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ACTIVE MOBILITY AND MENTAL HEALTH: EVIDENCE-BASED INSIGHTS AND A DIGITAL FRAMEWORK FOR PUBLIC HEALTH INTERVENTIONS

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Acronyms

ABs: Active Breaks

AUSL: Azienda Unità Sanitaria Locale

AM: Active Mobility

ANWI: Associazione Nordic Walking Italia

AR: Augmented Reality

BJJ: Brazilian Jiu-Jitsu

BRFSS: Behavioural Risk Factor Surveillance System

BRUMS: Brunel Mood Scale

CCHS: Canadian Community Health Survey

CBU: Bioethics Committee University *(clarify if this is the correct full name)*

CPD: Continuing Professional Development

COST Action: European Cooperation in Science and Technology Action

EDI: Equity, Diversity, and Inclusion Principles

EU: European Union

FAIR principles: Findable, Accessible, Interoperable, and Reusable principles

FBMH: Faculty of Biology, Medicine, and Health

GAD-7: Generalized Anxiety Disorder-7

GHQ: General Health Questionnaire

GM: Greater Manchester

GPS: Global Positioning System

HEAT: Health Economic Assessment Tool

HETT: Healthcare Excellence Through Technology

HSE: Health Survey for England

IHI: Innovative Health Initiative

IPANAS-SF: International Positive and Negative Affect Schedule - Short Form

IRCCS: Scientific Institutes for Research, Hospitalization, and Healthcare

ISA: Institute of Advanced Studies

ISS: Istituto Superiore di Sanità (Italian National Institute of Health)

LHUs: Local Health Units

LMICs: Low- and Middle-Income Countries

LTPA: Leasure-Time Physical Activity

MCHP: Manchester Centre for Health Psychology

MH: Mental health

NEAT: Non-Exercise Activity Thermogenesis

NIHR: National Institute for Health Research

NWBI: North West Biotech Initiative

ORCID: Open Researcher and Contributor ID

PANAS: Positive and Negative Affect Schedule

PASSI: Progressi delle Aziende Sanitarie per la Salute in Italia

PASTA: Physical Activity Through Sustainable Transport Approaches

PFPM: Immigrants from High Migration Pressure Countries

PA: Physical Activity

PHQ-2: Patient Health Questionnaire-2

PPIE: Public and Participant Involvement and Engagement

PRISMA: Preferred Reporting Items for Systematic Reviews and Meta-Analyses

QoL: Quality of Life

RCT: Randomized Controlled Trial

REAL study: Remote Exercise and Lifestyle

RPE scale: Rating of Perceived Exertion

SDGs: Sustainable Development Goals

SISMES: Società Italiana delle Scienze Motorie e Sportive

SHIELD: Social and Human Initiatives for Empowering Learning and Driving Change

SHIINE: Social cHange multI discIplinary innovatioN Education

SF: Short Form (e.g., SF-36 or other)

UnaVEx: Una Europa Virtual Exchanges for Sustainability

VAMS: Visual Analog Mood Scale

WHO: World Health Organization

WWF Italy: World Wildlife Fund Italy

XR: Extended Reality

ACTIVE MOBILITY AND MENTAL HEALTH:
EVIDENCE-BASED INSIGHTS AND A DIGITAL FRAMEWORK FOR PUBLIC HEALTH INTERVENTIONS

Abstract

Active Mobility (AM)—encompassing walking and cycling for transportation—has emerged as a crucial factor in promoting Mental health (MH), environmental sustainability, and overall quality of life (QoL). As an integral component of daily routines, AM offers an accessible and cost-effective means of enhancing physical health, reducing carbon emissions, and fostering mental well-being. Despite its profound implications across public health, urban planning, and environmental sciences, the relationship between AM and MH remains underexplored, often hindered by inconsistent methodologies, fragmented evidence, and the absence of robust, interdisciplinary research frameworks. This thesis addresses these gaps through a comprehensive approach, blending psychology, public health, digital health innovation, and urban planning to deliver evidence-based insights and practical solutions.

The first study undertakes a scoping review, synthesising global evidence on the relationship between AM and MH. This review stands out as the first to systematically map the existing literature, offering a detailed overview of methodological trends, study designs, and key findings in the field. By analysing a diverse range of studies, the review reveals significant gaps in research outcomes, with critical constructs like depressive symptoms, anxiety, sleep quality, eudaimonia, self-efficacy, and resilience remaining largely underexplored. Furthermore, it identifies methodological inconsistencies, non-standardized outcome definitions, and varying measurement tools as major obstacles to synthesising findings across diverse studies and populations. The dominance of non-psychological perspectives in existing literature highlights the pressing need for interdisciplinary collaboration and methodological standardization. The review identifies an important observation: while many countries worldwide have conducted AM-MH analyses using national health surveillance systems, Italy has notably lagged. This realisation underscored the necessity of the second study, aimed at leveraging national surveillance data to bridge this critical gap.

The second study focuses on national surveillance data from the PASSI system (2021–2022). While the analyses provide a national overview of AM-MH trends, the collaboration with experts from the AUSL Modena regional department (Emilia-Romagna) allowed for refined insights and regional contextualization. The study uncovers significant associations between AM behaviours (walking and cycling) and MH outcomes, revealing complex, age-dependent relationships. Notably, older adults engaging in AM displayed a lower prevalence of depressive symptoms, while younger adults exhibited more nuanced and occasionally adverse associations. These findings highlight the multifaceted nature of the AM-MH relationship and demonstrate the limitations of large-scale surveillance data in capturing individual-level behavioural patterns, environmental contexts, and real-time MH states. These constraints emphasised the need for a more precise and adaptable research approach, ultimately setting the stage for the third study.

The third study addresses the methodological challenges identified in the first two studies. The inconsistencies and fragmentation observed in the scoping review, coupled with the limitations of national surveillance data, revealed the need for a universal, evidence-based, and adaptable methodology capable of capturing both subjective (MH) and objective (AM) data in a structured and scalable way. Instead of contributing more inconclusive results to an already fragmented body of literature, I aimed to build a robust, structure-based research tool. This opportunity materialized through a collaboration with SelfLoops, an Italian company specializing in sports performance analysis and team management solutions. Historically, SelfLoops platforms have been employed in athletic and fitness contexts, but they lacked integration with scientifically validated MH measures. Recognising a critical gap in global methodologies—no existing tool combined validated MH instruments with objective physical activity (PA) metrics—this study developed the first-ever digital framework capable of capturing both dimensions simultaneously. The system integrates an online platform, the SPARK smartphone app, and wearable fitness trackers, enabling the seamless collection of subjective (e.g., mood, affect) and objective (e.g., steps taken, heart rate, environmental interactions) data. This interdisciplinary tool has far-reaching implications across public health, clinical

practice, urban planning, and digital health innovation, offering a robust methodology for understanding the nuanced interplay between PA and mental well-being. While the third study focused on the framework's development and usability testing, a pilot study conducted in Bologna was a preliminary validation step, ensuring the system's functionality, scalability, and participant engagement.

Collectively, these three studies form a coherent and progressive narrative, each building upon the limitations and insights of the previous one. The scoping review laid the groundwork by identifying gaps and setting research priorities. The PASSI study leveraged national surveillance data to provide population-level insights into AM-MH relationships, highlighting the need for more refined and context-specific tools. Finally, the digital framework introduced an innovative solution capable of capturing granular, real-time data, bridging existing methodological gaps, and paving the way for future interdisciplinary research and evidence-based interventions.

This thesis demonstrates that AM is not merely a transportation choice but a lifestyle intervention with profound implications for MH, environmental sustainability, and societal well-being. This research advances scientific knowledge and practical applications by combining insights from psychology, public health, epidemiology, and digital health innovation. It emphasises the need for tailored, population-specific interventions, advocates for evidence-based public health strategies, and offers a scalable digital solution for global research initiatives. Ultimately, this work lays the foundation for a holistic approach to active mobility and mental health, promoting healthier, more sustainable, and connected communities.

Chapter 1: Introduction

1.1 Active Mobility and Public Health. General intro to the topic

As urbanisation continues to shape our living environments, the need for sustainable and health-promoting modes of transportation has never been more critical. Active Mobility (AM) describes physical activities like walking and cycling for transportation purposes, "to get from one place to another", distinctive from walking and cycling for leisure, exercise and sports scopes. Scientists investigating AM and its health benefits have used many synonyms, such as *Active Transport, Active Commute, Active Travel, and Sustainable Transport*. The variety of definitions mirrors the inconsistency and diversity of approaches used to study this concept. This is probably due to the rapidly rising interest among academics and public bodies realising the pivotal role of AM as a cornerstone in global strategies aimed at enhancing public health, reducing environmental impact, and improving the quality of life (QoL). Promoting AM represents a strategy for achieving several Sustainable Development Goals (SDGs), including SDG 3 (Good Health and Well-being), SDG 9 (Industry, Innovation and Infrastructure), SDG 11 (Sustainable Cities and Communities), SDG 13 (Climate Action), and SDG 16 (Partnerships for the goals). Aligned with these global objectives, the WHO Global Action Plan on Physical Activity 2018-2030 underscores the urgent need for strategies that promote active lifestyles for individuals' well-being and its broader societal and environmental advantages. Walking and cycling are of interest from an urban and environmental perspective due to their potential to reduce traffic congestion and air pollution (Alattar et al., 2021). Given that purposeful travel, such as commuting to work or educational institutions, is a significant part of daily routines, AM offers a feasible alternative to motorised transport.

1.2 Active Mobility as a Form of Physical Activity

Physical Activity (PA) is universally recognised for its extensive benefits, including reducing chronic disease risks and enhancing mental health (MH) (Marques et al., 2020).

Regular PA has long-term benefits on population health, acting as a non-pharmacological therapy without drug side effects and being associated with improved physical performance, cardiovascular health, and overall life expectancy (Marques et al., 2020). Specifically, walking and cycling–active transportation modes–contribute to total PA levels across all age groups, promoting health and well-being (Kelly et al., 2018).

From a cardiovascular perspective, AM reduces the incidence of heart disease, hypertension, and stroke. Regular walking and cycling help improve blood circulation, lower cholesterol levels, and regulate blood pressure, which can reduce the risk of coronary heart disease and related conditions (Hamer & Chida, 2008). Furthermore, PA through AM enhances respiratory function, increasing lung capacity and efficiency, which supports overall cardiovascular health.

Beyond cardiovascular benefits, AM also contributes to weight management and obesity prevention. By engaging in moderate-intensity activities like walking and cycling, individuals can maintain a healthy body weight and reduce the risk of metabolic disorders such as type 2 diabetes (Warburton et al., 2006). This is particularly important given the global rise in sedentary lifestyles and associated health problems. Additionally, regular engagement in walking and cycling has been linked to improved musculoskeletal health, enhancing joint function and reducing the risk of conditions like osteoarthritis (Sandmeier, 2000).

In summary, AM promotes cardiovascular and metabolic health and improves overall physical fitness, supporting stronger muscles and bones, better balance and coordination, and enhanced flexibility. Collectively, these benefits highlight the critical role that active mobility plays in both preventing disease and improving overall physical well-being.

A considerable amount of research on health promotion has focused on specific outcomes, such as the relationship between PA and overall health and AM and physical health. However, no clear evidence exists of the relationship between AM and MH outcomes.

While the physical health benefits of AM are well-documented, its MH impacts remain under-researched, fragmented, and methodologically inconsistent. Addressing this gap is a core focus of this thesis.

1.3 Research Gap in Mental Health Benefits of Active Mobility. Problem Statement

AM, as a form of physical activity, offers substantial physical health benefits and fosters a virtuous cycle that promotes sustainable urban development. Encouraging active transportation modes reduces the need for motorised vehicles, creates demand for more green areas, and fosters change to make cities more human-friendly, walkable and cyclable. This shift, in turn, encourages further AM, ultimately lowering the economic burden associated with healthcare costs resulting from pollution and sedentary lifestyle habits. Despite AM's well-documented economic, environmental, and physical health benefits, a critical gap remains in understanding its full impact, particularly regarding MH outcomes.

Mental health problems contribute significantly to the global health burden (Kelly et al., 2018), and it is still unclear whether AM could also provide MH benefits. Many studies refer to MH and well-being as umbrella terms, typically assessed using instruments that measure various psychological health indicators. However, MH is a complex concept with multiple determinants, making it challenging to study consistently across several settings.

Most of the evidence for AM's positive impact on MH comes from the fields of economics or transport, not psychology. Consequently, there is a notable inconsistency in the definitions, study designs, and methodologies used across AM and MH studies, further complicating the synthesis of findings (Scrivano et al., 2023). The research community has not yet established a unified theoretical or methodological framework to assess AM's MH outcomes, underscoring the need for more rigorous research. This project seeks to address this gap by focusing on the MH benefits of active travelling, a vital aspect of improving individuals' QoL and promoting holistic well-being.

1.4 Mental Health Complexity and Measuring Outcomes

Mental health is a multifaceted construct encompassing many emotional, psychological, and social dimensions. While existing research often refers to MH and well-being as overarching terms, they are frequently operationalised through instruments that measure behavioural and psychological health components as total scores or divided across various domains (Tannenbaum et al., 2009). However, MH extends beyond simplified metrics, representing a complex interplay of health determinants, symptom severity, and subjective experiences. Understanding this complexity is essential for accurately assessing and interpreting the MH outcomes associated with AM.

Mental health is best explained as a combination of emotional, psychological, and social well-being (Keyes, 2007). “Well-being” is typically more closely linked to psychological than physical health (Galderisi et al., 2015), and QoL is a fundamental aspect of well-being that encompasses both physical and psychological components (De Geus et al., 2008). As such, QoL is among the most frequently studied MH outcomes in AM research. Other aspects of mental well-being, such as eudaimonia, life satisfaction, self-efficacy, and negative indicators like stress, anxiety, and depression, have also been evaluated in the context of AM.

More specific outcomes, such as travel or commuter satisfaction, have emerged as key variables in the context of AM and MH. These measures are derived from customer satisfaction research and have been linked to broader aspects of Mental health, such as overall life satisfaction (Olsson et al., 2013). Numerous factors mediate the relationship between AM and MH, including environmental factors like social support and personal factors such as self-esteem and resilience (Paudel et al., 2021; Pearson, 1986; Van Dyck et al., 2011).

1.5 Research Project Questions

This project seeks to address the following key questions, drawing attention to the relationship between AM and MH:

I. Does active mobility positively impact mental health and overall quality of life?

II. What is the current state of knowledge in the literature regarding the mental health benefits of active mobility habits?
III. Which mental health outcomes related to active mobility have been most extensively studied, and what research methodologies have been applied in these investigations?
IV. Given the diverse methodologies used, how can the reliability and generalisability of research findings be ensured when exploring the relationship between active mobility and mental health?

1.6 Research Project Objectives

The objectives of this project are:

I. Identify the mental health benefits associated with active mobility.
II. Identify demographic and contextual factors (e.g., age, gender, geographical location) that may influence the mental health outcomes of active mobility.
III. Develop and refine a practical digital framework to assess and monitor mental health outcomes in active commuters.
IV. Provide evidence-based recommendations for integrating findings into public health policies and urban planning strategies to promote active mobility.

1.7 Study Overview

This thesis is organised into three main studies, each addressing a different aspect of the research:

Study 1 provides a scoping literature review, offering an overview of the current state of research on AM and identifying critical gaps, particularly in the area of MH outcomes. Due to the variation in methodologies and questionnaires used across studies, a systemic review was not feasible. This scoping review, the first of its kind to investigate the range of studies on AM and MH, revealed the complexity and inconsistency in the existing literature, justifying further investigation.

Study 2 focuses on the Italian context, exploring the MH impacts of AM within this specific geographical and cultural setting. This study represents the first in-depth analysis in Italy, leveraging data from health institutions.

Study 3 involves developing and preliminary testing a digital framework to assess MH outcomes associated with AM. Initial trials with a small group of volunteers yielded promising results, suggesting the potential for broader application.

1.8 Significance of this Research Project

The findings from this research offer significant contributions to both scientific research and societal well-being. Scientifically, it provides a robust, evidence-based framework for assessing the health benefits of AM, particularly in terms of Mental health. This framework addresses a primary gap in the literature and serves as a valuable tool for future research across diverse populations and settings, promoting equality, diversity, and inclusion in health research. On a societal level, the findings will inform public health and urban planning strategies, helping to develop safe, sustainable transportation options that enhance public health outcomes and align with global policy objectives.

1.9 Thesis Structure

This thesis is organised into seven chapters, each contributing to a comprehensive understanding of the relationship between AM and MH:

- Chapter 1. *Introduction* introduces active mobility as a form of physical activity, exploring its features, global policy context, and physical health benefits. It also delves into the complexity of mental health and the challenges associated with measuring its outcomes.
- Chapter 2. *Study 1 – Active Mobility and Mental Health: A Scoping Review Towards a Healthier World* presents a published scoping review synthesising existing literature on the relationship between AM and MH outcomes. It identifies key gaps in research and provides the rationale for subsequent empirical studies.

- Chapter 3. *Study 2 – The PASSI Study: Active Mobility and Mental Health in the Italian Context* outlines the collaboration with the Italian National Institute of Health (ISS) to analyse data from the PASSI surveillance system. It investigates associations between AM and MH across Italy's diverse demographic and regional contexts.
- Chapter 4. *Study 3 – Innovation and science. A digital framework to measure Active Mobility and Mental Health* details the development and pilot testing of a digital framework designed to measure AM and MH outcomes using wearable devices and mobile applications.
- Chapter 5. *Beyond Publications – Milestones and Professional Growth*, a reflective chapter that moves beyond traditional research outputs to highlight significant milestones achieved during the PhD journey. It explores collaborations, academic presentations, public engagement initiatives, and professional development activities, emphasising their role in shaping the researcher and the research outcomes. The chapter also advocates for a more holistic approach to doctoral education that values diverse contributions and supports researcher well-being.
- Chapter 6. *General Discussion and Conclusion* synthesise findings from the three studies, offering a cohesive analysis of their theoretical and practical implications for public health, urban planning, and policy development. It also identifies directions for future research and highlights the unique contributions of this thesis to advancing knowledge in the field of AM and MH.

Chapter 2: Study 1 - Active Mobility and Mental Health: A scoping review towards a healthier world

This study was published in *Cambridge Prisms: Global Mental Health* on November 21, 2023. Scrivano, L., Tessari, A., Marcora, S. M., & Manners, D. N. (2024). Active Mobility and Mental Health: A scoping review towards a healthier world. *Cambridge Prisms: Global Mental Health*, *11*, e1. doi:10.1017/gmh.2023.74

Preliminary findings were presented at the '*XIII Congresso Nazionale Ricerca e Formazione Applicate alle Scienze Motorie e Sportive (SISMES)'*, held at the Università degli Studi di Milano, Italy (4–6 November 2022).

The completed findings were later presented at the '*Second Training School SHIINE*' part of the EU-funded COST Action 18236, hosted by the Faculty of Sport and Physical Education, University of Novi Sad, Serbia (3–5 July 2023).

* For a broader overview of events and presentations related to this research, refer to Chapter 5: Beyond Publications.

Keywords: global public health; lifestyle; quality of life; mental health; sustainable development

Overview

This chapter aims to provide an overview of the existing literature on the relationship between Active Mobility (AM) - walking and cycling for transportation - and Mental Health (MH) outcomes. This scoping review was conducted as the first step in understanding the breadth and depth of research in this field. While AM has been extensively recognised for its physical health benefits, the MH outcomes remain fragmented and underexplored. By systematically reviewing the available literature, this chapter identifies gaps in public health research, explores the methodological approaches used, and lays the groundwork for the subsequent studies presented in this thesis. The review focuses on studies involving adults (16 years and older), with AM as the exposure variable and various MH outcomes as the focus, including depression, anxiety, stress, self-esteem, psychological well-being, resilience, and quality of life. The decision to conduct a scoping rather than a systematic review was based on the broad and heterogeneous nature of the existing studies, which vary significantly in population, outcomes measured, and methodologies

used. Therefore, this review comprehensively maps the current knowledge state, highlighting what is known and what remains to be investigated. Furthermore, it emphasises the importance of developing a unified framework for studying the link between walking, cycling, and MH. The findings will contribute to shaping public health policies and urban planning strategies that promote active transportation as a sustainable and health-enhancing option.

