Associations between Environmental Attributes and Children's Active Travel to School

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ABSTRACT

Active travel (e.g., walking, cycling, or other non-motorised modes to destinations) is a convenient and regular form of promoting physical activity and health, and supports environmental sustainability through reducing traffic congestion and emissions. Active school travel (AST) can substantially reduce motorised vehicle use and enhance physical activity for children on a daily basis. Despite these benefits, less than half of New Zealand (NZ) children aged 5-14 years actively travel to school. There is growing consensus that multiple factors (i.e., policy, physical/built and social/cultural environments, schools, households, individuals) influence children's AST. These factors are commonly conceptualised using a socio-ecological model. The Behavioural Model of School Transportation (BMST) is a comprehensive conceptual model for children's school travel behaviour which incorporates the socio-ecological model. Drawn from the BMST and existing literature, the current research developed a study-specific conceptual model, entitled the Children's School Travel Behaviour Model (C-STBM). Based on the C-STBM, this research aims to assess how children's AST is associated with multiple environmental attributes through a series of a systematic literature review (Chapter 2) and empirical studies (Chapters 4 and 5). A systematic meta-analysis review, conducted on a separate, but related study, was included as a supplementary material (Appendix A).

Chapter 2 systematically identified and examined existing evidence of subjectively measured physical environment attributes as well as social and sociodemographic characteristics associated with children's AST. In Chapters 4 and 5, data were drawn from Neighbourhoods for Active Kids (NfAK), a cross-sectional study of 1102 children aged 8-13 years (school years 5-8) and their parents from nine intermediate (middle/junior high) and 10 primary (elementary) schools in Auckland, NZ. An online participatory mapping (softGIS) survey with children, a computer-assisted telephone interviewing survey with parents, and geographic information systems (GIS) for physical environment attributes were utilised to collect and describe data. Chapter 4 examined differences in geographical space and objective physical environment attributes which were derived from child-drawn routes using softGIS and GIS-modelled shortest routes. Chapter 5 employed a structural equation modelling technique to test the C-STBM and assess direct and indirect relationships between children's AST and physical and social environments, and household and child factors.

Findings from Chapter 2 showed that children's AST was associated with multiple environmental attributes including distance to school, walkability, safety, social interactions, and sociodemographic characteristics which informed the theorised structural model of the C-STBM. In Chapter 4, child-drawn routes using softGIS were significantly different from GIS-modelled shortest routes, informing the decision to use child-drawn routes rather than estimated routes for modelling in Chapter 5. Chapter 5 proved that the C-STBM sufficiently explained the complex mechanism of children's AST. Distance to school and safety were key to children's AST. Strategies to facilitate school zoning, advocate for local schools, and create AST-supportive neighbourhood built and social environments are recommended to reduce distance to school and improve safety. A community-centred, multilevel (i.e., policy, built and social environments, school, household, child) approach is important for AST programmes and interventions to actively engage and empower communities to drive changes to their environments. Use of online participatory mapping was employed to collect children's views and use of their environments. This approach recognised and respected the importance of children's participation as active citizens in efforts to understand and promote AST. This research provided a theory-based, evidence-supported conceptual model for children's AST (i.e., C-STBM) which can be used for future AST programmes and interventions, and contribute to informing and measuring changes in children's AST.

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Attestation of Authorship

I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person (except where explicitly defined in the acknowledgements), nor material which to a substantial extent has been submitted for the award of any other degree or diploma of a university or other institution of higher learning.

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Co-Authored Works

The current thesis contains jointly authored published articles in peer-reviewed journals (Chapters 2, 4, 5) and conference presentations (Chapters 2-5). The authors for all articles are:

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Chapter 2: Systematic Literature Review

Peer-reviewed publication:

Ikeda E, Hinckson E, Witten K, Smith M. Associations of children's active school travel with perceptions of the physical environment and characteristics of the social environment: a systematic review. Health Place [Internet]. 2018 Nov [cited 2018 Sep 25];54:118-31. Available from: https://www.sciencedirect.com/science/article/pii/S1353829217309371 doi:10.1016/j.healthplace.2018.09.009

Conference presentation:

Ikeda E, Hinckson E, Witten K, Smith M. What perceived physical and social environments are associated with children's active school travel? A systematic review. Paper presented at: Critical Health Education Studies Conference; 2018 May 29-Jun 1; Queenstown, New Zealand.

