) hierarchy of walking needs, which posits safety as a more fundamental requirement than social approval, a framework that will also be discussed in Chapter IV. Overall, this interaction suggests that policies and interventions aimed at reducing perceived danger, particularly through improvements in cycling infrastructure, may be essential for creating conditions in which social norms can be effectively leveraged to promote cycling.

Despite the insights provided by this study, several limitations warrant consideration. First, the sample was geographically and demographically restricted to participants from Cagliari, which may limit the generalizability of the findings to other urban contexts characterized by different infrastructural, cultural, or mobility-related conditions. In addition, participants were recruited through personal networks using a snowball sampling approach. As a non-probability sampling method, this strategy does not ensure representativeness of the broader population and may have introduced self-selection biases, suggesting that the results should be interpreted with appropriate caution.

Second, although the use of immersive video-based scenarios allowed for a controlled and ecologically grounded representation of cycling environments, the outcomes relied on self-reported intentions rather than observed behavior. While intention is widely recognized as a robust predictor of behavior within established frameworks such as the TPB (Ajzen, 1991), it does not invariably translate into actual behavioral enactment, as highlighted by the intention–behavior gap (Sheeran & Webb, 2016). Consequently, the present findings should be interpreted as indicative of motivational tendencies rather than definitive behavioral outcomes.

A further limitation concerns the manipulation of traffic conditions, which did not produce statistically significant effects. This result may partly reflect methodological constraints, particularly

the relatively small and uneven distribution of participants across low- and high-traffic conditions, potentially reducing statistical power. At the same time, it raises substantive questions regarding how traffic-related cues are perceived and processed within simulated environments. For this reason, the role of traffic and its interaction with infrastructural and socio-psychological factors is examined in greater depth in the subsequent study, where the experimental design is refined to more explicitly capture its influence.

### **3.3. Study 2**

#### **3.3.1. Objectives and hypotheses**

Study 2 aimed to extend the investigation initiated in Study 1 by further examining how perceptions of urban street scenarios influence individuals' intention to cycle in an urban context. Using immersive desktop-based reproductions of a street in Cagliari, the study assessed the effects of multiple scenarios on perceived danger, discomfort, negative interactions with traffic, and cycling intention, mirroring the core outcomes examined in the previous study.

Considering the non-significant effects of traffic manipulation observed in Study 1, particular attention was devoted to a more detailed exploration of traffic-related variations across scenarios. In addition, Study 2 expanded the analysis of social influence by focusing on descriptive norms, examining whether the perceived prevalence of cycling within each scenario contributed to shaping individuals' evaluations of the environment and their intention to cycle. The choice to focus on descriptive norms was theoretically grounded in prior research suggesting that they are more context-specific and sensitive to situational cues than injunctive norms, making them particularly suitable for scenario-based investigations (e.g., Ryoo & Kim, 2023; Shteynberg et al., 2009). In this regard, descriptive norms have been shown to primarily motivate behavior in the immediate context in which others' behavior can be observed, whereas injunctive norms tend to operate more broadly across contexts (Smith et al., 2012). In the present study, however, descriptive norms were necessarily based on participants' expectations about others' behavior within each scenario rather than on direct behavioral observation, thus reflecting an anticipated or inferred descriptive norm.

By maintaining continuity with the methodological approach of Study 1 while deepening the examination of traffic conditions and scenario-specific social norms, Study 2 provides a more fine-grained understanding of how physical and social cues jointly shape cycling intention. Rather than introducing a new theoretical framework, Study 2 refines the empirical investigation developed in Study 1 by simplifying the experimental design and focusing on two key aspects that emerged as particularly relevant: traffic conditions and scenario-specific social influence. This approach allows for a more controlled examination of how contextual cues embedded in urban environments jointly

shape cycling intentions. Based on the existing literature and the findings of Study 1, the following hypotheses were formulated:

Hypothesis 1 (H1). Scenarios including a bicycle lane, compared to the scenario without cycling infrastructure, were expected to be associated with:

H1a: Lower perceived danger;

H1b: Lower perceived discomfort;

H1c: Fewer negative vehicular interactions;

H1d: Higher intention to cycle.

Hypothesis 2 (H2). Scenarios enriched with urban greenery and street furniture, compared to scenarios including only a bicycle lane, were expected to be associated with:

H2a: Further reductions in perceived danger;

H2b: Further reductions in perceived discomfort;

H2c: Fewer negative vehicular interactions;

H2d: Higher intention to cycle.

Hypothesis 3 (H3). Scenarios characterized by more supportive cycling infrastructure and higher streetscape quality were expected to be associated with higher descriptive norms.

Hypothesis 4 (H4). High-traffic scenarios, compared to low-traffic scenarios, were expected to be associated with:

H4a: Higher perceived danger;

H4b: Higher perceived discomfort;

H4c: More negative vehicular interactions;

H4d: Lower intention to cycle.

Hypothesis 5 (H5). Descriptive norms were expected to be positively associated with intention to cycle across scenarios.

Furthermore, to explore the role of descriptive norms more specifically, the present study proposes the following research question: do descriptive norms mediate the relationship between traffic conditions and the intention to use the bicycle across different cycling scenarios?

### **3.3.2. Method**

#### **3.3.2.1. Sample**

Participants were recruited online via LimeSurvey through personal networks using a snowball sampling approach. The data collection began in late 2024 and continued until the spring of 2025, ensuring a broad temporal window for participant involvement. Because this is a non-probability sampling method, the sample cannot be considered representative of the broader population, and the results should therefore be interpreted with caution.

A total of 679 responses were initially collected. After excluding participants who did not complete the entire survey and removing outliers, the final sample used for all analyses comprised 388 participants, resulting in the exclusion of 291. Participants' ages ranged from 18 to 73 years ( $M = 44.5$ ,  $SD = 13.9$ ). The sample included 184 women (47.4%) and 204 men (52.6%). Regarding employment status, the majority of participants were employees (62.4%,  $n = 242$ ), followed by self-employed individuals (11.3%,  $n = 44$ ), university students (9.5%,  $n = 37$ ), postgraduate researchers/PhD students (8.8%,  $n = 34$ ), retirees (4.1%,  $n = 16$ ), with a small proportion being unemployed (0.5%,  $n = 2$ ), homemakers (0.5%,  $n = 2$ ), or categorized as other (2.8%,  $n = 11$ ). In terms of educational status, participants held a high school diploma (16%,  $n = 62$ ), a bachelor's degree (39.2%,  $n = 152$ ), a postgraduate degree (41.5%,  $n = 161$ ), a professional specialization (1%,  $n = 4$ ), or had completed elementary/middle school (2.3%,  $n = 9$ ). Regarding recent bicycle use (Ma et al., 2014), most participants (65.2%,  $n = 253$ ) reported not using a bicycle. The remaining participants indicated varying levels of use: 13.9% ( $n = 54$ ) reported cycling less than once a month, 8% ( $n = 31$ ) reported cycling one to three times per month, 2.6% ( $n = 10$ ) reported cycling once a week, and 10.3% ( $n = 40$ ) reported cycling more than once a week.

#### **3.3.2.2. Research design**

Study 2 adopted a  $2 \times 3$  experimental design, in which four independent variables were manipulated. The between-subjects variable was traffic condition, with two levels (high vs. low traffic). The within-subjects variables included the presence or absence of a bicycle lane, urban greenery, and street furniture (i.e., bus shelters and bicycle racks).

Compared to Study 1, the number of scenarios was reduced from five to three. This decision was driven by several considerations. First, unlike Study 1, Study 2 did not aim to examine the specific effects of individual infrastructural elements or to replicate previous findings. Instead, it focused on a more in-depth investigation of traffic manipulation and the role of social norms embedded within the scenarios.

Second, to facilitate the recruitment of a larger sample, particularly important given the between-subjects manipulation of traffic, as highlighted in the Discussion of Study 1 (see Section 3.2.4.), the overall length of the experiment was reduced. Limiting the number of scenarios was intended to make the study more concise and to minimize participant dropout. In line with this objective, not only was the number of videos reduced, but their duration was also shortened. In Study 2, videos had an average length of approximately 35 seconds.

As in Study 1, all videos were constructed within a virtual environment using Unity software (Unity Technologies, 2024). The scenarios were characterized as follows:

Baseline Scenario (BS): represents a real street in the city of Cagliari without a bicycle lane, urban greenery, or street furniture;

Scenario 1 (S1): in which car parking was removed, sidewalks were widened, and a raised shared pedestrian and bicycle path, with an asphalt-colored surface, was built on the eastern side of the corridor;

Scenario 2 (S2): urban greenery and street furniture were introduced in Scenario 1, and the color of the bicycle path was changed to red.

Participants were randomly assigned to one of two traffic conditions (high traffic or low traffic). The presentation of the various scenarios was also randomized, except for Baseline Scenario, which was shown first to all participants. Figure 22 illustrates the structure with which the different manipulated scenarios were presented.

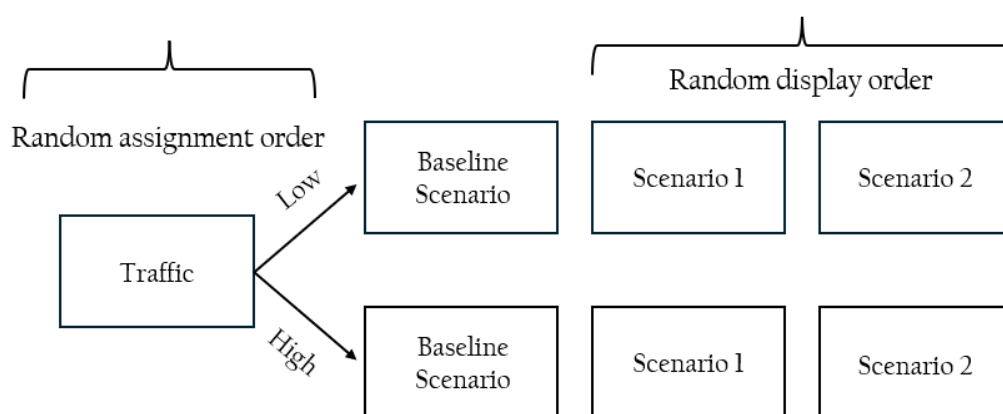


**Figure 22. Order of assignment to the two traffic conditions (high vs low) and order in which scenarios are displayed.**

For each scenario, participants viewed a video, accompanied by a representative photo of the video (see Figure 23 for the low-traffic scenarios and Figure 24 for the high-traffic scenarios). Because sensory fidelity is known to affect the perceived realism of virtual environmental stimuli, particularly

through auditory cues (Kort et al., 2003), the videos included real traffic sound to enhance immersion and ecological validity.

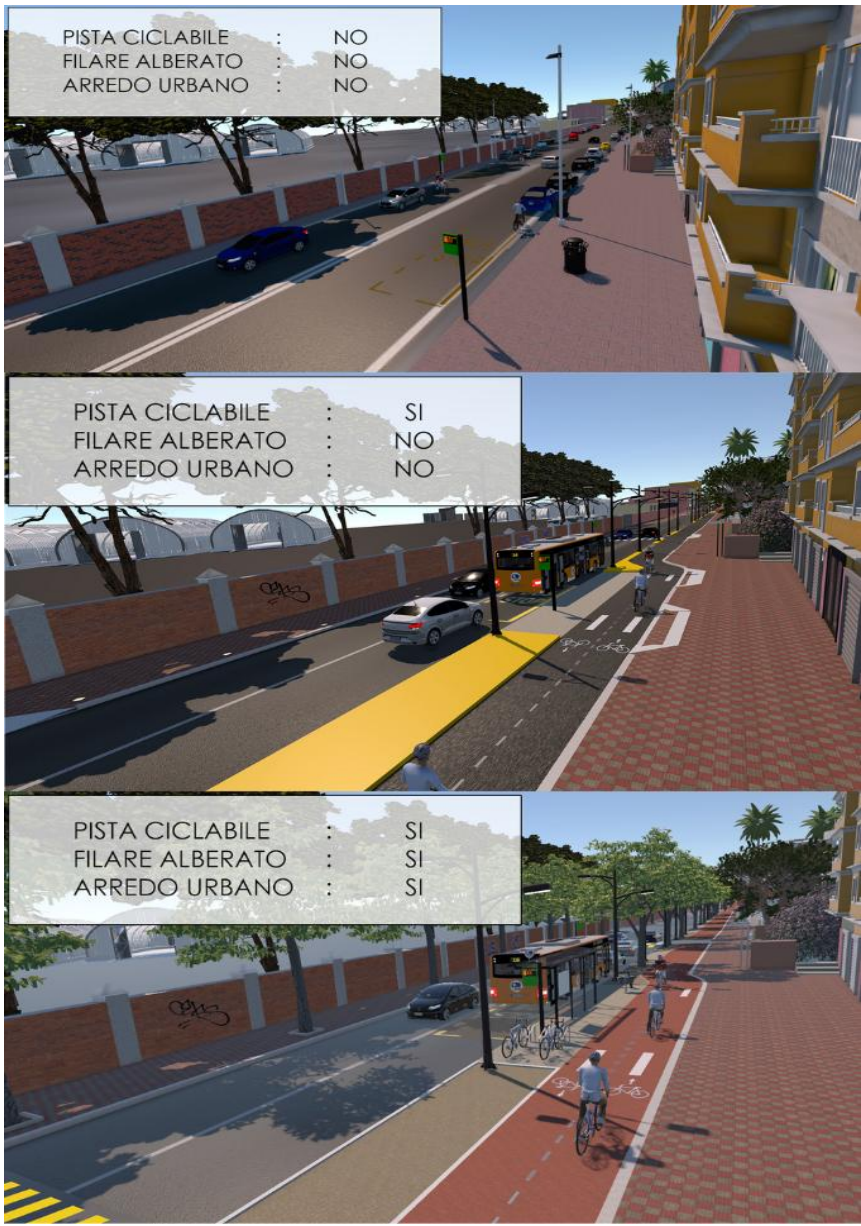


**Figure 23. Low-traffic scenarios. Top: Baseline Scenario without bicycle lane, greenery, or street furniture. Middle: Scenario 1 with removed parking, widened sidewalks, and a raised shared pedestrian–bicycle path. Bottom: Scenario adds to Scenario 1 urban greenery, street furniture and a red color to the bicycle path.**

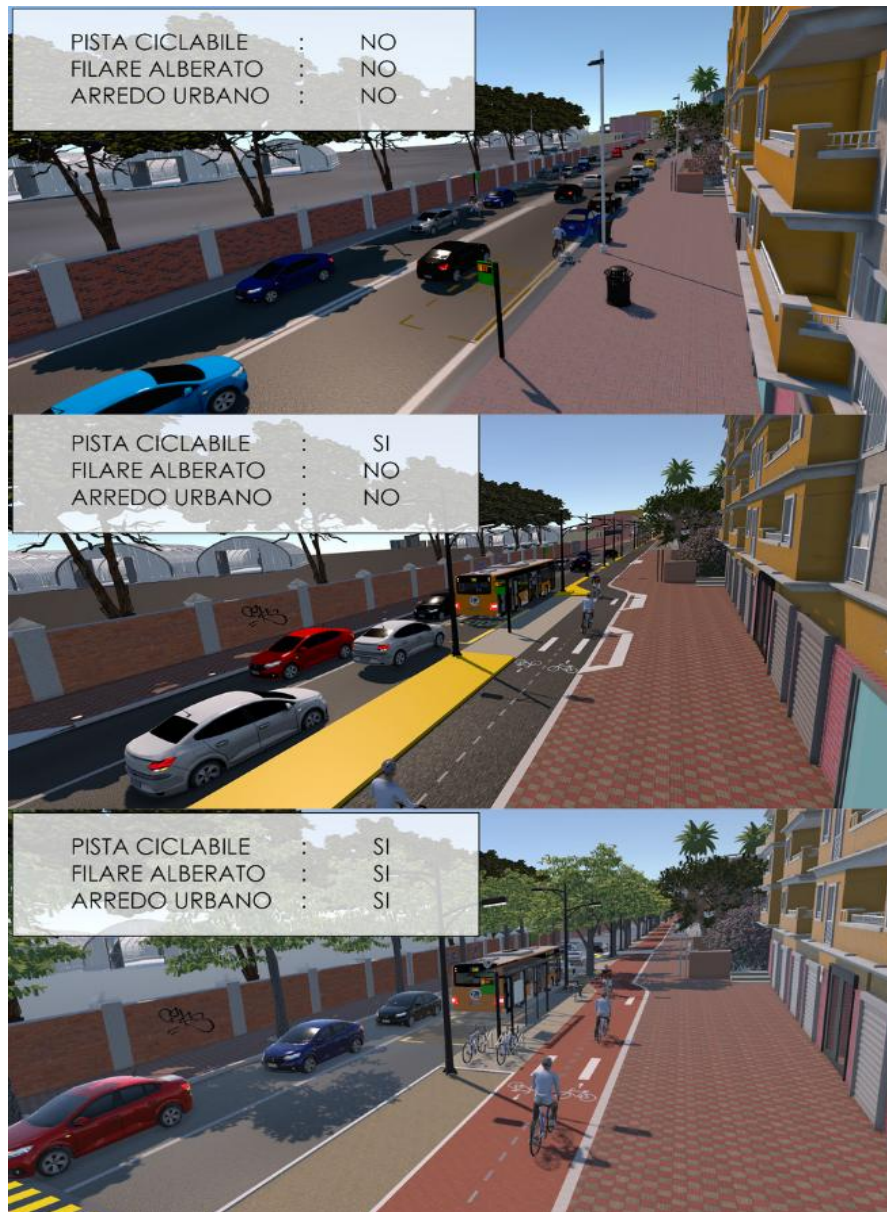


**Figure 24. High-traffic scenarios. Top: Baseline Scenario without a bicycle lane, greenery, or street furniture. Middle: Scenario 1 with removed parking, widened sidewalks, and a raised shared pedestrian–bicycle path. Bottom: Scenario adds to Scenario 1 urban greenery, street furniture and a red color to the bicycle path.**

The order of activities in the experimental protocol was as follows: initially, participants answered questions regarding socio-demographic characteristics, and frequency of bicycle use. Next, they viewed the three scenarios one at a time, answering questions about perception of danger, discomfort, negative vehicular interaction, the descriptive norm about whether people close to them would cycle in that scenario, and their own intention to cycle. All questionnaire items are presented in Italian, and all participants took part in the study voluntarily and did not receive any compensation.

### 3.3.2.3. Measures

The measuring instruments employed in the study were as follows.

*Perception of danger* was measured by three statements: “Considering the scenario you have just watched, imagine yourself as the cyclist in the video and provide a rating for each of the following attributes: presence of hazards, intersections are unsafe, crossings are unsafe”. Internal consistency was satisfactory, with Cronbach’s alpha values of .77, .88, and .93 for Baseline Scenario, Scenario 1, and Scenario 2, respectively.

*Perception of discomfort* was measured by three statements: “Considering the scenario you have just watched, imagine yourself as the cyclist in the video and provide a rating for each of the following attributes: creates a sense of discomfort, presence of visually unpleasant elements, presence of unpleasant sounds”. Internal consistency was satisfactory, with Cronbach’s alpha values of .74, .83, and .85 for Baseline Scenario, Scenario 1, and Scenario 2, respectively.

*Negative vehicular interaction* was measured by two statements: “Considering the scenario you have just watched, imagine yourself as the cyclist in the video and provide a rating for each of the following attributes: interaction with cars is problematic, interaction with cyclists is problematic”. Spearman’s rho correlation values for Baseline Scenario, Scenario 1, and Scenario 2 were .50, .61, .71, respectively with a p-value < 0.001.

*Descriptive norm* (adapted from Fornara et al., 2016) was measured by three statements: “Many people close to me would use a bicycle in this scenario”; “Many of my colleagues would use a bicycle in this scenario”; “Many of my fellow citizens would use a bicycle in this scenario”. Internal consistency was satisfactory, with Cronbach’s alpha values of .86, .93, and .93 for Baseline Scenario, Scenario 1, and Scenario 2, respectively.

All measures above were assessed using a seven-point Likert scale ranging from 1 (*Strongly disagree*) to 7 (*Strongly agree*). For each construct, item scores were averaged to create a composite index.

*Behavioral intention* was assessed with one statement, measuring the intention to choose the path: “If you were to travel along Viale Ciusa under the current conditions shown in the scenario, would you use a bicycle?” rated on a seven-point scale (1 = Absolutely not, 7 = Yes, absolutely).

All variables were assessed using ad hoc items, except for *descriptive norm*. Main socio-demographic indicators (i.e., gender, age, employment status, educational status, and bicycle usage frequency) were also collected for each participant.

#### **3.3.2.4. Data analysis**

Prior to hypothesis testing, internal consistency was assessed for all multi-item scales containing at least three items. As reported in the previous Section, Cronbach’s alpha coefficients met the minimum

acceptable thresholds, indicating satisfactory reliability across all measures (Kilic, 2016; Tavakol & Dennick, 2011). Composite scores were subsequently computed for each construct.