2.1. Introduction

As public health strategies evolve, there is a growing emphasis on sustainable alternatives to traditional practices. AM, which refers to walking and cycling for transportation, presents an alternative to motorised travel that aligns with public health and environmental goals. Despite the range of terminology, AM fundamentally involves physical activity (PA) intended for transportation, distinct from leisure activities or exercise routines. For instance, walking to work for transportation differs from walking solely to achieve a step count.

AM is widely recognised as a key strategy for addressing pressing global challenges related to public health, urban sustainability, and environmental well-being. Unlike recreational PA or structured exercise, AM refers to purposeful travel to reach a destination, such as commuting to work or school. Its role extends beyond individual health benefits, encompassing broader contributions to traffic decongestion, air quality improvement, and sustainable urban development (Alattar et al., 2021).

The physiological benefits of AM, including improved cardiovascular health and reduced risk of chronic diseases, are well-documented (Marques et al., 2020). Given that AM shares similar physical benefits with other forms of PA, it would be reasonable to expect that it offers comparable Mental health advantages. However, AM's impact on MH remains underexplored and fragmented despite this assumption. Existing studies often suffer from methodological limitations, including variability in outcome measures, population samples, and research designs, which hinder the comparability and generalizability of findings. Moreover, much of the available evidence originates from disciplines such as

economics and transport studies, with limited contributions from psychology and MH research. This disciplinary imbalance has resulted in a lack of psychological perspectives, further complicating efforts to draw robust conclusions about the AM-MH relationship. Additionally, inconsistencies in definitions and measurement tools have created methodological ambiguity, limiting the field's ability to generate actionable insights (Gupta, 2022).

Recognising these challenges, this chapter presents a scoping review to systematically synthesise the current state of evidence on AM and MH. By mapping key findings, identifying methodological patterns, and highlighting research gaps, this review serves as a foundation for advancing knowledge in this emerging field. It also underscores the need for interdisciplinary approaches and standardised methodologies to understand better and harness the benefits of AM for MH outcomes.

The primary research questions guiding this review include:

- What methodologies have been used to explore the relationship between active mobility and mental health?
- What evidence currently exists regarding active mobility's impact on mental health within the adult population?
- What limitations and gaps are evident in the existing literature?

This review aims to offer a comprehensive overview of the current evidence base while identifying clear directions for future research, ultimately supporting the development of evidence-based strategies to promote AM for improved MH outcomes.

2.2. Methods

2.2.1 Study Design

Given the relatively recent and varied approaches to studying the relationship between AM and MH, this review was conducted as a scoping study. This approach, based on Arksey and O'Malley's framework (Arksey & O'Malley, 2005), was selected to address the broad

and multifaceted nature of the topic, allowing for a comprehensive mapping of different study designs and methodologies.

2.2.2 Search Strategy

The search aimed to identify studies exploring the link between walking and cycling for transportation and MH outcomes, covering publications up to December 2022. Inclusion criteria required studies to be primary research with at least one MH outcome, AM as the exposure, and an adult sample (18 years and older) without specific health conditions (e.g., cancer, postpartum, fibromyalgia). Only studies published in peer-reviewed journals in English were included.

To ensure an extensive literature search, we accessed multiple electronic databases relevant to this topic, including EBSCOhost, PROQUEST, SCOPUS, Web of Science, and PubMed, with the final search conducted on January 30, 2023. No time restrictions were applied, allowing for the inclusion of any relevant studies available up to the search date.

The search terms included variations of "active mobility," "active travel," "active transport," "cycling," and "walking," combined with Mental health-related terms such as "Mental health," "psychological health," "cognitive function," "depression," "anxiety," "quality of life," "life satisfaction," "self-esteem," "stress," "psychological well-being," "resilience," "social support," and "loneliness." Given that much of the research on AM has historically focused on younger populations, we added the exclusion terms "NOT children," "NOT adolescents," and "NOT school" to filter out studies centred on school travel and cognitive functioning in younger groups.

2.2.3 Study Selection and Quality Assessment

Titles and abstracts were initially screened for relevance, followed by a full-text review of selected articles. Duplicate records were removed automatically. One author (L.S.) conducted the full-text screening, and a consensus on inclusion was reached in consultation with co-authors (D.N.M., A.T., S.M.M.). the Oxford Centre for Evidence-Based Medicine Levels of Evidence (OCEBM Levels of Evidence Working Group, 2011) were used To assess study quality, categorising studies into levels based on design types, such as

randomised trials (step 2), non-randomised cohort studies (step 3), and case-series or case-control studies (step 4). This assessment provided context regarding potential biases, particularly for higher-level study designs more susceptible to confounding variables.

2.2.4 Data Extraction and Management

Data extraction followed the FAIR principles for data management and PRISMA guidelines (Moher et al., 2009). Researchers systematically extracted Key study information into a chart, which included study characteristics, sample size, population demographics, MH outcomes, and methodologies used. One author (L.S.) conducted the data extraction, with verification by a second author (D.N.M.), and any discrepancies were resolved by consensus.

The extracted data were used to provide narrative summaries of findings related to each MH outcome and to identify research gaps. In alignment with Open Science principles, all supporting materials, including detailed data and metadata, are documented and transparently accessible in accompanying resources associated with this work.

2.2.5 Graphical Synthesis of Results

Several graphical methods were employed to synthesise and visualise findings, helping to facilitate qualitative comparisons across studies and highlighting key trends.

Word Cloud Analysis (Benoit et al., 2018): To identify common themes, two-word phrases frequently used in the studies were extracted, cleaned, and categorised by exposure, covariate, outcome, or study feature. A word cloud was generated to objectively visualise these themes based on the frequency of occurrence.

Geographical Mapping: The distribution of study populations was mapped globally, with sample sizes represented proportionally. Locations were determined based on cities or regions specified in each study or using the country's geographical centre for national samples.

Albatross Plot (Harrison et al., 2017): To provide an overview of study outcomes, an Albatross plot was created, presenting the p-values of statistical tests about sample size. This enabled a rough estimation of effect sizes, allowing readers to compare outcomes across studies. The plot focused on statistical comparisons between AM and other transportation modes (primarily car or public transport), with the caveat that p-values were inconsistently reported and should be interpreted cautiously.

2.2.6 Descriptive Analytical Synthesis

The final synthesis categorised studies according to specific MH outcomes (Table 2.1). Using a descriptive-analytical approach, we mapped the instruments employed across studies, noting instances where similar instruments were used to measure differently named outcomes or vice versa. Given the diversity in exposures, outcomes, and methodologies, we organised findings by each MH outcome in a narrative format, applying a standard framework to summarise the information systematically.

Table 2.1 Definitions of the included Mental health outcomes (Scrivano et al., 2023).

Mental health Outcome	Description
Mental health	A state of mental well-being that enables people to cope with the stresses of life, realize their abilities, learn well and work well, and contribute to their community (World Health Organization, 2022)
Quality of Life	An individual's perception of their position in life in the context of the culture and value system in which they live. This perception concerns their goals, expectations, standards and concerns (Bowling, 2001)
Affect (Mood)	Transitory emotional state. The presence of positive emotions and the absence of negative emotions represent the affective component of hedonic well-being (Diener & Emmons, 1984)
Eudaimonia	The experience of meaning or purpose, the development of personal strengths, and contribution to society. Also referred to as eudaimonic well-being (McMahan & Estes, 2011)
Life Satisfaction	Retrospective evaluation of overall happiness and satisfaction, measuring how people feel about their lives. The cognitive component of hedonic well-being (Diener et al., 1999)
Travel Satisfaction	A multi-item measure of how one feels about the travel experience. It comprises a cognitive (quality of travel independently of mode) and two affective components (context-specific factors that stimulate momentary affects) (Friman et al., 2013)
Stress	Any change that causes physical, emotional or psychological strain in response to anything that requires attention or action (World Health Organization, 2023)
Depressive Symptoms	Mood disorder is categorised by prolonged periods of low mood or lack of interest and/or pleasure in everyday activities, most of the time (American Psychiatric Association, 2013)
Anxiety	An emotion characterized by feelings of tension, worried thoughts, and physical changes like increased blood pressure (American Psychological Association, 2022)
Loneliness	A subjective, unpleasant, or distressing feeling of a lack of connection to other people, along with a desire for more, or more satisfying, social relationships (Position Statement: Addressing Social Isolation and Loneliness and the Power of Human Connection., 2022)
Social Support	Providing assistance or comfort to others, typically to help them cope with stressors. It may arise from any interpersonal relationship. It may be tangible (material assistance) or emotional (allowing the individual to feel valued, accepted, and understood) (APA Dictionary of Psychology, n.d.)
Self-efficacy	The degree of confidence that an individual has in their capacity to perform a given behaviour or to overcome barriers (Bandura, 1986)
Self-esteem	The extent to which we feel positive or negative about ourselves reflects an individual's subjective evaluation of self-worth and attitudes about the self (M. Rosenberg, 1965)
Resilience	Healthy functioning after a highly adverse event or a conscious effort to continue in an insightful and integrated positive manner as a result of lessons learnt from an adverse experience (Southwick et al., 2014)
Vitality/Exhaustion	Physical or intellectual vigour or energy/state of extreme fatigue (Ware & Sherbourne, 1992)
Sleep	Individual's self-satisfaction with all aspects of the sleep experience: sleep efficiency, latency, duration, and wake after sleep onset (Nelson et al., 2022)
Self-perceived health	Believes about personal health as excellent or poor and likely to get worse (Ware & Sherbourne, 1992)

2.3. Results

2.3.1 Search Results

Figure 2.1 provides an overview of the study selection process. The database search yielded 502 records, from which duplicates were removed. Each remaining article was screened first by title and abstract, followed by a full-text review for those that met the initial criteria. Studies were excluded if the exposure or outcome variables did not align with the research questions. In total, 55 studies were deemed relevant and included in the review.

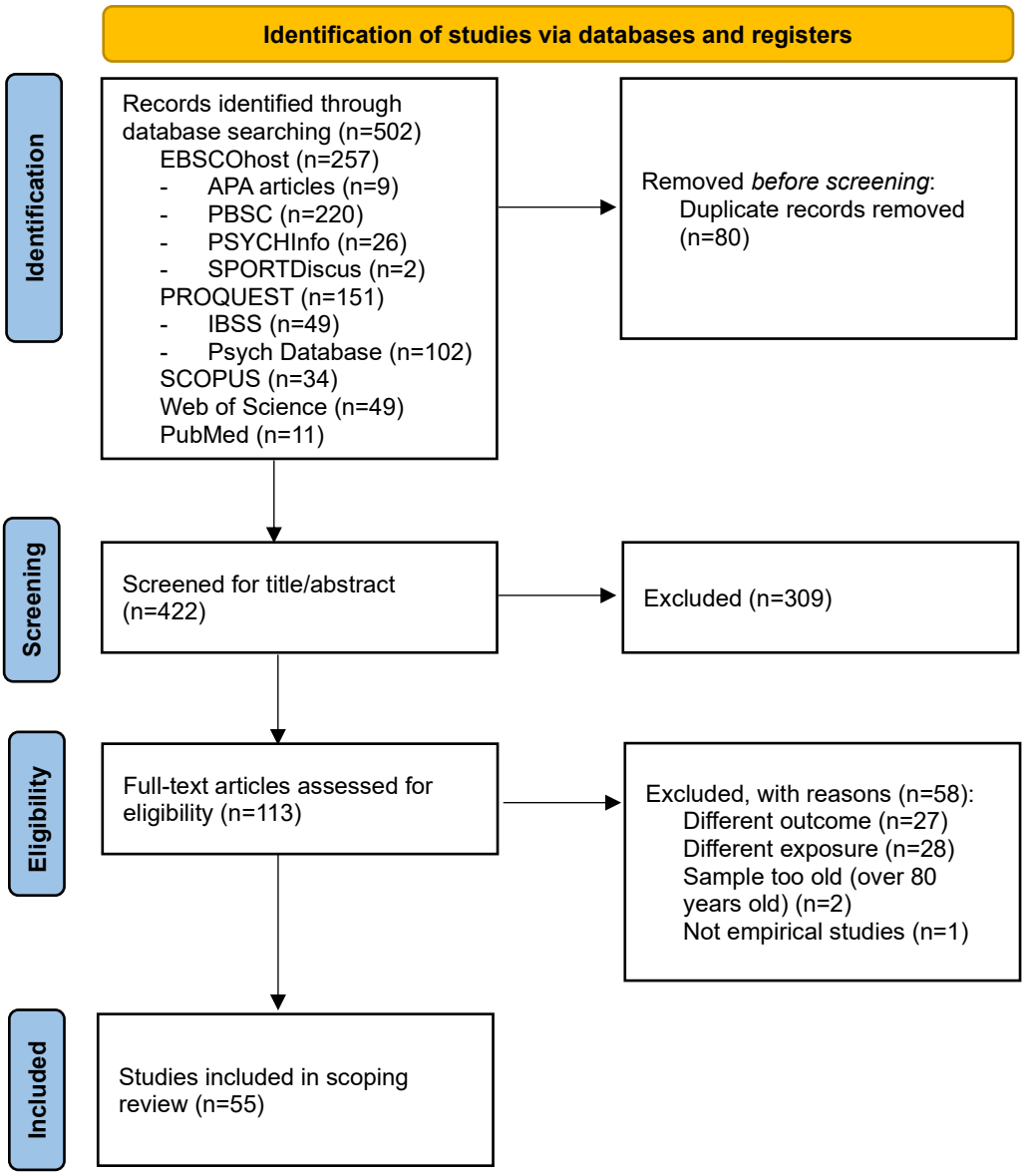


Figure 2.1. PRISMA 2020 flow diagram for new systematic reviews included searches of databases and registers only (reproduced with permission from Scrivano et al., 2023).

2.3.2 Study Characteristics

An overview of the study characteristics, including study designs, populations, and methodologies, is provided in Table 2 of the published article (Scrivano et al., 2023). Most studies (40) used a cross-sectional design, often drawing on data from public health surveys that included participants able to travel independently using active or passive transport modes. Nine studies reported a longitudinal design; however, these data were primarily analysed in a cross-sectional format. Additionally, two studies employed a

quasi-experimental design, assigning participants to intervention or control groups based on predetermined criteria.

Only one non-randomised controlled trial and four randomised controlled trials were identified, all of which investigated quality of life changes from 2000 to 2020. Study designs showed no clear evolution over time; for example, the earliest study (Mutrie et al., 2000) used a randomised controlled trial, while the most recent (Scarabottolo et al., 2022) employed a cross-sectional approach. Meanwhile, there has been a shift in outcome focus—from primarily examining quality of life and effect before 2010 to investigating additional Mental health outcomes in recent years.

Regarding demographics, most participants were women, with study populations ranging from 15 to 98 years of age, which was in line with our selection criteria. Some studies specifically targeted older adults (60–98 years), where AM, described as "outdoor mobility," was emphasised as vital for maintaining a high quality of life.

2.3.3 Graphical Mapping of Studies

The graphical analysis provided insights into key aspects of the reviewed literature. This mapping examined the terminology, geographical distribution, and relationships between AM and MH outcomes.

Mapping of Terminology

Word clouds (Figure 2.2) were generated to identify commonly occurring phrases related to outcomes and covariates. These visualisations helped validate the primary concepts addressed during data extraction.

Active Mobility Definitions:

- AM was consistently described as walking and cycling for transportation purposes, distinct from exercise, sport, or leisure activities. The term "active mobility" was favoured for its inclusivity and clarity, avoiding limitations of terms like "active commuting", which implies travel solely to work or school.

- Other terms, such as “active travel” and “sustainable transport”, were commonly used but often included overlapping or partially distinct concepts, such as combining walking and cycling with public transport.

Mental Health Outcomes:

- Outcomes were diverse and included 17 categories, such as depression, anxiety, quality of life, affect, life satisfaction, social support, and loneliness.
- Broad terms like “mental health” or “well-being” were often used as umbrella concepts but lacked specificity in their operationalisation. Therefore, outcomes were categorised into discrete components (e.g., eudaimonia, affect).
- Travel satisfaction, defined as the cognitive and emotional evaluation of travel experiences, emerged as a specific outcome linked to AM and overall well-being.

Moderating Variables:

- Factors like travel time, environmental characteristics, and social support were identified as potential moderators of the relationship between AM and MH. However, study designs often precluded the simultaneous examination of these variables.

Figure 2.2. Word clouds summarising the most common study-specific phrases found in articles included in the review are categorised as (a) related to outcomes or (b) related to covariates. The size of the text is proportional to the relative number of occurrences of the phrase (reproduced with permission from Scrivano et al., 2023).

Geographical Distribution of Studies

The geographical distribution of studies is depicted in a world map (Figure 2.3). The majority of research in this field has been conducted in Europe and English-speaking

countries, with additional contributions from Brazil and China. The largest studies primarily employed cross-sectional designs, often drawing on national survey data not explicitly designed to assess MH, active transport, or their relationship.

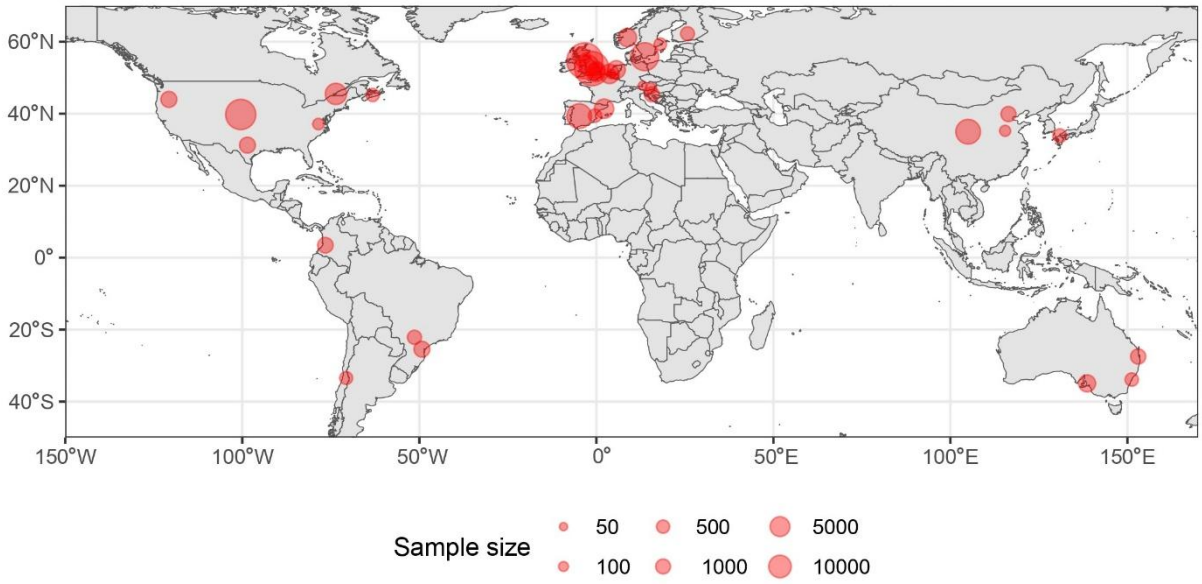


Figure 2.3. The study distribution in the review is projected onto the world map (left panel), while European studies are shown in the enlargement (right panel). The size of the symbols is related to the number of participants. The location of each symbol is centred on the centre of the city, region or country from which participants were drawn (reproduced with permission from Scrivano et al., 2023).

Outcome Measures and Results

The implicit effect sizes of statistically evaluated outcomes are summarised in Figure 2.4, dividing the findings into four quadrants to account for the variety of MH outcomes. The majority of studies suggest either a moderate benefit of AM on MH or no significant effect. Only one study reported a large negative association with AM.