EI acquired the literature and contributed in data extraction, quality assessment, analysis, and interpretation of data. MS conducted the 10% replication of data sourcing. EH conducted the 10% replication of quality assessment. KW resolved any disagreements in quality assessment.

- Erika Ikeda 80%
- Melody Smith 10%
- Erika Hinckson 5%
- Karen Witten 5%

Appendix A: Systematic Meta-analysis Review

Appendix A systematic meta-analysis review was included as a supplemental material (pp. 214-255). This work was conducted by EI in a research assistant role on a separate, but related, study led by MS. The total contribution of EI was less than 80%.

Peer-reviewed publication:

Ikeda E, Stewart T, Garrett N, Egli V, Mandic S, Hosking J, et al. Built environment associates of active school travel in New Zealand children and youth: a systematic meta-analysis using individual participant data. J Transp Health [Internet]. 2018 Jun [cited 2018 Jun 14];9:117-31. Available from: https://www.sciencedirect.com/science/article/pii/S2214140518300240?via%3Dihub doi:10.1016/j.jth.2018.04.007

Chapter 3: Research Philosophy, Theory, Methodology and Methods

Conference presentation:

Ikeda E, Oliver M, Witten K, Hinckson E. Development in measurement of children's perceptions on built environment and their school travel routes. In: 2016 ASICS Sports Medicine

Australia Conference, Australian Conference of Science and Medicine in Sport [Internet]; 2016 Oct 12-15; Melbourne, Australia. Albert Part (Australia): Sports Medicine Australia; 2017 [cited 2018 Nov 9]. [e121-2]. Available from: https://www.jsams.org/article/S1440-2440(17)30212-8/abstract

EI drafted the first complete abstract. MS, EH and KW critically revised and approved the final abstract.

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- Melody Smith 5%
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Chapter 4: School Travel Route Characteristics

Peer-reviewed publication:

Ikeda E, Mavoa S, Hinckson E, Witten K, Donnellan N, Smith M. Differences in child-drawn and GIS-modelled routes to school: impact on space and exposure to the built environment in Auckland, New Zealand. J Transp Geogr [Internet]. 2018 Jul [cited 2018 Jul 21];71:103-15. Available from: https://www.sciencedirect.com/science/article/pii/S0966692318302862 doi:10.1016/j.jtrangeo.2018.07.005

Ikeda E, Mavoa S, Hinckson E, Witten K, Donnellan N, Smith M. Corrigendum to "Differences in child-drawn and GIS-modelled routes to school: Impact on space and exposure to the built environment in Auckland, New Zealand" [Journal of Transport Geography 71 (2018) 103–115]. J Transp Geogr [Internet]. 2019 Jan [cited 2019 Mar 28];74:414-21. Available from: https://www.sciencedirect.com/science/article/pii/S0966692318307993 doi:10.1016/j.jtrangeo.2018.11.006

Conference presentation:

Ikeda E, Mavoa S, Hinckson E, Witten K, Donnellan N, Smith M. Child-drawn versus GIS-modelled routes to school: Impact on derived built environmental attributes. Paper presented at: New Zealand Geographical Society and the Institute of Australian Geographers Conference; 2018 Jul 11-14; Auckland, New Zealand.

EI contributed in data collection, analysis and interpretation of data. SM and ND conducted geographic information systems (GIS) data analysis. EH and KW participated in interpretation of data. MS involved in data analysis and interpretation of data.