First, differences between the three scenarios were examined using a non-parametric repeated-measures ANOVA on the original wide-format dataset. The analyses were conducted in Jamovi (version 2.3.28; The Jamovi Project, 2023) using the Friedman test (Friedman, 1940), chosen because the within-subject variables violated normality assumptions. Subsequently, to examine the influence of traffic condition on the scenario-specific outcomes, linear mixed-effects models were conducted on the long-format dataset. Scenario was included as a within-subject factor and traffic condition as a between-subject factor, with participant ID modeled as a random intercept and estimation performed using Restricted Maximum Likelihood (REML; Corbeil & Searle, 1976). The use of mixed-effects models allowed us to account for repeated measures and the non-normal distribution of residuals. Finally, to explore the potential mechanism underlying the effect of traffic condition on bicycle use intention, a mediation analysis was performed. For this purpose, mean scores across the three scenarios were computed for both descriptive norms and intention to use a bicycle. Traffic condition was entered as the independent variable, mean descriptive norms as the mediator, and mean intention as the dependent variable. Indirect effects were estimated using a bootstrap procedure with 5000 samples and percentile confidence intervals, which does not assume normality of the indirect effect distribution. Standardized estimates were reported. This approach ensured that the mediation analysis was robust despite the non-normal distribution of the original variables.

### 3.3.3. Results

#### 3.3.3.1. Descriptive statistics

Descriptive statistics for all measured variables, including perception of danger, perception of discomfort, vehicular interaction, descriptive norm, and intention to cycle, are reported in Table 13, with means, medians, and standard deviations presented for each scenario as well as across the entire sample.

**Table 13. Descriptive statistics (mean, median, and standard deviation) for the variables included in the analysis.**

|                              | Baseline Scenario |        |      | Scenario 1 |        |      | Scenario 2 |        |      | Total |        |      |
|------------------------------|-------------------|--------|------|------------|--------|------|------------|--------|------|-------|--------|------|
|                              | Mean              | Median | SD   | Mean       | Median | SD   | Mean       | Median | SD   | Mean  | Median | SD   |
| <b>Danger</b>                | 6.03              | 6.33   | 1.11 | 2.42       | 2.00   | 1.40 | 2.47       | 2.00   | 1.50 | 3.64  | 3.00   | 2.16 |
| <b>Discomfort</b>            | 5.12              | 5.00   | 1.46 | 2.47       | 2.00   | 1.39 | 2.63       | 2.33   | 1.49 | 3.41  | 3.00   | 1.89 |
| <b>Vehicular interaction</b> | 5.82              | 6.00   | 1.23 | 2.13       | 2.00   | 1.34 | 2.29       | 2.00   | 1.42 | 3.41  | 3.00   | 2.16 |
| <b>Descriptive norm</b>      | 2.03              | 1.67   | 1.14 | 4.57       | 4.67   | 1.62 | 4.64       | 4.67   | 1.68 | 3.75  | 3.67   | 1.93 |
| <b>Intention to cycle</b>    | 2.18              | 2.00   | 1.52 | 5.22       | 5.50   | 1.74 | 5.13       | 6.00   | 1.77 | 4.17  | 4.00   | 2.19 |

**Note:** *SD* = Standard Deviation.

### 3.3.3.2. Differences across scenarios

To verify H1 (a, b, c, d), H2 (a, b, c, d), and H3, the differences between the scenarios were checked. The Friedman tests revealed significant scenario effects for all dependent variables.

For perceived danger, differences across scenarios were significant ( $\chi^2 = 532$ ,  $df = 2$ ,  $p < .001$ ). Post hoc Durbin–Conover tests showed higher perceived danger in Baseline Scenario compared with Scenario 1 (statistic = 35.13,  $p < .001$ ) and Scenario 2 (statistic = 36.00,  $p < .001$ ). This indicates that the scenario without a bicycle lane, urban greenery, or street furniture (Baseline Scenario) was perceived as more dangerous than both the scenario featuring only a bicycle lane with the same color as the roadway (Scenario 1), and the scenario including a red-colored bicycle lane, urban greenery, and street furniture (Scenario 2). In contrast, no significant differences in perceived danger were observed between the scenario featuring only a bicycle lane with the same color as the roadway (Scenario 1) and the scenario including a red-colored bicycle lane, urban greenery, and street furniture (Scenario 2; statistic = 0.87,  $p = .384$ ).

For perceived discomfort, the Friedman test was significant ( $\chi^2 = 460$ ,  $df = 2$ ,  $p < .001$ ). Post hoc Durbin–Conover tests showed higher perceived discomfort in Baseline Scenario than in Scenario 1 (statistic = 29.70,  $p < .001$ ) and Scenario 2 (statistic = 28.36,  $p < .001$ ). This indicates that the scenario without a bicycle lane, urban greenery, or street furniture (Baseline Scenario) was perceived as more uncomfortable than both the scenario featuring only a bicycle lane with the same color as the roadway (Scenario 1), and the scenario including a red-colored bicycle lane, urban greenery, and street furniture (Scenario 2). In contrast, no significant differences in perceived discomfort were observed between the scenario featuring only a bicycle lane with the same color as the roadway (Scenario 1) and the scenario including a red-colored bicycle lane, urban greenery, and street furniture (Scenario 2; statistic = 1.34,  $p = .179$ ).

For negative vehicular interaction, the Friedman test again showed significant differences ( $\chi^2 = 563$ ,  $df = 2$ ,  $p < .001$ ). Post hoc Durbin–Conover tests showed higher negative vehicular interaction in Baseline Scenario compared with Scenario 1 (statistic = 39.98,  $p < .001$ ) and Scenario 2 (statistic = 38.23,  $p < .001$ ). This indicates that the scenario without a bicycle lane, urban greenery, or street furniture (Baseline Scenario) was perceived as producing more negative vehicular interaction than both the scenario featuring only a bicycle lane with the same color as the roadway (Scenario 1), and the scenario including a red-colored bicycle lane, urban greenery, and street furniture (Scenario 2). In contrast, no significant differences in negative vehicular interaction were observed between the scenario featuring only a bicycle lane with the same color as the roadway (Scenario 1) and the

scenario including a red-colored bicycle lane, urban greenery, and street furniture (Scenario 2; statistic = 1.75,  $p = .080$ ).

For descriptive norm, the Friedman test was significant ( $\chi^2 = 413$ ,  $df = 2$ ,  $p < .001$ ). Post hoc Durbin–Conover tests showed lower perceived likelihood of others cycling in Baseline Scenario relative to Scenario 1 (statistic = 25.44,  $p < .001$ ) and Scenario 2 (statistic = 25.98,  $p < .001$ ). This indicates that the scenario without a bicycle lane, urban greenery, or street furniture (Baseline Scenario) was perceived as producing less perceived likelihood of others cycling than both the scenario featuring only a bicycle lane with the same color as the roadway (Scenario 1), and the scenario including a red-colored bicycle lane, urban greenery, and street furniture (Scenario 2). In contrast, no significant differences in perceived likelihood of others cycling were observed between the scenario featuring only a bicycle lane with the same color as the roadway (Scenario 1) and the scenario including a red-colored bicycle lane, urban greenery, and street furniture (Scenario 2; statistic = 0.54,  $p = .591$ ).

Finally, for behavioral intention, the Friedman test indicated significant differences ( $\chi^2 = 519$ ,  $df = 2$ ,  $p < .001$ ). Post hoc Durbin–Conover tests showed lower intention to cycle in Baseline Scenario compared with Scenario 1 (statistic = 34.95,  $p < .001$ ) and Scenario 2 (statistic = 33.44,  $p < .001$ ). This indicates that the scenario without a bicycle lane, urban greenery, or street furniture (Baseline Scenario) was perceived as producing less intention to cycle than both the scenario featuring only a bicycle lane with the same color as the roadway (Scenario 1), and the scenario including a red-colored bicycle lane, urban greenery, and street furniture (Scenario 2). In contrast, no significant differences in intention to cycle were observed between the scenario featuring only a bicycle lane with the same color as the roadway (Scenario 1) and the scenario including a red-colored bicycle lane, urban greenery, and street furniture (Scenario 2; statistic = 1.50,  $p = .134$ ).

#### **3.3.3.3. Effects of traffic condition, scenario, and past behavior on cycling-related outcomes**

To verify H4 (a, b, c, d), the role of traffic manipulation (high vs. low) was examined.

Regarding the perception of danger, a linear mixed-effects model estimated via REML was used to examine the factors influencing perception of danger ratings. The model included traffic condition, scenario, bicycle usage frequency, and their interaction as fixed effects, while participant ID was entered as a random intercept. The model showed a satisfactory fit (AIC = 3977.71; BIC = 4045.32; Log-likelihood = -1990.89) and converged without issues. The marginal  $R^2$  indicated that fixed effects accounted for 61.3% of the variance, while the conditional  $R^2$  reached 67.3% when including the random component.

The analysis of fixed effects revealed a strong effect of scenario ( $F(2, 772) = 1086.54, p < .001$ ), whereas traffic condition ( $F(1, 385) = 2.68, p = .103$ ), bicycle usage frequency ( $F(1, 385) = 2.67, p = .103$ ), and their interaction ( $F(2, 772) = 0.89, p = .413$ ) were not statistically significant. Parameter estimates showed that Scenarios 1 and 2 produced significantly lower perception of danger ratings compared to Baseline Scenario (Scenario 1:  $b = -3.49, SE = 0.12, p < .001$ ; Scenario 2:  $b = -3.50, SE = 0.12, p < .001$ ). The remaining coefficients were not significant.

Post hoc comparisons confirmed a pronounced effect of scenario, with significant differences between Baseline Scenario and Scenario 1 ( $p < .001$ ) and between Baseline Scenario and Scenario 2 ( $p < .001$ ), while no difference emerged between Scenarios 1 and 2 ( $p = 1.00$ ), confirming the results of the previous analysis in Section 3.3.3.2. Regarding traffic condition, the comparison between low and high traffic did not reach significance ( $p = .103$ ).

Finally, the random-effects structure indicated a participant-level variance of 0.282 ( $SD = 0.531$ ), with an ICC of 0.156, suggesting a moderate proportion of variance attributable to individual differences. The model is shown in Figure 25.

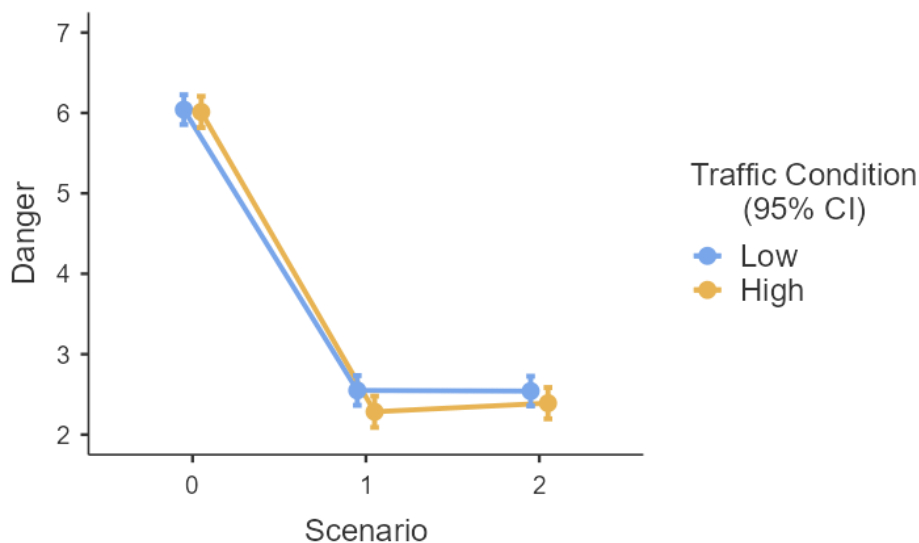


**Figure 25. Linear mixed-effects model predicting perception of danger. Scenario showed a strong significant effect, while traffic condition, bicycle usage frequency, and their interaction were non-significant. Error bars indicate 95% confidence intervals.**

Regarding the perception of discomfort, a linear mixed-effects model estimated via REML was conducted to examine factors influencing perception of discomfort ratings. The model included traffic condition, scenario, bicycle usage frequency, and their interaction as fixed effects, with participant ID entered as a random intercept. The model converged successfully and showed acceptable fit indices ( $AIC = 4102.04$ ;  $BIC = 4168.72$ ;  $\text{Log-likelihood} = -2025.59$ ). The marginal  $R^2$  indicated that

fixed effects accounted for 41.4% of the variance, whereas the conditional  $R^2$  reached 56.6% when including random effects.

Analysis of fixed effects revealed a significant effect of scenario ( $F(2, 772) = 550.31, p < .001$ ), while traffic condition ( $F(1, 385) = 0.33, p = .564$ ), bicycle usage frequency ( $F(1, 385) = 3.06, p = .081$ ), and their interaction ( $F(2, 772) = 1.19, p = .304$ ) were not statistically significant. Parameter estimates showed that Scenarios 1 and 2 were associated with significantly lower perception of discomfort ratings compared to Baseline Scenario (Scenario 1:  $b = -2.53, SE = 0.12, p < .001$ ; Scenario 2:  $b = -2.47, SE = 0.12, p < .001$ ). The remaining coefficients were not significant.

Post hoc comparisons confirmed that both Scenario 1 and Scenario 2 differed significantly from Baseline Scenario (Baseline Scenario vs. Scenario 1:  $p < .001$ ; Baseline Scenario vs. Scenario 2:  $p < .001$ ), whereas the difference between Scenario 1 and 2 was not significant ( $p = .167$ ), confirming the results of the previous analysis. Similarly, comparisons between low and high traffic conditions were non-significant ( $p = .564$ ).

The random effects showed a participant-level variance of 0.539 ( $SD = 0.734$ ), with an ICC of 0.258, indicating that approximately 26% of the variance in perception of discomfort ratings could be attributed to individual differences. The model is shown in Figure 26.

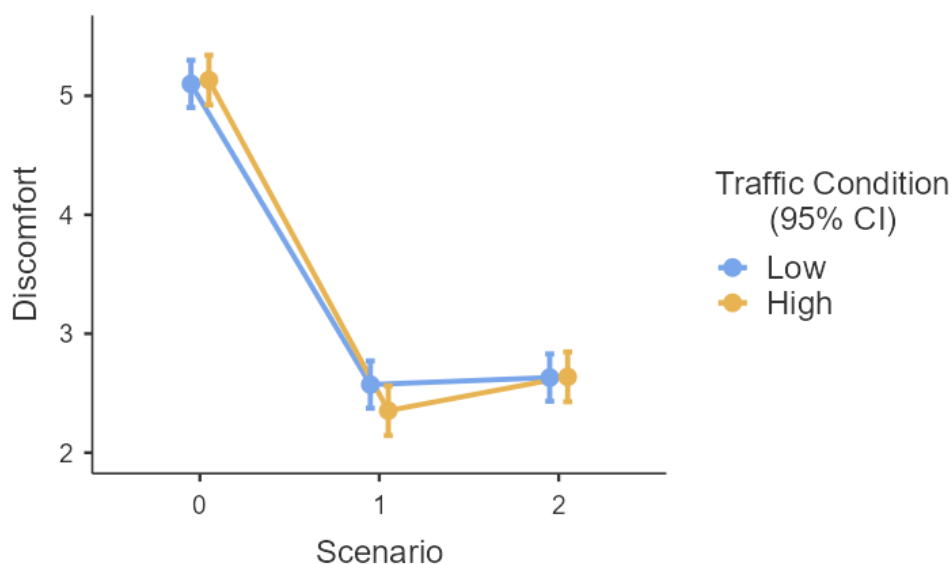


**Figure 26. Linear mixed-effects model predicting perception of discomfort. Scenario showed a strong significant effect, while traffic condition, bicycle usage frequency, and their interaction were non-significant. Error bars indicate 95% confidence intervals.**

Regarding the negative vehicular interaction, a linear mixed-effects model estimated via REML was used to examine factors influencing negative vehicular interaction. The model included traffic condition, scenario, bicycle usage frequency, and their interaction as fixed effects, with participant

ID specified as a random intercept. The model converged successfully and showed good fit indices (AIC = 3944.97; BIC = 4012.70; Log-likelihood = -1974.58). The marginal  $R^2$  indicated that fixed effects accounted for 62.0% of the variance, whereas the conditional  $R^2$  reached 69.6% when including random effects.

Analysis of fixed effects revealed a significant effect of scenario ( $F(2, 772) = 1179.66, p < .001$ ), while traffic condition ( $F(1, 385) = 2.42, p = .121$ ), bicycle usage frequency ( $F(1, 385) = 0.06, p = .803$ ), and their interaction ( $F(2, 772) = 0.16, p = .854$ ) were not statistically significant. Parameter estimates showed that Scenarios 1 and 2 were associated with significantly lower negative vehicular interaction ratings compared to Baseline Scenario (Scenario 1:  $b = -3.66, SE = 0.12, p < .001$ ; Scenario 2:  $b = -3.54, SE = 0.12, p < .001$ ). All other coefficients were not significant.

Post hoc comparisons confirmed that both Scenario 1 and Scenario 2 differed significantly from Baseline Scenario (Baseline Scenario vs. Scenario 1:  $p < .001$ ; Baseline Scenario vs. Scenario 2:  $p < .001$ ), whereas the difference between Scenario 1 and 2 was not significant ( $p = .161$ ), confirming the results of the previous analysis. Similarly, comparisons between low and high traffic conditions were non-significant ( $p = .121$ ).

The random-effects component indicated a participant-level variance of 0.353 ( $SD = 0.594$ ), with an ICC of 0.198, suggesting that approximately 20% of the variance in negative vehicular interaction ratings was attributable to individual differences. The model is shown in Figure 27.

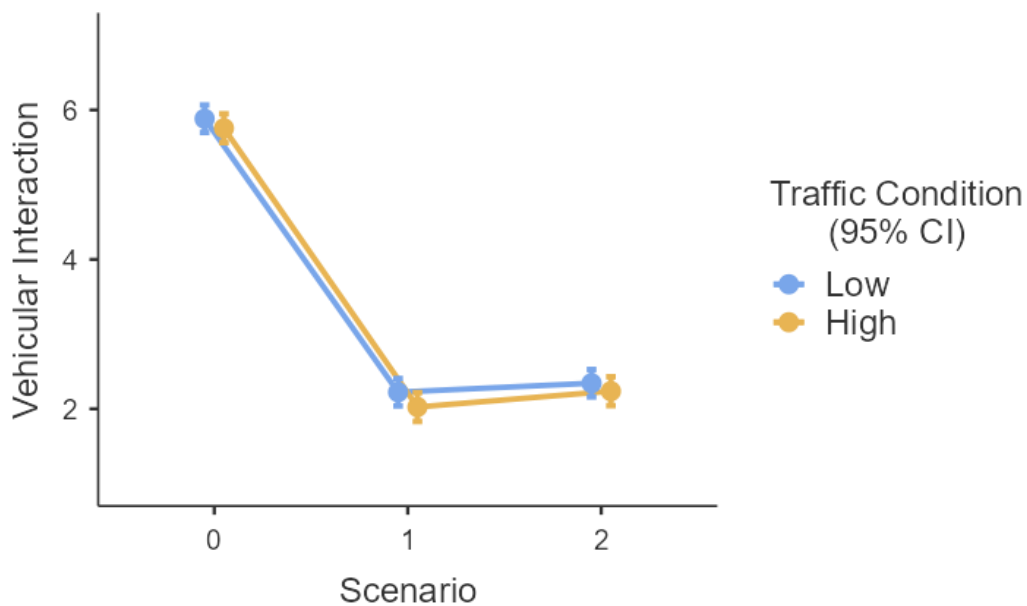


**Figure 27. Linear mixed-effects model predicting negative vehicular interaction. Scenario showed a strong significant effect, while traffic condition, bicycle usage frequency, and their interaction were non-significant. Error bars indicate 95% confidence intervals.**

Regarding the descriptive norms, a linear mixed-effects model estimated via REML was conducted to examine factors influencing descriptive norms. The model included traffic condition, scenario, bicycle usage frequency, and their interaction as fixed effects, with participant ID specified as a random intercept. The model converged successfully and showed acceptable fit indices (AIC = 4249.35; BIC = 4315.50; Log-likelihood = -2125.98). The marginal  $R^2$  indicated that fixed effects accounted for 40.1% of the variance, while the conditional  $R^2$  reached 43.9% when including random effects.

Analysis of fixed effects revealed significant effects of traffic condition ( $F(1, 385) = 4.03, p = .045$ ), scenario ( $F(2, 772) = 408.79, p < .001$ ), and bicycle usage frequency ( $F(1, 385) = 6.03, p = .015$ ). The interaction between traffic condition and scenario was not significant ( $F(2, 772) = 0.03, p = .975$ ). Parameter estimates indicated that Scenarios 1 and 2 were associated with higher descriptive norms compared to Baseline Scenario (Scenario 1:  $b = 2.56, SE = 0.14, p < .001$ ; Scenario 2:  $b = 2.60, SE = 0.14, p < .001$ ), and higher bicycle usage frequency scores predicted slightly higher descriptive norms ( $b = 0.087, SE = 0.036, p = .015$ ). The main effect of traffic condition was not significant in the parameter estimates table ( $b = -0.188, SE = 0.152, p = .218$ ), but the Bonferroni-corrected post hoc comparison between low and high traffic conditions reached significance ( $p = .045$ ).

Post hoc comparisons confirmed significant differences between Baseline Scenario and both Scenario 1 ( $p < .001$ ) and Scenario 2 ( $p < .001$ ), while Scenario 1 and Scenario 2 did not differ ( $p = 1.00$ ), confirming the results of the previous analysis.

The random-effects component indicated a participant-level variance of 0.142 ( $SD = 0.377$ ), with an ICC of 0.064, suggesting that only a small proportion of the variance in descriptive norms was attributable to individual differences. The model is shown in Figure 28.