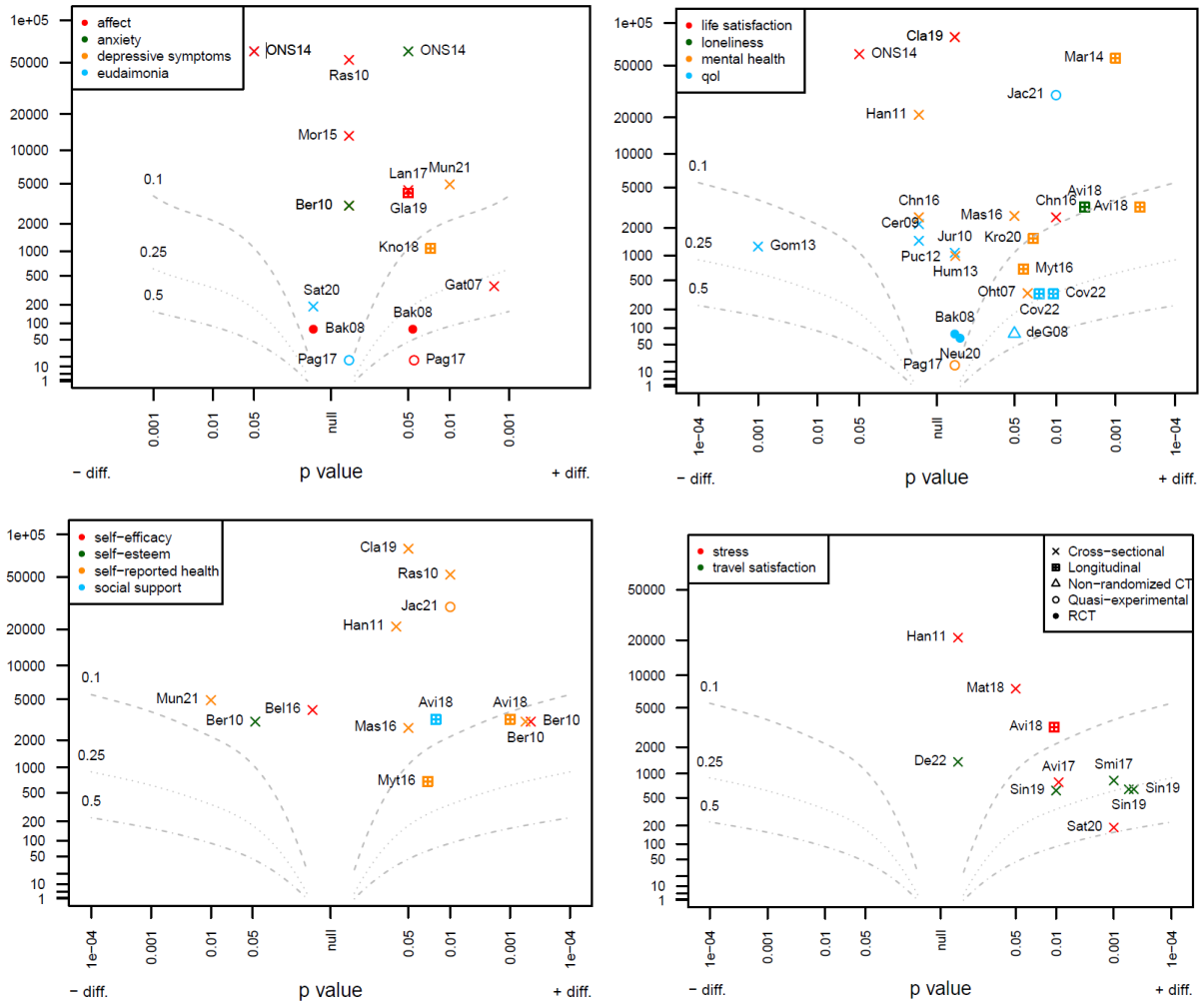


Figure 2.4. Albatross plots showing the imputed effect sizes of studies comparing Mental health outcomes between active and motorised transport users. Points indicate effect sizes, with the x-axis showing p-values (benefit for active mobility to the right) and the y-axis displaying participant numbers on a logarithmic scale. Results are grouped into four panels for clarity, with symbols denoting study design and labels referencing authors and publication years (reproduced with permission from Scrivano et al., 2023).

Brief mentions of key outcomes are as follows:

- MH and Well-Being: Positive associations were observed in longitudinal studies, though cross-sectional results were mixed.
- Quality of Life: Experimental and longitudinal studies consistently reported benefits, while cross-sectional findings were inconclusive.
- Affect, Life Satisfaction, and Eudaimonia: Results were context-dependent, with mixed findings across methodologies.
- Travel Satisfaction: Strong and consistent positive correlations were observed across all studies.

- Stress, Anxiety, and Depression: Evidence was mixed, with some studies showing benefits, particularly for cycling.
- Social Support, Loneliness, and Self-Efficacy: Limited evidence suggested modest positive effects, often context specific.
- Sleep and Vitality: Few studies explored these outcomes, with inconsistent findings.
- Self-Reported Health: Both subjective and objective measures strongly supported the benefits of AM.

2.4. Discussion

This review represents the first comprehensive examination of the relationship between AM and a wide range of MH outcomes in healthy adults. The findings highlight promising evidence of AM's potential for MH promotion and symptom reduction, though the strength of evidence varies across outcomes. Mental health, quality of life, and affect received the most attention, with experimental and quasi-experimental studies supporting positive associations. Travel satisfaction, life satisfaction, and social support showed encouraging but limited evidence, while outcomes like stress, sleep, vitality, and loneliness had mixed results. Self-esteem and resilience were notably absent from the literature.

This section addresses the primary research questions guiding this review, synthesising the evidence on methodologies, findings, and gaps in the literature regarding the relationship between AM and MH in adults.

2.4.1 What methodologies have been used to explore the relationship between Active Mobility and Mental Health?

The reviewed studies utilised a variety of research designs, including cross-sectional (the majority), longitudinal, quasi-experimental, and randomised controlled trials (RCTs). However, the reliance on cross-sectional designs limited causal inference. Longitudinal studies and experimental designs were comparatively rare, with the most recent experimental studies dating back nearly two decades.

Methodological diversity reflected the interdisciplinary nature of this field, spanning public health, transportation, economics, and exercise science. While self-reported AM and Mental health outcomes predominated, several studies used objective measures (e.g., GPS tracking) to validate self-reports. Instruments varied widely, with many studies employing well-established tools like the General Health Questionnaire (GHQ-12) or the Mental Component Score of the SF-36.

Despite this diversity, inconsistency in defining AM (e.g., whether to include walking/cycling combined with public transport) and operationalising MH outcomes hampered comparability across studies. Future research would benefit from a unified framework for defining and measuring both AM and MH outcomes to improve the comparability and reliability of results.

2.4.2 What evidence currently exists regarding Active Mobility's impact on Mental Health within the adult population?

This review identified promising but fragmented evidence regarding the MH benefits of AM. Key findings included:

- **Most Investigated Outcomes:** Mental health, quality of life, and affective well-being were the most extensively studied outcomes, with evidence suggesting positive associations between AM and these factors, particularly in experimental and quasi-experimental studies.
- **Encouraging Outcomes:** Limited but encouraging evidence linked AM to travel satisfaction, self-reported health, life satisfaction, stress, loneliness, and social support.
- **Mixed or Limited Outcomes:** Outcomes like eudaimonia, depressive symptoms, anxiety, vitality, and sleep showed mixed or limited findings with little experimental evidence.
- **Underexplored Outcomes:** Self-esteem and resilience, considered protective MH factors, were notably absent from the literature. Cognitive and neurological health were also largely overlooked despite their relevance to MH.

Although the reviewed evidence aligns with public health goals, inconsistencies in results and methodologies highlight the need for further research, mainly using experimental designs to strengthen causal claims.

2.4.3 What limitations and gaps are evident in the existing literature?

Key gaps and limitations in the literature include:

- **Definitional Ambiguities:** Variability in defining AM and its components (e.g., distinguishing walking/cycling for transport from leisure) created challenges in synthesising findings. Studies also lacked clarity on contextual factors like trip purpose or environmental settings.
- **Measurement Challenges:** While validated tools exist for many MH outcomes, their inconsistent use, coupled with a predominance of self-reported measures, limits cross-study comparability.
- **Underexplored Moderators:** Factors like age, gender, socioeconomic status, and environmental characteristics (e.g., green spaces and air pollution) were inconsistently examined as moderators of the AM-MH relationship.
- **Study Designs:** The over-reliance on cross-sectional designs and limited use of experimental approaches restricts causal inference. Existing experimental evidence is outdated, necessitating more rigorous and contemporary studies.
- **Neglected Populations and Outcomes:** Research disproportionately focused on specific groups (e.g., workers, older adults) and ignored others, such as younger or more diverse populations. Outcomes like self-esteem, resilience, and cognitive health also remain underexplored.

These limitations underscore the need for a unified conceptual framework with precise definitions, properly operationalised variables, and validated measurement tools to enhance the reliability and comparability of future research.

2.4.4 Future Directions

Future research should prioritise addressing key gaps identified in this review. Methodological rigour is essential, focusing on conducting more longitudinal and experimental studies to establish causal links between AM and MH. Developing a unified framework that includes standardised definitions and measurement tools for both AM and MH outcomes will be critical to enhancing cross-study comparability. Additionally, it is essential to explore the moderating effects of various factors, such as travel purpose, environmental characteristics, and personal demographics, to understand better how these elements influence the relationship between AM and MH.

Expanding research to encompass younger and more diverse populations and underexplored outcomes like self-esteem, resilience, and cognitive health will provide a more comprehensive understanding of AM's impact. While the evidence suggests that AM has potential MH benefits, addressing these limitations and inconsistencies will offer more robust insights into leveraging AM for Mental health promotion and urban planning initiatives.

2.5. Conclusion

This scoping review highlights the current evidence regarding the relationship between active mobility—defined as walking and cycling for transportation—and mental health outcomes. While the findings suggest significant potential benefits of AM for MH, most evidence remains limited to cross-sectional studies, with experimental designs primarily focusing on quality of life. Since the early 2000s, research has expanded to include broader MH outcomes such as positive and negative affect, self-reported health, stress, and life and travel satisfaction. However, critical outcomes like depressive symptoms, anxiety, sleep quality, eudaimonia, self-efficacy, self-esteem, and resilience remain underexplored despite their relevance to individual and public health.

Inconsistencies in methodologies, outcome definitions, and measurement tools highlight the challenges of synthesising findings across diverse studies and populations. The evidence often reflects a non-psychological perspective, underscoring the need for

interdisciplinary collaboration and standardisation in future research. By addressing these gaps, future studies can provide more robust evidence to support the integration of AM into public health strategies, contributing to sustainable lifestyles and improved well-being.

This review is a foundation for advancing research on the intersection of active mobility and mental health, emphasising the importance of systematic, holistic, and inclusive approaches to understand better and harness the benefits of active transportation.

Chapter 3: Study 2 - The PASSI Study: Active Mobility and Mental Health in the Italian Context

Preliminary findings from this study were presented at the *XIV Congresso Nazionale della Società Italiana delle Scienze Motorie e Sportive (SISMES)*, held at the Università degli Studi di Napoli "Parthenope," Naples, Italy (2–4 November 2023).

This study has been successfully submitted for consideration for publication in *Cambridge Prisms: Global Mental health* on December 21, 2024.

* For a broader overview of events and presentations related to this research, refer to Chapter 5: Beyond Publications.

Keywords: active mobility; mental health; public health; sustainability; Italian population; national health survey

Overview

This study investigates the association between Active Mobility (AM) (walking and cycling for daily commuting) and depressive symptoms among Italian adults using 2021–2022 PASSI surveillance data. Results reveal significant age-specific patterns: older adults (50–69 years) engaging in walking and cycling report a significantly lower prevalence of depressive symptoms, indicating potential protective effects, while younger adults (18–34 years) show a higher prevalence, particularly with walking. Middle-aged adults (35–49 years) display neutral or context-dependent associations, with regional variations such as lower prevalence linked to cycling in Southern Italy. Stratified analyses further highlight the influence of chronic conditions, employment status, and socioeconomic factors on these associations, emphasising the need for tailored interventions. The findings underscore the importance of AM for public health in Italy while also pointing to broader implications for sustainable urban policies, fostering healthy lifestyle habits, and mental health (MH) promotion through active transportation.

3.1 Introduction

National health surveys, such as the Health Survey for England (HSE) in the UK(Martin et al., 2014), the BRFSS (Behavioural Risk Factor Surveillance System) in the United States, and the Canadian Community Health Survey (CCHS), play a pivotal role in understanding

population health trends and informing public health policies worldwide. While these surveys provide critical data on health and lifestyle factors, targeted analyses, such as those on walking and cycling, are essential to explore their potential benefits for mental well-being, including reductions in depressive symptoms, stress, and anxiety (Mueller et al., 2015; Scrivano et al., 2023).

Despite the growing evidence, much of this research has been concentrated in high-income countries, particularly Northern Europe (De Geus et al., 2008; Friman et al., 2017; Lancée et al., 2017; Zijlema et al., 2018) and English-speaking regions like the UK (Brainard et al., 2019; Merom et al., 2010; Ogilvie et al., 2010), Canada (St-Louis et al., 2014), USA (Smith, 2017), and Australia (Cobbold et al., 2022), but emerging work has explored AM and MH in Nepal (Paudel et al., 2021), Latin America (Lira & Paez, 2021; Scarabottolo et al., 2019), New Mexico (Sener et al., 2017), Brazil (Scarabottolo et al., 2019), and New Zealand (Tin Tin et al., 2009). Additionally, initiatives like the PASTA project have explored AM in diverse European cities, demonstrating its role in promoting public health and sustainability (Gerike et al., 2016). Findings from these regions demonstrate the MH benefits of AM, but they often reflect unique sociocultural and environmental conditions, such as urban infrastructure and public transportation systems, which may not be generalised to other settings.

The relationship between AM and MH in Italy remains underexplored, mainly using nationally representative datasets. The Italian National Institute of Health (*Istituto Superiore di Sanità, ISS*) manages the PASSI (Progressi delle Aziende Sanitarie per la Salute in Italia) surveillance system, which collects data on health-related behaviours and outcomes, including AM (walking and cycling for transport) and MH indicators such as depressive symptoms and self-perceived health in adults aged 18–69. While PASSI has provided critical insights into various health behaviours across Italy (Ferrante et al., 2013; Gigantesco et al., 2015; Nobile et al., 2022), its potential to investigate the relationship between AM and MH has not been thoroughly investigated.

Building on the findings from Chapter 2 (Study 1), which underscored the growing but fragmented evidence for AM's impact on MH globally, this study focuses on the Italian

population. Specifically, this chapter examines the prevalence of depressive symptoms among individuals who regularly walk or cycle for transport compared to those who do not, accounting for a range of sociodemographic and geographic factors. By leveraging nationally representative PASSI data, this study addresses the following objectives:

1. Evaluate the relationship between active mobility (walking and cycling) and depressive symptoms among Italian adults.
2. Identify potential interactions between active mobility and sociodemographic or environmental factors that may influence mental health outcomes.
3. Compare findings to international evidence, highlighting cultural and contextual factors unique to Italy.

The significance of this chapter lies in addressing a clear research gap: while national survey-based evidence exists in other countries and European regions, Italy lacks comparable analyses. This study contributes to understanding the role of AM within the Italian setting while recognising its broader implications for public health and sustainability. Promoting walking and cycling not only has the potential to enhance mental well-being but also aligns with strategies to develop urban environments that reduce traffic congestion, improve air quality, and foster healthier, more resilient communities (Garrard et al., 2008; Mueller et al., 2018; Ogilvie et al., 2011; Rissel et al., 2013; Singleton, 2019). Findings from this study aim to inform public health policies, promote active travel awareness and behaviours, and support the development of urban environments that prioritise walking and cycling infrastructure.

3.2 Methods

3.2.1 Study Design and Data Source

The PASSI (Progressi delle Aziende Sanitarie per la Salute in Italia) surveillance system, managed by the Italian National Institute of Health (Istituto Superiore di Sanità, ISS), provided the data for this study. PASSI is an ongoing national initiative to monitor health-related behaviours and outcomes among Italian adults aged 18–69. This chapter focuses

on data collected between 2021 and 2022, during which 50,851 telephone interviews were conducted across Local Health Units (LHUs) covering 90% of the national territory.

Participants were selected using stratified proportional random sampling based on gender and age groups (18–34, 35–49, and 50–69 years) to ensure a representative sample of the Italian population. The sampling methodology and data collection procedures adhered to established protocols detailed in previous studies (Nobile et al., 2022).

3.2.2 Study Population

Participants included in this study were adults aged 18–69 who completed the PASSI survey between 2021 and 2022. Eligibility for inclusion required complete data on Mental health status, AM behaviours, and sociodemographic characteristics. Individuals were excluded if they had missing data on key variables or met PASSI's general non-eligibility criteria, which included lack of a telephone, non-residency or transient living situations in Italy, hospitalisation during the interview period, insufficient Italian language proficiency, or severe physical or mental disabilities that impeded participation.

3.2.3 Measures and Variables

The primary outcome was the presence of depressive symptoms, assessed using the Patient Health Questionnaire-2 (PHQ-2). The PHQ-2 consists of two items measuring the frequency of depressed mood and anhedonia over the preceding two weeks, scored on a 4-point scale (0 = not at all; 3 = nearly every day). Total scores ranged from 0 to 6, with scores of ≥3 indicating individuals at risk for depression (Kroenke et al., 2003). The PHQ-2 is widely validated and effectively integrated into large-scale health surveillance systems.

The primary exposure variables were AM habits, specifically the frequency of walking and cycling for daily transport. Leisure time and physical exercise activities were not included in this analysis. Sociodemographic variables included age, gender, education level, economic hardship, employment status, and citizenship status. Additional variables encompassed chronic disease presence, geographic region, and urbanisation level. Definitions and detailed descriptions of these variables are comprehensively

documented and transparently accessible in the supporting resources associated with this work, adhering to Open Science principles.

3.2.4 Statistical Analyses

All analyses accounted for the survey design using appropriate weights to ensure nationally representative estimates. Analyses were conducted using Stata software (version 16.1, StataCorp LLC, College Station, TX). Proportions for key characteristics, such as gender and age, were calculated, along with the prevalence of depressive symptoms in subgroups based on AM behaviours. Statistical uncertainty was expressed as 95% confidence intervals (95%CI), with non-overlapping 95%CI considered statistically significant.

The association between AM habits and depressive symptoms was assessed using Poisson regression models. Adjustments were made for potential confounders, including sociodemographic variables, chronic diseases, and urbanisation levels. Interaction terms were added to evaluate potential effect modifiers, with the Wald Test used to test interaction significance. Results were expressed as Prevalence Ratios (PRs) with corresponding 95%CI. Statistical significance was set at $p < 0.05$.

3.2.5 Ethical Considerations

The study adhered to the ethical principles outlined in the 1964 Helsinki Declaration and its subsequent amendments (World Medical Association, 2013). PASSI is conducted under the approval of the institutional review board at the Istituto Superiore di Sanità (Istituto Superiore di Sanità, 2023). Informed consent was obtained from all participants to use their anonymised data for secondary analysis. Data from the PASSI system remain confidential and are analysed internally by statisticians affiliated with the ISS, ensuring consistency with national health surveillance protocols and participant privacy.