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- Melody Smith 7%
- Suzanne Mavoa 5%
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- Karen Witten 3%
- Niamh Donnellan 2%

Chapter 5: Structural Equation Modelling

Peer-reviewed publication:

Ikeda E, Hinckson E, Witten K, Smith M. Assessment of direct and indirect associations between children active school travel and environmental, household and child factors using structural equation modelling. Int J Behav Nutr Phys Act [Internet]. 2019 [cited 2019 Mar 28] doi:10.1186/s12966-019-0794-5

Conference presentation:

Ikeda E, Hinckson E, Witten K, Smith M. Development of a theoretical framework of children's school travel behaviour. In: 7th International Society for Physical Activity and Health Congress [Internet]; 2018 Oct 15-17; London, England. Birmingham (AL): Human Kinetics, Inc.; 2018 [cited 2018 Nov 9]. [S103]. Available from: https://journals.humankinetics.com/toc/jpah/15/10+Suppl+1

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Ethics approval

Ethical approval to conduct the research was granted by the Auckland University of Technology Ethics Committee (AUTEC, 14/263, 3 September 2014) (Appendices B, pp. 256-257; C, pp. 258-260; D, pp. 261-262; E, pp. 263-264; F, p. 265; G, pp. 266-267).

Confidential material

According to publishers' guidelines, permissions for use of the articles (Chapters 2, 4, 5) in this thesis have been granted for non-commercial purposes. To avoid jeopardising the further intellectual property rights of the author by the open access to the thesis content, an embargo for the period of 36 months was applied to Chapters 2, 4 and 5.

ABBREVIATIONS

AST	Active school travel
AVE	Average variance extracted
BMI	Body mass index
BMST	Behavioural Model of School Transportation
CATI	Computer-assisted telephone interview
CFA	Confirmatory factor analysis
CFI	Comparative fit index
CR	Construct reliability
C-STBM	Children’s School Travel Behaviour Model
ECAC	Ecological and Cognitive Active Commuting
EECA	Energy Efficiency and Conservation Authority
EFA	Exploratory factor analysis
EPHPP	Effective Public Health Practice Project
GIS	Geographic information systems
GPS	Global positioning systems
ICC	Interclass correlation coefficient
M-CAT	Model of Children’s Active Travel
MVPA	Moderate-to-vigorous intensity physical activity
NDAI-C	Child-specific neighbourhood destination accessibility
NEWS	Neighbourhood Environment Walkability Scale
NfAK	Neighbourhoods for Active Kids
NZ	New Zealand
OR	Odds ratio

PN	Pedestrian network including footpaths
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
RMSEA	Root mean square error of approximation
SEM	Structural equation modelling
SN	Street network excluding motorways
SNm	Street network including motorways
SRMR	Standardised root mean residual
TLI	Tucker-Lewis index
WHO	World Health Organization
WLSMV	Weighted least squares means and variance adjusted

Chapter 1 Introduction

This chapter outlines the overarching research rationale, questions, and objectives; as well as the overall structure of the thesis. The context of the current research is provided with a focus on policy and practice in relation to children's active school travel (AST).

1.1 Background

Physical activity is defined as any bodily movement produced by skeletal muscles and that requires energy expenditure. The New Zealand physical activity guidelines for children and young people, aged 5-17 years, suggest an accumulation of at least 60 minutes of moderate-to-vigorous intensity physical activity (MVPA) each day (1). Benefits of physical activity are wide ranging and include supporting physical, mental, and social health and wellbeing (2-5). A major focus in the field of physical activity and health research is the role of physical activity in reducing rates of overweight and obesity in childhood (6, 7). Childhood obesity (often defined as body mass index (BMI) percentile ≥ 98^{th}) is associated with risk factors for non-communicable diseases such as diabetes and cardiovascular diseases (e.g., dyslipidaemia, blood pressure) and has a negative impact on mental health, quality of life, and wellbeing (6, 8, 9). Childhood obesity and overweight can track into adulthood (10). Therefore, prevention of childhood obesity has been prioritised in public health promotion efforts worldwide and in New Zealand (NZ) (11).