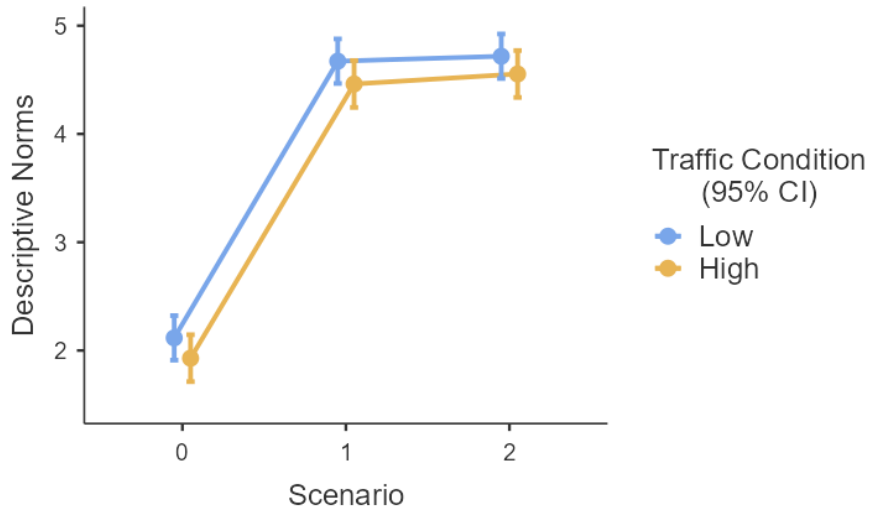


**Figure 28. Linear mixed-effects model predicting descriptive norms. Scenario and bicycle usage frequency had significant effects, and traffic condition showed a small but significant effect, with slightly higher descriptive norms under low traffic compared to high traffic. The interaction was not significant. Error bars represent 95% confidence intervals.**

Regarding the behavioral intention, a linear mixed-effects model estimated via REML was conducted to examine factors influencing bicycle use intention. The model included traffic condition, scenario, bicycle usage frequency, and their interaction as fixed effects, with participant ID specified as a random intercept. The model converged successfully and showed acceptable fit indices (AIC = 4234.28; BIC = 4300.05; Log-likelihood = -2118.26). The marginal  $R^2$  indicated that fixed effects accounted for 49.9% of the variance, while the conditional  $R^2$  reached 66.0% when including random effects.

Analysis of fixed effects revealed significant effects of scenario ( $F(2, 772) = 702.85, p < .001$ ) and bicycle usage frequency ( $F(1, 385) = 120.04, p < .001$ ), whereas traffic condition ( $F(1, 385) = 0.10, p = .756$ ) and the interaction between traffic condition and scenario ( $F(2, 772) = 0.85, p = .428$ ) were not significant. Parameter estimates showed that Scenarios 1 and 2 were associated with higher bicycle use intention compared to Baseline Scenario (Scenario 1:  $b = 3.13, SE = 0.13, p < .001$ ; Scenario 2:  $b = 3.05, SE = 0.13, p < .001$ ). Higher bicycle usage frequency scores also predicted higher intentions to use a bicycle ( $b = 0.488, SE = 0.045, p < .001$ ). All other coefficients were not significant.

Post hoc comparisons confirmed significant differences between Baseline Scenario and both Scenario 1 ( $p < .001$ ) and Scenario 2 ( $p < .001$ ), whereas Scenario 1 and Scenario 2 did not differ ( $p = 1.00$ ), confirming the results of the previous analysis in Section 3.2. Comparisons between low and high traffic conditions were not significant ( $p = .756$ ).

The random-effects component indicated a participant-level variance of 0.778 ( $SD = 0.882$ ), with an ICC of 0.322, suggesting that approximately 32% of the variance in bicycle use intention was attributable to individual differences. The model is shown in Figure 29.

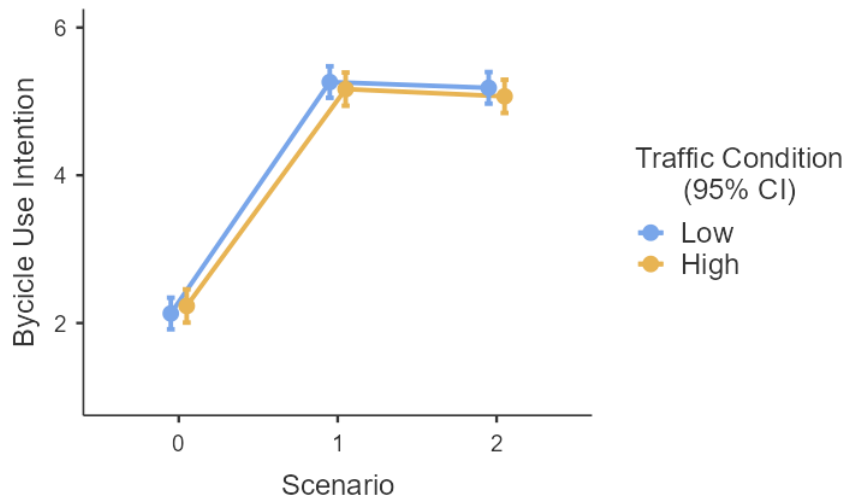


**Figure 29.** Linear mixed-effects model predicting bicycle use intention. Scenario and bicycle usage frequency had significant effects, while traffic condition and the interaction were not significant. Error bars indicate 95% confidence intervals.

#### 3.3.3.4. Mediation analysis: effect of traffic condition on bicycle use intention via descriptive norms

To verify H5, the relationship between descriptive norms and intention to use the bicycle was investigated using a mediation model. Furthermore, this analysis was useful for exploring the following research question: do descriptive norms mediate the relationship between traffic conditions and the intention to use the bicycle across different cycling scenarios?

A mediation analysis was conducted using a Generalized Linear Model (GLM) approach to examine whether the effect of traffic condition (0 = low, 1 = high) on participants' intention to use the bicycle was mediated by descriptive norms (see Figure 30). The analysis revealed that traffic condition significantly predicted descriptive norms (path a: Estimate = -0.1864, SE = 0.0937, 95% CI [-0.371, -0.00422],  $\beta = -0.1005$ ,  $z = -1.990$ ,  $p = .047$ ), and descriptive norms, in turn, significantly predicted intention to cycle (path b: Estimate = 0.5697, SE = 0.0679, 95% CI [0.434, 0.706],  $\beta = 0.4016$ ,  $z = 8.395$ ,  $p < .001$ ).

The indirect effect of traffic condition on intention via descriptive norms was marginally non-significant (Estimate = -0.1062, SE = 0.0546, 95% CI [-0.220, -0.00250],  $\beta = -0.0404$ ,  $z = -1.944$ ,  $p = .052$ ). The direct effect of traffic condition on intention, not through descriptive norms, was not significant (Estimate = 0.0743, SE = 0.1243, 95% CI [-0.161, 0.327],  $\beta = 0.0282$ ,  $z = 0.598$ ,  $p = .550$ ),

nor was the total effect (Estimate = -0.0319, SE = 0.1345, 95% CI [-0.299, 0.232],  $\beta$  = -0.0121,  $z$  = -0.237,  $p$  = .812).

These results suggest a tendency for descriptive norms to mediate the relationship between traffic condition and intention to use the bicycle, although the mediation effect did not reach conventional levels of statistical significance.

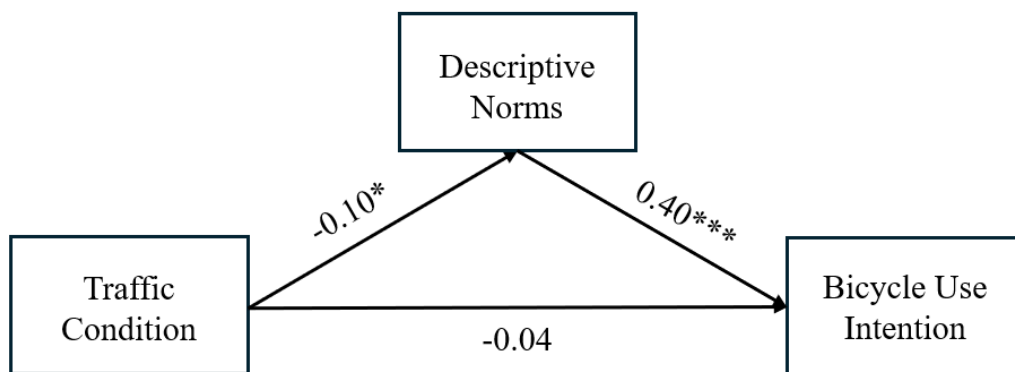


**Figure 30. Mediation model illustrating the effect of traffic condition on intention to use a bicycle, with descriptive norms as a mediator. Standardized coefficients ( $\beta$ ) and significance levels are shown for each path. Note: \* =  $p < .05$ ; \*\*\* =  $p < .001$ .**

### 3.3.4. Discussion

The results of Study 2 confirmed the presence of significant differences in perceived danger, discomfort, negative vehicular interaction, and intention to use the bicycle, in line with the findings previously observed in Study 1. In addition, the present study allowed for a more detailed examination of the effects of traffic manipulation on the investigated variables, with particular attention devoted to the role of expected descriptive norms. Although these findings provide valuable insights, they should be interpreted with caution, as participants were recruited through a non-probability snowball sampling method, which limits the generalizability of the results. Furthermore, not all hypotheses received full empirical support.

Regarding H1, the results provided clear confirmation. Specifically, all sub-hypotheses (H1a, H1b, H1c, and H1d) were supported. The analyses revealed significant differences across scenarios, with the Baseline Scenario differing consistently from both Scenario 1 and Scenario 2 in terms of perceived danger, perceived discomfort, negative vehicular interaction, and intention to use the bicycle. These findings are consistent with previous research highlighting the fundamental role of cycling infrastructure, not only in promoting bicycle use (e.g., Bagloee et al., 2016; Bogacz et al., 2021; Chen et al., 2018; Heinen et al., 2010; Huemer et al., 2022; Parker et al., 2013), but also in enhancing perceived safety (e.g., Nazemi et al., 2021) and travel comfort (e.g., Piras et al., 2023).

In contrast, H2 and all related sub-hypotheses (H2a, H2b, H2c, and H2d) were rejected. No significant differences emerged between Scenario 1 and Scenario 2 for any of the investigated variables. H2 aimed to explore the contribution of additional urban infrastructural elements, such as street furniture, urban greenery, and the color of the bicycle lane. Contrary to previous studies that emphasized the positive effect of red-colored bicycle lanes on perceived safety (e.g., Ullmann et al., 2022; van Goeverden & Godefrooij, 2011), no such effect was observed in the present study.

However, these results should be interpreted cautiously, as the experimental design did not allow for the assessment of the individual contribution of each infrastructural element. This limitation represents an important direction for future research, which could adopt more fine-grained experimental manipulations to disentangle the specific effects of greenery, street furniture, and lane color. Moreover, unlike the findings of Study 1, no differences emerged between Scenario 1 and Scenario 2 in perceived safety, discomfort, negative vehicular interaction, or behavioral intention. This contrasts with prior research suggesting a positive role of urban greenery in enhancing attractiveness, comfort, and willingness to cycle (e.g., Bialkova et al., 2022; Wahlgren & Schantz, 2012; Wendel-Vos et al., 2004), as well as the importance of street furniture in improving perceived street quality (e.g., Kaparias et al., 2013).

One possible explanation lies in the increased complexity of the scenarios. As the number of environmental elements and their interactions increases, so does the cognitive effort required to process them (Van Merriënboer et al., 2010; Tremblay et al., 2023), potentially reducing participants' sensitivity to specific design features. An alternative interpretation is that, from the users' perspective, the presence of a dedicated bicycle lane represents the primary and most salient determinant of cycling intention, a conclusion that aligns with a substantial body of previous literature (e.g., Bagloee et al., 2016; Bogacz et al., 2021; Chen et al., 2018; Heinen et al., 2010; Huemer et al., 2022; Parker et al., 2013).

Similarly, H3 was not supported. No significant differences emerged between Scenario 1 and Scenario 2 with respect to expected descriptive norms. In other words, participants did not perceive differences in the extent to which others would cycle between the scenario featuring only a bicycle lane and the scenario enriched with additional infrastructural elements. As in previous analyses, significant differences were observed only between the Baseline Scenario and the two infrastructure-based scenarios, further suggesting that the presence of a bicycle lane may play a decisive role not only in individual perceptions but also in shaping social expectations related to cycling behavior.

Regarding traffic manipulation, results mirrored those obtained in Study 1. No significant differences emerged between high-traffic and low-traffic conditions in perceived danger, perceived discomfort,

negative vehicular interaction, or intention to use the bicycle. Consequently, H4 was rejected. One possible explanation is that participants may not have perceived a sufficiently salient difference in the number of vehicles between traffic conditions. Previous research has shown that the perceived quantity and visibility of vehicles play a crucial role when traffic is manipulated in scenario-based studies (e.g., Nazemi et al., 2021). Nevertheless, this null finding provides a valuable direction for future research, emphasizing the need for more pronounced or alternative traffic manipulations, particularly given the consistent evidence showing the negative impact of traffic on cycling behavior in real-world contexts (Fraser & Lock, 2011; Foster et al., 2011; Pucher et al., 2010; Winters et al., 2011).

H5 was supported. Expected descriptive norms regarding bicycle use emerged as significant predictors of intention to cycle. This finding is consistent with previous studies demonstrating that individuals' behavior is influenced by their expectations about what significant others or fellow citizens are likely to do (e.g., Baeli et al., 2022; Frater et al., 2017a; Liu et al., 2023), although inconsistencies have also been reported in the literature (e.g., Bourke et al., 2018; Muñoz et al., 2013).

Finally, to address the research question examining whether descriptive norms mediate the relationship between traffic conditions and intention to use the bicycle across different cycling scenarios, the analysis first assessed the association between traffic manipulation and descriptive norms. Since descriptive norms showed a significant difference across traffic levels, a mediation analysis was conducted with traffic condition as the independent variable, descriptive norms as the mediator, and intention to use a bicycle as the dependent variable. The results indicated that traffic condition was associated with descriptive norms, which in turn were associated with cycling intention. However, the indirect effect of traffic condition on intention through descriptive norms was marginally non-significant ( $p = .052$ ). These results may suggest a trend, although the effect did not reach conventional levels of statistical significance.

Despite this limitation, the results provide meaningful indications for future research by highlighting the role played by social expectations in shaping mobility-related intentions. Moreover, they point to the relevance of traffic conditions in scenario-based evaluations, particularly when interpreted through a socio-psychological lens. From an applied perspective, these insights may be valuable for policymakers, urban planners, and transport engineers when designing cycling infrastructure and communication strategies aimed at promoting active mobility.

### 3.4. Conclusion

Overall, the two studies presented in this Chapter contribute to a more articulated understanding of how physical characteristics of the urban environment and socio-psychological factors jointly shape individuals' intention to use the bicycle as a mode of transport. By adopting a scenario-based experimental approach grounded in video simulations, the research allowed for the systematic manipulation of infrastructural and traffic-related features while simultaneously accounting for subjective perceptions and social norms. Taken together, the findings provide converging evidence on some key mechanisms, while also revealing important limits and ambiguities that warrant careful interpretation.

Across both Study 1 and Study 2, a consistent pattern emerged regarding the central role of cycling infrastructure. In line with a substantial body of previous literature, the presence of a dedicated bicycle lane represented the most salient determinant of perceived safety, perceived comfort, perceived interaction with vehicles, and intention to cycle (e.g., Bagloee et al., 2016; Bogacz et al., 2021; Chen et al., 2018; Heinen et al., 2010; Huemer et al., 2022; Parker et al., 2013). In both studies, the Baseline Scenario, characterized by the absence of cycling infrastructure, was systematically associated with higher perceived danger and lower intention to use the bicycle. These results reinforce the notion that infrastructure constitutes a necessary precondition for cycling adoption, shaping not only individual evaluations of risk and comfort but also broader expectations concerning the legitimacy and feasibility of cycling within the urban context. From a planning perspective, this finding reinforces the priority of implementing dedicated cycling infrastructure as a foundational intervention, without which other design refinements are unlikely to substantially enhance cycling uptake.

At the same time, the findings suggest that the effects of additional infrastructural elements beyond the bicycle lane are more nuanced and less robust. In Study 1, the inclusion of urban greenery or street furniture appeared to further reduce perceived danger and, to a lesser extent, discomfort, although these effects did not increase linearly when multiple elements were combined, pointing instead to a possible threshold effect. In Study 2, however, no significant differences emerged between scenarios featuring a bicycle lane alone and those enriched with additional design features, including greenery, street furniture, and lane coloration. This divergence highlights an important interpretative issue: while certain environmental elements may contribute to cyclists' perceptions under specific conditions, their influence appears secondary to, and potentially overshadowed by, the presence of core cycling infrastructure. Moreover, increasing environmental complexity may reduce perceptual sensitivity to individual design components, suggesting that not all infrastructural refinements are equally salient from the users' perspective (Tremblay et al., 2023; Van Merriënboer et al., 2010). This

suggests that, in applied urban design, investments in secondary environmental features should be carefully evaluated in terms of their marginal contribution relative to core infrastructure, particularly under resource constraints.

With respect to traffic conditions, both studies yielded null results, as no significant differences emerged between high-traffic and low-traffic scenarios in any of the main outcome variables, except for descriptive norms, which showed a significant difference. While this finding contrasts with extensive real-world evidence documenting the deterrent effect of motorized traffic on cycling (e.g., Fraser & Lock, 2011; Foster et al., 2011; Pucher et al., 2010; Winters et al., 2011), it underscores the methodological challenges of representing traffic intensity in simulated environments. The results indicate that traffic manipulations may need to be more pronounced, differently operationalized, or complemented by additional sensory cues to elicit reliable perceptual differences. Importantly, these null effects should not be interpreted as evidence of the irrelevance of traffic, but rather as a limitation of the experimental setting adopted in the present research. Consequently, policy implications regarding traffic reduction should not be derived directly from these findings but remain supported by the broader empirical literature on cycling deterrents.

A further contribution of this Chapter lies in the integration of social norms within the analysis of cycling-related perceptions and intentions. Study 1 highlighted the role of injunctive norms, showing that perceived social approval is positively associated with intention to cycle and may interact with perceived danger, albeit in an exploratory manner. Study 2 extended this perspective by focusing on expected descriptive norms, which emerged as significant predictors of cycling intention and suggested a potential mediating role in the relationship between traffic conditions and behavioral intention, although the mediation results did not reach conventional levels of statistical significance. Although some effects did not reach conventional levels of statistical significance, the results consistently point toward the relevance of social-contextual factors in shaping mobility-related intentions, particularly when evaluated in relation to concrete, visually presented urban scenarios. From a policy standpoint, these results point to the potential relevance of complementary interventions targeting social norms, such as communication campaigns or visibility-enhancing strategies, alongside infrastructural measures.

Despite these contributions, several limitations must be acknowledged. First, both studies relied on non-probability snowball sampling, with samples geographically concentrated in a single urban context. This limits the external validity of the findings and calls for caution when generalizing the results to cities with different infrastructural, cultural, or mobility characteristics. Second, the use of self-reported intentions, while theoretically grounded, does not allow direct inference about actual

cycling behavior, leaving open the well-documented intention–behavior gap (Sheeran & Webb, 2016).

A further limitation concerns the fixed order of scenario presentation. In both studies, the Baseline Scenario was always shown first, before the infrastructure-based scenarios. This design choice may have introduced an order effect, potentially influencing participants' subsequent evaluations. Exposure to a scenario characterized by the absence of cycling infrastructure may have established a reference point against which later scenarios were implicitly compared, thereby amplifying perceived improvements in safety, comfort, or cycling intention. As a result, differences observed between the Baseline Scenario and the other scenarios may partially reflect contrast or primacy effects rather than solely the intrinsic characteristics of the environments themselves.

An additional methodological limitation relates to the sensory conditions under which the video-based simulations were experienced. Although the videos included environmental sound, it was not possible to verify the volume level at which participants experienced it. This aspect could have affected the degree of perceived realism and immersion elicited by the scenarios. Previous research in environmental psychology has shown that auditory information plays a crucial role in shaping users' sense of presence and in enhancing the comparability between real and virtual environments (Kort et al., 2003). Variability in sound exposure across participants may therefore have reduced the ecological validity of the simulations and contributed to variability in perceptual responses, particularly in relation to traffic-related cues.

In sum, the two studies jointly suggest that cycling infrastructure functions as a foundational condition for both perceived safety and social normalization of cycling, whereas additional environmental features exert more context-dependent and method-sensitive effects. By combining environmental manipulations with socio-psychological variables, this Chapter provides a more integrated perspective on cycling intention, while also highlighting the need for refined experimental designs to better capture the complex interplay between physical space, perception, and social meaning, and to inform more evidence-based urban planning strategies.

# Chapter IV. Snow and Lighting Effects on Pedestrian Environmental Appraisals: A Video-Based Experimental Study (Study 3)

*The study presented in this Chapter was carried out during a visiting period at Lund University, under the supervision of Professor Maria Johansson and Johan Rahm, and within the framework of the NorDark project.*

## **4.1. Introduction**

### **4.1.1. Snow and environmental perception: current state of knowledge**

Snow is a noticeable but still understudied environmental element that could affect how natural and urban places look, sound, and feel. Despite its ubiquity in many regions, affecting all outdoor activities, including opportunities for physical active mobility, empirical research in psychology examining how snow influences human perception, affect, and behavior remains limited. Existing studies have largely focused on restorative effects, how exposure to snow-covered environments contributes to psychological recovery (e.g., Bielinis et al., 2018, 2019, 2021), and walkability outcomes (e.g., Chapman et al., 2017; Crosby et al., 2025) while other dimensions, such as perceived safety, and comfort, have received little attention.