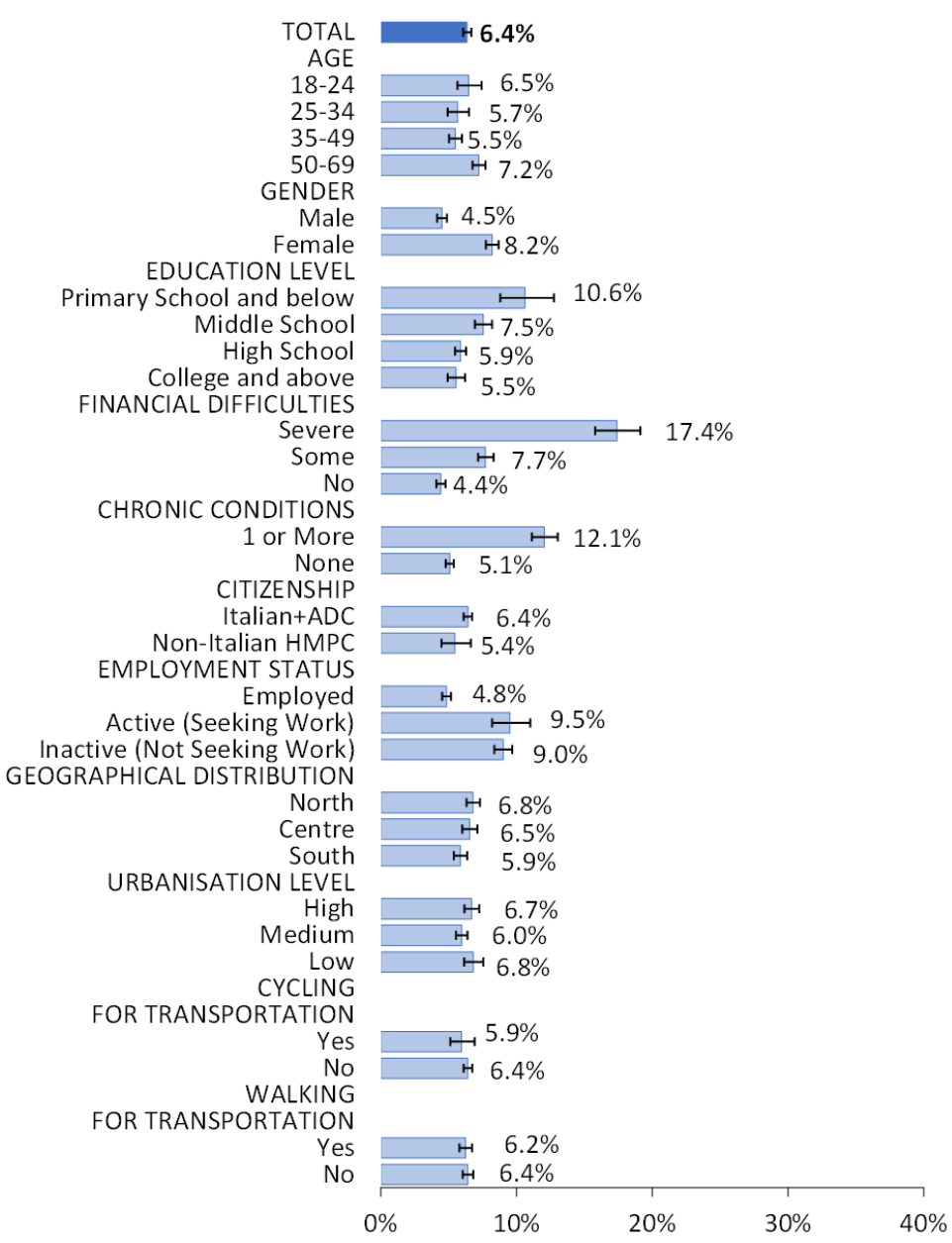
3.3 Results

3.3.1 Overall Prevalence of Active Mobility and Depressive Symptoms

In 2021–2022, 42.4% of Italian adults reported engaging in AM activities such as walking or cycling for transportation purposes. Among these individuals, 10.6% (95%CI: 10.2–10.9) used bicycles for daily commuting, while 39.3% (95%CI: 38.7–39.8) walked, with some overlap between these two groups.

The prevalence of depressive symptoms in the overall sample was 6.4% (95%CI: 6.06–6.66). Significant variations were observed across demographic and socioeconomic groups, with the most pronounced differences linked to factors such as age, financial difficulties, chronic health conditions, and employment status (Figure 3.1).

Regarding AM-specific subgroups, individuals who cycled for transportation had a slightly lower prevalence of depressive symptoms (5.9%, 95%CI: 5.1–6.9) than non-cyclists (6.4%, 95%CI: 6.1–6.7). Similarly, individuals who walked for transportation exhibited a prevalence rate of 6.2% (95%CI: 5.8–6.7), comparable to those who did not walk (6.4%, 95%CI: 6.0–6.8). However, these differences were not statistically significant.



* Italians/Foreigners PSA: Individuals with Italian citizenship or from other Advanced Development Countries (PSA); Foreigners PFPM: Immigrants from High Migration Pressure Countries (PFPM). Only foreigners capable of holding a conversation in Italian are eligible for the PASSI survey, thus including those who are potentially more integrated; this may introduce bias into the results.

Figure 3.1. Distribution of depressive symptoms in the adult population in Italy (aged 18-69) according to 2021-2022 PASSI surveillance data. Box indicates the mean value for a given sub-population. Whiskers indicate 95%CI

3.3.2 Poisson Regression Models

Poisson regression analyses were conducted to explore the relationship between AM—specifically walking and cycling—and the prevalence of depressive symptoms, adjusting for various sociodemographic factors.

The results, detailed in Table 3.1, reveal distinct patterns in the association between walking, cycling, and depressive symptoms. Individuals who walked for transportation exhibited a prevalence of depressive symptoms that was over 10% lower than those who did not walk (PR=0.87; 95%CI: 0.79–0.96). Cycling for transportation was also associated with a lower prevalence of depressive symptoms (PR=0.94; 95%CI: 0.81–1.11), although this finding was not statistically significant.

Additionally, the analyses underscore the significant association between depressive symptoms and certain sociodemographic factors, regardless of whether individuals engaged in AM behaviours. Table 3.1 highlights these associations.

Table 3.1. Poisson Regression Model for depressive symptoms – Italy, PASSI 2021-2022.

	Walking for transportation				Cycling for transportation			
Variables	**PR**	**95%CI**		**p-value**	**PR**	**95%CI**		**p-value**
AGE								
18-34	1.19	1.05	1.35	0.007	1.18	1.04	1.34	0.009
35-49	1.00	0.89	1.13	0.962	1.01	0.89	1.14	0.908
50-69*	1.00				1.00			
GENDER								
Female	1.71	1.55	1.90	<0.005	1.70	1.53	1.88	<0.005
Male*	1.00				1.00			
EDUCATION LEVEL								
Middle school and below	0.99	0.88	1.10	0.815	0.99	0.89	1.10	0.844
High School and above*	1.00				1.00			
FINANCIAL DIFFICULTIES								
Severe	3.60	3.13	4.14	<0.005	3.60	3.13	4.12	<0.005
Some	1.66	1.49	1.86	<0.005	1.69	1.51	1.89	<0.005
None*	1.00				1.00			
CHRONIC CONDITION								
1 or more	2.11	1.90	2.33	<0.005	2.12	1.91	2.34	<0.005
None*	1.00				1.00			
CITIZENSHIP								
Italian+ADC	1.53	1.25	1.88	<0.005	1.57	1.28	1.92	<0.005
Non-Italian HMPC*	1.00				1.00			
EMPLOYMENT STATUS								
Inactive (Not seeking work)	1.46	1.30	1.64	<0.005	1.45	1.29	1.62	<0.005
Active (Seeking work)	1.39	1.17	1.66	<0.005	1.35	1.14	1.61	<0.005
Employed*	1.00				1.00			
GEOGRAPHICAL DISTRIBUTION								
North	1.49	1.33	1.68	<0.005	1.46	1.30	1.64	<0.005
Centre	1.28	1.14	1.45	<0.005	1.28	1.13	1.44	<0.005
South*	1.00				1.00			
URBANISATION LEVEL								
High	1.03	0.91	1.18	0.618	1.02	0.89	1.16	0.803
Medium	0.93	0.82	1.05	0.230	0.90	0.79	1.02	0.102
Low*	1.00				1.00			
WALKING/CYCLING FOR TRANSPORTATION								
Yes	0.87	0.79	0.96	<0.005	0.94	0.81	1.11	0.475
No*	1.00				1.00			

** Reference category*

The relationship between AM and depressive symptoms was found to be influenced by age. Additional analyses were performed to investigate these interactions further, and they are presented in Table 3.2 and Table 3.3 for walking and cycling, respectively.

The relationship between walking trips and depressive symptoms varies significantly by age group. Among younger adults (18–34 years), individuals who engaged in walking trips were more likely to report depressive symptoms compared to their peers who did not walk (PR=1.82; 95%CI: 1.43–2.33; p<0.001). In the 35–49 age group, walkers also reported a higher prevalence of depressive symptoms compared to non-walkers, though the association was minor (PR=1.32; 95%CI: 1.04–1.67; p=0.020). In contrast, older adults

(50–69 years) reported a lower prevalence of depressive symptoms when engaging in walking trips (PR=0.69; 95%CI: 0.60–0.79; p<0.001).

Table 3.2. Poisson Regression Model for Depressive Symptoms with interaction between walking for transportation and age category - Italy, PASSI 2021-2022.

Variables	PR	95%CI		p-value
GENDER				
Female	1.00			
Male^	1.71	1.54	1.89	0.000
EDUCATION LEVEL				
Middle school and below	0.98	0.88	1.10	0.747
High School and above^	1.00			
FINANCIAL DIFFICULTIES				
Severe	3.60	3.13	4.14	0.000
Some	1.67	1.49	1.87	0.000
None^	1.00			
CHRONIC CONDITION				
1 or more	1.00			
None^	2.10	1.90	2.32	0.000
CITIZENSHIP				
Italian+ADC	1.54	1.25	1.89	0.000
Non-Italian HMPC^	1.00			
EMPLOYMENT STATUS				
Inactive (Not seeking work)	1.00			
Active (Seeking work)	1.40	1.17	1.67	0.000
Employed^	1.47	1.31	1.65	0.000
GEOGRAPHICAL DISTRIBUTION				
North	1.50	1.33	1.68	0.000
Centre	1.29	1.14	1.46	0.000
South^	1.00			
URBANISATION LEVEL				
High	1.04	0.91	1.19	0.545
Medium	0.93	0.82	1.06	0.271
Low^	1.00			
AGE				
18-34	0.92	0.78	1.09	0.350
35-49	0.90	0.78	1.04	0.173
50-69^	1.00			
WALKING FOR TRANSPORTATION				
Yes	0.69	0.60	0.79	0.000
No^	1.00			
Age*Walking for transportation				
18-34yo*yes	1.82	1.43	2.33	0.000
35-49yo*yes	1.32	1.04	1.67	0.020

^ *Reference category*

interaction p-value = 0.0000

Similar trends were observed for cycling. Among younger adults (18–34 years), cycling was associated with a significantly higher prevalence of depressive symptoms compared to non-cyclists (PR=1.67; 95%CI: 1.14–2.45; p=0.008). No statistically significant differences were observed among middle-aged adults (35–49 years) between cyclists and non-cyclists (PR=

1.17; 95%CI: 0.81–1.70; p=0.398). In older adults (50–69 years; reference category), cycling was linked to a significantly lower prevalence of depressive symptoms (PR=0.77; 95%CI: 0.60–0.99; p=0.044).

Table 3.3. Poisson Regression Model for Depressive Symptoms with interaction between cycling for transportation and age category - Italy, PASSI 2021-2022.

Variables	PR	95%CI		p-value
GENDER				
Female	1.00			
Male^	1.70	1.53	1.88	0.000
EDUCATION LEVEL				
Middle school and below	0.99	0.89	1.10	0.795
High School and above^	1.00			
FINANCIAL DIFFICULTIES				
Severe	3.59	3.13	4.11	0.000
Some	1.69	1.51	1.89	0.000
None^	1.00			
CHRONIC CONDITION				
1 or more	1.57	1.28	1.93	0.000
None^	1.00			
CITIZENSHIP				
Italian+ADC	1.00			
Non-Italian HMPC^	2.12	1.91	2.34	0.000
EMPLOYMENT STATUS				
Inactive (Not seeking work)	1.00			
Active (Seeking work)	1.35	1.13	1.61	0.001
Employed^	1.45	1.29	1.62	0.000
GEOGRAPHICAL DISTRIBUTION				
North	1.47	1.31	1.65	0.000
Centre	1.27	1.13	1.44	0.000
South^	1.00			
URBANISATION LEVEL				
High	1.02	0.89	1.16	0.813
Medium	0.90	0.79	1.02	0.101
Low^	1.00			
AGE				
18-34	1.11	0.98	1.27	0.101
35-49	0.99	0.88	1.13	0.917
50-69^	1.00			
CYCLING FOR TRANSPORTATION				
Yes	1.00			
No^	0.77	0.60	0.99	0.044
Age*Cycling for transportation				
18-34yo*yes	1.67	1.14	2.45	0.008
35-49yo*yes	1.17	0.81	1.70	0.398

^ *Reference category*

interaction p-value = 0,0284

These results highlight that the relationship between AM and depressive symptoms is complex and age dependent. While walking and cycling are associated with a lower prevalence of depressive symptoms in older adults, this association appears to be potentially adverse in younger individuals.

3.3.3 Stratified Analyses

To explore the relationship between AM and depressive symptoms in greater detail, the analysis stratified the data by socioeconomic and demographic characteristics, differentiating between individuals who used walking or cycling for transportation. While

some variables—such as gender, education level, financial difficulties, citizenship, employment status, job type, geographical distribution, and degree of urbanisation—did not appear to influence the association between AM and depressive symptoms, notable patterns emerged in other groups (Figure 3.2).

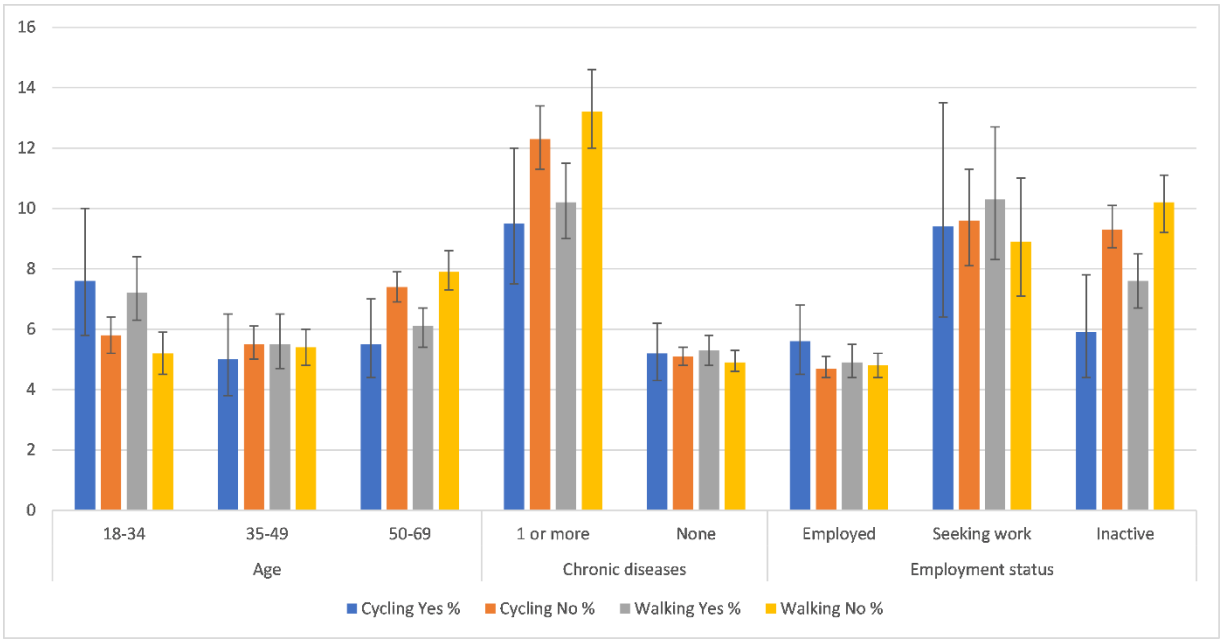


Figure 3.2. Distribution of depressive symptoms in the adults in Italy (aged 18-69) stratified by active mobility (walking/cycling) and factors identified as significant modulators, according to 2021-2022 PASSI data. Box indicates the mean value for a given sub-population. Whiskers indicate 95%CI.

Age was confirmed as a key variable shaping the observed associations. Detailed comparisons of depressive symptom prevalence between individuals who engaged in walking or cycling for transportation versus those who did not, stratified by socioeconomic characteristics and age groups (18–34, 35–49, and 50–69 years), are presented in Tables 3.4 and 3.5 below.

Among younger adults (18–34 years), walking for daily transportation was associated with a higher prevalence of depressive symptoms than non-walkers (7.2%, 95%CI: 6.3–8.4 vs. 5.2%, 95%CI: 4.5–5.9). This pattern was particularly evident among individuals without chronic conditions (6.9% vs. 4.9%) and those with Italian citizenship or from other highly developed countries (7.4% vs. 5.2%). While cycling did not show statistically significant differences in this age group, there was a trend toward a higher prevalence of depressive

symptoms among cyclists (7.6%, 95%CI: 5.8–10.0) compared to non-cyclists (5.8%, 95%CI: 5.2–6.4).

In the middle-aged group (35–49 years), no significant differences in depressive symptom prevalence were observed overall between AM practitioners and non-practitioners. However, geographical variation was evident: among residents of Southern Italy, cycling was associated with a notably lower prevalence of depressive symptoms (2.2%, 95%CI: 1.2–4.1) compared to non-cyclists (5.0%, 95%CI: 4.3–5.9). This suggests regional and cultural factors may influence the association between AM and Mental health outcomes.

For older adults (50–69 years), AM was associated with a lower prevalence of depressive symptoms. Walking was linked to a reduced prevalence of depressive symptoms among men (7.6% vs. 10.6%), individuals with lower educational attainment (6.9% vs. 9.4%), those without financial difficulties (3.5% vs. 5.1%), and individuals with at least one chronic condition (9.6% vs. 14.6%). Additional reductions in prevalence were observed among Italian citizens or those from other highly developed countries (5.9% vs. 8.0%), inactive individuals (7.2% vs. 11.6%), residents of Southern Italy (5.6% vs. 8.5%), and individuals living in moderately urbanised areas (5.4% vs. 7.6%).

Cycling also showed associations with a reduced prevalence of depressive symptoms in older adults. Among individuals with lower education levels, cycling was linked to a lower prevalence (5.5% vs. 8.8%), as was the case for those reporting some financial difficulties (6.0% vs. 9.5%), individuals with at least one chronic condition (8.6% vs. 13.0%), and inactive individuals (5.3% vs. 10.1%).

Table 3.4. Distribution of Depressive Symptoms Among Those Who Do and Do Not Walk for Daily Commuting - PASSI 2021-2022.