International comparisons suggest NZ exhibits one of the highest rates of childhood overweight and obesity worldwide (12, 13). Latest health statistics showed one in eight NZ children, aged 2-14 years, were classified as obese (14). Obesity rates were inequitably distributed, with the highest rates reported in Pacific (29%) and Māori (18%) children (14). Children who lived in the most deprived areas were two and half times as likely to be obese as those who lived in the least deprived areas (14). Despite an extremely high rate of childhood overweight and obesity, and the known benefits of physical activity, the 2018 NZ Physical Activity Report Card for Children and Adolescents showed only 20-26% of children and adolescents aged 5-17 years were sufficiently active for health (15). Thus, improvement in participation of children in activity behaviours can play an important role in obesity prevention and health promotion across the lifespan.

Active travel (e.g., walking, cycling, or other non-motorised modes to destinations) is a convenient and habitual means for children to accumulate physical activity. Growing evidence suggests that changes in policies and environments to support mode shifts from motorised vehicles to active travel can encourage health and physical activity behaviours (4, 16). Active travel can also diminish traffic congestion and emissions which contribute to environmental sustainability (17). In 2016 economic and social costs of traffic congestion in Auckland, NZ (the country's largest city) were estimated at approximately NZ$1.9 billion (18). Since 1990, gross greenhouse emissions in NZ have increased by 20% of which carbon dioxide emissions from motorised transportation modes was a key contributor (19).

Given children travel to and from school approximately 200 days per year (20), school travel is one area where substantial reduction in use of motorised vehicles and enhancement of physical activity could be achieved. Systematic reviews have shown children and young people who actively travel to school are more likely to meet recommended levels of physical activity than passive travellers (e.g., those using car, public transport) (21-23). However, recent nationally representative surveys demonstrated that less than half of NZ children aged 5-14 years actively travelled to school (15). There is a need for research identifying factors that influence children's AST, and understanding interrelationships between these factors to inform policy-making process and cost-effective intervention strategies for increasing this behaviour.

Empirical research to date shows that factors across multiple levels (i.e., policy, physical/built and social/cultural environments, schools, households, individuals) influence children's AST (24-27). These dynamic interrelationships are commonly conceptualised using a socio-ecological model, which bridges the gap between individual focused theories (e.g., social cognitive theory, theory of planned behaviour) and informs how behavioural changes can be facilitated through recognising the broader context in which individuals act (28).

National and regional policies on transport and land use are inextricably linked with the built environment and subsequently influence children's AST (29). In NZ, urban planning policies are prone to concentrate on efficient economic production in which the efficient movement of people and goods by motorised vehicles is prioritised over other modes (30). There is a need for policies and plans that strive for environmentally sustainable transport and mobility by improving walking and cycling infrastructure and public transit, as well as providing widespread traffic calming for pedestrian and cyclist safety (4, 31). School policies and practices such as school enrolment zones, school bus services, road safety education, and AST programmes may encourage or discourage children's AST (32).

The physical environment refers to a combination of natural (e.g., weather, topography) and built environments (33, 34). The built environment is defined as the human-made surroundings within which people live and includes buildings, streets, and transport systems (34, 35). Urban design has a goal of creating urban areas that meet the everyday functional needs of citizens. It is concerned with the location, pattern, attractiveness, and sustainability of buildings, streets, and public spaces. In relation to active travel, urban design has been subjectively and objectively measured using indices of accessibility (i.e., the ability to travel to places in which opportunities are located) and walkability (i.e., the ability to access places on foot and thus the potential of a space to be "walkable") (36). The measurement can vary depending on disciplines (e.g., public health, traffic engineering) and the purpose of active travel (e.g., transportation, recreation) (25, 36-38). In the field of public health, walkability for school travel behaviour has predominantly been measured using residential density, street connectivity, and land use mix (25, 27). In this context, a more walkable neighbourhood indicates the area with higher population density, more connected streets, and higher mixture of land use. More recently, a child-specific walkability index has been developed using pedestrian network to measure street connectivity (i.e. Pedshed) and road hierarchy as a proxy for traffic volume to measure traffic exposure (39).