A growing body of research in environmental psychology has demonstrated that snow can modify both the aesthetic and perceptual characteristics of landscapes under daylight conditions (e.g., Bielinis et al., 2019) and under electric light conditions (e.g., Wåseth et al., 2025). In forest settings, the presence of snow transforms color composition, texture, and brightness, concealing ground vegetation and replacing the dominant green-brown hues with shades of white (Bielinis et al., 2019). This chromatic alteration has been hypothesized to influence relaxation processes, as previous work indicated that lower levels of green are associated with weaker restorative responses (e.g., Choi et al., 2016). Nevertheless, empirical results from morning daylight studies suggest that forest environments retain significant restorative potential even when snow-covered (e.g., Bielinis et al., 2018, 2019). Brief exposure to snow-covered forests, such as 15-minute sessions of rest or slow walking, has been found to improve positive mood states and reduce negative affect among young adults, confirming the psychological benefits of winter recreation in natural settings (Bielinis et al., 2019). Furthermore, Wåseth and colleagues (2025) found significant differences between snowy and non-snowy places

under electric lighting conditions: in fact, when snow was present, faces appeared more brightly lit. Similarly, Lowden and Dincel (2025) reported that overall light exposure in urban areas, in this case during daylight, is higher in snow cover rather than in no-snow cover situations.

Additional findings from Bielinis et al. (2021) further indicate that visual contact with snowy forests enhances restorative effects, compared with exposure to build environments under identical winter conditions. Interestingly, while participants viewing snow-covered buildings exhibited a decline in perceived restoration, those exposed to snow-covered forests experienced significant psychological relaxation.

More recent studies have also looked at urban environments. Bao et al. (2023) showed that also white spaces may elicit positive sensations, analogously to what has largely evidenced for green spaces. Participants evaluated snowy parks positively, describing them as calm and visually attractive, which suggests that the color white itself may promote restorative effects. However, other studies do not fully support this view. For instance, Zhu et al. (2023) found that the presence of snow had a negative impact on perceived restoration in residential urban areas in northern regions, thus the restorative role of white space seems still unclear.

Beyond restoration, very few studies have examined the broader behavioral implications of snow. Research on winter mobility indicates that adverse weather conditions, including the presence of snow, can act as barriers to outdoor activity, particularly walking (e.g., Bergen et al., 2023; Clarke et al., 2017; de Montigny et al., 2012). However, empirical outcomes have shown mixed evidence. For instance, Crosby et al. (2025) showed that snow had no significant effect in predicting various levels of physical activity, unlike Chapman et al. (2017), who showed that snow played a role in facilitating winter mobility. Moreover, previous studies have highlighted the relevance of environmental conditions, including weather and lighting, in shaping pedestrian behavior. For example, darkness and low visual accessibility are consistently associated with increased fear and reduced mobility during dark hours, particularly among women (Toet et al., 2016). Similarly, Chapman et al. (2017) showed that darkness emerged as a barrier to walking. Intervention such as providing better lighting or improving urban design may reduce these negative effects, and virtual environments have been shown to be effective tools for testing and improving such solutions in controlled conditions (Boomsma & Steg, 2014a, 2014b; Cozens & Love, 2015).

One reason why empirical research on snow is limited is in part due to the challenges of conducting field studies under winter conditions, such as accessibility, safety, and unpredictable weather (Newman, 2025; van der Ham et al., 2015). In particular, the presence of snow is difficult to manipulate systematically in real-world settings, as its intensity, coverage, and interaction with

lighting conditions cannot be controlled independently. This limits the possibility of isolating the specific contribution of snow to environmental appraisals and behavioral intentions. Experimental approaches that allow for controlled variation of environmental features are therefore required to disentangle the effects of snow from other contextual factors (Paljic, 2017; Rossetti & Hurtubia, 2020). In this regard, video-based virtual environments offer the possibility to simulate realistic pedestrian experiences while ensuring a high degree of experimental control (Bhagavathula et al., 2018; Kasraian et al., 2020). Such approaches make it possible to examine how snow and lighting conditions jointly shape perceptions of accessibility, safety, comfort, and experiential quality without exposing participants to real-world risks (Chamilothori et al., 2019; Liao et al., 2022).

Existing literature reveals both the potential psychological salience of snow and the substantial gaps that remain in understanding its effects. Addressing these gaps requires experimental designs capable of isolating the influence of snow while maintaining ecological validity, a methodological challenge that motivates the use of virtual and video-based environments, an approach adopted in the present study. While the experimental studies presented in Chapter III focused on cycling-related intentions, the present chapter addresses walking behavior. This reflects the broader structure of the thesis, which examines active mobility within the framework of sustainable transportation, with a specific focus on both cycling and walking as complementary modes. The present study therefore extends the investigation by shifting from cycling to pedestrian mobility, while maintaining the same general approach to environmental appraisal and behavioral intention.

#### **4.1.2. Theoretical background**

The theoretical roots of Study 3 stem from the Human–Environment Interaction (HEI) model (Küller, 1991), which conceives behavior as the result of ongoing interactions between a person and the physical and social aspects of the place where an activity happens. Both personal traits (such as attitudes, age, and gender) and environmental features influence internal processes, for instance how people feel or evaluate a given situation, which then shape their behavior. The HEI model has been also applied to walking patterns (Ferreira et al., 2016; Johansson, 2006; Johansson et al., 2016).

In the present study, the focus is on the intention to either walk along or avoid a pedestrian path under different conditions of lighting (daylight versus electric light) and weather (snow versus no-snow).

In this regard, we relied on Alfonzo's (2005) hierarchy of walking needs (see also Rahm, 2019; Tsiakiris et al., 2025), which describes five types of needs related to those environmental features that support walking intentions, i.e. *feasibility, accessibility, safety, comfort, and pleasurability*. The

hierarchy is useful because it highlights which environmental attributes are most directly tied to walking intentions.

About *feasibility*, it has to do with the ability to physically walk for a certain distance. Concerning *visual accessibility*, it refers to how easily people can see and understand a space, including finding their way, noticing obstacles, and recognizing others, skills that are especially important in winter and under artificial lighting (Rahm & Johansson, 2021). The ideas of prospect and escape, derived from the Prospect–Refuge Theory (Appleton, 1975; Nasar, 2008), address related aspects: how easy it is to read a space and how many available escape routes seem to be present. Both are important for judging risks and deciding whether to move through a space alone, especially at night. And this is strictly connected to the *perception of safety*. In this regard, studies have shown that poor visibility and darkness often increase fear and reduce movement during dark hours, particularly for women (Toet et al., 2016), highlighting why prospect and escape are key for understanding safety under different lighting conditions. Regarding *comfort*, for outdoor illumination it includes two dimensions established in lighting research: perceived strength quality (PSQ), which is the perception of light intensity, and perceived comfort quality (PCQ), which is how pleasant and non-irritating the light appears (Johansson et al., 2014), whilst glare was conceived separately as a sign of discomfort (Hickcox et al., 2022). Comfort is also related to the assessment of the naturalness of colors (like those of plants or of the sky), which is influenced by how much light makes the environment look realistic and appealing (Kuhn et al., 2013). These aspects of lighting are especially important in winter because snow changes how surfaces reflect light and affect colors, altering both the actual and perceived quality of illumination. Finally, *pleasurability* addresses the perceived restorative potential, based on Attention Restoration Theory (Kaplan, 1995). Restorative qualities describe how well an environment can restore attention and improve affective states. As mentioned before, snow can hide some restorative features, like plants, but can also add new visual qualities, such as brighter light and better visibility, which can either reduce or increase restorative effects depending on the situation (Bao et al., 2023; Bielinis et al., 2018, 2019, 2021; Zhu et al., 2023). Therefore, restorative potential depends on how landscape type, surface conditions, and lighting situation interact.

Building upon this theoretical framework, Study 3 integrates these conceptual dimensions to investigate how snow and lighting conditions jointly influence environmental appraisals and walking-related intentions in simulated contexts.

#### **4.1.3. Objectives and hypotheses**

The objective is to examine environmental appraisals of an urban forest path under daylight and electric lighting in the presence of snow, and their intention to choose or avoid walking in the given environment.

Hypothesis 1 (H1). In daylight, the presence of snow is expected to be appraised similarly to conditions without snow. Specifically:

H1a: Visual accessibility will not differ significantly between conditions with and without snow;

H1b: Prospect will not differ significantly between conditions with and without snow;

H1c: Escape will not differ significantly between conditions with and without snow;

H1d: Perceived safety will not differ significantly between conditions with and without snow;

H1e: Perceived strength quality will not differ significantly between conditions with and without snow;

H1f: Perceived comfort quality will not differ significantly between conditions with and without snow;

H1g: Glare will not differ significantly between conditions with and without snow;

H1h: Color evaluation will not differ significantly between conditions with and without snow;

H1i: Sky lighting will not differ significantly between conditions with and without snow;

H1l: Sky color will not differ significantly between conditions with and without snow;

H1m: Restorative potential will not differ significantly between conditions with and without snow;

H1n: Intention to choose the path will not differ significantly between conditions with and without snow;

H1o: Intention to avoid the path will not differ significantly between conditions with and without snow.

Hypothesis (H2). Under electric lighting, the presence of snow is expected to yield more positive appraisals than conditions without snow. Specifically:

H2a: Visual accessibility will be significantly higher in condition with snow than in condition without snow;

H2b: Prospect will be significantly higher in condition with snow than in condition without snow;

H2c: Escape will be significantly higher in condition with snow than in condition without snow;

H2d: Perceived safety will be significantly higher in condition with snow than in condition without snow;

H2e: Restorative potential will be significantly higher in condition with snow than in condition without snow;

H2f: Intention to choose the path will be significantly higher in condition with snow than in condition without snow;

H2g: Intention to avoid the path will be significantly lower in condition with snow than in condition without snow.

Previous research indicates that snow's effect on lighting comfort is ambiguous, as higher reflectance may simultaneously improve visibility and induce glare or color distortion, precluding a clear directional expectation for this dimension.

## **4.2. Method**

### **4.2.1. Sample**

The study included a total of 31 participants, of whom 17 women (54.8%), 12 men (38.7%), and 2 non-binary individuals (6.5%), ranging from 19 to 60 years ( $M = 28.4$  years,  $SD = 9.27$ ). Regarding employment status, 19 participants reported being students, 11 reported being employed, and 1 indicated neither category.

### **4.2.2. Research design**

The study employed a  $2 \times 2$  within-subjects experimental design, i.e. time of the day (daytime vs. electric light) and weather conditions (without vs. with snow on the ground), resulting in four distinct, digitally generated scenarios:

Scenario A: Daytime without snow on the ground;

Scenario B: Electric light without snow on the ground;

Scenario C: Daytime with snow on the ground;

Scenario D: Electric light with snow on the ground.

The digital environment was designed as a first-person navigable space, like a video game. Videos were created by recording a researcher moving through the environment using a keyboard and mouse,

which were then presented to participants in the laboratory along with related questions. Within this environment, various characteristics could be modified, including time of day, day of the week, month, cloud conditions, precipitation intensity (i.e., snow or rain), vegetation density, and other environmental features. These adjustments allowed for the creation of realistic scenarios closely matching real-world conditions.

The resulting videos were then edited using Microsoft Clipchamp to ensure uniform duration (approximately 40 seconds each) and a consistent viewpoint across all scenarios. To ensure that participants' responses were based on the current scenario rather than memory, each page presenting questions included an image of the specific scenario being evaluated (see Figures 31-32). This provided a constant visual reference throughout the questionnaire and minimized recall bias. Similarly to Study 1 and 2, background sounds were added to enhance the realism of the virtual environment (Kort et al., 2003).

To ensure realism, the virtual scenarios were calibrated based on real-world observations. In the study by Tsiakiris et al. (2025), Figures 5 and 6 present representative images of the pedestrian path in Uppsala (Sweden) under daytime and electric light conditions. Following this reference, the following parameters were adjusted in the digital scenarios: vegetation density was set to 0.27 on a scale from 0 (no vegetation) to 1 (maximum vegetation), based on photographic comparisons with real locations in Uppsala; snow coverage was set to 0.70 on a scale from 0 (no snow) to 1 (maximum snow); and cloud condition was set to "Cloudy" (chosen among five possible levels: Clear, Sparse, Cloudy, Overcast, Stormy) to match in-situ observations. The month was set to November, both because in-person data collection began in that month and because it provided realistic lighting conditions for every scenario. Time settings were 14:20 for daytime and 00:20 for dark hours.

The lighting characteristics of the virtual environment were adapted using Prisma Light Elton 730 DNW streetlights (3000 K, 18 W, 2100 lm). To address a limitation observed in Study 1 and 2 related to the lack of audio control (see Section 3.4.), sound settings were standardized: headphone and video volumes were set to maximum, while the computer volume was fixed at 16 (on a scale from 0 to 100). This configuration ensured a consistent and realistic soundscape in which natural ambient sounds and footsteps remained perceptible in the background. Videos were displayed on a 27-inch monitor (resolution  $2560 \times 1440$ , refresh rate 60 Hz; monitor dimensions: 13.5 cm height  $\times$  24 cm width), providing consistent visual quality across all participants.

Figure 31 shows the daytime and electric light scenarios without snow on the ground, comparable to the images presented by Tsiakiris et al. (2025), while Figure 32 presents representative images of the modified scenarios with snow on the ground, as shown to participants during the experiment. Finally,

to further address a limitation identified in Study 1 and 2 (see Section 3.4.), the order of scenario presentation was randomized for each participant to minimize order effects. All possible permutations of the four scenarios were generated, resulting in a total of 24 possible presentation orders.



**Figure 31. Representative images of the virtual environment without snow.**  
**Scenario A: Daytime without snow on the ground (left); Scenario B: Electric light without snow on the ground (right).**



**Figure 32. Representative images of the virtual environment under snowy conditions.**  
**Scenario C: Daytime with snow on the ground (left); Scenario D: Electric light with snow on the ground (right).**

#### **4.2.3. Setting**

The experimental setting was carefully controlled to minimize external influences. All windows in the laboratory were covered with black drapes to block both natural daylight and electric light from the corridor. The only source of illumination was a single overhead lamp positioned above the participants' desk, providing uniform and calibrated lighting conditions for all participants. The light intensity was adjusted to ensure comfortable computer use without causing glare or eye strain. The

light source was located approximately 142 cm above the desk surface and extended about 136 cm in length, corresponding to the full width of the desk on which the computer was placed.

To ensure precise documentation of the lighting environment, illuminance and color characteristics were measured at three points on the desk using a calibrated photometric instrument. Measurements of illuminance (lx), correlated color temperature (Tcp/K), and chromaticity ( $v'$ ) were taken at the center of the desk as well as at the midpoints between the center and the left and right edges. At the left-center point, illumination measured 38.0 lx, with a Tcp of 2892 K and a  $v'$  value of 0.5228. At the center point, readings were 40.8 lx, Tcp = 2908 K,  $v' = 0.5226$ . Finally, at the right-center point, illumination measured 35.8 lx, Tcp = 2899 K,  $v' = 0.5235$ . These measurements confirmed that the lighting conditions were uniform and consistent across the working area, supporting the reliability and replicability of participants' visual experience during the experiment. This procedure ensured that external light conditions and within-room luminance variability could not influence participants' perceptual or affective responses.

In addition to controlling illumination, the main physical characteristics of the laboratory environment were measured and documented, including the room dimensions, the size and coverage of the blackout curtains, and the distance between the participant's seat and the computer monitor, among other parameters. The distance between the participant's seat and the computer monitor was approximately 60 cm, ensuring an optimal and standardized viewing position across participants. These measurements are illustrated in Figure 33, which provides a schematic representation of the experimental setup.

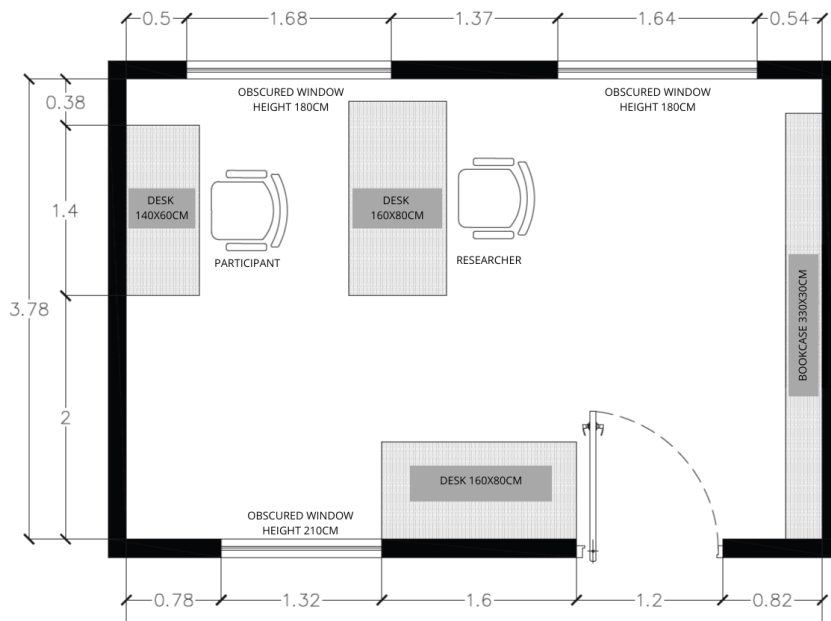


**Figure 33. Schematic representation of the laboratory setup used during the experiment. The figure shows the main physical measurements of the room, including the dimensions of the space, the desks, the position of the participant, the researcher, and the size and coverage of the blackout curtains.**

#### 4.2.4. Procedure

Participants were recruited through multiple channels, including face-to-face interactions, social media announcements, and internal promotion within the department. With the support of colleagues, the study was also advertised at other universities and on specialized research participation websites to reach a broader pool of volunteers. The advertisements briefly described the purpose of the study, the type of tasks involved, and practical details such as location, duration, and incentives. All participants were individually invited to participate in the study, which was conducted in a controlled laboratory setting. Data collection was carried out between August and September 2025.

Following the presentation and signing of the informed consent form, each participant watched four scenario-based videos and answered a series of questions after each video on the Sunet Survey website. All questionnaires were administered entirely in Swedish to ensure comprehension and consistency across participants. In addition to these scenario-specific questions, participants also completed a set of socio-demographic questions at the end of the experimental session. Each participant completed the study individually. Upon completion, participants received compensation for their participation in the form of a gift card worth approximately €10.

#### 4.2.5. Measures

To evaluate the objectives and hypotheses outlined above, several measures were used.

*Visual accessibility* (Johansson et al., 2011; Rahm et al., 2024): It was measured by seven statements: “I was able to notice objects such as branches and stones on the walkway”; “I would have been able to read the text on signs”; “I would have been able to recognize people’s faces”; “I was able to detect cracks and unevenness on the walkway”; “I was able to distinguish trees and bushes along the walkway”; “I was able to see what was growing on the ground along the walkway”; “Overall, I was able to see well”. A five-point response scale was used (1 = Absolutely not, to 5 = Yes, absolutely), and the responses were averaged into an index (Cronbach’s alpha values for Scenarios A, B, C, and D were .83, .86, .81, and .78, respectively).

*Prospect-escape* (Rahm et al., 2021): Prospect was assessed by the statement “I have a good overview of the surroundings along the walkway”, and escape was assessed by the statement “The surroundings give me the possibility to escape from the walkway in case of danger”. Both items were rated using five-point scales (1 = Absolutely not, to 5 = Yes, absolutely).

*Perceived safety* (Blöbaum & Hunecke, 2005; Johansson et al., 2011): It was assessed by five statements: “I would take detours to avoid the walkway”<sup>1</sup>; “I felt uneasy along the walkway”; “I would hurry to get away from the walkway”; “I found this walkway unpleasant”; “I can imagine walking alone along the walkway”. Participants rated each statement using a five-point scale (1 = Absolutely not, to 5 = Yes, absolutely). Responses were averaged into an index (Cronbach’s alpha values for Scenarios A, B, C, and D were .84, .93, .88, .96, respectively).

*The perceived outdoor lighting quality scale* (Johansson et al., 2014): It was used, with ten bipolar adjectives on seven-point scales: PSQ with five adjectives (Subdued-Brilliant; Strong-Weak; Dark-Light; Unfocused-Focused; Clear-Drab. Cronbach’s alpha values for Scenarios A, B, C, and D were .69, .78, .64, .72, respectively) and PCQ with five adjectives (Mild-Sharp, Hard-Soft, Warm-Cool, Glaring-Shaded, Natural-Unnatural. Cronbach’s alpha values for Scenarios A, B, C, and D were .61, .87, .70, .81, respectively). Participants were also asked if they experienced any discomfort due to glare, with the response alternatives No/Yes (Hickcox et al., 2022).

*The perception of color naturalness* (Kuhn et al., 2013): It was measured using three bipolar adjectives about grass, bushes and trees. Responses were given on five-point scales (Unnatural-Natural) and averaged into an index (Cronbach’s alpha values for Scenarios A, B, C, and D were .83, .78, .86, .84, respectively). In addition, participants were asked to rate their perception of sky (Kuhn et al., 2013) characteristics using two bipolar adjectives on five-point scales (Unlit-Lit, Dark-Colored).

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<sup>1</sup> Note: items marked by underlining were reverse-coded.