	Total							18-34							35-49							50-69						
	Yes walking			No walking			sign.	Yes walking			No walking			sign.	Yes walking			No walking			sign.	Yes walking			No walking			sign.
	%	CI95%		%	CI95%			%	CI95%		%	CI95%			%	CI95%		%	CI95%			%	CI95%		%	CI95%		
TOTAL	**6.2**	5.8	6.7	**6.4**	6.0	6.8	ns	**7.2**	6.3	8.4	**5.2**	4.5	5.9	s	**5.5**	4.7	6.5	**5.4**	4.8	6.0	ns	**6.1**	5.4	6.7	**7.9**	7.3	8.6	s
AGE																												
18-34	**7.2**	6.3	8.4	**5.2**	4.5	5.9	s																					
35-49	**5.5**	4.7	6.5	**5.4**	4.8	6.0	ns																					
50-69	**6.1**	5.4	6.7	**7.9**	7.3	8.6	s																					
GENDER																												
Female	**4.6**	4.0	5.2	**4.4**	4.0	4.9	ns	**5.6**	4.5	7.0	**4.0**	3.2	5.0	ns	**4.2**	3.0	5.8	**3.5**	2.9	4.2	ns	**4.1**	3.4	5.0	**5.4**	4.7	6.2	ns
Male	**7.6**	6.9	8.3	**8.7**	8.0	9.4	ns	**8.7**	7.3	10.5	**6.6**	5.5	7.9	ns	**6.5**	5.5	7.7	**7.6**	6.7	8.7	ns	**7.6**	6.7	8.7	**10.6**	9.5	11.8	s
EDUCATION LEVEL																												
Middle school and below	**7.2**	6.3	8.2	**8.2**	7.5	9.0	ns	**9.6**	6.9	13.1	**5.7**	4.2	7.7	ns	**6.5**	4.6	9.1	**6.7**	5.6	7.9	ns	**6.9**	5.9	8.1	**9.4**	8.3	10.5	s
High School and above	**5.9**	5.4	6.5	**5.6**	5.2	6.1	ns	**6.9**	5.9	8.1	**5.1**	4.3	5.9	ns	**5.3**	4.4	6.3	**5.0**	4.4	5.7	ns	**5.5**	4.8	6.4	**6.8**	6.0	7.8	ns
FINANCIAL DIFFICULTIES																												
Severe	**16.6**	14.1	19.4	**18.4**	16.3	20.8	ns	**14.0**	9.1	20.9	**10.2**	6.9	14.6	ns	**16.3**	12.5	20.9	**17.8**	14.2	22.1	ns	**17.8**	14.2	22.2	**21.6**	18.3	25.3	ns
Some	**7.5**	6.7	8.5	**7.7**	7.0	8.5	ns	**8.6**	6.8	10.8	**6.3**	5.0	8.0	ns	**5.8**	4.4	7.6	**6.1**	5.2	7.2	ns	**8.1**	6.9	9.5	**9.6**	8.4	11.0	ns
None	**4.4**	3.9	5.0	**4.4**	4.0	4.9	ns	**6.1**	5.0	7.5	**4.2**	3.5	5.1	ns	**4.0**	3.2	5.1	**3.7**	3.0	4.4	ns	**3.5**	2.9	4.2	**5.1**	4.5	5.9	s
CHRONIC CONDITION																												
1 or more	**10.2**	9.0	11.5	**13.2**	12.0	14.6	s	**10.3**	7.1	14.7	**8.8**	6.3	12.2	ns	**12.1**	9.6	15.2	**10.9**	9.1	13.1	ns	**9.6**	8.2	11.2	**14.6**	12.9	16.4	s
None	**5.3**	4.8	5.8	**4.9**	4.6	5.3	ns	**6.9**	5.9	8.1	**4.9**	4.2	5.7	s	**4.4**	3.6	5.4	**4.6**	4.0	5.3	ns	**4.6**	3.9	5.3	**5.3**	4.7	6.0	ns
CITIZENSHIP																												
Italian+ADC	**6.2**	5.7	6.7	**6.5**	6.1	6.9	ns	**7.4**	6.3	8.5	**5.2**	4.5	6.0	s	**5.5**	4.6	6.4	**5.5**	4.9	6.1	ns	**5.9**	5.3	6.6	**8.0**	7.3	8.7	s
Non-Italian HMPC	**6.8**	5.0	9.1	**4.5**	3.5	5.9	ns	**5.5**	3.0	9.8	**4.7**	2.9	7.4	ns	**6.1**	3.5	10.6	**3.8**	2.5	5.8	ns	**9.1**	6.2	13.2	**5.7**	3.6	8.8	ns
EMPLOYMENT STATUS																												
Inactive (Not seeking work)	**4.9**	4.4	5.5	**4.8**	4.4	5.2	ns	**6.3**	5.1	7.7	**4.4**	3.7	5.4	ns	**4.5**	3.7	5.4	**4.2**	3.7	4.8	ns	**4.5**	3.8	5.4	**5.5**	4.8	6.4	ns
Active (Seeking work)	**10.3**	8.3	12.7	**8.9**	7.1	11.0	ns	**10.3**	6.9	15.0	**5.6**	3.5	8.8	ns	**8.7**	6.0	12.5	**10.3**	7.2	14.6	ns	**12.4**	9.2	16.7	**14.4**	10.4	19.6	ns
Employed	**7.6**	6.7	8.5	**10.2**	9.2	11.1	s	**7.6**	6.0	9.6	**6.6**	5.2	8.3	ns	**9.3**	6.5	13.0	**11.5**	9.3	14.2	ns	**7.2**	6.2	8.3	**11.6**	10.3	12.9	s
GEOGRAPHICAL DISTRIBUTION																												
North	**7.0**	6.2	7.8	**6.6**	6.0	7.3	ns	**9.0**	7.2	11.1	**6.7**	5.4	8.2	ns	**6.5**	5.2	8.2	**6.0**	5.1	7.1	ns	**6.1**	5.2	7.1	**7.1**	6.1	8.2	ns
Centre	**6.9**	6.0	7.9	**6.3**	5.7	7.1	ns	**8.4**	6.4	10.9	**5.1**	3.9	6.8	ns	**5.7**	4.3	7.6	**5.0**	4.1	6.2	ns	**6.9**	5.6	8.4	**8.0**	6.9	9.3	ns
South	**5.0**	4.3	5.8	**6.2**	5.6	6.9	ns	**4.9**	3.7	6.3	**4.0**	3.1	5.2	ns	**4.3**	3.1	5.8	**5.1**	4.2	6.1	ns	**5.6**	4.5	6.9	**8.5**	7.4	9.8	s
URBANISATION LEVEL																												
High	**6.8**	6.1	7.7	**6.5**	5.8	7.2	ns	**7.9**	6.3	9.9	**5.3**	4.3	6.7	ns	**5.8**	4.5	7.5	**5.2**	4.3	6.3	ns	**6.9**	5.8	8.2	**8.2**	7.0	9.5	ns
Medium	**5.7**	5.1	6.4	**6.1**	5.6	6.7	ns	**6.9**	5.5	8.7	**4.7**	3.8	5.8	ns	**4.9**	4.0	6.1	**5.5**	4.7	6.4	ns	**5.4**	4.5	6.4	**7.6**	6.7	8.6	s
Low	**6.3**	5.3	7.5	**6.9**	6.0	7.9	ns	**6.7**	4.9	9.1	**6.1**	4.3	8.4	ns	**6.6**	4.4	9.6	**5.5**	4.3	7.0	ns	**5.9**	4.8	7.3	**8.3**	6.9	9.9	ns

Table 3.5. Distribution of Depressive Symptoms Among Those Who Do and Do Not Use a Bicycle for Daily Commuting - PASSI 2021-2022.

	Total							18-34							35-49							50-69						
	Yes cycling			No cycling			sign.	Yes cycling			No cycling			sign.	Yes cycling			No cycling			sign.	Yes cycling			No cycling			sign.
	%	CI95%		%	CI95%			%	CI95%		%	CI95%			%	CI95%		%	CI95%			%	CI95%		%	CI95%		
TOTAL	**5.9**	5.1	6.9	**6.4**	6.1	6.7	ns	**7.6**	5.8	10.0	**5.8**	5.2	6.4	ns	**5.0**	3.8	6.5	**5.5**	5.0	6.1	ns	**5.5**	4.4	7.0	**7.4**	6.9	7.9	ns
AGE																												
18-34	**7.6**	5.8	10.0	**5.8**	5.2	6.4	ns																					
35-49	**5.0**	3.8	6.5	**5.5**	5.0	6.1	ns																					
50-69	**5.5**	4.4	7.0	**7.4**	6.9	7.9	ns																					
GENDER																												
Female	**3.6**	2.8	4.6	**4.6**	4.2	5.0	ns	**5.7**	3.9	8.4	**4.5**	3.8	5.3	ns	**2.3**	1.5	3.5	**4.0**	3.3	4.7	ns	**3.1**	2.0	4.6	**5.1**	4.6	5.7	ns
Male	**8.6**	7.1	10.3	**8.2**	7.7	8.7	ns	**10.0**	6.8	14.6	**7.2**	6.3	8.2	ns	**8.0**	5.8	11.0	**7.0**	6.3	7.8	ns	**8.1**	6.1	10.8	**9.5**	8.7	10.4	ns
EDUCATION LEVEL																												
Middle school and below	**5.9**	4.4	8.0	**8.1**	7.4	8.7	ns	**10.8**	4.9	22.0	**6.8**	5.5	8.4	ns	**3.8**	2.2	6.5	**6.7**	5.7	8.0	ns	**5.5**	4.0	7.4	**8.8**	8.0	9.7	s
High School and above	**5.9**	5.0	7.1	**5.7**	5.4	6.1	ns	**7.1**	5.3	9.4	**5.6**	5.0	6.3	ns	**5.3**	3.9	7.1	**5.2**	4.6	5.8	ns	**5.6**	4.0	7.7	**6.4**	5.7	7.1	ns
FINANCIAL DIFFICULTIES																												
Severe	**17.5**	12.6	23.6	**17.5**	15.8	19.4	ns	**16.3**	6.9	34.0	**10.4**	7.7	13.8	ns	**14.9**	8.5	24.9	**17.1**	14.4	20.3	ns	**20.4**	13.3	30.1	**20.4**	17.7	23.3	ns
Some	**6.8**	5.2	9.0	**7.8**	7.2	8.4	ns	**9.9**	5.8	16.4	**7.0**	5.9	8.3	ns	**5.4**	3.2	8.9	**6.0**	5.2	7.0	ns	**6.0**	4.2	8.3	**9.5**	8.5	10.5	s
None	**4.5**	3.6	5.6	**4.4**	4.1	4.8	ns	**5.9**	4.2	8.3	**4.9**	4.2	5.7	ns	**3.7**	2.5	5.3	**3.9**	3.3	4.6	ns	**4.1**	2.8	6.1	**4.4**	3.9	5.0	ns
CHRONIC CONDITION																												
1 or more	**9.5**	7.5	12.0	**12.3**	11.3	13.4	ns	**13.6**	7.4	23.8	**8.9**	6.7	11.7	ns	**10.1**	6.3	15.8	**11.9**	10.2	13.9	ns	**8.6**	6.2	11.7	**13.0**	11.7	14.3	s
None	**5.2**	4.3	6.2	**5.1**	4.8	5.4	ns	**7.1**	5.2	9.7	**5.6**	5.0	6.2	ns	**4.2**	3.0	5.8	**4.6**	4.1	5.1	ns	**4.4**	3.1	6.1	**5.1**	4.6	5.6	ns
CITIZENSHIP																												
Italian+ADC	**6.1**	5.2	7.2	**6.4**	6.1	6.8	ns	**8.1**	6.0	10.7	**5.8**	5.2	6.5	ns	**5.2**	4.0	6.9	**5.5**	5.0	6.1	ns	**5.5**	4.3	7.0	**7.4**	6.9	8.0	ns
Non-Italian HMPC	**4.2**	2.3	7.3	**5.7**	4.6	7.0	ns	**3.5**	1.3	9.1	**5.3**	3.5	7.9	ns	**3.3**	1.1	9.5	**5.0**	3.4	7.4	ns	**7.1**	3.0	15.8	**7.0**	5.1	9.5	ns
EMPLOYMENT STATUS																												
Inactive (Not seeking work)	**5.6**	4.5	6.8	**4.7**	4.4	5.1	ns	**7.5**	5.2	10.8	**4.8**	4.1	5.5	ns	**4.8**	3.5	6.5	**4.3**	3.8	4.9	ns	**5.2**	3.5	7.5	**5.1**	4.6	5.8	ns
Active (Seeking work)	**9.4**	6.4	13.5	**9.6**	8.1	11.3	ns	**8.8**	4.5	16.6	**7.6**	5.5	10.5	ns	**6.7**	3.4	12.8	**9.6**	7.3	12.6	ns	**16.0**	9.5	25.8	**13.4**	10.6	16.8	ns
Employed	**5.9**	4.4	7.8	**9.3**	8.7	10.1	s	**7.3**	4.2	12.5	**7.1**	6.0	8.4	ns	**5.6**	2.6	11.9	**10.7**	8.9	12.9	ns	**5.3**	3.7	7.4	**10.1**	9.2	11.1	s
GEOGRAPHICAL DISTRIBUTION																												
North	**6.7**	5.5	8.1	**6.8**	6.3	7.4	ns	**8.7**	6.0	12.5	**7.5**	6.4	8.9	ns	**6.6**	4.7	9.1	**6.3**	5.4	7.3	ns	**5.5**	4.0	7.5	**6.8**	6.1	7.6	ns
Centre	**5.8**	4.2	8.2	**6.6**	6.0	7.2	ns	**9.2**	5.0	16.4	**6.1**	5.0	7.4	ns	**3.8**	2.1	6.7	**5.4**	4.5	6.4	ns	**5.2**	3.2	8.2	**7.7**	6.8	8.7	ns
South	**4.2**	3.0	5.8	**6.0**	5.5	6.5	ns	**4.2**	2.6	6.8	**4.4**	3.6	5.3	ns	**2.2**	1.2	4.1	**5.0**	4.3	5.9	s	**5.9**	3.5	10.0	**7.7**	6.8	8.7	ns
URBANISATION LEVEL																												
High	**6.9**	5.5	8.7	**6.7**	6.1	7.3	ns	**9.6**	6.5	14.0	**5.9**	5.0	7.1	ns	**6.3**	4.2	9.4	**5.5**	4.6	6.5	ns	**5.5**	3.7	8.2	**7.9**	7.0	8.9	ns
Medium	**5.5**	4.3	7.0	**6.0**	5.6	6.5	ns	**6.7**	4.1	10.5	**5.4**	4.6	6.4	ns	**4.4**	2.9	6.6	**5.3**	4.6	6.0	ns	**5.5**	3.8	7.9	**6.9**	6.2	7.6	ns
Low	**5.1**	3.6	7.2	**7.0**	6.2	7.8	ns	**5.8**	2.5	13.0	**6.5**	5.2	8.3	ns	**3.4**	1.7	6.7	**6.2**	5.0	7.7	ns	**5.7**	3.8	8.5	**7.7**	6.6	8.9	ns

3.3.4 Specific Associations

In addition to age, chronic health conditions and employment status emerged as critical factors in the observed relationships between AM and depressive symptoms. Among individuals with at least one chronic condition, engaging in walking for transportation was associated with a notably lower prevalence of depressive symptoms (10.2%, 95%CI: 9.0–11.5) compared to those who did not walk (13.2%, 95%CI: 12.0–14.6). Similarly, cycling was associated with a reduced prevalence of depressive symptoms in this group (9.5%, 95%CI: 7.5–12.0) compared to non-cyclists (12.3%, 95%CI: 11.3–13.4). However, the difference observed for cycling did not reach statistical significance. These findings suggest that AM may be particularly relevant for Mental health among individuals managing chronic illnesses.

Employment status further modified the associations between AM and depressive symptoms. For employed individuals aged 50–69, walking was linked to a significantly lower prevalence of depressive symptoms (7.2%, 95%CI: 6.2–8.3) compared to non-walkers in the same group (11.6%, 95%CI: 10.3–12.9). Similarly, cycling was associated with a reduced prevalence of depressive symptoms among employed individuals in this age group (5.3%, 95%CI: 3.7–7.4) compared to non-cyclists (10.1%, 95%CI: 9.2–11.1). These findings highlight the potential role of employment-related factors, such as daily routines and commuting behaviours, in shaping the MH benefits of AM.

Overall, these results underscore the multifaceted nature of the association between AM and depressive symptoms, with notable variations depending on age, health conditions, and employment status.

3.4. Discussion

This study examined the association between AM (walking and cycling for daily commuting) and depressive symptoms among Italian adults, leveraging data from the PASSI surveillance system. The findings reveal that AM's association with depressive symptoms is multifaceted, varying significantly across age groups, health conditions, employment status, and regional contexts.

These findings underscore the importance of contextual and demographic factors in understanding the Mental health implications of AM. Below, we discuss the results in relation to the study objectives, comparing them with international evidence and highlighting implications for public health and urban planning.

3.4.1 Relationship Between Active Mobility and Depressive Symptoms in Italian Adults: The Role of Age

Age emerged as a pivotal factor in moderating the association between AM and depressive symptoms. Among older adults (50–69 years), walking and cycling were consistently linked to a lower prevalence of depressive symptoms. These findings align with studies indicating that regular physical activity (PA) in older adults contributes to enhanced psychological well-being, improved physical function, and greater social engagement (Scarabottolo et al., 2019; Vancampfort et al., 2018). Walking, in particular, may be an accessible and low-barrier activity that supports mental and physical health, especially among individuals with limited mobility or chronic conditions (Grigoletto et al., 2021). Additionally, these patterns of consistent engagement in AM may reflect long-standing lifestyle habits, and the observed MH benefits could partly stem from cumulative exposure to active living over time. In contrast, among younger adults (18–34 years), engaging in AM was associated with a higher prevalence of depressive symptoms compared to their non-practicing peers. This unexpected finding mirrors evidence from other contexts suggesting that younger individuals face unique external stressors, such as academic, social, or workplace pressures, which may offset the potential MH benefits of active commuting. As suggested in prior studies, urban environmental factors, such as perceived safety and infrastructural inadequacies, may further exacerbate stress during commuting for this demographic (Chataway, 2020). These results call for more nuanced public health interventions addressing the specific needs of younger individuals. Middle-aged adults (35–49 years) showed neutral or context-dependent associations between AM and depressive symptoms. For instance, in Southern Italy, cycling was associated with a lower prevalence of depressive symptoms, suggesting that cultural and geographic

factors may shape the MH benefits of active commuting. These results emphasise the importance of regional and environmental contexts in tailoring AM interventions.

3.4.2 Other Socioeconomic, Health, and Regional Factors

Individuals with chronic conditions demonstrated significant MH benefits from AM, mainly walking. Among this group, walking was associated with a notably lower prevalence of depressive symptoms, consistent with prior research highlighting the therapeutic potential of PA for managing chronic illnesses (Hamer & Chida, 2008; Schuch et al., 2018; Vancampfort et al., 2018). While cycling also appeared beneficial, the association was less pronounced, potentially due to the physical demands of cycling or infrastructural barriers in certain regions.

Employment status further influenced these associations, particularly among older adults. Employed individuals aged 50–69 who engaged in AM, whether walking or cycling, experienced reduced depressive symptom prevalence. This aligns with international evidence suggesting that integrating PA into daily routines mitigates workplace stress and enhances overall mental well-being (Page & Nilsson, 2017). These findings indicate that AM may serve dual purposes for this demographic: supporting MH and addressing work-related stressors.

Individuals with lower education levels or more significant financial difficulties often showed stronger associations between AM and reduced depressive symptoms. This suggests that vulnerable populations may derive particular psychological advantages from walking and cycling, potentially due to the accessibility and cost-effectiveness of these modes of transportation. These findings align with studies in other contexts, such as Latin America and Europe, which emphasise the value of AM for promoting equity in health outcomes (Lira & Paez, 2021; Raser et al., 2018).

Geographic and environmental factors also moderated the relationship between AM and MH. For example, the association between cycling and lower depressive symptoms was particularly evident in Southern Italy among middle-aged adults. This finding may reflect regional cultural norms or infrastructural characteristics that facilitate or encourage

cycling. Moreover, prior research highlights the importance of commuting through green spaces or aesthetically pleasing environments, which amplify the psychological benefits of active travel (Schmied et al., 2020; Zijlema et al., 2018).

These findings underscore the need for tailored interventions and policies considering Italy's unique regional and socioeconomic contexts. Urban planning initiatives that prioritise safe, accessible, and green AM infrastructure may provide MH benefits for vulnerable populations while supporting broader public health and sustainability goals. Additionally, fostering behavioural change through targeted awareness campaigns, promoting healthy lifestyle habits, and encouraging shifts in public perception towards the benefits of AM are equally critical. Such multifaceted approaches can amplify AM's MH and well-being outcomes, contributing to a healthier and more resilient society.

3.4.3 Limitations and Future Directions

The cross-sectional design limits causal inferences, and self-reported data may introduce biases. Unmeasured factors, such as social support (Avila-Palencia et al., 2018), urban environment quality (Cobbold et al., 2022), and access to transport infrastructure (Schmied et al., 2020), could influence the findings. Small subgroup sizes, such as young cyclists, reduce statistical power, highlighting the need for larger, more representative samples.

Future research should prioritise longitudinal studies to explore these relationships over time, investigate the psychological mechanisms underlying walking and cycling benefits, and consider sociodemographic and cultural contexts. Differences in outcomes suggest unique MH benefits: walking's accessibility may explain its stronger association with reduced depressive symptoms, while cycling outcomes likely depend on environmental and infrastructural factors (Grigoletto et al., 2021).

3.5 Conclusion

This study highlights the nuanced relationship between active mobility and mental health, focusing on depressive symptoms among Italian adults. Walking and cycling, as modes of daily transportation, were associated with MH benefits, particularly among older adults

(50–69 years). Walking was strongly associated with reduced depressive symptoms, while cycling outcomes varied by age and context. For younger adults (18–34 years), the associations were less apparent or adverse, possibly reflecting unique stressors in this demographic. Chronic conditions and employment status further influenced these associations, with notable MH benefits observed among those managing chronic illnesses or employed individuals. These findings underscore the importance of tailoring public health strategies to specific subgroups, particularly older adults and vulnerable populations. Future research should prioritise longitudinal designs to explore causal pathways and assess the roles of urban infrastructure, social support, and environmental quality. Policies must address age-specific and mode-specific needs to optimise interventions. From a public health perspective, expanding safe walking and cycling infrastructure and fostering behavioural change are essential. Encouraging AM among older adults and addressing barriers younger individuals face can enhance mental well-being. Public health initiatives can improve mental health, encourage healthy lifestyles, and support broader sustainability and quality-of-life goals by promoting active mobility.

Chapter 4: Study 3 - Innovation and Science. The Development of a Digital Framework to measure Active Mobility and Mental Health

This study was presented at the *Faculty of Biology, Medicine and Health Digital Health Research Showcase*, held at the Michael Smith Lecture Theatre, University of Manchester, UK, on 26 March 2024.

The findings were further disseminated at the *LifePsych Society Inaugural Meeting*, held in Sabassa Rotja, Mallorca, Spain, from 16–19 June 2024.

The study was also presented at the *XV Congresso Nazionale della Società Italiana delle Scienze Motorie e Sportive (SISMES)*, held at the University of Chieti, Chieti, Italy, from 19–21 September 2024.