It is promising that urban design for environmentally sustainable and child-friendly cities can provide improvements in children's AST and other activity behaviours for larger population groups (16, 30). Furthermore, several systematic reviews on policy interventions and environmental changes for AST indicated that these interventions and changes were likely to produce promising improvements in AST (28, 40, 41).

Coupled with legalistic (i.e., policy) and mechanistic (i.e., physical environment) approaches, a fundamental adaptation in social and cultural norms, as well as individual values and beliefs, is required to achieve long-term behavioural changes. Although evidence is limited, extant research suggests that social interactions in the neighbourhood are positively associated with sense of community and safety perceptions, which may encourage children's AST (42-44). A car-dependent society and modern industrial culture may cultivate individualism and diminish a sense of belonging which can impede community connections and decrease neighbourhood surveillance (30, 45). A "social trap" can also occur when parents drive their children to/from school because of traffic and stranger danger in which the parents themselves can contribute to these hazards (30). Conversely, "safety in numbers" where children actively travel to/from school in larger groups can alleviate parental safety concerns (30, 45). Walking school buses are one example of successful AST programmes, with research demonstrating children enjoyed socialising with friends and felt safer during their travel to school (46). However, challenges exist in such programmes, which require sufficient coordination, parent volunteers, and school and community involvement (47, 48). Given shortfalls in research on the social environment, there is a need to comprehensively identify social factors associated with children's AST.

Parents play a vital role in decision-making on children's school travel behaviour. Parental decision-making is likely to be influenced by a combination of factors such as household activity-patterns, travel schedules, and socio-demographic characteristics, as well as fears of traffic and safety and confidence about children's physical and cognitive abilities (32, 49). The degree of children's self-efficacy (i.e., one's belief in one's ability to exercise control over one's own functioning and over environmental events (50)) can influence their school travel behaviour and independent mobility (i.e., children's freedom to move around their neighbourhood and travel to school without adult supervision) (32, 51). Children's experiences as school travellers allow them to perceive and understand their environments between home and school sensibly and uniquely (52, 53), and in turn their perceptions of AST differ from parents (54). Hence, understanding children's own viewpoints on what facilitates and hinders their AST is critical (46).

In summary, AST is an important activity to promote for improving children's physical activity, and ultimately their health; yet, AST levels in NZ children are low. A growing body of evidence shows multifaceted factors are associated with children's AST. These pieces of evidence, from different constructs (e.g., policy, physical, social and school environments, the household, the child), can be linked with each other to determine what is truly associated with children's AST, how this behaviour can be promoted, and how barriers to this behaviour might be reduced. Furthermore, the development of a child-centred approach is required to capture and include children's perspectives on school travel behaviour.

Therefore, it is crucial to explicitly and specifically identify factors that influence children's AST (e.g., policy, physical, social and school environments, the household, the child), and determine interrelationships between these factors in the NZ context. Furthermore, regular examination and development of existing conceptual models of children's school travel behaviour is required to comprehend the complex mechanism of children's AST and evaluate existing interventions and advance more effective and sustainable interventions.

1.2 Research question and objectives

The overarching research question of this thesis is:

"How is children's active school travel associated with multiple environmental attributes?"

This research aims to assess how children's AST is associated with multiple environmental attributes and develop a conceptual model of children's school travel behaviour.

To achieve these aims, the research objectives are to:

1. Systematically identify associations between school travel mode in children aged 5-13 years and perceived physical environment attributes and social and sociodemographic characteristics from the extant international studies (Chapter 2)
2. Establish a children's school travel routes measure by comparing spatial overlaps and built environment attributes derived from child-drawn routes using online participatory mapping (i.e., softGIS) with those derived from GIS-modelled shortest routes (Chapter 4)
3. Develop and test a conceptual model, Children's School Travel Behaviour Model (C-STBM) (Chapter 5)
4. Assess direct and indirect relationships between children's AST and the physical environment, the social environment, and household and child factors using structural equation modelling (SEM) (Chapter 5)

Objectives were achieved through a systematic review and the analysis of data on children's school travel behaviour gathered via the Neighbourhoods for Active Kids (NfAK) study using a child-centred online participatory mapping (softGIS) survey.