*Perceived restorative potential* (Hartig et al., 1997): respondents indicated the perceived restorative potential of the setting by the statements: “There was a lot to discover and explore along the walkway”; “Spending time along the walkway would give me a break from my daily routines”; “Along the walkway, I would be able to get away from what usually demands my attention”; “The walkway was fascinating”; “I liked the walkway”. Responses were given on five-point scales (1 = Absolutely not, to 5 = Yes, absolutely) and averaged into an index (Cronbach’s alpha values for Scenarios A, B, C, and D were .89, .85, .91, .81, respectively).

*Behavioral intention* (Johansson et al., 2016): It was assessed with two statements, measuring the intention to choose or to avoid the path: “Intention to choose” and “Intention to avoid” rated on a five-point scale (1 = Absolutely not, 5 = Yes, absolutely).

#### **4.2.6. Data analysis**

All statistical analyses were conducted using Jamovi (version 2.3.28; The Jamovi Project, 2023) and IBM SPSS Statistics (version 29.0; IBM Corp., 2022). Prior to hypothesis testing, internal consistency was assessed for all multi-item scales containing at least three items. As reported in the previous Section, Cronbach’s alpha coefficients met the minimum acceptable thresholds, indicating satisfactory reliability across all measures (Kilic, 2016; Tavakol & Dennick, 2011). Composite scores were subsequently computed for each construct, following the original scale structures. The resulting aggregated variables included perceived visual accessibility, perception of safety, perceived strength quality, perceived comfort quality, and color evaluation of the light, and perceived restorative potential of the natural setting. In addition, several single-item measures were retained for analysis, namely prospect, escape, glare, sky lighting, sky color, intention to choose, and intention to avoid.

The distribution of each variable was examined for normality by inspecting skewness and kurtosis values, as well as the standardized z-scores of these parameters. Variables were considered approximately normally distributed when their z-values fell within the  $\pm 1.96$  range. The inspection revealed that while some measures conformed to normality assumptions, others showed deviations.

To ensure the robustness of the findings, both parametric and non-parametric analyses were performed. First, a series of repeated-measures ANOVAs were conducted to test for within-subject differences across the four experimental scenarios. When significant effects emerged, Bonferroni-adjusted post hoc comparisons were applied to identify pairwise differences.

In parallel, non-parametric tests were carried out to verify the consistency of the results. Specifically, Friedman tests (Friedman, 1940) were used to assess overall differences among the four scenarios, followed by pairwise Wilcoxon signed-rank tests (Wilcoxon, 1992). To correct for multiple

comparisons, the significance threshold was adjusted to  $p < .008$  (i.e.,  $.05/6$ ), reflecting the six possible scenario pairs (A–B, A–C, A–D, B–C, B–D, C–D). Importantly, the pattern of results obtained from the non-parametric analyses was fully consistent with that obtained from the parametric analyses: both approaches led to the same conclusions regarding significant and non-significant effects, confirming the robustness of the observed results.

### 4.3. Results

The means, medians, and standard deviations of the variables are presented in Table 14.

**Table 14. Descriptive statistics (mean, median, and standard deviation) for the variables included in the analysis.**

| Variables                    | Scenario A |        |           | Scenario B |        |           | Scenario C |        |           | Scenario D |        |           | Total |        |           |
|------------------------------|------------|--------|-----------|------------|--------|-----------|------------|--------|-----------|------------|--------|-----------|-------|--------|-----------|
|                              | Mean       | Median | <i>SD</i> | Mean       | Median | <i>SD</i> | Mean       | Median | <i>SD</i> | Mean       | Median | <i>SD</i> | Mean  | Median | <i>SD</i> |
| Visual accessibility         | 4.41       | 4.57   | 0.62      | 2.77       | 2.57   | 0.79      | 4.28       | 4.28   | 0.61      | 3.58       | 3.57   | 0.69      | 3.76  | 4.00   | 0.94      |
| Prospect                     | 4.29       | 4.00   | 0.69      | 2.10       | 2.00   | 1.33      | 4.45       | 5.00   | 0.63      | 3.29       | 4.00   | 1.35      | 3.53  | 4.00   | 1.41      |
| Escape                       | 3.74       | 4.00   | 0.89      | 2.29       | 2.00   | 1.04      | 3.71       | 4.00   | 0.78      | 2.94       | 3.00   | 0.96      | 3.17  | 3.00   | 1.10      |
| Safety                       | 4.48       | 4.60   | 0.60      | 2.45       | 2.20   | 1.15      | 4.43       | 4.80   | 0.72      | 3.31       | 3.60   | 1.19      | 3.67  | 4.00   | 1.27      |
| PSQ                          | 4.07       | 4.20   | 1.00      | 4.34       | 4.40   | 1.31      | 4.19       | 4.00   | 0.95      | 5.10       | 5.20   | 1.00      | 4.43  | 4.40   | 1.14      |
| PCQ                          | 5.41       | 5.60   | 0.88      | 2.69       | 2.60   | 1.31      | 5.31       | 5.40   | 0.94      | 3.29       | 3.40   | 1.12      | 4.17  | 4.40   | 1.61      |
| Glare                        | NA         | NA     | NA        | 3.47       | 4.00   | 1.73      | 2.00       | 1.00   | 1.73      | 3.30       | 4.00   | 1.70      | 3.29  | 4.00   | 1.65      |
| Color                        | 3.63       | 4.00   | 1.12      | 3.28       | 3.33   | 1.03      | 3.32       | 3.67   | 1.16      | 3.56       | 3.67   | 0.94      | 3.45  | 3.67   | 1.06      |
| Sky lighting                 | 3.87       | 4.00   | 1.15      | 1.52       | 1.00   | 0.72      | 3.61       | 4.00   | 1.09      | 1.61       | 1.00   | 0.80      | 2.65  | 2.00   | 1.45      |
| Sky color                    | 4.13       | 4.00   | 0.89      | 1.35       | 1.00   | 0.84      | 4.13       | 4.00   | 0.99      | 1.71       | 2.00   | 0.78      | 2.83  | 3.00   | 1.57      |
| Restorativeness              | 3.78       | 4.20   | 0.83      | 2.43       | 2.40   | 0.91      | 3.72       | 3.80   | 0.88      | 3.07       | 3.20   | 0.87      | 3.25  | 3.20   | 1.02      |
| Intention to choose the path | 4.16       | 4.00   | 0.97      | 2.26       | 2.00   | 1.13      | 4.03       | 4.00   | 0.95      | 3.03       | 3.00   | 1.30      | 3.37  | 4.00   | 1.33      |
| Intention to avoid the path  | 1.61       | 1.00   | 0.96      | 3.68       | 4.00   | 1.35      | 1.55       | 1.00   | 0.85      | 2.71       | 2.00   | 1.37      | 2.39  | 2.00   | 1.44      |

**Note:** *SD* = Standard deviation; PSQ = Perceived Strength Quality; PCQ = Perceived Comfort Quality; NA = Not Available.

The results of the differences between scenarios, to test H1 (a, b, c, d, e, f, g, h, I, l, m, n, o) and H2 (a, b, c, d, e, f, g), are shown below. For clarity and consistency, the results refer to non-parametric analyses.

Visual accessibility: the Friedman test indicated significant differences among scenarios ( $\chi^2 = 54.947$ ,  $df = 3$ ,  $p < .001$ ), warranting further investigation. Wilcoxon signed-rank tests revealed significant pairwise differences between A-B, A-D, B-C, B-D, C-D, and no difference between A-C, confirming H1a. In terms of visual accessibility, the scenario with the highest score was the one with daytime condition without snow (Scenario A). This scenario received a significantly higher score, similarly to the daytime with snow condition (Scenario C), than those with electric lighting, both with (Scenario D) and without snow (Scenario B). Finally, regarding the two electric light conditions being compared, the condition with snow (Scenario D) showed a significantly higher score than the condition without snow (Scenario B), confirming H2a.

Prospect: the Friedman test was significant ( $\chi^2 = 46.682$ ,  $df = 3$ ,  $p < .001$ ). Wilcoxon tests showed significant differences between A-B, A-D, B-C, B-D, C-D, and no difference between A-C, confirming H1b. In terms of prospect, the scenario with the highest score was the one with daytime condition with snow (Scenario C), even though it did not show a significant difference compared to the daytime condition without snow (Scenario A). The daytime with snow condition (Scenario C), similarly to the daytime without snow condition (Scenario A), was rated more positively than the two conditions with electric light, with (Scenario D) and without snow (Scenario B). Finally, regarding the two electric light conditions being compared, the condition with snow (Scenario D) showed a significantly higher score than the condition without snow (Scenario B), confirming H2b.

Escape: the Friedman test yielded a significant result ( $\chi^2 = 46.262$ ,  $df = 3$ ,  $p < .001$ ), and subsequent Wilcoxon tests indicated significant differences for A-B, A-D, B-C, B-D, C-D, and no difference between A-C, confirming H1c. In terms of escape, the scenario with the highest score was the one with daytime condition without snow (Scenario A). This scenario received a significantly higher score, similarly to the daytime with snow condition (Scenario C), than those with electric lighting, both with (Scenario D) and without snow (Scenario B). Finally, regarding the two electric light conditions being compared, the condition with snow (Scenario D) showed a significantly higher score than the condition without snow (Scenario B), confirming H2c.

Perception of safety: the Friedman test showed significant differences ( $\chi^2 = 64.899$ ,  $df = 3$ ,  $p < .001$ ). Wilcoxon tests indicated significant pairwise differences: A-B, A-D, B-C, B-D, C-D, and no difference between A-C, confirming H1d. In terms of safety, the scenario with the highest score was the one with daytime condition without snow (Scenario A). This scenario received a significantly

higher score, similarly to the daytime with snow condition (Scenario C), than those with electric lighting, both with (Scenario D) and without snow (Scenario B). Finally, regarding the two electric light conditions being compared, the condition with snow (Scenario D) showed a significantly higher score than the condition without snow (Scenario B), confirming H2d.

Perceived strength quality: a significant Friedman test ( $\chi^2 = 16.316$ ,  $df = 3$ ,  $p < .001$ ) was followed by Wilcoxon comparisons revealing differences between A-D, B-D, C-D, and no differences between A-B, A-C, and B-C, confirming H1e. In terms of strength quality of light, the scenario with the highest score was the one with electric lighting condition with snow (Scenario D). This scenario received a significantly higher score than those with daytime conditions, both with (Scenario C) and without snow (Scenario A), and with electric lighting condition without snow (Scenario B).

Perceived comfort quality: the Friedman test was significant ( $\chi^2 = 49.485$ ,  $df = 3$ ,  $p < .001$ ), with Wilcoxon tests showing differences for A-B, A-D, B-C, C-D, and no differences between A-C, and B-D, confirming H1f. In terms of comfort quality of light, the scenario with the highest score was the one with daytime condition without snow (Scenario A). This scenario received a significantly higher score, similarly to the daytime with snow condition (Scenario C), than those with electric lighting, both with (Scenario D) and without snow (Scenario B).

Glare: significant Friedman results ( $\chi^2 = 31.400$ ,  $df = 3$ ,  $p < .001$ ) were followed by Wilcoxon tests for A-B, A-D, B-C, C-D, and no differences between A-C, and B-D, confirming H1g. In terms of glare, the scenario with the highest score was the one with electric lighting condition without snow (Scenario B). This scenario received a significantly higher score, similarly to the electric lighting condition with snow (Scenario D), than those with daytime conditions, both with (Scenario C) and without snow (Scenario A).

Color evaluation: the Friedman test was not significant ( $\chi^2 = 3.835$ ,  $df = 3$ ,  $p = .280$ ), and no further pairwise comparisons were conducted. In this case, H1h cannot be confirmed.

Sky lighting: the Friedman test was significant ( $\chi^2 = 65.445$ ,  $df = 3$ ,  $p < .001$ ), with Wilcoxon tests revealing differences for A-B, A-D, B-C, C-D, and no differences between A-C, and B-D, confirming H1i. In terms of sky lighting, the scenario with the highest score was the one with daytime condition without snow (Scenario A). This scenario received a significantly higher score, similarly to the daytime with snow condition (Scenario C), than those with electric lighting, both with (Scenario D) and without snow (Scenario B).

Sky color: significant Friedman results ( $\chi^2 = 77.135$ ,  $df = 3$ ,  $p < .001$ ) were followed by Wilcoxon tests indicating differences for A-B, A-D, B-C, C-D, and no differences between A-C, and B-D,

confirming H1l. In terms of sky color, the scenarios with the highest score were those with daytime conditions without snow (Scenario A) and with snow (Scenario C). These scenarios received a significantly higher score than those with electric lighting, both with (Scenario D) and without snow (Scenario B).

Perceived restorative potential: the Friedman test was significant ( $\chi^2 = 36.480$ ,  $df = 3$ ,  $p < .001$ ). Wilcoxon tests revealed significant differences between A-B, A-D, B-C, B-D, C-D, and no difference between A-C, confirming H1m. In terms of restorative potential, the scenario with the highest score was the one with daytime condition without snow (Scenario A). This scenario received a significantly higher score, similarly to the daytime with snow condition (Scenario C), than those with electric lighting, both with (Scenario D) and without snow (Scenario B). Finally, regarding the two electric light conditions being compared, the condition with snow (Scenario D) showed a significantly higher score than the condition without snow (Scenario B), confirming H2e.

Intention to choose the path: the Friedman test was significant ( $\chi^2 = 57.531$ ,  $df = 3$ ,  $p < .001$ ), and Wilcoxon tests indicated differences for A-B, A-D, B-C, B-D, C-D, and no difference between A-C, confirming H1n. In terms of intention to choose the path, the scenario with the highest score was the one with daytime condition without snow (Scenario A). This scenario received a significantly higher score, similarly to the daytime with snow condition (Scenario C), than those with electric lighting, both with (Scenario D) and without snow (Scenario B). Finally, regarding the two electric light conditions being compared, the condition with snow (Scenario D) showed a significantly higher score than the condition without snow (Scenario B), confirming H2f.

Intention to avoid the path: the Friedman test was significant ( $\chi^2 = 57.734$ ,  $df = 3$ ,  $p < .001$ ), and Wilcoxon tests revealed differences for A-B, A-D, B-C, B-D, C-D, and no difference between A-C, confirming H1o. In terms of intention to avoid the path, the scenario with the highest score was the one with electric lighting condition without snow (Scenario B). This scenario received a significantly higher score, similarly to the electric lighting with snow condition (Scenario D), than those with daytime conditions, both with (Scenario C) and without snow (Scenario A). Finally, regarding the two electric light conditions being compared, the condition with snow (Scenario D) showed a significantly lower score than the condition without snow (Scenario B), confirming H2g.

Complete results are presented in Table 15.

**Table 15. Results of non-parametric pairwise comparisons between scenarios.**

| Variables                           | A – B    |          |          | A – C    |          |          | A – D    |          |          | B – C    |          |          | B – D    |          |          | C – D    |          |          |
|-------------------------------------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|
|                                     | <i>Z</i> | <i>p</i> | <i>r</i> | <i>Z</i> | <i>p</i> | <i>r</i> | <i>Z</i> | <i>p</i> | <i>r</i> | <i>Z</i> | <i>p</i> | <i>r</i> | <i>Z</i> | <i>p</i> | <i>r</i> | <i>Z</i> | <i>p</i> | <i>r</i> |
| <b>Visual accessibility</b>         | 4.803    | <.001    | .086     | n.s.     | n.s.     | n.s.     | 4.011    | <.001    | 0.72     | -4.842   | <.001    | 0.87     | -3.952   | <.001    | 0.71     | 4.179    | <.001    | 0.78     |
| <b>Prospect</b>                     | 4.596    | <.001    | 0.87     | n.s.     | n.s.     | n.s.     | 3.134    | .002     | 0.58     | -4.589   | <.001    | 0.85     | -3.538   | <.001    | 0.77     | 3.582    | <.001    | 0.76     |
| <b>Escape</b>                       | 4.284    | <.001    | 0.86     | n.s.     | n.s.     | n.s.     | 2.906    | .004     | 0.59     | -4.013   | <.001    | 0.77     | -2.784   | .005     | 0.64     | 3.286    | .001     | 0.72     |
| <b>Safety</b>                       | 4.677    | <.001    | 0.84     | n.s.     | n.s.     | n.s.     | 4.123    | <.001    | 0.79     | -4.785   | <.001    | 0.87     | -4.178   | <.001    | 0.79     | 4.045    | <.001    | 0.78     |
| <b>PSQ</b>                          | n.s.     | n.s.     | n.s.     | n.s.     | n.s.     | n.s.     | -3.253   | .001     | 0.59     | n.s.     | n.s.     | n.s.     | -3.066   | .002     | 0.58     | -3.233   | .001     | 0.59     |
| <b>PCQ</b>                          | 4.363    | <.001    | 0.78     | n.s.     | n.s.     | n.s.     | 4.647    | <.001    | 0.84     | -4.462   | <.001    | 0.80     | n.s.     | n.s.     | n.s.     | 4.372    | <.001    | 0.78     |
| <b>Glare</b>                        | -3.873   | <.001    | 0.99     | n.s.     | n.s.     | n.s.     | -3.162   | .002     | 0.99     | 3.742    | <.001    | 0.99     | n.s.     | n.s.     | n.s.     | -2.714   | .007     | 0.82     |
| <b>Color</b>                        | n.s.     | n.s.     | n.s.     | n.s.     | n.s.     | n.s.     | n.s.     | n.s.     | n.s.     | n.s.     | n.s.     | n.s.     | n.s.     | n.s.     | n.s.     | n.s.     | n.s.     | n.s.     |
| <b>Sky lighting</b>                 | 4.713    | <.001    | 0.86     | n.s.     | n.s.     | n.s.     | 4.667    | <.001    | 0.87     | -4.607   | <.001    | 0.87     | n.s.     | n.s.     | n.s.     | 4.677    | <.001    | 0.88     |
| <b>Sky color</b>                    | 4.830    | <.001    | 0.88     | n.s.     | n.s.     | n.s.     | 4.760    | <.001    | 0.88     | -4.683   | <.001    | 0.89     | n.s.     | n.s.     | n.s.     | 4.657    | <.001    | 0.85     |
| <b>Restorativeness</b>              | 4.305    | <.001    | 0.77     | n.s.     | n.s.     | n.s.     | 3.064    | .002     | 0.55     | -4.247   | <.001    | 0.76     | -3.756   | <.001    | 0.72     | 2.964    | .003     | 0.60     |
| <b>Intention to choose the path</b> | 4.566    | <.001    | 0.82     | n.s.     | n.s.     | n.s.     | 3.400    | <.001    | 0.69     | -4.269   | <.001    | 0.79     | -3.698   | <.001    | 0.85     | 3.262    | .001     | 0.70     |
| <b>Intention to avoid the path</b>  | -4.460   | <.001    | 0.86     | n.s.     | n.s.     | n.s.     | -3.206   | .001     | 0.72     | 4.749    | <.001    | 0.88     | 3.670    | <.001    | 0.84     | -3.895   | <.001    | 0.89     |

**Note:** PSQ = Perceived Strength Quality; PCQ = Perceived Comfort Quality; n.s. = Not significant.

#### 4.4. Discussion

The present study aimed to investigate how snow and lighting conditions jointly shape environmental appraisals and walking-related intentions in an urban forest context. Building on a human–environment interaction framework and previous research on winter environments, the discussion is structured around the two main hypotheses, followed by a broader interpretation of the role of snow, lighting, and methodological considerations related to the use of a virtual environment.

Regarding H1, the results confirmed the expected pattern. Under daylight conditions, no significant differences emerged between scenarios with (Scenario C) and without snow on the ground (Scenario A) across visual accessibility (H1a), prospect (H1b), escape (H1c), perceived safety (H1d), PSQ (H1e), PCQ (H1f), Glare (H1g), sky lighting (H1i), sky color (H1l), perceived restorative potential (H1m), intention to choose the path for walking (H1n), and intention to avoid the path for walking (H1o). The only sub-hypothesis that cannot be accepted is H1h, since the color evaluation did not yield significant results in the Friedman test. In other words, participants did not differentiate between the two daylight scenarios in terms of environmental appraisal and behavioral intention. These findings are consistent with previous research suggesting that snow-covered environments can retain restorative qualities comparable to those observed in snow-free conditions. Studies conducted in forest settings have shown that exposure to snowy landscapes during daylight still supports psychological restoration, even when vegetation is visually obscured (Bielinis et al., 2018, 2019). From this perspective, the absence of differences between snow and no-snow conditions may indicate that daylight provides sufficient visual information and environmental clarity to sustain positive appraisals regardless of ground surface conditions. However, the present results diverge from those reported by Yilmaz et al. (2008) and Lowden and Dincel (2025), who found that snow cover under daylight conditions increases exposure to light in urban environments compared to snow-free situations. The lack of a corresponding effect in the current study suggests that the relationship between snow, light, and visual accessibility may be more context-dependent than previously assumed (Yilmaz et al., 2008). First, it should be noted that this study was conducted using a computer; therefore, participants viewed the environments digitally, which differs from evaluating environments in real-life settings (Gatersleben & Andrews, 2013; Kjellgren & Buhrkall, 2010; Mayer et al., 2009). Another possible explanation relates to the role of the sky. In both daylight scenarios, sky conditions were identical in terms of illumination and cloud cover. Given evidence suggesting that the sky contributes to perceptions of naturalness (e.g., Sztuka et al., 2022), it is plausible that a stable sky configuration may have reduced the perceptual relevance of changes occurring at ground level. In this sense, participants may have relied more strongly on overhead light cues than on surface reflectance when forming their judgments. This possibility was not directly examined in the present

study but represents an important avenue for future research. In addition, it is important to clarify that, in the present experiment direct solar radiation was absent in both scenarios, under daylight conditions. Participants were exposed exclusively to diffuse daylight rather than to direct sunbeams striking the snow surface. This aspect is particularly relevant, as the strong reflective effects reported in previous studies are largely associated with direct solar incidence on snow-covered ground. Probably, in presence of direct sunlight the results might have aligned more closely with those of Yilmaz et al. (2008) and Lowden and Dincel (2025), who documented increased brightness and visual disturbance under such conditions. Moreover, to enhance realism and approximate real-world conditions of the selected environment, the digital setting included dense vegetation. As reported by Yilmaz et al. (2008), areas located in proximity to trees tend to exhibit substantially lower levels of reflected light intensity compared to open fields. The presence of dense vegetation in the simulated environment may therefore have further mitigated potential brightness differences between snow and no-snow conditions, reducing the perceptual impact of snow cover during daytime. At the same time, the absence of differences should not be interpreted as a failure to capture the effect of snow. Rather, the results suggest that under daylight conditions, snow does not substantially alter experiential evaluations in this specific setting. This interpretation is reinforced by the fact that clear snow-related effects emerged under electric lighting, indicating that the experimental design was sensitive enough to detect meaningful differences when they occurred.