The framework was also presented at the *Digital Futures & Sustainable Futures PhD Workshop*, held at the University of Manchester, on 30 October 2024.

* For a broader overview of events and presentations related to this research, refer to Chapter 5: Beyond Publications.

Keywords: digital health research; research methodology; active mobility; mental health; sustainability

Overview

Active Mobility (AM) and Mental Health (MH) are increasingly recognised as interconnected domains with profound implications for public health, urban planning, and clinical interventions. Despite their significance, research exploring these relationships is often limited by inconsistent methodologies and a lack of standardised tools for assessing the interplay between AM and MH. This chapter introduces a novel digital framework to address these gaps by integrating validated psychological assessments with objective physical activity (PA) metrics. The framework was developed in collaboration with SelfLoops (SelfLoops.com, 2023), an Italian company specialising in wearable device data integration. It incorporates a multi-component system, including the SPARK smartphone app by SelfLoops (SelfLoops.com, 2023), an online platform, and fitness trackers, to collect, integrate, and analyse diverse datasets. Key features of the framework include customisable mood assessments based on validated instruments, compatibility with multiple fitness trackers, and the ability to capture contextual details

such as trip purpose and environmental factors. The design prioritises accessibility, featuring intuitive interfaces, multilingual support, and optional onboarding assistance, making it adaptable for varied populations and settings. The framework was pilot-tested to evaluate its usability and functionality, offering preliminary insights into its practical application and potential for refinement. This chapter positions the digital framework as a pioneering tool for interdisciplinary research, with potential applications in public health strategies, urban sustainability initiatives, and clinical practices. By providing a robust and evidence-based methodology, the framework addresses critical gaps in current research and contributes to scalable solutions for individual and societal challenges.

4.1 Introduction

AM—defined as walking and cycling for transportation—has gained increasing recognition for its multifaceted contributions to public health, urban planning, and environmental sustainability. Unlike leisure-time physical activity (LTPA) or structured exercise, AM refers to purposeful travel to reach a destination, such as commuting to work or school (Scrivano et al., 2023). Its relevance extends beyond individual health benefits, offering scalable solutions to address global challenges such as sedentary lifestyles, traffic congestion, and air pollution (Alattar et al., 2021; Marques et al., 2020).

While AM's physical health benefits, including improved cardiovascular function and enhanced physical fitness, are well established (Marques et al., 2020), its MH advantages remain underexplored and inconsistently documented. Existing research highlights the potential protective effects of AM against conditions such as anxiety, depression, and stress (Kelly et al., 2018). However, these findings are fragmented, often relying on heterogeneous methodologies, inconsistent definitions, and self-reported measures, which limit their reliability and comparability across studies (Gupta, 2022).

Moreover, much of the current evidence on AM-MH originates from disciplines such as transport economics and urban planning, with limited input from psychological research. This disciplinary gap has contributed to the absence of a unified, evidence-based framework capable of capturing both subjective (e.g., mood, affect) and objective (e.g., PA

metrics) measures of AM and MH. Addressing these limitations requires a robust, standardised methodology integrating validated psychological tools with objective data.

In response to these gaps, this chapter introduces an innovative digital framework developed in collaboration with SelfLoops, an Italian company specialising in digital solutions for wearable technology, team performance, and data integration. The framework integrates multiple components, including the SPARK app, an online platform, and fitness trackers, to create a seamless system for capturing and analysing data. Crucially, this tool introduces validated MH measures alongside objective PA metrics, filling a significant void in existing methodologies.

Validated methodologies play a critical role in enhancing the reliability and applicability of research findings. They provide a foundation for policymakers, urban planners, and public health practitioners to design interventions that maximise AM's physical and MH benefits (Kimberlin & Winterstein, 2008). Without such tools, the broader potential of AM to improve well-being and foster sustainable, healthy lifestyles remains underutilised.

The development of this framework reflects an interdisciplinary approach, blending insights from public health, digital health research, psychology, and sports science. Its design prioritises accessibility, usability, and adaptability, ensuring it can be applied across diverse populations and research contexts. This framework aims to advance research on the AM-MH relationship by providing a standardised and scalable methodology, supporting evidence-based public health interventions and urban planning strategies.

The primary objectives of this study are:

1. To establish a standardised methodology for assessing the relationship between active mobility and mental health.
2. To enhance the usability and scalability of digital tools for diverse demographic and cultural contexts.
3. To generate evidence-based insights that inform public health strategies, urban policies, and clinical practices.

This chapter outlines the digital framework's development, key features, and potential applications. It underscores the value of integrating validated tools and interdisciplinary perspectives to address long-standing methodological gaps in AM-MH research, offering a foundation for future studies and real-world interventions.

4.2 Methods

4.2.1 Framework Development

Developing a digital framework for measuring AM and MH was a cornerstone of this PhD research. This framework was designed to bridge the gaps in existing methodologies by integrating digital tools, including an online platform, a smartphone app, wearable fitness trackers, and online forms. It aimed to establish an accessible, scalable, and user-friendly system for collecting subjective (e.g., mood, affect) and objective (e.g., distance travelled, activity type) data. The development process unfolded in three key stages:

Conceptualisation: Establishing the framework's structure and objectives based on prior research and identified gaps.

Design Process: Iterative improvement through interdisciplinary collaboration.

Tool Selection: Ensuring compatibility, accessibility, and reliability in the chosen tools and devices.

4.2.1.1 Conceptualisation and Collaboration

The conceptualisation of the digital framework was shaped through a collaborative partnership with SelfLoops, an Italian company specialising in wearable device data integration and digital performance monitoring. This collaboration provided access to SelfLoops' robust technological infrastructure, including the SPARK smartphone app and its integrated online platform. These tools facilitated seamless data synchronisation across multiple fitness trackers, offered customisable metrics tailored to research needs, and enabled advanced data visualisation for in-depth analysis (Figure 4.1).

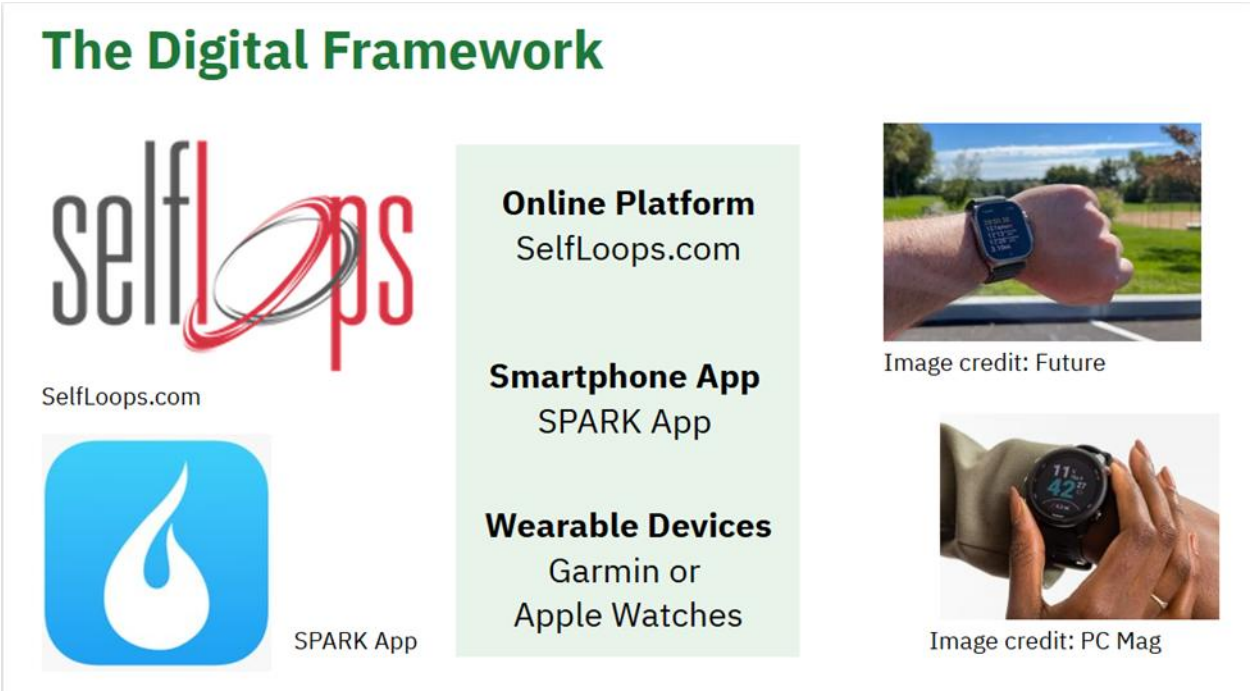


Figure 4.1. The Digital Framework: Overview of the core components of the digital framework, including the SelfLoops online platform, SPARK smartphone app, and wearable devices, such as Garmin® watches (Garmin Ltd., USA) and Apple Watches® Apple Inc. (2024). These tools collaborate to collect, integrate, and analyse active mobility and MH data. Adapted from the main author's presentation at the XV Congresso Nazionale SISMES 2024 – Sustainability and Technology – University of Chieti, Chieti, Italy.

Over six months, from June 30, 2023, to December 31, 2023, the lead researcher (LS) actively engaged with the SelfLoops team to gain proficiency in managing both "athlete" and "coach" accounts. This dual perspective was essential for understanding and optimising participant interactions with the digital tools. Participants used the SPARK app and online platform to log physical activities and mood states, and the researcher's familiarity with these functionalities ensured smooth onboarding, troubleshooting, and efficient data management.

The conceptual design was further guided by insights from the scoping review discussed in Chapter 2 (Scrivano et al., 2023). This review underscored a notable reliance on affective states—such as mood, happiness, and emotional well-being—in previous AM-MH research. These findings informed the integration of validated psychological instruments, including the PANAS (Positive and Negative Affect Schedule), I-PANAS-SF (International PANAS Short Form), and VAMS (Visual Analog Mood Scale), into the framework. These tools provided standardised, reliable assessments of MH outcomes, bridging a key methodological gap in existing literature.

Beyond instrumentation, significant attention was dedicated to designing participant workflows that balanced accessibility, user-friendliness, and scientific rigour. These workflows covered critical aspects such as recruitment, informed consent, data collection protocols, and feedback mechanisms, ensuring transparency and participant engagement throughout the study. Each step was methodically structured to maintain ethical standards and data integrity while fostering a seamless participant experience.

This phase laid the groundwork for a comprehensive, scientifically sound, and adaptable digital framework that captures the nuanced relationship between AM and MH across diverse populations and settings.

4.2.1.2 Design Process

The design process of the digital framework was characterised by iterative refinement and interdisciplinary collaboration, combining the technological expertise of SelfLoops with the research knowledge provided by the lead author (LS). While the SelfLoops platform and SPARK app already offered advanced tools for tracking physical performance and perceived exertion (e.g., RPE scale, Hardy & Rejeski, 1989), their capacity for MH assessment was initially limited to non-validated psychological tools commonly found in fitness-tracking platforms.

To address this limitation, the collaboration introduced scientifically validated psychological instruments, including the PANAS (Positive and Negative Affect Schedule), VAMS (Visual Analog Mood Scale), and BRUMS (Brunel Mood Scale; Terry & Lane, 2003). This integration significantly improved the framework's validity, reliability, and depth of MH assessments. In addition, data visualisation tools were enhanced to allow for user-friendly exports (e.g., Excel formats), ensuring researchers could efficiently analyse large datasets without technical obstacles.

Device compatibility and accessibility were central considerations in the design phase. Data were collected using Garmin watches were prioritised due to their availability at the University of Bologna's sports lab (30 units dedicated to research). In parallel, Apple Watches were included to accommodate their widespread usage among the general

population. Furthermore, integrations with third-party platforms such as Strava and Polar expanded the framework's flexibility, enabling users with diverse preferences to participate seamlessly.

Overall, this phase focused on refining technical functionality, user experience, and methodological robustness to create a flexible, scalable, and user-friendly digital framework capable of capturing both physical and MH metrics with scientific precision.

4.2.2 Challenges Encountered During Development

The development of the digital framework was not without challenges. These obstacles provided critical insights for refinement and improvement, ensuring the final design was practical and scientifically robust. Key challenges included:

- Access to Fitness Trackers: Reliance on wearable devices posed inclusivity challenges, particularly in low- and middle-income countries (LMICs), where access to such tools may be limited. While Garmin trackers were locally provided by the University of Bologna's sports lab, scaling access globally would require institutional partnerships and resource mobilisation.
- Ethical and Procedural Delays: Finalising ethical approvals for digital consent forms and ensuring data anonymity introduced delays. Adhering to bioethical standards across regional contexts required ongoing adjustments and alignment with local bioethics guidelines.
- User Experience and Workflow Simplicity: A critical focus was ensuring participants could intuitively navigate the SPARK app. Early iterations revealed that more extended MH tools, such as PANAS, could overwhelm participants and disrupt workflow simplicity. Collaborative refinement led to the inclusion of a flexible suite of validated tools, including BRUMS, PANAS, I-PANAS-SF, VAMS, and Overall Feeling Today assessments. This balance ensured that both usability and scientific rigour were maintained.
- Mental health Measurement Options: Choosing the most suitable MH instruments posed an additional challenge. While mood-based tools (e.g., VAMS) offered

practicality, broader instruments (e.g., PHQ-2 by Kroenke et al., 2003); GAD-7 by Spitzer et al., 2006) were excluded to avoid overburdening participants and to maintain streamlined usability without compromising data integrity.

- Participant Training and Support: Recognising varying levels of digital literacy among participants, onboarding materials and user guides were developed to provide clear, step-by-step instructions. Additionally, optional one-on-one onboarding sessions and ongoing technical support were implemented to ensure participants could confidently engage with the digital tools.

Each challenge underscored the importance of adaptability, participant-centred design, and cross-disciplinary collaboration in building a comprehensive digital framework that addresses the complexities of AM and MH research.

4.2.3 Ethical and Procedural Design

Ethical considerations were central to the framework's development. Digital consent and participation forms were created using Microsoft Forms® (Microsoft Corporation, USA), an online tool approved by the University of Bologna's Bioethics Committee (CBU). Participants were required to upload e-signature images to ensure compliance with ethical standards.

Although the framework development did not necessitate formal ethical approval, the University of Bologna's Bioethics Committee reviewed and approved its application under protocol number 0313511 on November 10, 2024. This ethical oversight ensured participant anonymity and data protection adhered to the highest standards, laying the groundwork for future studies.

4.3 Results

The digital framework for measuring AM and MH offers an innovative, evidence-based methodology integrating digital tools to capture, analyse, and visualise data comprehensively. Designed to address methodological gaps in AM-MH research, the framework combines subjective psychological assessments with objective PA metrics,

providing a robust tool for researchers, practitioners, and policymakers to investigate the AM-MH relationship effectively.

The framework comprises digital tools, including the SelfLoops online platform, the SPARK smartphone app, wearable devices (e.g., Garmin and Apple Watches), and online questionnaires on the Microsoft Forms website (Figure 4.2).

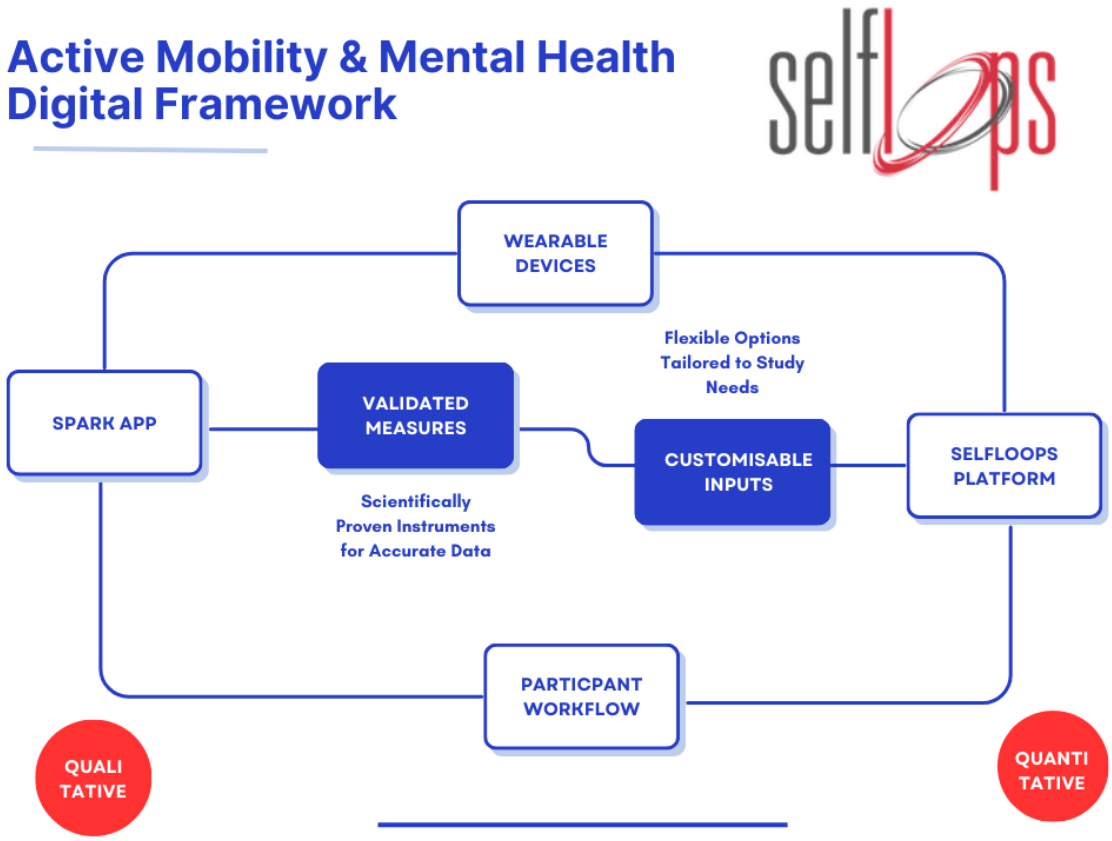


Figure 4.2. Conceptual Diagram of the active mobility and Mental health Digital Framework: A schematic representation illustrating the integration of wearable devices, validated measures, customisable inputs, and participant workflow for comprehensive data collection and analysis.

4.3.1 Functionality and Key Features

The digital framework integrates physical and MH metrics into a cohesive system, facilitating robust and scalable data collection and analysis.

Activity Tracking:

The framework tracks essential PA metrics, including steps taken, heart rate, distance travelled, and Non-Exercise Activity Thermogenesis (NEAT)—a category encompassing

non-structured PA patterns (Chung et al., 2018). Beyond quantitative measures, it captures contextual data, such as the purpose of trips, interactions with green and blue spaces, and public transport use, adding valuable qualitative dimensions to the dataset.

Mood and Mental health Assessment:

Scientifically validated psychological tools, including PANAS, I-PANAS-SF, BRUMS, and VAMS, are integrated into the platform to measure mood states and emotional well-being with precision and reliability. These tools allow researchers to select the most appropriate assessment instruments based on specific study objectives while maintaining scientific rigour.

Integrated Notes Section:

Participants can add qualitative contextual details related to their activities, such as trip purposes, interactions with natural environments, and transport modes (Sallis et al., 2016). These insights enrich quantitative data, enabling a nuanced understanding of the environmental and psychological factors influencing AM behaviour and MH outcomes.

Data Visualisation:

Advanced visualisation tools simplify data exports (e.g., Excel spreadsheets) and support the creation of user-friendly charts and graphs. These features facilitate seamless analysis, ensuring accessibility for diverse users, including researchers, practitioners, and policymakers.

These core features enable the digital framework to offer a holistic assessment of AM-MH interactions, capturing quantitative trends and qualitative nuances.

4.3.2 Participant Workflow

The participation process was meticulously designed to ensure simplicity, inclusivity, and scientific rigour, guiding participants through a well-defined workflow. Each step was carefully planned to optimise data quality and user engagement (Figure 4.3).

Figure 4.3. Participant Flow Infographic: Overview of the workflow for participants in the study, detailing each phase of their participation to ensure a clear, easy-to-follow, and smooth experience.

1. Recruitment: Participants were recruited through online platforms, in-person outreach, and snowball sampling to ensure diversity in demographics and activity levels.