The next section outlines the structure and links between each chapter in the thesis.

1.3 Thesis structure

This thesis comprises a combination of discrete published journal articles (Chapters 2, 4, 5) and comprehensive chapters (Chapters 3, 6), as illustrated in Figure 1 (p. 8). A series of published journal articles are presented as stand-alone chapters in which inevitable repetition of some information occurs across the chapters (e.g., methods).

Chapter 2 reviewed existing literature and identified current research gaps focusing on children's AST and its associations with perceived physical environment attributes and social and sociodemographic characteristics. Chapter 2 critically appraised and synthesised existing evidence from international studies which were heterogeneous in terms of the geographic context. Areas of common ground regarding children's AST and its associations with perceived physical environment attributes and social environment (social and sociodemographic) characteristics were identified. Findings from Chapter 2 informed the development of a conceptual model and the formulation of direct and indirect relationships between variables in Chapter 5.

Despite a growing body of research on children's AST, methodological limitations are still evident regarding how to measure children's school travel routes and their potential exposure to the environment (see 1.3.1 The role of Appendix A and its contribution to the thesis). There was also a dearth of studies taking a holistic approach to understand the complexity of associations between children's AST and the environmental attributes. To address these research gaps and answer the proposed research question, two distinct but allied studies were designed and conducted (Chapters 4 and 5).

Chapter 4 adopted two measurement approaches to inform methodological decision-making around measurement of children's school travel routes: (i) comparison of spatial overlaps between buffers around child-drawn routes to school using online participatory mapping against GIS-modelled shortest routes, and (ii) assessment of differences in physical environment attributes derived from child-drawn routes using online participatory mapping with those derived from GIS-modelled shortest routes.

To understand the multifaceted and interactive influence of environmental attributes on children's active school travel that were identified in the systematic review and extant literature (including Appendix A), Chapter 5 developed and evaluated a conceptual model (i.e., C-STBM, Figure 14, p. 67) specifically focusing on direct and indirect relationships between children's school travel mode and the built and social environments, and the characteristics and beliefs of the household and the child.

Chapter 3 summarises all components of the methods employed in the current research with reference to research philosophy, theory, and methodology. Chapter 6 provides a recap of key findings in each study, and discusses research strengths, limitations, and implications which may direct future research and advocate potential interventions to promote children's AST.

The structure of the thesis is informed by the behavioural epidemiology framework developed by Sallis et al. (55) in which a fundamental sequence of studies leads to evidence-based, health-related behaviour interventions in populations. The current research employed this framework to investigate the health-related behaviour defined as AST. The framework consists of five phases:

- Phase 1: Establish links between behaviour and health. This has been achieved by documenting associations between AST and health with the anchor of physical activity. Chapters 1 (1.1 Background) and 2, as well as Appendix A, provide evidence and a rationale for the current research.
- Phase 2: Develop methods for measuring AST by comparing a new measure with extant measures. Chapter 4 established the utility of an online participatory mapping (i.e., softGIS) to measure children's school travel routes by comparing child-drawn routes using softGIS with the most commonly used GIS-modelled shortest routes.
- Phase 3: Identify factors that influence AST by testing and developing a conceptual model for children's AST. Chapter 5 assessed direct and indirect associations between children's AST and environmental attributes (i.e., built and social environments, household, and child characteristics and beliefs) based on a behavioural model of school transportation (32) using SEM.
- Phase 4: Evaluate interventions to change AST. Although the evaluation of existing policies and interventions for children's AST was not explicitly and systematically investigated in the current research, Chapter 1 (1.4.1 Policy and practice) highlights possible impacts from the existing policies and interventions in the Auckland, NZ context.
- Phase 5: Translate research into practice. Chapter 6 takes findings from Phases 1-4 into account to discuss the extent to which the policies and/or interventions for children's AST should be maintained and improved in the future.