In contrast to daylight conditions, significant differences emerged between scenarios with (Scenario D) and without snow on the ground (Scenario B) under electric lighting, providing support for H2. Specifically, visual accessibility (H2a), prospect (H2b), escape (H2c), perceived safety (H2d), perceived restorative potential (H2e) and, intention to choose the path (H2f) were all rated more positively in the presence of snow. Similarly, H2g is also confirmed. These findings align closely with a recent work by Wåseth et al. (2025), who reported that faces were perceived as better illuminated in snowy conditions under electric light. The present results extend this evidence by showing that improved illumination associated with snow reflectance translates into broader environmental appraisals, including safety perception and walking intentions. A plausible explanation lies in the reflective properties of snow (Pomeroy & Brun, 2001). When illuminated by artificial light sources, snow increases surface luminance (Jechow & Hölker, 2019), thereby enhancing spatial legibility and visibility. Improved visual accessibility is linked to greater perceptions of safety (Johansson et al., 2014; Rahm et al., 2021) and clearer opportunities for prospect and escape (Haans & De Kort, 2012), which in turn influence route choice and avoidance behavior (Rahm et al., 2021). From a human–environment interaction perspective, snow can be interpreted as a mediator that modifies the experiential quality of electric lighting rather than acting as an isolated environmental feature.

Interestingly, snow also contributed to higher perceived restorative potential under electric light. This result is consistent with studies reporting positive associations between snow and restoration (e.g., Bao et al., 2023; Bielinis et al., 2019;), but contrasts with findings by Zhu et al. (2023), who identified negative restorative effects of snow in northern urban residential contexts. These inconsistencies highlight that the restorative role of snow is not uniform but may be contingent on contextual factors. In the present study, the combination of enhanced visibility and increased luminance may have offset potential negative aspects associated with winter environments. Overall, the results tend to indicate that snow exerts a meaningful experiential influence primarily when light is scarce. Under electric lighting, snow appears to amplify the functional and perceptual qualities of illumination, whereas under daylight its contribution becomes comparatively marginal.

Across almost all variables, daylight scenarios (A and C) were evaluated more positively than electric lighting scenarios (B and D), regardless of the presence or absence of snow on the ground. This general pattern is consistent with a substantial body of literature demonstrating that natural daylight is associated with higher visual accessibility (e.g., Rahm et al., 2024), perceived safety (e.g., Ye et al., 2025), and environmental preference (e.g., Tsiakiris et al., 2025). An important exception concerns color evaluation, for which no significant differences emerged across scenarios. This result may be attributable to characteristics of the virtual environment, where color rendering and chromatic adaptation may not fully replicate real-world perceptual processes. While participants were sensitive to differences in brightness, accessibility, and safety, color-related judgments may have been constrained by the digital medium itself. Regarding comfort, only limited differences emerged between snow (Scenario D) and no-snow on the ground (Scenario B) under electric lighting, except for PSQ scale. This pattern suggests that when the same light source is used, participants tend to experience a relatively similar overall lighting comfort, even if surface conditions vary. From one perspective, this can be interpreted as a positive outcome, as it indicates internal consistency in how lighting conditions were perceived across scenarios. At the same time, it raises an important methodological question: to what extent was the virtual environment able to accurately reproduce the reflective properties of snow? Digital environments, while offering high experimental control (Rossetti & Hurtubia, 2020), struggle to fully reproduce light-surface interactions as they occur in real-world conditions (Gatersleben & Andrews, 2013; Kjellgren & Buhrkall, 2010; Mayer et al., 2009). Consequently, some perceptual effects, particularly subtle variations in comfort and color, may have been attenuated. This limitation does not invalidate the findings, but it suggests caution when interpreting fine-grained lighting evaluations and reinforces the importance of continued methodological development in virtual environment research.

## 4.5. Conclusion

The present Chapter examined how snow and lighting conditions jointly influence environmental appraisals and walking-related intentions in an urban forest context, using a controlled video-based experimental design. Grounded in a human–environment interaction perspective, the study aimed to examine the experiential role of snow under daylight and electric lighting conditions, addressing a gap in environmental psychology research where winter environments remain comparatively understudied.

Overall, the findings indicate that the psychological relevance of snow is contingent on lighting conditions. Under daylight, participants did not differentiate between environments with and without snow in terms of visual accessibility, perceived safety, comfort, restorative potential, or intention to choose the path. These results suggest that when natural daylight is available, environmental evaluations may rely primarily on broader visual cues such as overall brightness and sky illumination. In contrast, under electric lighting, the presence of snow systematically enhanced environmental appraisals. Snow was associated with higher perceived visual accessibility, greater feelings of safety, increased restorative potential, and stronger intentions to choose the path for walking. These results support the notion that snow, when combined with artificial lighting, can substantially modify the experiential quality of the environment by amplifying perceived illumination and spatial legibility.

Taken together, the findings suggest that snow does not operate as a uniformly positive or negative environmental feature. Rather, its psychological impact appears to emerge primarily under conditions of limited light, where reflective properties may compensate for otherwise reduced visibility. From a human–environment interaction perspective, snow can therefore be understood as a contextual modifier that interacts with lighting conditions to shape environmental perception and behavioral intentions. This interactional view may help reconcile previously inconsistent findings in the literature and highlights the importance of considering seasonal surface conditions together with lighting when evaluating pedestrian environments.

Despite these contributions, several limitations should be acknowledged. First, the study relied on a video-based virtual environment, which, although offering high experimental control (Bhagavathula et al., 2018; Kasraian et al., 2020), cannot fully reproduce real-world light–surface interactions (Gatersleben & Andrews, 2013; Kjellgren & Buhrkall, 2010; Mayer et al., 2009). Subtle perceptual phenomena related to glare, color rendering, and chromatic adaptation may therefore have been attenuated. As a result, findings related to fine-grained lighting comfort should be interpreted with caution. Second, participants evaluated the environments passively rather than through actual walking, which limits conclusions regarding embodied experience and real behavior. While intentions

to choose or avoid the path provide meaningful insight into decision-making processes, they cannot be equated with observed mobility behavior. Third, the study was conducted with a relatively small sample size, which may limit the generalizability. Although the within-subject design helped reduce inter-individual variability and yielded consistent patterns across parametric and non-parametric analyses, replication with larger and more diverse samples is necessary. In addition, the experimental scenarios were restricted to one urban forest context with dense vegetation and diffuse daylight conditions. Different environmental configurations, such as open areas, direct solar radiation, or varying snow depth, may produce different perceptual outcomes and warrant further investigation. Finally, while the study isolated the effects of snow and lighting, other winter-related factors such as temperature, wind, and thermal comfort were not included. These elements are likely to interact with walking-related constraints in real-world settings (Chapman et al., 2017) and should be incorporated in future multi-sensory approaches to winter mobility.

In conclusion, this chapter suggests that snow may play a psychologically meaningful role in pedestrian environments primarily when light is scarce, enhancing environmental appraisal under electric lighting but exerting limited influence under daylight. By integrating environmental psychology, lighting research, and winter context considerations, the findings contribute to a more nuanced understanding of how seasonal surface conditions shape everyday mobility experiences. These insights underscore the importance of accounting for winter-specific environmental characteristics in the planning and design of pedestrian infrastructure in northern climates.

# Chapter V. Understanding MaaS Adoption: A Technology Acceptance Model Approach in an Italian University Context (Study 4)

*The study presented in this Chapter was conducted under the supervision of Professor Marco Lauriola at Sapienza University of Rome.*

## 5.1. Introduction

In recent years, the concept of Mobility-as-a-Service (MaaS) has attracted growing attention in both academic literature and public debate, due to its potential to integrate multiple transport modes into a single, user-centered digital platform (Jittrapirom et al., 2017; Sochor et al., 2018). MaaS aims to facilitate daily travel by combining public transport, car-sharing, bike-sharing, taxis, and ride-sharing services (Smith e Hensher, 2020) through integrated ticketing and payment systems, often based on subscription models or pay-as-you-go schemes (Fioreze et al., 2019). This potential is particularly relevant in contexts such as Italy, where private car use remains largely dominant compared to more sustainable transport modes (ISFORT, 2025). Consistently, a growing number of empirical studies have recently examined MaaS-related dynamics within the Italian context (e.g., Meloni et al., 2024; Piras et al., 2025).

Despite the increasing scholarly interest in MaaS (for comprehensive literature reviews, see Cisterna et al., 2023; Hasselwander & Bigotte, 2023; Kamargianni et al., 2016; Phonsitthangkun & Arreeras, 2024), a universally accepted definition of the concept is still lacking. This so-called “conceptual fluidity” (Sochor et al., 2018) implies that MaaS implementations and their impacts vary considerably across urban contexts and service designs (Hensher, 2017; Sochor et al., 2018). Nevertheless, Kamargianni et al. (2016) identified three core elements that jointly enable integrated intermodal travel within MaaS systems. These are:

- (1) integration of ticketing and payment, whereby a single smart card or travel account grants access to all included transport modes, and charges are consolidated within one account;
- (2) mobility packages, allowing users to prepay a predefined amount of mobility services, measured in time or distance;

(3) information and communication technologies (ICT) integration, referring to the presence of a single digital interface or application through which users can access information and services across transport modes.

In this sense, integration represents the defining feature of MaaS, as also emphasized by Meloni et al. (2024). From a psychological perspective, MaaS represents a shift from mode-specific mobility choices to a more systemic form of decision-making. Unlike traditional approaches that focus on the adoption of a single transport mode, MaaS requires users to evaluate mobility as an integrated set of options, in which active modes such as walking and cycling coexist with public transport and shared services within a unified framework (Kamargianni et al., 2016). This intermodal logic implies that acceptance is no longer driven solely by attitudes toward a specific behavior, but by broader cognitive and motivational evaluations of the mobility system (Meloni et al., 2025). As a result, MaaS offers a complementary perspective to studies that examine intentions to use individual transport modes under specific infrastructural conditions. While such approaches are essential for understanding how environmental features shape active mobility behaviors, they do not fully capture how users form intentions when mobility is framed as an integrated service ecosystem. In this perspective, MaaS can be interpreted as an enabler of intermodal mobility, including active modes such as walking and cycling. By integrating multiple transport options within a single digital interface, MaaS systems facilitate seamless transitions between modes, allowing users to combine public transport with first- and last-mile active mobility. This suggests that MaaS may not replace active behaviors but rather embed them within more flexible mobility patterns. At the same time, MaaS may indirectly contribute to reducing private car use by increasing the accessibility and convenience of alternative transport options. Given the central role of car dependency as a barrier to sustainable mobility, particularly in contexts such as Italy, MaaS can be understood not only as a technological innovation, but also as a systemic mechanism supporting more sustainable mobility transitions.

A growing body of research has highlighted that the success of MaaS systems strongly depends on user behavior and preferences (e.g., Athanasopoulou et al., 2022; Fioreze et al., 2019; Ho, 2022; Phonsitthangkun & Arreeras, 2024; Yu et al., 2024). Empirical evidence from European pilot projects, such as UbiGo in Gothenburg (Sochor et al., 2014) and Smile in Vienna (Karlsson et al., 2017), suggests that initial motivations for adoption, often driven by curiosity or technological interest, do not necessarily translate into long-term usage. Instead, practical factors such as flexibility, time savings, and ease of travel appear to play a decisive role in shaping everyday mobility choices (Fioreze et al., 2019; Karlsson et al., 2017; Sochor et al., 2014). Conversely, perceived environmental

or health-related benefits tend to have a marginal influence, highlighting a “green gap” between pro-environmental intentions and actual travel behavior (Schikofsky et al., 2020).

To better understand the determinants of MaaS adoption, several theoretical frameworks have been applied in the literature. These include the Unified Theory of Acceptance and Use of Technology (UTAUT; Venkatesh et al., 2003), the TPB (Ajzen, 1991), the Value-Belief-Norm (VBN) theory (Stern et al., 1999), and the TAM (Davis, 1989) (e.g., Kant et al., 2023; Pellegrini et al., 2025a; Pellegrini et al., 2025b; Wen et al., 2025). According to the TAM, the adoption of a new technological system primarily depends on two key constructs: perceived usefulness, defined as the degree to which a person believes that using a particular system would enhance his or her job performance, and perceived ease of use, defined as the degree to which a person believes that using a particular system would be free of effort (Davis, 1989).

As reported by Rafique et al. (2020), the TAM has been widely employed to investigate technology acceptance across diverse geographical contexts, including the United States, Saudi Arabia, Korea, and China (e.g., Rafique et al., 2018; Yoon, 2016; Zha et al., 2015), as well as across multiple application domains. These include mobile shopping (e.g., Hubert et al., 2017), e-learning (e.g., Jeong, 2011), online libraries (e.g., Zhao et al., 2015), digital libraries (e.g., Zha et al., 2015), and mobile library applications (MLA) (e.g., Aharony, 2014; Joo & Choi, 2015). For instance, Ibrahim et al. (2017) examined university students’ acceptance of e-learning using a modified TAM incorporating six constructs, applied to a sample from Tunku Abdul Rahman University College. Their findings indicated that computer self-efficacy significantly influences perceived ease of use, which in turn directly affects the intention to use e-learning systems, underscoring the importance of basic technological competencies. Similarly, Rafique et al. (2020) analyzed the factors influencing the acceptance and usage intention of mobile digital library applications by testing a TAM-derived model on a sample of 340 users through Structural Equation Modelling (SEM). Their results indicate that perceived usefulness and perceived ease of use directly affect usage intention, while system quality and habit act as additional determinants, with relevant implications for the design and management of MLAs. Nair and Das (2012), focusing on high school mathematics teachers in Kerala, applied the TAM to examine attitudes towards the use of information technologies in education. While the perceived usefulness of such technologies was generally positive, the study revealed that limited practical familiarity constrained effective acceptance, making ease of use a crucial factor in shaping attitudes towards technological innovation.

More recent applications of the TAM to the MaaS context confirm the relevance of its core constructs, while also highlighting context-specific dynamics related to mobility behavior. For example,

Schikofsky et al. (2020) investigated the motivational mechanisms underlying MaaS adoption intentions by combining qualitative interviews with a quantitative model. Their findings emphasized the central role of psychological needs, such as autonomy, competence, and social relatedness, as well as cognitive congruence with existing mobility habits, suggesting that MaaS acceptance is driven not only by perceived usefulness but also by experiential and motivational factors. Similarly, Vafaei-Zadeh et al. (2026) analyzed MaaS adoption intentions in Malaysia using an extended model that integrates the TAM with the Task–Technology Fit framework (Goodhue & Thompson, 1995) and additional socio-psychological variables. Their results indicate that perceived usefulness, perceived ease of use, and alignment between the technology and daily mobility needs foster adoption, whereas perceived risk acts as a barrier, highlighting the importance of social and contextual factors alongside technological considerations.

Building on this theoretical and empirical background, the present study adopts a data-driven approach to investigate MaaS adoption dynamics. The analysis is based on an existing dataset provided for this research, which was initially explored through descriptive and exploratory analyses to assess data structure, distributions, and underlying patterns. Subsequently, the key constructs of the TAM were operationalized and identified within the dataset, allowing for an empirical examination of perceived usefulness, perceived ease of use, and their relationships with MaaS adoption-related outcomes. This approach facilitates the integration of established theoretical frameworks with empirical evidence, contributing to a more nuanced understanding of user acceptance mechanisms in the MaaS context.

## **5.2. Method**

### **5.2.1. Sample**

The survey, administered online via Qualtrics Survey, targeted the university population from five Italian universities: Politecnico di Bari, University of Cagliari, University of Milano-Bicocca, University of Napoli Federico II, and University of Padova. Although the survey was part of a national research project involving multiple universities, the present study focuses exclusively on data collected at the University of Cagliari, in line with the project's data governance structure and analytical responsibilities assigned to each participating research unit. Data collection took place between December 2023 and April 2024. Since the survey was addressed exclusively to the university population, the sample cannot be considered representative of the general population; therefore, the results should be interpreted with caution.

The initial sample consisted of 2,511 respondents. After data cleaning procedures, which included the exclusion of incomplete questionnaires, the final sample included 1,470 participants. The mean age

of respondents was 30.9 years ( $SD = 13.3$ ), with a minimum age of 18 and a maximum age of 80. The sample comprised 489 men (33.3%) and 981 women (66.7%). With regard to employment status, most respondents were students ( $n = 1,074$ ; 73.1%), followed by technical-administrative staff ( $n = 185$ ; 12.6%), professors or researchers ( $n = 159$ ; 10.8%), PhD candidates or postgraduate ( $n = 35$ ; 2.4%), contract lecturers ( $n = 5$ ; 0.3%), research fellows ( $n = 4$ ; 0.3%), and scholarship holders or collaborators ( $n = 8$ ; 0.5%). Regarding the primary mode of transportation used for commuting between home and university, the most frequently reported modes were urban bus ( $n = 508$ ; 34.6%) and private car as driver ( $n = 454$ ; 30.9%). Other modes included walking for at least five minutes ( $n = 133$ ; 9.0%), train ( $n = 135$ ; 9.2%), extra-urban bus ( $n = 115$ ; 7.8%), car as passenger ( $n = 41$ ; 2.8%), motorcycle or scooter ( $n = 20$ ; 1.4%), tram or trolleybus ( $n = 16$ ; 1.1%), light metro ( $n = 14$ ; 1.0%), bicycle ( $n = 11$ ; 0.7%), university shuttle service ( $n = 2$ ; 0.1%), electric scooter ( $n = 4$ ; 0.3%), and other modes ( $n = 17$ ; 1.2%).

### **5.2.2. Measures**

For the purposes of this study, only a specific subset of the original dataset was employed. These measures were assessed through a structured set of questionnaire items. Specifically, a total of twenty-one items were used to capture individual-level characteristics relevant to MaaS adoption. Of these, seventeen items focused on users' perceptions and attitudes towards MaaS, including evaluations related to its usefulness, ease of use, and broader experiential aspects. The remaining four items collected socio-demographic information, covering variables such as gender, age, employment status and mode of transportation. Together, these measures provide a comprehensive representation of both socio-psychological determinants and background characteristics, allowing for a nuanced analysis of MaaS acceptance that accounts for individual differences alongside perceptual and attitudinal factors.

Although the questionnaire items in the dataset were originally labelled according to predefined constructs (i.e., Multimodal mobility, Attitude, Willingness to pay, Behavioral intention, Perceived ease of use, Perceived usefulness), these labels were not assumed a priori in the present study. Instead, the underlying structure of the socio-psychological items was empirically examined through Exploratory Graph Analysis (EGA), to assess how the items naturally clustered based on their observed relationships. This data-driven approach allowed the identification of construct groupings grounded in the empirical structure of the data rather than solely in their original specification. A complete overview of all items included in the analysis is provided in Table 16.

**Table 16. Socio-psychological measures included in the analysis.**

|                       |                                                                                                                                                                                                               |
|-----------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Multimodal mobility   | I choose to travel by public transport or to share rides in order to reduce travel costs <sup>1</sup>                                                                                                         |
|                       | I do not care which mode of transport I use, as long as it meets my travel needs <sup>1</sup>                                                                                                                 |
|                       | I am willing to try new ways of traveling <sup>1</sup>                                                                                                                                                        |
| Attitude              | Innovative mobility services (such as Uber, BlaBlaCar, bike-sharing, etc.) excite me <sup>2</sup>                                                                                                             |
| Willingness to pay    | I prefer paying for trips through a smartphone application or other digital methods rather than using paper tickets <sup>1</sup>                                                                              |
|                       | I am willing to try new smartphone applications <sup>1</sup>                                                                                                                                                  |
|                       | I would use a smartphone application if it provided easy access (e.g., payment, information, routes, travel times) to all modes of transport <sup>1</sup>                                                     |
|                       | I frequently use smartphone applications to obtain information about transport services and to plan my trips <sup>1</sup>                                                                                     |
| Behavioral intention  | I would be willing to subscribe to a single subscription plan (weekly or monthly) that includes the use of multiple transport services (public transport, sharing services, taxis, etc.) <sup>3,4</sup>       |
|                       | I would be willing to try new modes of transport that I have not used before if they were included in my integrated mobility services subscription <sup>3,4</sup>                                             |
|                       | I would be willing to use, or to increase my use of, sustainable transport modes if a single application provided easy access to them (e.g., payment, information, routes, travel times, etc.) <sup>3,4</sup> |
| Perceived ease of use | It is easy for me to find the vehicle/access point to the service when it is displayed on the map in the application (smartphone app) <sup>4</sup>                                                            |
|                       | I think it would be easy for me to become skilled at using an application that offers innovative and integrated mobility services <sup>4</sup>                                                                |
|                       | I think that learning how to use new innovative and integrated mobility services would be easy for me <sup>4</sup>                                                                                            |
| Perceived usefulness  | An integrated subscription plan for innovative mobility services would be useful for my daily mobility <sup>4</sup>                                                                                           |
|                       | An integrated subscription plan for innovative mobility services would allow me to carry out my daily trips more quickly <sup>4</sup>                                                                         |

Using an integrated subscription plan for innovative mobility services would enhance the effectiveness of my daily mobility<sup>4</sup>

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**Note:** <sup>1</sup> = Alonso-González et al., 2020; <sup>2</sup> = Fioreze et al., 2019; <sup>3</sup> = Kamargianni et al., 2018; <sup>4</sup> = Schikofsky et al., 2020.