2. Consent: Participants provided digital consent via Microsoft Forms, aligning with established bioethical guidelines. These forms outlined the study objectives, procedures, and data protection measures to ensure informed participation.
3. Registration: Participants created accounts on the SelfLoops platform, connecting their fitness trackers (e.g., Garmin, Apple Watch) to enable seamless data integration.
4. Initial Questionnaire: A 15-minute baseline survey collected essential data on sociodemographic characteristics, health habits, and perceptions of AM and MH.
5. Data Collection (10-Day Period):
    - Participants reported their "Overall Feeling Today" using mood scales each morning (A. R. Rosenberg et al., 2018).
    - They activated fitness trackers to log PA metrics (e.g., steps, heart rate, distance).
    - Activities were categorised into training, race, or NEAT-specific sessions.
    - Participants used validated mood assessment tools (e.g., VAMS) post-session.
    - Contextual details, such as trip purposes, green/blue space interactions, and transport modes, were recorded in the integrated notes section.
6. Final Questionnaire: At the end of the data collection phase, participants completed a 10-minute follow-up survey evaluating behavioural changes, MH outcomes, and methodological feedback.
7. Ongoing Support: Participants had access to optional onboarding sessions and technical assistance, ensuring a smooth and user-friendly experience.

This workflow balanced scientific rigour with a participant-centric design, fostering data quality and user satisfaction.

4.3.3 Usability and Adaptability

The framework's usability was prioritised throughout its development, focusing on simplicity, adaptability, and user-friendliness to ensure seamless integration into research settings and real-world applications. Participants navigated a structured workflow, from logging PA using fitness trackers to inputting MH data via the SPARK app.

The intuitive design allowed participants to customise data inputs, selecting the most appropriate MH tools available on the platform without compromising scientific rigour. Additionally, the notes section enabled trip-specific insights, enhancing the contextual depth of the data collected.

The framework was built with multilingual support (SelfLoops tools are available in seven languages) and included optional onboarding guidance, ensuring accessibility across diverse cultural, demographic, and technical backgrounds. These features collectively contribute to the framework's adaptability, making it suitable for individual users, researchers, and public health practitioners.

4.3.4 Data Analysis and Interpretation Potentialities

The digital framework presented in this study offers extensive potential for analysing and interpreting data on AM and MH. Its modular structure, integration of subjective and objective measures, and customisable design enable researchers to adopt diverse analytical strategies tailored to their research questions and objectives.

At its core, the framework allows the examination of cross-sectional and longitudinal data, supporting analyses ranging from simple descriptive statistics to more complex multivariate modelling. Researchers can explore associations between PA metrics (e.g., step count, heart rate, duration of activity) and MH outcomes (e.g., mood states, affective scores) while accounting for contextual variables such as trip purpose, environmental exposures, and temporal patterns.

Descriptive analyses provide foundational insights, summarising participant characteristics, AM patterns, and MH trends. For instance, researchers can evaluate average mood scores before and after AM sessions or compare PA metrics across different user demographics. Both SelfLoops and Microsoft Forms facilitate seamless data exports into Excel format, enabling immediate access to structured datasets for analysis. SelfLoops, in particular, offers advanced features such as customisable column selection, immediate visualisation tools, and automatically generated graphs and summaries on its online platform. These tools allow researchers to perform essential

analyses without additional statistical software, ensuring accessibility even for those with limited technical expertise or resources.

Inferential statistical techniques, such as regression models, enable researchers to explore associations between AM and MH outcomes while adjusting for potential confounders (e.g., age, gender, socioeconomic status). Researchers may also investigate interaction effects to understand how specific variables (e.g., age or environmental context) moderate the AM-MH relationship. These analyses are particularly critical in longitudinal studies and randomised controlled trials (RCTs), where establishing causal relationships and understanding temporal patterns are essential. As the field advances, these analytical approaches will become increasingly central to validating the framework's efficacy and ensuring its findings can inform robust public health interventions.

Time-series analyses represent another powerful framework application, particularly for longitudinal data collected over multiple days or weeks. These approaches allow researchers to identify AM and MH patterns' trends, seasonal variations, and temporal dependencies. Additionally, clustering techniques can uncover distinct user profiles based on activity patterns, mood states, and contextual data. Such insights may reveal subgroups with shared behavioural or psychological characteristics, providing valuable information for targeted interventions.

Qualitative data collected via the integrated notes section enriches quantitative findings by offering contextual narratives about participants' experiences, motivations, and perceptions. These insights deepen the understanding of AM-MH interactions and provide valuable feedback for refining the framework's design and functionality. Thematic analysis or mixed-method approaches can help bridge qualitative and quantitative insights, enhancing the overall depth and relevance of findings while guiding future improvements to meet user needs and research objectives better.

It is important to note that the framework's flexibility empowers researchers to prioritise specific variables and outcomes based on their study objectives. While the tools and data

structure offer a broad analytical canvas, each researcher can focus on particular aspects of the AM-MH relationship, applying tailored statistical or qualitative techniques accordingly.

In essence, the digital framework does not prescribe a single analytical path and does not specify a preferential one—at least for now. Instead, it offers a robust foundation for diverse analytical approaches, ensuring adaptability to various research aims, from exploratory investigations to hypothesis-driven studies. As more studies adopt and experiment with this framework, recurring analytical pathways may emerge, providing structured yet flexible approaches tailored to different research contexts and objectives. This iterative process will refine the framework's analytical potential, supporting academic inquiry and apply public health interventions.

4.3.5 Limitations of the Current Prototype

The development and initial deployment of the digital framework revealed several limitations, which offer opportunities for future refinement:

- Dependency on Digital Tools: Access to fitness trackers and varying levels of digital literacy among participants posed challenges. These barriers are particularly pronounced in low-resource settings, where institutional partnerships may be required to ensure equitable access.
- Short Study Duration: The 10-day data collection period, while practical and supported by existing literature (Hilden et al., 2023), may not fully capture long-term behavioural patterns or the sustained psychological impacts of AM. Future iterations could explore longer study durations, provided strategies for participant retention are in place.

Scalability for Large-Scale Studies: Expanding the framework for population-level research introduces logistical and financial challenges, particularly in managing and analysing large datasets across diverse devices and platforms.

These limitations underscore the need for ongoing refinement, institutional collaborations, and technical enhancements to maximise the framework's applicability and scalability across varied research and public health contexts.

4.3.6 Strengths of the Framework

The digital framework represents a significant advancement in AM-MH research, offering unique strengths that set it apart from existing methodologies:

- Device Compatibility and Integration: The SelfLoops platform supports multiple fitness tracking applications (e.g., Garmin, Apple Health, Strava, Polar, and Withings), ensuring flexibility and accessibility for diverse user preferences.
- Integration of Subjective and Objective Measures: Combining objective PA metrics (e.g., steps taken, heart rate, distance) with validated psychological tools (e.g., PANAS, VAMS) allows for a holistic analysis of the AM-MH relationship.
- Contextual Enrichment: The integrated notes section captures qualitative insights (e.g., trip purpose, environmental context), complementing quantitative data with richer behavioural and environmental dimensions.
- Sustainable and User-Friendly Design: The digital nature of the framework eliminates the need for paper-based tools, offering a modern, scalable, and environmentally friendly solution.
- Global Applicability: With multilingual support and an adaptable design, the framework can be applied across diverse cultural, geographic, and demographic contexts, supporting local and global research initiatives.
- Scientifically Validated Methodology: Unlike commercial tools that rely on non-validated psychological assessments, this framework integrates scientifically validated instruments, ensuring data integrity and research credibility.
- Bridging Methodological Gaps: The framework addresses the long-standing lack of standardised methodologies in AM-MH research, setting a new benchmark for future studies.
- Diverse Applications: The framework's modular design supports applications across public health interventions, clinical monitoring, urban planning, and individual wellness initiatives.

In summary, the digital framework offers a comprehensive, adaptable, and scientifically robust tool for studying the relationship between AM and MH. Bridging critical methodological gaps lays a solid foundation for future interdisciplinary research and evidence-based interventions, advancing academic knowledge and public health outcomes.

4.4 Discussion

4.4.1 Overview of the Framework's Contributions

The digital framework developed in this study offers a groundbreaking approach to investigating the relationship between AM and MH. Integrating validated MH instruments with objective PA metrics bridges critical methodological gaps, providing a comprehensive tool for researchers, practitioners, and policymakers. This framework standardises methodologies in AM-MH research and opens avenues for interdisciplinary collaboration, supporting theoretical inquiry and practical applications.

4.4.2 Framework Applications

Designed for versatility, the framework serves multiple stakeholders by translating evidence-based research into actionable strategies to improve health and well-being. The framework's adaptability supports a range of practical applications across key sectors.

Researchers can rely on its standardised methodology to generate robust and reproducible findings, contributing to the evidence base on AM and MH. Clinicians can use the framework to monitor MH outcomes alongside PA data, aiding personalised interventions for MH treatment and rehabilitation. Urban planners and policymakers can leverage insights from the framework to inform evidence-based decisions on infrastructure development, such as designing pedestrian-friendly spaces and cycling networks. Finally, individual users, including athletes and fitness enthusiasts, can track their MH with PA metrics, fostering informed, health-conscious routines.

4.4.3 Comparison with Existing Tools

Compared to existing tools, the framework uniquely integrates validated MH measures and objective PA data. Unlike commercial fitness platforms, which often rely on non-validated psychological tools, this framework maintains scientific rigour, ensuring validity and reliability in data collection.

Similarly, tools such as the Health Economic Assessment Tool (HEAT) and the PASTA (Physical Activity through Sustainable Transport Approaches) provide valuable insights but focus primarily on AM's economic and environmental aspects. These instruments lack the dual capacity to capture individual-level MH data or integrate subjective MH outcomes and objective activity metrics. Including customisable workflows, advanced visualisation tools, and compatibility with widely-used devices like Garmin and Apple Watch positions this framework as a versatile tool for researchers and practitioners, offering a more holistic and adaptable approach.

4.4.4 Framework Implications

The digital framework presented in this chapter carries significant implications across multiple domains, contributing to advancements in research, practice, and policy:

Theoretical Advancements: The framework addresses long-standing methodological inconsistencies by standardising the measurement of the relationship between AM and MH. It enables robust, interdisciplinary research that can be applied across diverse populations and contexts, laying the groundwork for longitudinal studies and randomised controlled trials (RCTs) essential for establishing causal relationships.

Practical Applications: The framework bridges the gap between academic research and real-world implementation. Public health officials, urban planners, and clinicians can use its data-driven insights to design interventions and environments promoting PA and mental well-being. Its adaptability ensures usability across varied professional and social contexts.

Environmental Impact: By emphasising AM, the framework supports sustainable urban development by generating evidence for green infrastructure projects, such as bike lanes,

pedestrian pathways, and accessible public transport systems. These initiatives contribute to reducing carbon emissions, mitigating traffic congestion, and improving overall air quality.

Social Equity: The framework highlights disparities in access to AM opportunities, providing evidence to guide interventions that address health inequities and foster inclusivity. Encouraging a culture of active lifestyles promotes social cohesion, reduces barriers to PA, and supports the creation of healthier, more connected communities.

Global Relevance: Its modular and adaptable design allows the framework to be implemented across diverse cultural, economic, and environmental settings. This scalability facilitates cross-border collaborations, enabling countries and institutions to share insights, best practices, and evidence-based strategies to address global health challenges related to AM and MH.

The framework's contributions extend beyond research outcomes, offering actionable insights that intersect public health, environmental sustainability, and social well-being. Its potential to address critical societal challenges underscores its relevance in local and global contexts.

4.4.5 Refinements and Future Directions

While the framework marks a significant methodological advancement, ongoing efforts are needed to enhance the framework's utility, inclusivity, and scalability.

Quantitative Validation:

Longitudinal studies and RCTs are crucial for capturing sustained behavioural and psychological changes and establishing causal relationships between AM and MH outcomes.

Scalability Testing:

Future research should assess the framework's performance in large-scale studies, including community-based interventions and public health programs.

Cultural Adaptation:

Testing the framework in varied urban, rural, and cultural settings will enhance its applicability and maintain equity, diversity, and inclusion (EDI) principles.

Accessibility Improvements:

Collaborations with institutions to improve access to wearable devices, simplify onboarding processes, and provide multilingual support are necessary for global adoption.

Participant Involvement:

Public and Participant Involvement and Engagement (PPIE) initiatives remain essential to refine workflows, improve usability, and incorporate real-world feedback.

The iterative nature of the framework ensures continuous adaptation based on researcher insights and participant feedback. Its evidence-based foundation and interdisciplinary approach are valuable tools for advancing research, informing policies, and fostering health-promoting environments across diverse global settings.

4.5 Conclusion

This chapter presented an innovative digital framework to integrate validated Mental health measures with objective active mobility metrics, addressing significant methodological and practical gaps in the existing research landscape. By combining subjective (e.g., mood assessments) and objective (e.g., physical activity metrics) data, the framework establishes a robust, adaptable, and scalable methodology that bridges the divide between academic research, public health practice, and digital health innovation.

The framework's key strengths lie in its interdisciplinary approach, user-centred design, and emphasis on flexibility. It allows researchers, clinicians, and policymakers to generate reliable, evidence-based insights to inform interventions, shape urban infrastructure, and support MH treatment plans. Additionally, its compatibility with widely used fitness tracking devices, user-friendly interfaces, and customisable MH tools make it accessible to diverse populations and adaptable across various study designs and cultural contexts.

While the framework demonstrates substantial potential, challenges remain. Issues related to accessibility, scalability, and cross-platform integration highlight the need for continuous refinement and adaptation. Longitudinal studies and randomised controlled trials (RCTs) are essential to fully realise the framework's potential, enabling sustained data collection and robust causal analyses.

Beyond academic contributions, the framework offers practical tools for addressing global health challenges. Its insights can drive evidence-based urban planning, support sustainable development initiatives, and foster community engagement in health-promoting behaviours. Notably, the analytical flexibility embedded in the framework allows researchers to tailor their methodologies to specific study objectives, ensuring both depth and relevance in their findings.

In conclusion, this framework represents a significant advancement in standardising and advancing research at the intersection of active mobility and mental health. Its adaptable and scalable design ensures relevance across diverse contexts, fostering a deeper understanding of the interplay between physical activity, mental well-being, and broader sustainability goals. By bridging research and real-world applications, the framework provides a robust foundation for future studies, policy-making, and public health initiatives, contributing to healthier lifestyles, inclusive communities, and evidence-based strategies for addressing global health challenges.

Chapter 5: Beyond Publications. Professional and Academic Milestones

5.1. Introduction

While publications remain a central outcome of doctoral research, the reality of a PhD journey encompasses far more than journal articles and citation metrics. It involves collaborations across disciplines, knowledge dissemination through presentations and workshops, community engagement initiatives, and professional training programs. These activities collectively advance academic scholarship and societal well-being while equipping researchers with diverse skills for addressing contemporary challenges.

Structured as a collaborative doctoral program, this PhD was designed to bridge academia, industry, and international research environments. This format combined rigorous academic training with practical professional experience, fostering adaptability, interdisciplinary knowledge, and a broader perspective on health and sustainability challenges.

Significant contributions were made to international collaborations, interdisciplinary projects, public outreach initiatives, and specialised training programs throughout this journey. These milestones enhanced the research outcomes and strengthened the capacity to operate effectively across academic, professional, and community-based contexts.

This chapter provides an overview of these essential dimensions of the doctoral experience, organised thematically to highlight key activities, contributions, and outcomes. The sections outline roles assumed during this journey, including those of researcher, collaborator, presenter, advocate, and communicator—focusing on tangible achievements and their relevance to the broader research landscape.

This chapter underscores the value of integrating diverse professional and academic experiences into doctoral training by documenting these milestones. Recognising and supporting such contributions is essential for developing well-rounded researchers capable of navigating complex professional environments and driving meaningful change across disciplines and sectors.

5.2. Methods: Thematic Organization of Milestones

5.2.1 Research Collaborations and Interdisciplinary Projects

Collaboration is a cornerstone of scientific progress, driving innovation and fostering connections across disciplines, institutions, and industry partners. Throughout this doctoral journey, meaningful partnerships were established with academic colleagues,

national health institutions, and industry stakeholders, significantly enriching research outcomes and professional expertise.

In March 2022, an exploratory **collaboration with PhD colleague** Roberto Tedeschi at the University of Bologna was initiated to investigate the intersections of physical activity, quality of life, and footwear quality, merging expertise in MH with biomechanics. While the project remained in the conceptualisation phase, it provided valuable insights into the processes and challenges of interdisciplinary research.

A pivotal milestone in this research was the **collaboration with the Italian National Institute of Health (Istituto Superiore di Sanità – ISS)** in June 2023. This partnership, anchored in the analysis of the PASSI surveillance data (Study 2), formed the foundation for Chapter 3 of this thesis. The research focused on investigating associations between Active Mobility (AM), i.e., walking and cycling, and MH outcomes among Italian adults, with attention to regional and sociodemographic variations. The methodological approach was refined through collaborative exchanges with ISS experts, ensuring alignment with national public health priorities.

Between June and December 2023, **collaboration with SelfLoops**, an Italian company specialising in wearable technology and sports performance analysis, was central to advancing methodological innovation (Study 3). In close partnership with founders Christian Del Rosso and Piero Ribichini, a digital framework was developed to measure AM and MH. This included integrating validated psychological tools into the SelfLoops platform, optimising data classification from fitness trackers, and enhancing user engagement features. The collaboration highlighted the potential of bridging academia, industry, and public health to drive impactful technological advancements.

In **collaboration with PhD colleague** Marianna Olivadese, a study exploring the relationship between eco-anxiety and green spaces was conceptualised in November 2023. The researchers worked on the initial drafting phase, and the collaborative effort highlighted the value of interdisciplinary research in addressing emerging environmental

MH challenges. The initiative underscored the potential for integrating psychological and environmental perspectives in future research endeavours.

Another significant collaboration occurred between March and July 2023 with **the Active Breaks (ABs) Research Team at the University of Bologna**. Led by Prof. Laura Dallolio, Prof. Andrea Ceciliani, and Dr. Alice Masini, the initiative investigated the psycho-physical benefits of active breaks in secondary school settings. Contributions included designing the research framework, facilitating focus group interviews, and analysing student feedback. These efforts culminated in a poster titled "Active Breaks in High School: Students' Perspectives", presented as part of the BRAVE study. The presentation emphasised key facilitators, barriers, and perceived benefits of active breaks, particularly their role in fostering cooperation, empathy, and self-management skills.

From January to June 2024, a six-month research placement was undertaken at the University of Manchester in collaboration with **Dr Joseph Firth and the e-PHIT team**. The placement centred on the REAL study, investigating digital lifestyle interventions to improve MH outcomes. Immersion in this multidisciplinary environment involved contributing to the study's implementation, co-authoring a reflective piece exploring findings and future directions, and serving as the primary author of a scientific article based on qualitative data collected at the intervention's conclusion. This placement provided invaluable experience in applying innovative methodologies to real-world healthcare challenges while fostering professional connections with global experts in digital health research.

In June 2024, participation in **the inaugural LifePsych Society meeting** in Mallorca, Spain, further emphasised the collaborative spirit of this doctoral journey. The event brought together international lifestyle psychiatry experts under Dr. Joseph Firth's leadership. Contributions included moderating discussion sessions, facilitating knowledge-sharing workshops, and managing the editing of expert interview videos for dissemination via the society's YouTube channel. Additionally, significant input was provided in organising meeting notes and contributing to a Letter of Proceedings intended for publication in a prestigious psychiatry journal, with authorship acknowledgement

among the primary contributors. This experience exemplified the impact of cross-disciplinary collaboration in advancing MH research.

5.2.2 Academic Presentations and Conferences

Academic presentations and conferences have been pivotal platforms for disseminating research findings, receiving constructive feedback, and fostering professional connections. Each event contributed to advancing the quality and clarity of the research while facilitating collaboration and knowledge exchange across disciplines.

In November 2022, a poster titled “The Relationship between Active Mobility and Mental Health – A Systematic Review” was presented at the **XIII Congresso Nazionale SISMES in Milan, Italy**. This presentation provided valuable feedback from peers and experts, which informed the transition from a systematic review to a scoping review approach. Connections made during this event also laid the groundwork for future collaborations, including participation in the SHIINE Training School.

The **XIV Congresso Nazionale SISMES** in Naples, held in November 2023, offered another opportunity to share research outcomes. A two-minute teaser presentation and accompanying poster, titled “Active Mobility and Mental Health in Italy: The PASSI Surveillance Data”, summarised key findings from the analysis of the PASSI dataset. The poster “Active Breaks in High School: Students’ Perspectives” was also presented during the same event, highlighting insights into the psycho-social benefits of structured physical activity interventions in educational settings. Both presentations facilitated valuable discussions on the broader public health and education implications.