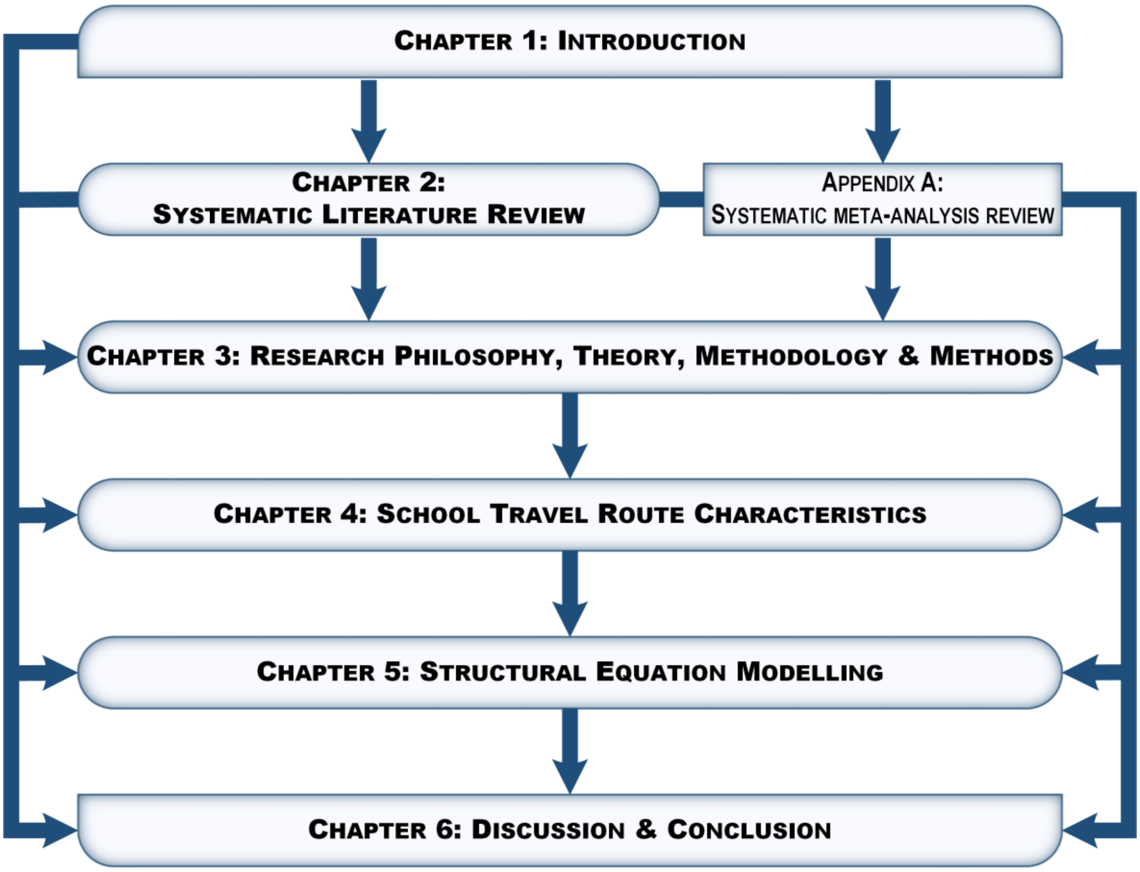


Figure 1. The structure and flow of this thesis.

1.3.1 The role of Appendix A and its contribution to the thesis

Alongside Chapter 2, a systematic meta-analysis review was separately conducted to identify and examine context-specific associations between AST in NZ children and youth aged 5-19 years and objectively measured built environment attributes drawing from recent national studies. Despite its relevance to the current thesis, this work was performed by EI as a research assistant rather than a doctoral candidate. Under this circumstance, this review was treated as supplementary material and included as Appendix A rather than an independent chapter.

Compared to Chapter 2, Appendix A focused on context-specific evidence from NZ studies to identify what objectively measured built environment attributes and sociodemographic characteristics were associated with children's AST. Appendix A shifted the scope from wider global research to a narrower national level to obtain geographically relevant evidence (especially regarding variables measured using GIS). This systematic review highlighted a need for methods which sustain the specificity and sensitivity of actual school travel routes for large population groups such as online participatory mapping compared to GIS-modelled shortest routes. As illustrated in Figure 1, findings from Appendix A considerably contributed to developing the design of Chapters 4 and 5, and the overall discussion in Chapter 6.