### 5.2.3. Data analysis

The statistical analysis was conducted using R (version 4.4.1; R Development Core Team, 2024; Rstudio Team, 2024), employing a multi-step psychometric approach to investigate the dimensional structure and the relationships among the variables. The analysis followed a three-step logic, moving from the identification of the latent dimensional structure of the data, to the computation of network-based scores, and finally to the testing of theoretically driven relationships through SEM (Jöreskog, 1970; Zyphur et al., 2023). In this framework, Exploratory Graph Analysis (EGA; Golino & Epskamp, 2017) was used to uncover the underlying structure of measures in a data-driven way, identifying clusters of items that naturally group together. SEM, in contrast, served to test a theoretically specified causal model, allowing for an examination of the directional relationships among the key constructs derived from the TAM.

First, to determine the number of dimensions underlying the dataset, an EGA was performed using the EGAnet package. Unlike traditional factor analysis, EGA uses a network psychometrics framework to identify clusters of variables. The network was estimated via a Gaussian Graphical Model (GGM) with a Graphical Least Absolute Shrinkage and Selection Operator (GLASSO) estimation. The Walktrap algorithm was selected for community detection, as it provided the best fit according to the Total Entropy Fit Index (TEFI; Golino et al., 2021). To ensure the robustness of this structure, a non-parametric bootstrap procedure (500 iterations) was executed, evaluating both structural consistency and item stability. Subsequently, individual scores for the identified dimensions, perceived usefulness (PU), perceived ease of use (PEOU), willingness to pay (WTP), and behavioral intention (BI), were calculated using the `net.scores` function. This method allowed for the derivation of standardized Z-scores weighted by the network topology, rather than simple sum scores. The inter-correlations between these factors were then assessed through a Pearson correlation matrix to verify convergent validity. Finally, the theoretical framework was tested through SEM using the `lavaan` package. The model parameters were estimated using the Robust Maximum Likelihood (RML; Bertsimas & Nohadani, 2019) estimator to account for potential non-normality. Model fit was evaluated through standard indices, including the Comparative Fit Index (CFI; Bentler, 1990), the Tucker-Lewis Index (TLI; Tucker & Lewis, 1973), and the Root Mean Square Error of Approximation (RMSEA; Steiger & Lind, 1980).

### 5.3. Results

Preliminary inspection of item-level descriptive statistics showed adequate variability and no substantial deviations from normality (see Table 17).

**Table 17. Item-level descriptive statistics.**

|        | Mean | Median | <i>SD</i> | Min | Max | Skewness | SE   | Kurtosis | SE   |
|--------|------|--------|-----------|-----|-----|----------|------|----------|------|
| ATT_1  | 2.89 | 3.00   | 1.14      | 1   | 5   | -0.01    | 0.06 | -0.65    | 0.13 |
| MULT_1 | 3.58 | 4.00   | 1.18      | 1   | 5   | -0.64    | 0.06 | -0.38    | 0.13 |
| MULT_2 | 3.64 | 4.00   | 1.11      | 1   | 5   | -0.63    | 0.06 | -0.34    | 0.13 |
| MULT_3 | 3.66 | 4.00   | 1.01      | 1   | 5   | -0.64    | 0.06 | 0.08     | 0.13 |
| WTP_1  | 3.98 | 4.00   | 1.18      | 1   | 5   | -1.00    | 0.06 | 0.10     | 0.13 |
| WTP_2  | 4.01 | 4.00   | 1.00      | 1   | 5   | -1.02    | 0.06 | 0.78     | 0.13 |
| WTP_3  | 4.26 | 5.00   | 0.98      | 1   | 5   | -1.45    | 0.06 | 1.87     | 0.13 |
| WTP_4  | 4.27 | 5.00   | 1.06      | 1   | 5   | -1.62    | 0.06 | 2.02     | 0.13 |
| BI_1   | 3.89 | 4.00   | 1.10      | 1   | 5   | -0.95    | 0.06 | 0.32     | 0.13 |
| BI_2   | 3.89 | 4.00   | 1.03      | 1   | 5   | -0.94    | 0.06 | 0.62     | 0.13 |
| BI_3   | 3.80 | 4.00   | 1.09      | 1   | 5   | -0.82    | 0.06 | 0.20     | 0.13 |
| PEOU_1 | 4.10 | 4.00   | 0.94      | 1   | 5   | -1.13    | 0.06 | 1.22     | 0.13 |
| PEOU_2 | 4.12 | 4.00   | 0.93      | 1   | 5   | -1.09    | 0.06 | 1.16     | 0.13 |
| PEOU_3 | 4.05 | 4.00   | 0.96      | 1   | 5   | -1.02    | 0.06 | 0.89     | 0.13 |
| PU_1   | 3.69 | 4.00   | 1.11      | 1   | 5   | -0.66    | 0.06 | -0.17    | 0.13 |
| PU_2   | 3.53 | 4.00   | 1.19      | 1   | 5   | -0.52    | 0.06 | -0.52    | 0.13 |
| PU_3   | 3.61 | 4.00   | 1.14      | 1   | 5   | -0.59    | 0.06 | -0.32    | 0.13 |

**Note:** ATT = Positive attitude; MULT = Multimodal mobility; WTP = Willingness to pay; BI = Behavioral intention; PEOU = Perceived ease of use; PU = Perceived usefulness; *SD* = Standard deviation; SE = Standard error.

#### 5.3.1. Exploratory graph analysis

To identify the most stable and parsimonious solution, two community detection algorithms, Louvain and Walktrap, were compared. Model selection was guided by the TEFI, with lower values indicating superior fit. The Walktrap solution demonstrated better performance (TEFI = -8.494) relative to the Louvain algorithm (TEFI = -8.153) and was therefore retained for subsequent analyses. This solution revealed a clear four-dimensional structure, with items clustering into theoretically coherent communities corresponding to distinct psychological constructs. The robustness of the identified dimensional structure was evaluated through a non-parametric bootstrap procedure with 500 iterations. The results indicated excellent structural replicability. Dimensions 2, 3, and 4 exhibited perfect stability (stability coefficient = 1.000), being reproduced in all bootstrap samples. Dimension 1 also showed high stability (0.786), suggesting a well-defined core structure with limited variability across resamples (see Figure 34).

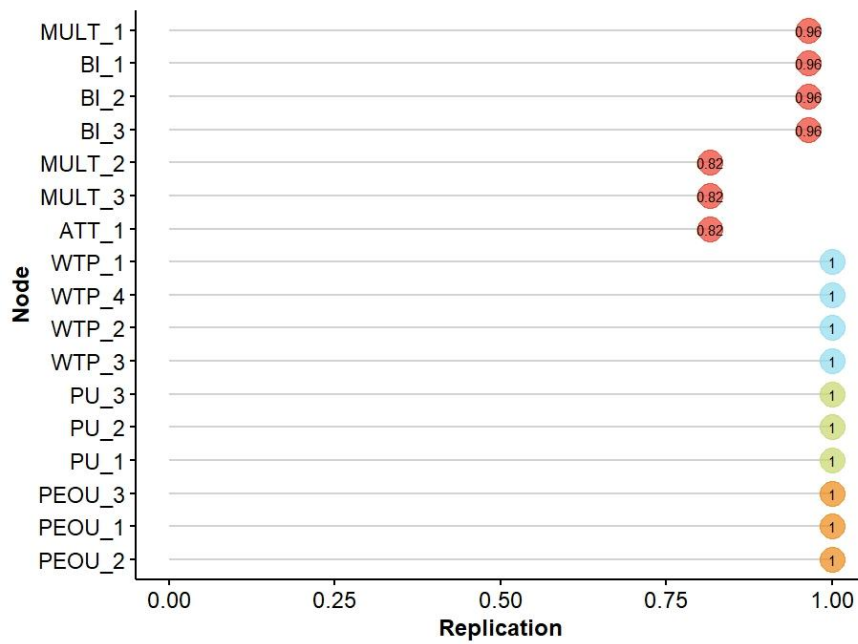


**Figure 34. Distribution of items across the four dimensions.**

Item-level stability further supported the solidity of the network solution (see Table 18). Items measuring willingness to pay, perceived usefulness, and perceived ease of use demonstrated perfect assignment stability (1.000), consistently loading onto their respective dimensions. Items related to multimodal mobility, attitude, and behavioral intention also displayed high stability coefficients (ranging from .816 to .972), confirming their reliability as indicators of the underlying constructs.

**Table 18. Item stability within clusters.**

|        | Cluster      |          |          |          |       |
|--------|--------------|----------|----------|----------|-------|
|        | 1            | 2        | 3        | 4        | 5     |
| ATT_1  | <b>0.816</b> | 0        | 0        | 0        | 0.184 |
| MULT_1 | <b>0.970</b> | 0        | 0        | 0.002    | 0     |
| MULT_2 | <b>0.816</b> | 0        | 0        | 0        | 0.184 |
| MULT_3 | <b>0.816</b> | 0        | 0        | 0        | 0.184 |
| WTP_1  | 0            | <b>1</b> | 0        | 0        | 0     |
| WTP_2  | 0            | <b>1</b> | 0        | 0        | 0     |
| WTP_3  | 0            | <b>1</b> | 0        | 0        | 0     |
| WTP_4  | 0            | <b>1</b> | 0        | 0        | 0     |
| BI_1   | <b>0.972</b> | 0        | 0        | 0        | 0.028 |
| BI_2   | <b>0.972</b> | 0        | 0        | 0        | 0.028 |
| BI_3   | <b>0.972</b> | 0        | 0        | 0        | 0.028 |
| PEOU_1 | 0            | 0        | 0        | <b>1</b> | 0     |
| PEOU_2 | 0            | 0        | 0        | <b>1</b> | 0     |
| PEOU_3 | 0            | 0        | 0        | <b>1</b> | 0     |
| PU_1   | 0            | 0        | <b>1</b> | 0        | 0     |
| PU_2   | 0            | 0        | <b>1</b> | 0        | 0     |

|      |   |   |   |   |   |
|------|---|---|---|---|---|
| PU_3 | 0 | 0 | 1 | 0 | 0 |
|------|---|---|---|---|---|

**Note:** ATT = Positive attitude; MULT = Multimodal mobility; WTP = Willingness to pay; BI = Behavioral intention; PEOU = Perceived ease of use; PU = Perceived usefulness.

Overall, the EGA results provide strong empirical support for a four-factor model characterized by high structural consistency and precise item-to-dimension correspondence. Figure 35 illustrates the network of connections among the items. Four clusters are highlighted using different colors: red represents the cluster including behavioral intention, multimodal mobility, and attitude; light blue indicates the willingness to pay cluster; green corresponds to perceived usefulness; and orange represents perceived ease of use.

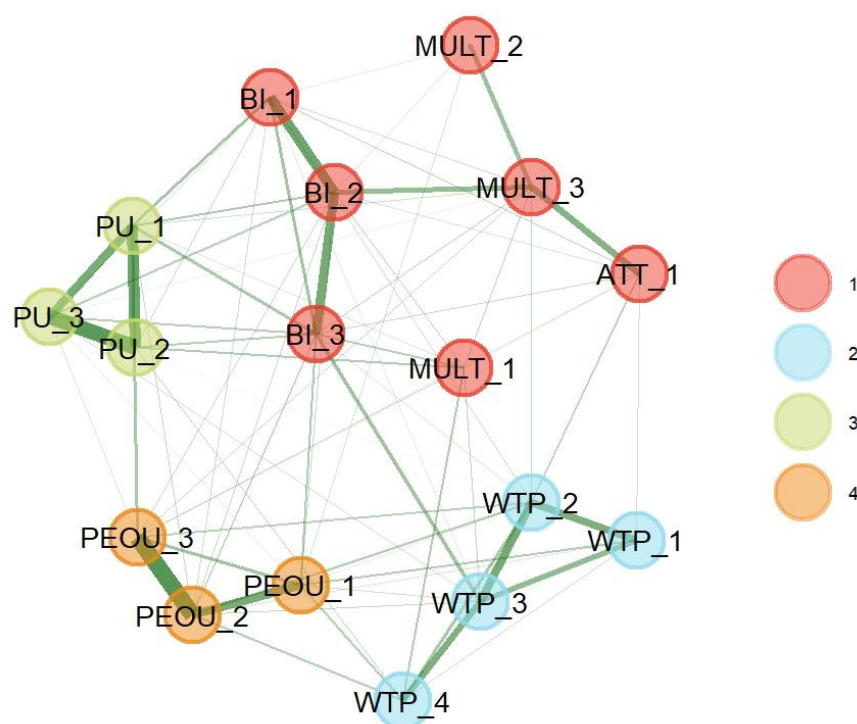


Figure 35. Exploratory graph analysis with TAM construct dimensions.

### 5.3.2. Network-based scoring and data standardization

Following the identification of the optimal network structure, individual scores were computed using a network-based scoring approach (net.scores). Unlike traditional sum-score methods, this procedure estimates individual latent scores by weighting items according to their relative centrality and contribution within each community of the GGM, thereby preserving the relational information encoded in the network structure. Scores were derived using the “original” loading method and subsequently standardized (Z-scores;  $M = 0$ ,  $SD = 1$ ) to ensure comparability across the four dimensions: behavioral intention, willingness to pay, perceived usefulness, and perceived ease of use. Inspection of the score distributions (Table 19) indicated substantial inter-individual variability. The standardized metrics allowed for a clear differentiation between participants with uniformly high

endorsement across dimensions (e.g., Participant 1, Perceived usefulness = 1.48) and those showing selectively low propensities, particularly in terms of Willingness to Pay (e.g., Participant 4, Willingness to pay = -1.31). This scoring strategy provides a psychometrically robust foundation for subsequent inferential analyses, as it combines the sensitivity of network models with the analytical tractability of continuous standardized variables.

**Table 19. Network-based standardized scores across the four dimensions.**

| Participant | Scores               |                    |                      |                       |
|-------------|----------------------|--------------------|----------------------|-----------------------|
|             | Behavioral intention | Willingness to pay | Perceived usefulness | Perceived ease of use |
| 1           | 0.5109718            | 1.0077684          | 1.485640             | 1.0302627             |
| 2           | -0.3594918           | 0.6496564          | -0.643239            | 1.0302627             |
| 3           | -0.9821930           | -0.1533718         | -0.643239            | -1.2356491            |
| 4           | -0.9821930           | -1.3145119         | -0.643239            | -1.2356491            |
| 5           | 0.8589507            | -0.5680393         | 1.485640             | 0.5387037             |
| 6           | -0.7768248           | -0.3674472         | -0.643239            | -1.2356491            |

### 5.3.3 Correlations among network scores

Associations among the four psychological dimensions were examined using Pearson correlation coefficients computed on the standardized network scores. The resulting correlation matrix (see Table 20) revealed uniformly positive relationships, supporting the internal coherence of the conceptual framework. The strongest correlation emerged between behavioral intention and perceived usefulness ( $r = .649, p < .001$ ), indicating that higher perceived functional value of the system is closely associated with a stronger intention to use it. Perceived ease of use was also strongly related to behavioral intention ( $r = .554, p < .001$ ) and willingness to pay ( $r = .521, p < .001$ ), underscoring the central role of usability in shaping both motivational and economic outcomes. Willingness to pay showed a strong association with behavioral intention ( $r = .481, p < .001$ ), while its relationship with perceived usefulness was comparatively weaker ( $r = .388, p < .001$ ). Taken together, these findings suggest that although the four constructs are empirically distinct, they form an interrelated system in which functional perceptions (usefulness and ease of use) are tightly linked to motivational dispositions and downstream financial commitment.

**Table 20. Pearson correlation matrix among the four psychological dimensions.**

|                       | 1        | 2        | 3        | 4        |
|-----------------------|----------|----------|----------|----------|
| Behavioral intention  | 1.000    | -        | -        | -        |
| Willingness to pay    | 0.481*** | 1.000*** | -        | -        |
| Perceived usefulness  | 0.649*** | 0.388*** | 1.000*** | -        |
| Perceived ease of use | 0.554*** | 0.521*** | 0.488*** | 1.000*** |

Note: \*\*\* =  $p < .001$ .

### 5.3.4. Structural equation modeling

To formally test the hypothesized relationships among the constructs, SEM was conducted using the lavaan package, with robust maximum likelihood estimation (MLR) to account for potential deviations from multivariate normality. Competing models were estimated to identify the most plausible representation of the psychological mechanisms underlying system adoption. The robust chi-square test indicated a statistically significant result ( $\chi^2 = 622.083$ ,  $df = 114$ ,  $p < .001$ ). The final structural model demonstrated a good overall fit to the data. Fit indices exceeded recommended thresholds, with a robust Comparative Fit Index (CFI = .943) and Tucker–Lewis Index (TLI = .932). Residual-based indices further supported model adequacy (RMSEA = .063; SRMR = .053). The measurement model showed strong standardized factor loadings, generally above .70, indicating that the latent constructs were well captured by their respective indicators.

Consistent with the TAM, the structural paths revealed a hierarchical pattern of influence among the constructs. Perceived ease of use significantly predicted perceived usefulness ( $\beta = .541$ , 95% CI [0.548, 0.737]), confirming that greater usability enhances the perceived value of the system. Behavioral intention was strongly predicted by both perceived usefulness ( $\beta = .572$ , 95% CI [0.713, 0.998]) and perceived ease of use ( $\beta = .364$ , 95% CI [0.502, 0.794]), with the model explaining a substantial proportion of its variance ( $R^2 = .684$ ). In turn, behavioral intention emerged as the primary determinant of willingness to pay ( $\beta = .655$ , 95% CI [0.376, 0.570]). Notably, perceived usefulness did not exert a significant direct effect on willingness to pay once intention was included in the model (see Table 21). In sum, the SEM results indicate that ease of use and perceived utility function as foundational drivers of user acceptance, while behavioral intention acts as a crucial mediating mechanism linking cognitive evaluations of the system to users' financial commitment. See Figure 36 for a graphical representation of the model.

**Table 21. Standardized parameter estimates, 95% confidence intervals, and hypothesis testing for the structural model.**

| Path                  | $\beta$ | Lower CI (95%) | Upper CI (95%) | <i>P</i> -value |
|-----------------------|---------|----------------|----------------|-----------------|
| PEOU $\rightarrow$ PU | 0.541   | 0.548          | 0.737          | <.001           |
| PU $\rightarrow$ BI   | 0.572   | 0.713          | 0.998          | <.001           |
| PEOU $\rightarrow$ BI | 0.364   | 0.502          | 0.794          | <.001           |
| BI $\rightarrow$ WTP  | 0.655   | 0.376          | 0.570          | <.001           |
| PU $\rightarrow$ WTP  | -0.037  | -0.186         | 0.106          | 0.595           |

**Note:** PEOU = Perceived ease of use; PU = Perceived usefulness; BI = Behavioral intention; WTP = Willingness to pay; CI = Confidence interval.

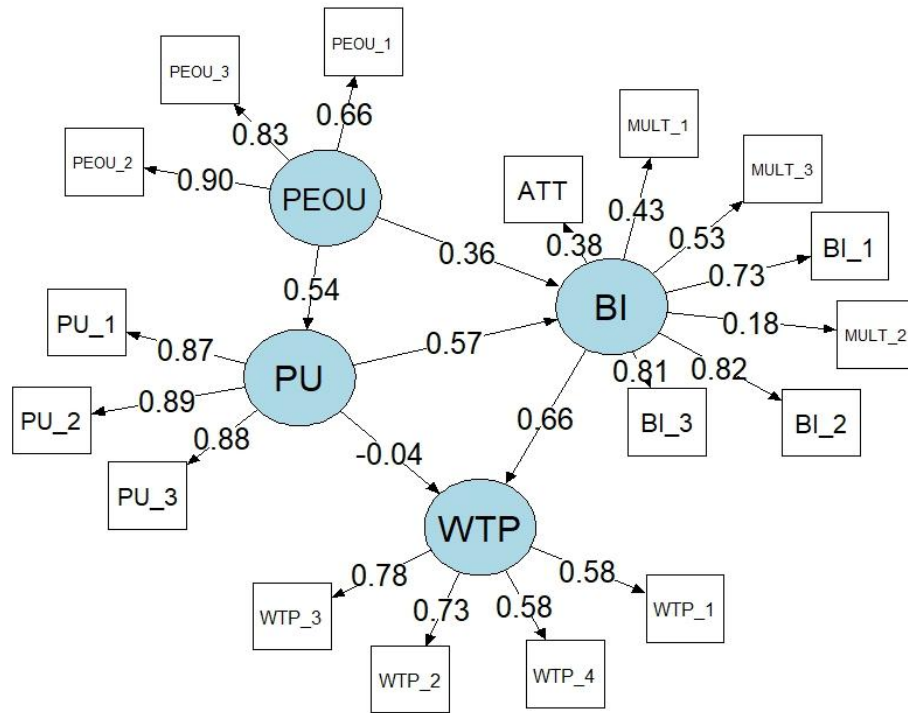


Figure 36. SEM path diagram: TAM-based model of intentions to use MaaS.