In March 2024, **the Faculty of Biology, Medicine and Health Digital Health Research Showcase** at the University of Manchester provided a platform to present preliminary insights from the collaboration with SelfLoops. The poster, “Innovation and Science: A Digital Framework to Measure Active Mobility and Mental Health”, emphasised the potential of integrating wearable technology with validated psychological measures for sustainable health promotion.

In September 2024, a Short Communication on the digital framework was delivered at the **XV Congresso Nazionale SISMES** in Chieti, Italy. This presentation focused on the dual objectives of classifying activity data and incorporating mood-tracking functionalities, fostering engaging discussions on the intersection of technology, MH, and sustainable urban planning.

Subsequently, in October 2024, **the Digital Futures & Sustainable Futures PhD Workshop** at the University of Manchester featured a 7-minute Lightning Talk on the interdisciplinary aspects of the digital framework. This presentation underscored its adaptability and potential applications across public health, urban planning, and clinical practice. Positive feedback from peers and experts reaffirmed this methodological contribution's relevance and innovative value.

5.2.3 Community and Public Engagement Initiatives

Public engagement and science communication were central to my PhD journey, offering opportunities to bridge academic research with societal impact. These initiatives provided opportunities to connect with diverse audiences, share evidence-based knowledge, and advocate for healthier, more sustainable lifestyles.

In March 2022, participation in the **14th Edition of Le Case della Scienza in Imola** included delivering a session titled "Cognitive and Emotional Benefits of Physical Activity Across the Lifespan." The event combined scientific theory with interactive engagement, introducing attendees to the biological and psychological mechanisms underpinning the benefits of physical activity. The session concluded with a "Silent Walk," an experiential activity demonstrating the cognitive and emotional effects of mindful walking, conducted by a PhD colleague, Dr Alessia Grigoletto. This initiative emphasised the importance of translating complex scientific concepts into accessible and actionable insights for the general public.

In December 2022, contributions were made to the Innovative **Health Initiative (IHI) 2023 Research Mapping Project** in collaboration with the University of Bologna and three IRCCS Institutes. The PhD project, "Let's MOVE for a Greener World," was featured in the

initiative's official booklet, highlighting its relevance to public health frameworks. This engagement underscored the value of aligning individual research projects with broader health innovation goals and fostering visibility across academic and industry networks.

In March 2023, a guest lecture titled "Mental health Benefits of Green Exercise" was delivered at the **University of Turin's Department of Sport Science**. The lecture explored the intersection of physical activity, nature exposure, and MH, focusing on Nordic Walking as a therapeutic intervention. The session facilitated meaningful dialogue with students and highlighted the importance of evidence-based approaches in sports science education.

Participation in the **2nd SHIINE Training School** (July 2023) part of the **COST Action 18236 at the University of Novi Sad,** Serbia, provided a valuable platform for dissemination. Two posters were presented: "Active Breaks in High School: Students' Perspectives" and "Active Mobility and Mental Health: A Scoping Review." These presentations facilitated interdisciplinary discussions and underscored the role of translating academic findings into actionable strategies.

Between July and September 2023, a project proposal exploring the MH benefits of Nordic Walking was developed in collaboration with Prof. Giuliano Scrivano from the University of Turin. This initiative, part of **WWF Italy and ANWI's Urban Nature 2023 campaign, "La Natura si fa Cura",** emphasised the intersection of environmental sustainability and public health promotion. Moreover, the project showcased the potential for cross-sector partnerships to create impactful community health interventions.

In October 2023, participation in **Giornata Mondiale della Salute Mentale (International Mental health Day)** included delivering a presentation titled "Proposta laboratoriale: Pause Attive – Contrastare la sedentarietà e promuovere la salute a scuola." The initiative presented scalable school-based interventions designed to reduce sedentary behaviour and improve mental and physical well-being among adolescents. The presentation underscored the alignment of such interventions with public health policies and their potential societal benefits.

In June 2024, participation in the **Growing Minds: Cultivating Positive Mental health & Green Living Workshop** at Hulme Garden Centre, Manchester, offered an opportunity to deliver a presentation titled "Green Exercise and Mental health." The session highlighted outdoor physical activity's physiological and psychological benefits and provided practical strategies for integrating green spaces into daily routines. The workshop also included interactive activities, emphasising the connection between MH and environmental care.

Finally, in December 2024, participation in the **MCHP PGR Christmas Showcase** included delivering a presentation titled "The PhD Rollercoaster: Buckle Up!" The session used an interactive "Feelings Meter" to explore the emotional dimensions of doctoral research, sparking discussions around resilience, MH, and well-being in academic life.

5.2.4 Professional Development and Training Programs

Professional development and continuous learning played a pivotal role, equipping me with essential skills, broadening my perspectives, and preparing me to navigate the evolving academic and professional landscape. Through immersive training programs, international workshops, and skill-building initiatives, I gained valuable insights that transcended the boundaries of my primary research focus.

In July 2023, participation in the **2nd SHIINE Training School** under the COST Action 18236 – **"Hack the Future by Social Innovation"** in Novi Sad, Serbia, combined research dissemination with interactive learning experiences. The program included a transformative hackathon challenge titled "Train Students not for Jobs but for Society," where collaboration with an international team led to the development of the SHIELD prototype (Social and Human Initiatives for Empowering Learning and Driving Change). The project secured first place, resulting in an invitation to present at the Final COST Action event in Brussels (March 2024). This experience strengthened leadership, teamwork, and problem-solving skills while fostering meaningful connections with international peers. Furthermore, relationships established during the training school

facilitated opportunities to contribute as a peer reviewer for journals such as BMC Public Health and PLOS One, contributions now reflected on the ORCID profile.

In February 2024, attendance at two key events—the GM Connected Health Ecosystem: XR in Mental health and the **HETT (Healthcare Excellence Through Technology) North 2024** – Digital Health Innovation Conference in Manchester—provided critical insights into emerging trends in digital health interventions. At the **GM Connected Health Ecosystem | XR in Mental health**, discussions centred on the applications of Extended Reality (XR), Augmented Reality (AR), and Artificial Intelligence (AI) in MH therapies. Expert presentations by Prof. Panos Constantinides and Dr. Thomas Ward highlighted advancements in digital health solutions and their practical applications. Similarly, the HETT North Conference emphasised scalable digital interventions for patient-centred care, awarding 7 CPD hours/points to recognise the professional skills gained. Both events highlighted the importance of integrating digital technologies into MH research and the value of interdisciplinary collaboration in addressing complex health challenges.

In June 2024, participation in the **NIHR and MRC Global Health Visit and Workshop** at the University of Manchester facilitated valuable exchanges among researchers, policymakers, and public health professionals. Discussions focused on funding strategies, global health research priorities, and the complexities of implementing health interventions in low-resource settings. Interactive sessions emphasised the importance of context-specific, adaptable health solutions and provided a platform for exploring how digital frameworks, such as the one developed during this PhD, could be effectively adapted for international applications.

Later, in November and December 2024, training under the **Una Europa Virtual Exchanges for Sustainability (UnaVEx) Moderators' Program**—an EU-funded Erasmus+ initiative—offered advanced skills in virtual facilitation, intercultural communication, and active engagement strategies. Designed to foster cross-cultural dialogues between European and African students, the program prepared moderators to lead five virtual exchange sessions scheduled for February–March 2025. This initiative reinforced

facilitation and leadership skills while contributing to global sustainability education efforts.

5.2.5 Science Communication and Advocacy

Participation in competitions, structured programs, and targeted initiatives provided valuable opportunities to develop transferable skills and engage with diverse academic and professional communities. These experiences strengthened communication, innovation, and adaptability—key competencies for effective science advocacy.

In November 2023, participation in the **1st Edition of the ISA Doctoral Prize Competition** at the University of Bologna showcased the doctoral research project "Active Mobility and Mental Health. Let's Move for a Healthier World." The submission emphasised AM's mental and physical health benefits, aligning with the World Health Organization's Global Action Plan on Physical Activity. Advancing to the final phase, the project was presented to an expert panel, refining skills in communicating complex scientific concepts effectively to a broad audience.

In February 2024, engagement in the **Medical Communications Competition, organised by the North West Biotech Initiative (NWBI) and VML** at the University of Manchester, focused on transforming complex scientific findings into accessible communication materials. The submission included an infographic and slide presentation titled "Lecanemab in Early Alzheimer's Disease: A Turning Point." This process enhanced skills in visual storytelling, audience engagement, and scientific dissemination while emphasising the importance of clarity and precision in communicating health-related findings.

In March 2024, participation in the **COST Action 18236 Final Conference** in Brussels followed the success of the SHIINE Training School hackathon. The SHIELD prototype (Social and Human Initiatives for Empowering Learning and Driving Change) was presented, highlighting its innovative approach to fostering essential life skills through social innovation within university systems. This platform facilitated meaningful

exchanges with educators, policymakers, and international researchers, emphasising the value of collaborative solutions in addressing societal challenges.

In July 2024, participation in the **School of Health Sciences (SHS) Social Responsibility Dragon's Den** at the University of Manchester offered a platform to present the project "Promoting Active Lifestyles through Active Mobility." The proposal outlined evidence-based initiatives to enhance community health and environmental sustainability through walking and cycling interventions. Shortlisted for the final phase, the project was presented through a five-minute pitch and an interview with a panel of stakeholders. Although not selected for funding, the experience significantly strengthened competencies in project design, stakeholder engagement, and effectively articulating public health value propositions.

The **DOCABILITY 2 Program**, an initiative bridging academia and industry within the Emilia-Romagna region, provided further professional development opportunities. Phase 1, completed in December 2024, included workshops on sustainability, collaborative innovation, and applied research solutions. Progressing to Phase 2 in January 2025, participation in targeted working groups facilitated the practical application of academic expertise within industry contexts, strengthening the ability to align research insights with real-world challenges.

In December 2024, selection into the **Manchester Young Academics Programme** marked another milestone in science communication and mentorship. This initiative supports and inspires future academics through mentorship and educational activities targeting high school students from disadvantaged backgrounds. The role of the *Student Instructor* includes mentoring participants, delivering interactive workshops, and fostering resilience and character development through evidence-based education strategies. Training sessions within the program refined leadership, communication, and mentorship abilities, ensuring practical contributions to an impactful educational initiative.

5.3. Results: Holistic PhD Programs

Integrating professional development activities into PhD programs is essential for preparing researchers to address complex global challenges. Opportunities such as participation in workshops, training schools, public science initiatives, and cross-sector collaborations are integral components of doctoral education. These activities equip researchers with the skills to bridge academia and society, fostering professionals capable of contributing to diverse fields and driving meaningful change.

Mentorship and institutional support play a pivotal role in facilitating these experiences. Effective mentorship extends beyond academic supervision to include career guidance, access to professional opportunities, and constructive feedback. Equally, institutional frameworks that formally recognise contributions beyond academic publications—such as leadership roles, teaching, community engagement, and science communication—create a more comprehensive and rewarding doctoral experience.

Notably, PhD programs aim for the holistic development of researchers, emphasising academic excellence, adaptability, resilience, and the ability to collaborate across disciplines. A doctoral journey prioritises both professional and personal growth.

Success in doctoral education extends beyond traditional academic outputs to encompass the development of skilled, adaptable researchers prepared to navigate diverse career landscapes within and beyond academia. An inclusive and supportive approach in PhD programs ensures that research-generated knowledge is effectively translated into societal impact. Equally important, it fosters a culture where researchers have the confidence, resilience, and well-being to contribute meaningfully to science, policy, and public health.

5.4. Discussion and Conclusion

The milestones described in this chapter demonstrate that a PhD is not solely an academic endeavour but a transformative process that integrates research, collaboration, professional growth, and societal contribution. These achievements—spanning research

collaborations, academic presentations, public engagement, professional development, and science communication—reflect the multifaceted nature of doctoral work.

This journey underscores that the role of a researcher extends beyond publishing academic papers. It involves cultivating meaningful connections with peers, experts, and communities, translating research findings into practical applications, and fostering spaces where knowledge inspires action and innovation.

The collaborative nature of this doctoral program, which bridged academic, industrial, and international environments, further highlights the importance of interdisciplinary perspectives and cross-sector partnerships.

Ultimately, this chapter serves as a reflection on the diverse dimensions of doctoral training and the broader understanding of what constitutes success in academic research. Researchers are knowledge producers and, first and foremost, also agents of change—bridging disciplines, sparking innovation, and contributing to societal progress.

Achieving balance—between academic rigour and well-being, individual objectives and collective impact, knowledge creation and its real-world application—emerges as a central theme. This balance marks the successful completion of this PhD and sets the foundation for an ongoing commitment to curiosity, collaboration, and meaningful contribution.

Chapter 6: General Discussion and Future Directions

This chapter synthesises the key findings of this thesis, aligning them with the research questions and objectives outlined in Chapter 1. The discussion highlights theoretical and practical contributions to Active Mobility (AM) and Mental Health (MH), addressing strengths and limitations. Additionally, this chapter identifies pathways for future research and proposes actionable recommendations for public health policies and urban planning.

6.1 Mental Health Benefits of Active Mobility

The findings across the three studies collectively support the hypothesis that AM has tangible benefits for MH and overall well-being. Both walking and cycling were associated with reduced depressive symptoms, improved mood states, and better quality of life outcomes across different demographic groups. However, these benefits were not uniformly distributed, with age, gender, and employment status playing moderating roles.

These findings align with existing literature suggesting that physical activity improves Mental health outcomes through physiological and psychosocial mechanisms. Physiologically, AM promotes the release of endorphins and reduces stress hormones, while socially, it fosters feelings of independence, achievement, and environmental connectedness. However, it is important to acknowledge that the observed associations do not necessarily indicate a direct causal relationship. Individuals who engage in AM may already be motivated to support their mental wellbeing or may experience incidental psychological benefits from the physical activity involved. Future research should explore whether AM acts as a proactive coping strategy or delivers unintended psychological advantages, even in the absence of MH challenges.

6.2 Demographic and Contextual Factors

The analysis revealed significant variations in MH outcomes based on demographic and contextual factors. For example, older adults seemed to derive greater MH benefits from AM compared to younger populations. Similarly, individuals in urban environments

reported different psychological responses to active commuting compared to those in rural settings.

These findings emphasise the importance of context-specific interventions. Public health initiatives and urban planning strategies must consider these demographic and environmental nuances to maximize the MH benefits of AM.

6.3 Research Methodologies and the Digital Framework

The thesis highlighted inconsistencies in methodologies used to study AM and MH, contributing to fragmented evidence and limited generalisability. The digital framework developed during this project (Study 3) represents a step toward addressing these gaps. By integrating wearable technology and self-reporting tools, the framework offers a standardized approach to assessing MH outcomes linked to AM.

This methodological contribution holds potential for scalability and cross-context validation, allowing future researchers and policymakers to accurately monitor AM's impact on MH.

6.4 Reliability, Generalisability, and Policy Recommendations

Ensuring the reliability and generalisability of findings remains a critical challenge in AM-MH research. This thesis demonstrated the value of combining large-scale surveillance data (Study 2) with innovative digital tools for real-time monitoring (Study 3).

The findings underscore the need for evidence-based policy recommendations. Urban planning should prioritize pedestrian and cycling infrastructure, while public health campaigns should emphasise the Mental health benefits of AM. Additionally, educational initiatives targeting specific demographic groups could address barriers to active commuting.

Acknowledging Current Limitations and Addressing Motivation Barriers

A key limitation across existing research — including parts of this thesis — is the limited exploration of individual motivations and perceived barriers to AM. Most large-scale datasets and quantitative studies fail to capture the "why" behind behavioural patterns,

focusing instead on frequency and mode of transport. This omission restricts the interpretability of findings, particularly when developing interventions or policies aimed at promoting active lifestyles. However, the digital framework developed in this thesis aims to address this gap by incorporating self-reported data on the purpose of each AM trip, as well as changes in participants' attitudes and habits over time. Through its use of pre- and post-questionnaires and in-app trip categorization, the framework offers a novel opportunity to better understand both motivators and obstacles to AM in real-world settings.

These findings do not imply that reduced AM causes depressive symptoms. It remains possible that individuals experiencing poor MH are less likely to engage in AM, or that other underlying factors contribute to both reduced mobility and higher symptom levels.

6.5 Research Implications

This section explores how this thesis's findings contribute to theoretical understanding and practical applications in Mental health, public health, and urban planning.

Theoretical Implications:

This research advances theoretical understanding of the relationship between AM and MH by addressing key conceptual and methodological inconsistencies that have previously limited progress in the field. By integrating validated psychological tools with objective physical activity measures, the digital framework presented in this thesis offers a standardized approach to studying AM-MH dynamics. Furthermore, the scoping review (Study 1) highlights the fragmented nature of existing evidence, emphasising the need for cross-disciplinary theoretical models that account for social, psychological, and environmental factors influencing AM and MH outcomes. This thesis also reinforces the importance of distinguishing between AM and leisure-time physical activity when assessing MH benefits, thereby refining existing theoretical constructs and contributing to more nuanced research frameworks. Beyond differentiating between AM and leisure-time physical activity, this thesis also points to the need for positioning AM within a 24-hour movement framework (Rosenberger et al., 2019; Tremblay et al., 2016). Emerging models

in physical activity research stress the interdependence of physical activity, sedentary behaviour, and sleep within a full-day cycle. Understanding AM's specific contribution to MH, both independently and in conjunction with other activity domains, represents a valuable direction for theory development and research refinement.

Practical Implications:

The findings of this thesis offer tangible applications for public health, policy, and urban planning. The insights derived from the PASSI study provide policymakers with population-level evidence to design interventions that promote AM as a MH strategy, especially in vulnerable demographic groups. Developing a digital framework represents a scalable and adaptable tool that can be implemented in real-world contexts, supporting public health professionals, clinicians, and researchers in collecting robust AM-MH data. Additionally, this work emphasises the need for cities to prioritize AM-friendly infrastructure, including pedestrian zones, cycling paths, and green spaces, to foster environments that promote physical and mental well-being. Notably, the interdisciplinary nature of this thesis highlights the value of collaboration across sectors—bridging urban planning, public health, and behavioural science—to create sustainable, evidence-based interventions that improve societal well-being on multiple levels.

6.6 Future Directions

While the thesis makes significant contributions, several areas require further exploration to unlock the full potential of AM for MH:

- **Longitudinal and Cohort Studies, and RCTs:** Future research should prioritise longitudinal designs, including prospective and retrospective cohort studies, alongside randomized controlled trials to establish causal relationships between active mobility and mental health outcomes. Such designs enable deeper understanding of long-term exposure patterns and their effects on MH, helping to distinguish between lifestyle-related trends and incidental associations.
- **24-Hour Activity Cycle Perspective**: Future research should investigate active mobility within the context of the full 24-hour activity cycle, considering how AM

interacts with other movement behaviours like structured exercise, sedentary time, and sleep (Chaput et al., 2014). Examining the independent and synergistic contributions of these domains may yield a more comprehensive understanding of how movement patterns influence MH outcomes.

- **Scalability Testing:** Expanding the framework's application across diverse geographical, cultural, and socioeconomic contexts will enhance its global relevance and generalizability.
- **Refinement of Analytical Pathways:** Repeated application of the framework will allow for identifying and refining structured analytical pathways tailored to specific research questions.
- **Participant Engagement and Feedback:** Continued emphasis on Public and Participant Involvement and Engagement (PPIE) will ensure ongoing improvements based on user insights and real-world applicability.
- **Integration into Broader Research Agendas:** The framework offers opportunities for cross-disciplinary collaborations exploring intersections between AM, MH, environmental health, and social policies.
- **Technological Enhancements:** Further digital tool refinement, including improved user interfaces and data-sharing capabilities, will maximize the framework's utility for diverse stakeholders.

6.7 Final Reflections

In conclusion, this research demonstrates that active mobility holds immense potential as a scalable and accessible intervention for improving mental health outcomes and it bridges critical gaps in AM-MH research by combining global evidence, population-level insights, and innovative digital tools.

By addressing methodological challenges, contextual factors, and technological opportunities, the research paves the way for more comprehensive, inclusive, and impactful studies in the future.

The findings advocate for a broader understanding of AM—not just as a mode of transportation but as a vital contributor to Mental health and societal well-being. As we move forward, integrating these insights into policy, research, and everyday life will be essential for building healthier and more sustainable communities.

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