#### 5.4. Discussion

Study 4 aimed to analyze the mechanisms underlying the adoption of MaaS within a university population, through an empirical operationalization of the central constructs of the TAM. Overall, the results confirm the relevance of TAM-based frameworks for understanding MaaS acceptance, consistent with previous applications both in technological contexts (e.g., Aharony, 2014; Hubert et al., 2017; Ibrahim et al., 2017; Jeong, 2011; Joo & Choi, 2015; Nair & Das, 2012; Rafique et al., 2020; Zha et al., 2015; Zhao et al., 2015) and in mobility research (e.g., Pellegrini et al., 2025a; Schikofsky et al., 2020; Vafaei-Zadeh et al., 2026). At the same time, the results highlighted specific contextual dynamics that refine and, in part, challenge simplified interpretations of MaaS adoption processes. It is important to note that this investigation aimed to examine MaaS by empirically testing a model without exploring which individuals might be predisposed to use it, as done by Alonso-González et al. (2020), or the barriers and facilitators of MaaS adoption, as studied by Piras et al. (2025).

The correlation structure further supported the convergent validity of the TAM framework in the MaaS context. The strong association between perceived usefulness and behavioral intention confirmed a core assumption of TAM: adoption motivation is primarily driven by expectations of functional benefits (Davis, 1989). This finding aligned with previous articles reporting a positive relationship between perceived usefulness and intention to use (e.g., Pellegrini & Tagliabue, 2024;

Pellegrini et al., 2025a; Xu et al., 2010; Yoon, 2016). Similar patterns have been documented in studies specifically focused on MaaS, where perceived efficiency, flexibility, and time savings are more influential than environmental or regulatory considerations in shaping user intentions (e.g., Fioreze et al., 2019; Schikofsky et al., 2020).

Perceived ease of use also showed robust relationships with behavioral intention, reinforcing the idea that usability may function as a key enabling condition rather than merely a technical attribute. This result is consistent with previous evidence indicating a positive relationship between perceived ease of use and intention to use (e.g., Pellegrini & Tagliabue, 2024; Pellegrini et al., 2025a; Sheikhshoei & Oloumi, 2011; Yoon, 2016).

Structural equation modeling provided a more nuanced view of MaaS adoption mechanisms. In line with classic TAM formulations, perceived ease of use significantly predicted perceived usefulness, supporting the assumption that simpler interaction facilitates recognition of system value (Davis, 1989). This relationship is consistent with other studies reporting that perceived ease of use positively influences perceived usefulness (e.g., Liao et al., 2024; Vafaei-Zadeh et al., 2026). Both constructs significantly contribute to behavioral intention, with perceived usefulness exerting a stronger effect, a pattern previously observed in MaaS adoption studies (e.g., Pellegrini et al., 2025a; Schikofsky et al., 2020).

An important finding concerns willingness to pay, which was predicted by behavioral intention. This aligned with results from studies such as Yang et al. (2024), though other research has not found a relationship between these variables (e.g., Kasilingam & Krishna, 2022). This discrepancy highlights the fact that behavioral intention does not always translate into actual behavior, as is well known (Sheeran & Webb, 2016). Nevertheless, in many validated models, such as the TPB (Ajzen, 1991) and TAM (Davis, 1989), intention is the primary dependent variable. In this study, the model performed as expected, and willingness to pay was predicted by MaaS usage intention, suggesting that greater acceptance of intermodal mobility and stronger usage intention may increase individuals' readiness to pay for the service. Unlike studies that focus on the amount individuals are willing to pay (e.g., Ho et al., 2018), this research examined only general willingness to pay.

Despite the robustness of the analytical approach and the internal coherence of the results, several limitations should be acknowledged, as they constrain the scope and generalizability of the findings. First, the study relied on a non-representative sample drawn exclusively from a university population, and, more specifically, from a single Italian university. Although universities constitute a relevant context for investigating MaaS adoption (Coppola et al., 2025; Le Pira et al., 2023), given the concentration of young, digitally skilled individuals with heterogeneous mobility needs, this sample

was likely to overrepresent profiles that are more familiar with smartphone-based services and more open to technological innovation. As a result, the observed strength of relationships involving perceived ease of use and behavioral might have been inflated relative to what would be expected in the general population, where lower digital literacy and more entrenched mobility habits are more common. This limitation suggests caution in extending the conclusions to other socio-demographic groups.

Second, the cross-sectional nature of the data prevents any causal interpretation of the relationships identified in the structural model. Although the SEM results were theoretically consistent with the TAM, the temporal ordering of constructs such as perceived usefulness, behavioral intention, and willingness to pay cannot be empirically verified. MaaS adoption is inherently dynamic, involving learning processes, habit formation, and potential shifts in attitudes over time (Meloni et al., 2025; Schikofsky et al., 2020). Consequently, the present analysis captured intentions and perceptions at a single point in time, rather than actual adoption of trajectories or sustained usage. Longitudinal designs would be necessary to assess how intentions translate into real behavior and whether willingness to pay remains stable once users are exposed to real MaaS offerings.

A further limitation concerns the operationalization of MaaS within the study. Respondents were asked to evaluate a largely hypothetical or generalized MaaS concept, rather than an existing, fully operational service embedded in their daily mobility routines. This abstraction may have captured encouraged respondents to base their answers on idealized expectations rather than on concrete experiences, particularly with respect to willingness to pay. As a result, the measures employed may capture attitudinal readiness more than realistic economic commitment.

Finally, the analytical focus on socio-psychological variables implies that several relevant contextual factors were not explicitly modeled. Variables such as service availability, quality of public transport, pricing schemes, institutional trust, and local governance arrangements are known to play a crucial role in MaaS adoption (Piras et al., 2025), yet they fell outside the scope of the present analysis. Consequently, the model explained willingness to pay primarily through individual perceptions and intentions, potentially underestimated the influence of structural and infrastructural constraints that shape real-world mobility choices.

Taken together, these limitations do not compromise the validity of the findings but rather delineate the boundaries within which they should be interpreted. They also point to clear directions for future research, emphasizing the need for more diverse samples, longitudinal designs, and integrative models that combine psychological, economic, and contextual dimensions of MaaS adoption.

## 5.5. Conclusion

The findings of Study 4 try to provide insights into the adoption of MaaS within a university context, highlighting both the theoretical and practical implications of TAM constructs. While the empirical evidence confirms the central role of perceived usefulness, perceived ease of use, and behavioral intention in driving acceptance, broader contextual and institutional factors may be critical in shaping actual user engagement.

In particular, the predominance of private car use in Italy and the characteristics of the university population may influence the generalizability of these findings. Private car users have been consistently identified as less likely to adopt MaaS (Alonso-González et al., 2020; Hoerler et al., 2020), less interested in exploring alternative travel options (Alonso-González et al., 2020; Ho et al., 2018), and more inclined to perceive their current mode of transport as essential for meeting mobility needs (Matyas, 2020; Sjöman et al., 2020). As reported by Pellegrini and Tagliabue (2024), in Italy, car ownership also has a symbolic and emotional value, making it the European country with the highest number of circulating vehicles per 100 inhabitants compared to Germany, Spain, and France. Conversely, high digital literacy among students (Yi & Siqian, 2025) may amplify the role of perceived ease of use, reducing variability in basic technology acceptance and shifting the key determinants toward motivational and economic dimensions.

These contextual insights underscore that MaaS outcomes are highly sensitive to local and institutional conditions, suggesting caution when generalizing results to other populations or national settings (Hensher, 2017; Sochor et al., 2018). For MaaS to become a widely adopted solution in Italy, several structural and operational challenges must be addressed, including inefficiencies in public transport systems, fragmented management of services, and the lack of integrated ticketing and payment mechanisms (Carteni et al., 2020; Tuveri et al., 2019). Only with reliable, integrated, and user-centered mobility services can MaaS realize its full potential in promoting sustainable and efficient travel behaviors.

Overall, this study suggests that, although the TAM provides a robust framework for understanding the socio-psychological determinants of MaaS adoption, actual adoption in practice may also depend on broader infrastructural, cultural, and institutional factors. Future research should further investigate these contextual constraints, identifying specific barriers and facilitators that influence willingness to adopt and pay for integrated mobility services across diverse populations and urban settings.

# Chapter VI. General Discussion and Conclusions

## 6.1. Summary of findings and critical reflection

This thesis investigated the socio-psychological, environmental, and contextual determinants of sustainable mobility through a combination of a scoping review and four empirical studies. Rather than identifying a single dominant determinant, the results suggest that mobility behaviors emerge from the interaction of multiple factors operating at different levels. Infrastructure, perceptions of safety, social norms, environmental conditions, and institutional contexts do not act independently but influence one another in shaping the feasibility and attractiveness of sustainable mobility options.

Across empirical analyses, infrastructure consistently emerged as a foundational condition for the adoption of sustainable mobility behaviors. In the cycling studies, the presence of a dedicated bike lane clearly distinguished scenarios perceived as viable from those perceived as unsafe. The absence of infrastructure was systematically associated with higher perceived risk, greater expected conflict with motorized traffic, and lower intention to cycle. These findings align with previous research indicating that infrastructural provision strongly predicts cycling intentions and behaviors (e.g., Bagloee et al., 2016; Bogacz et al., 2021; Chen et al., 2018; Heinen et al., 2010; Huemer et al., 2022; Parker et al., 2013). However, the results suggest a more structural interpretation of its role. Infrastructure does not simply facilitate behavior by making it more convenient; it defines the basic conditions under which cycling becomes socially legitimate and practically possible. In other words, it shapes what individuals perceive as realistically possible within the urban environment. Secondary environmental elements such as urban greenery, street furniture, or colored lanes showed weaker and less consistent effects. While these elements sometimes improved perceptions of comfort or reduced perceived danger, their impact appeared limited compared to the presence of basic infrastructure. This pattern suggests the existence of perceptual thresholds: once essential conditions are met, the addition of further environmental features may not necessarily produce proportional improvements in the subjective experience of mobility.

Another central finding concerns the role of perceived safety. In the discussion of the scoping review, the conceptual ambiguity surrounding this construct in the existing literature was highlighted, as safety was treated interchangeably as either an environmental attribute or a subjective perception. Empirical findings support the idea that perceived safety functions as a psychological evaluation in relation to how individuals interpret environmental conditions. Moreover, the overall trends in the

results, although some were not statistically significant, may suggest that perceived safety operates as a hierarchically prior determinant of mobility intentions. Across cycling studies, a possible trend emerges suggesting that the influence of social norms may be more pronounced under conditions of lower perceived danger. However, when scenarios are perceived as risky, this influence appears to weaken or is not clearly detectable. It is important to emphasize that this pattern remains suggestive rather than conclusive, as the moderation analyses did not reach conventional levels of statistical significance. This pattern may indicate that motivational and social factors do not operate in a purely additive manner. Rather, their influence appears to be contingent upon the presence of basic safety conditions, in line with hierarchical interpretations of mobility behavior such as Alfonzo's (2005) hierarchy of walking needs. Social approval and cultural normalization may encourage sustainable mobility, but only when individuals do not perceive excessive exposure to risk.

The results also highlighted the nuanced role of social norms in shaping mobility intentions. Both injunctive norms (perceived social approval) and descriptive norms (expectations about others' behavior) were positively associated with intentions to cycle. These findings are consistent with a growing body of literature emphasizing the importance of social influence in sustainable mobility adoption (e.g., Baeli et al., 2022; Frater et al., 2017a; Liu et al., 2023; Xu et al., 2020). However, the emerging trends in the results suggest that normative influence could be context-sensitive. Social norms appear to play a more prominent role when individuals already perceive cycling as feasible and relatively safe. However, this pattern should be interpreted with caution, as it reflects only a tentative trend. Under conditions of high perceived danger, their effect appears to weaken, although this difference is not statistically significant. This interaction suggests that interventions relying solely on social norms are unlikely to produce substantial behavioral change if infrastructural and safety conditions remain unfavorable. Rather, social influence appears to function primarily as a reinforcing mechanism once basic structural barriers have been addressed.

The walkability study introduced a different perspective by examining how environmental factors interact in shaping mobility experiences. Rather than focusing on infrastructure alone, the study explored how seasonal elements such as snow interact with lighting conditions in an urban forest environment. The results showed that snow does not have a fixed or intrinsic psychological meaning. Its effects appear to depend on the broader perceptual context. In daytime scenarios, snow did not significantly influence environmental evaluations or walking intentions. Under electric lighting, however, the presence of snow increased perceived visibility, safety, restorative potential, and the intention of choosing the path. These findings support an interactional view of environmental perception. Snow acted as a perceptual amplifier of artificial lighting by increasing light reflection

and visual accessibility. This suggests that environmental elements should not be interpreted in isolation; their psychological effects emerge from the way they combine within the overall sensory configuration of a space.

The analysis of MaaS adoption extended the investigation beyond physical environments to mobility systems and services. The results confirmed the explanatory strength of the TAM: perceived usefulness and perceived ease of use strongly predicted intention to use MaaS, which in turn was associated with willingness to pay. At the same time, the discussion of results highlighted the limitations of purely socio-psychological interpretations of service adoption. Structural factors such as the quality of public transport, the degree of service integration, and cultural dependence on private cars remain critical in determining whether intentions translate into actual usage. Although these results fit well within the TAM framework, showing that intention to use is predicted by perceived usefulness and perceived ease of use, they should also be interpreted considering the broader structural conditions shaping mobility choices. Mobility behaviors cannot be explained exclusively through individual attitudes or perceptions; institutional arrangements and service infrastructures play a crucial role in enabling or constraining behavioral change.

Taken together, the results suggest that sustainable mobility behaviors emerge from layered and interdependent processes. Physical infrastructure defines the range of feasible choices; perceived safety shapes how individuals evaluate these possibilities; social norms could influence behavioral intentions under favorable conditions; environmental contexts affect the experiential quality of mobility; and institutional arrangements determine the practical availability of mobility alternatives. This integrated perspective highlights the limits of one-dimensional approaches to mobility promotion. Interventions that target only one component, whether infrastructural, psychological, or institutional, are unlikely to produce substantial changes unless they align with the broader system within which everyday mobility decisions are embedded.

## **6.2. Encountered challenges and limitations**

The development of this thesis involved a series of challenges and limitations that cannot be considered merely marginal aspects of the research process, but substantially influenced the conceptual, methodological, and interpretative choices made. Explicitly acknowledging them allows not only for a clearer delimitation of the scope of the results, but also for an understanding of the structural constraints within which the overall contribution of the work is situated.

A first challenge concerns the heterogeneity of the study objects and levels of analysis considered. The thesis addresses different forms of mobility (i.e., cycling, walking, and mobility as a service),

which, while sharing a conceptual framework oriented toward sustainability and socio-psychological determinants, present specific dynamics and distinct constraints. This diversity has been valuable from an exploratory perspective, but has made it complex to maintain a consistent level of direct comparability across studies. It was not always possible to apply the same constructs, instruments, or experimental designs, necessitating continuous conceptual and methodological adaptation that may have introduced discontinuities among the results.

A second relevant limitation concerns the exclusively intentional nature of the measures used. In all empirical studies conducted, the analysis was based on behavioral intentions, subjective evaluations, and self-reported willingness, rather than on observed behaviors. Although this choice is consistent with the theoretical models referenced and with practical constraints related to research feasibility, it inevitably exposes the results to the well-known intention–behavior gap (Sheeran & Webb, 2016). This limitation is particularly evident in the MaaS study, where intentions to use and willingness to pay cannot be considered equivalent to actual adoption of the service, especially in the absence of a concrete offer that is stably integrated into participants' daily lives.

Sample characteristics represent an additional source of limitation. Studies 1 and 2 used samples recruited through snowball sampling procedures, geographically concentrated within a single urban context, while Study 4 focused on a university population. These choices, partly dictated by access, project and resource constraints, limit the generalizability of the results and make any extension of the conclusions to broader populations or different urban contexts cautious. It is plausible that younger, more educated, and digitally skilled individuals show greater openness to innovative or sustainable forms of mobility compared to the general population (Yi & Siqian, 2025), with the risk of overestimating the impact of certain socio-psychological variables.

Another challenge arose in the design and use of video scenarios. On the one hand, these tools allowed for a high level of experimental control and systematic manipulation of environmental variables; on the other hand, they inevitably involved a trade-off with ecological validity in reproducing real-world mobility experiences. In particular, the perception of traffic, interactions with vehicles, and complex sensory conditions proved difficult to simulate in a sufficiently salient and embodied way. The null results observed regarding traffic manipulation in Studies 1 and 2, as well as some attenuated evaluations in Study 3, suggest that certain environmental stimuli may not have been perceived with the same intensity or immediacy as they would be in real situations. This pattern highlights a broader methodological tension between experimental control and ecological validity in video-based simulation studies. While such approaches are particularly valuable for isolating specific environmental variables under controlled conditions, their interpretative strength depends on how

closely the simulated experience approximates real-world perception and behavior. This limitation therefore raises broader questions about the extent to which findings derived from simulated environments can be directly generalized and underscores the importance of complementing them with more immersive or in situ observational methodologies.

Some experimental design choices also introduced potential biases. In particular, the fixed order of scenario presentation in Studies 1 and 2, with the baseline always shown first, may have generated contrast or primacy effects (Digirolamo & Hintzman, 1997), amplifying the perceived differences between scenarios with and without infrastructure. Although this choice was motivated by the requirements of the larger project of which this thesis is a part, it represents an interpretative limitation that does not allow the influence of exposure order on subsequent evaluations to be completely ruled out.

Finally, a limitation of the entire work concerns the impossibility of systematically including all relevant contextual factors. Variables such as local policies, the quality of transport services, actual weather conditions, and time constraints were not directly modeled, even though they play a crucial role in everyday mobility choices (Piras et al., 2025; Yilmaz et al., 2008). Focusing on socio-psychological and perceptual dimensions allowed for an in-depth analysis of these processes but necessarily left some contextual determinants in the background.

Overall, the challenges and limitations encountered do not weaken the contribution of the thesis but rather define its scope of validity more precisely. They highlight the intrinsic complexity of studying sustainable mobility and reinforce the idea that no single methodological or theoretical approach is sufficient on its own to capture all its dimensions. In this sense, the limitations identified also serve as a starting point for methodological reflections and future developments, rather than simply being constraints to list.

### **6.3. Future directions and conclusions**

Taken together, the results of this thesis contribute to a more nuanced understanding of sustainable mobility behaviors, showing how these behaviors emerge from the interaction between infrastructural, socio-psychological, and contextual factors. The analysis suggests that mobility choices cannot be interpreted as the simple outcome of individual preferences, nor as a mechanical response to the characteristics of the urban environment. Rather, they appear as the product of dynamic, situated, and often non-linear processes. This awareness represents the main conceptual contribution of work and, at the same time, the starting point for future developments.

At a more general level, the results of the different studies can be brought together within a unified interpretative framework that integrates environmental, socio-psychological, technological, and methodological dimensions of sustainable mobility. Infrastructure and the physical characteristics of the urban environment define the range of perceived possibilities and the material basis of mobility choices. On this level, socio-psychological processes, such as perceptions of safety and social norms, shape the subjective evaluation of available alternatives. In parallel, technological and service-based systems, such as MaaS, operate at a more systemic level, influencing the structure of mobility supply and its actual accessibility. Finally, the methodological choices adopted across the different studies do not merely represent analytical tools but also contribute to defining which phenomena can be observed and how these different levels can be investigated and related to one another. From this perspective, the empirical chapters do not describe separate processes, but rather different manifestations of a single system of interdependent determinants of sustainable mobility.

A first research direction concerns the need to further explore the temporal dimension of mobility behaviors. Most of the evidence analyzed, including the empirical studies presented in this thesis, is based on cross-sectional designs or hypothetical evaluations, which allow the study of intentions, perceptions, and preferences at a specific moment, but do not make it possible to observe how these change over time. Longitudinal and quasi-experimental studies could clarify how repeated exposure to specific urban configurations or to new mobility services contributes to the formation of habits, the consolidation of social norms, and the stabilization of sustainable behaviors. From this perspective, the transition from intention to action remains one of the central challenges for future research.

Another possible development concerns the refinement of the methodological tools used to study mobility. The use of scenarios has been shown useful for isolating specific perceptual and environmental factors, but future research could combine these techniques with behavioral data or field observations. A multimodal approach would help reduce the gap between what people say they do or prefer and what they do in urban space, offering a more realistic representation of everyday mobility practices.

Regarding MaaS, the results suggest that future research should shift attention from the abstract acceptance of integrated systems to their concrete implementation. Studying real users within functioning mobility ecosystems would make it possible to better understand how economic, institutional, and organizational factors interact with individual perceptions. In this sense, closer collaboration between academic research, public administrations, and mobility operators could support studies that are more closely grounded in the complexity of real-world contexts.

In conclusion, this thesis has attempted to show that promoting sustainable mobility does not simply mean offering alternatives to private transport, but requires understanding how people interpret, evaluate, and experience these alternatives in their everyday lives. The results obtained do not provide definitive solutions but help to clarify the mechanisms through which the urban environment, perceptions, and intentions influence one another. In this sense, the main value of this work lies in highlighting that mobility policies and interventions tend to be more effective when they engage with the psychological processes that guide individual choices, while also considering the structural constraints that characterize contemporary urban contexts.

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