1.3.2 The originality of thesis

This thesis provided original and significant contributions to the knowledge base in the field of children's AST. These contributions involved:

- A child-centred approach of online participatory mapping (i.e., softGIS) survey for use in children aged 8-13 years to measure their school travel behaviour (Chapter 3).
- A practical application of internet-based child-drawn routes using softGIS and an evidence-supported route buffer generation method to increase the sensitivity and specificity of objective built environment measures using GIS (Chapter 4).
- Identification of geographical and environmental differences between child-drawn school travel routes and estimated shortest school travel routes using GIS (Chapter 4).
- A rigorous method (i.e., SEM) of analysing the dynamic interrelationships between children's AST and multiple environmental (i.e., physical, social, household, child) factors (Chapter 5).
- Development of a new model (i.e., C-STBM) for use in children's school travel behaviour in the Auckland, NZ context (Chapter 5).

Furthermore, the systematic review (Chapter 2) provided comprehensive and harmonised evidence of factors related to children's AST which built on existing knowledge.

Research outcomes may contribute to creating NZ's active societies, environments, people, and systems which have been proposed as the main four objectives of the World Health Organization (WHO)'s global action plan on physical activity (11). The child-centred approach demonstrates the importance of increasing opportunities for empowering and engaging children and giving voice to children. The softGIS methodology may be an effective and sensible approach to gather children's real-life voice about their active travel and more widely of their activity space in the neighbourhood. This research may advance children's active participation in the development of policies, interventions, programmes, and research in AST. Research findings from the SEM may contribute to decision making processes of policies and interventions tailored to the context of

Auckland, NZ. Evidence-based practices of C-STBM, child-drawn school travel routes and SEM may benefit future research direction around children's AST.

1.3.3 Thesis delimitations

This thesis established some delimitations to narrow the scope of the current research. This research was cross-sectional and conducted in Auckland, NZ. Children in school years 5-8 years (approximate ages 9-12 years) were the population of interest to capture transitions in their school travel behaviour between primary (years 5-6; elementary) and intermediate (years 7-8; middle/junior high) schools. The research also focused on travel modes and routes 'to' school because those 'from' school are more likely to have daily variations due to after-school activities and trip-chaining.

In the following section, the current status and structure of policies and practices on children's AST in Auckland, NZ are described to contextualise the current research.

1.4 Research context

The current research is embedded in the context of Auckland, NZ. NZ is characterised as a highly suburbanised nation with a total population of 4.9 million in 2018 of which 13% were children aged 5-14 years (56). In November 2010, Auckland's regional and seven local councils were merged into a single 'super city'. Auckland, located in the North Island, is NZ's largest city comprising 33.4% of the total population in 2013 (57). Over the last decade urban development and house price inflation in the Auckland region has encouraged urban sprawl and car dependency. Economic and social costs of traffic congestion in Auckland was estimated at approximately NZ$1.9 billion in 2016 (18). To combat this situation, national government agencies (i.e., Ministry of Transport, Ministry of Education, NZ Transport Agency) and local agencies (i.e., Auckland Council, Auckland Transport) have collaboratively developed strategies for improving sustainable transport and active travel. Challenges exist however – in 2018 Auckland Transport signed off a new 10-year land transport plan focusing on road safety, congestion reduction, and public transport access in which only half the proposed active travel projects were approved, and the majority of funding was allocated to road improvement such as making roads wider, longer, or better (58, 59).

1.4.1 Policy and practice

Policy (e.g., rule, law, guideline, procedure) and practice (e.g., programmes, interventions) about children's AST are often informed and implemented by national and regional governments, local councils, school communities, as well as their stakeholders and partners (60). In NZ, several government agencies and organisations (public and private sector) have been involved to promote children's AST (Figure 2).

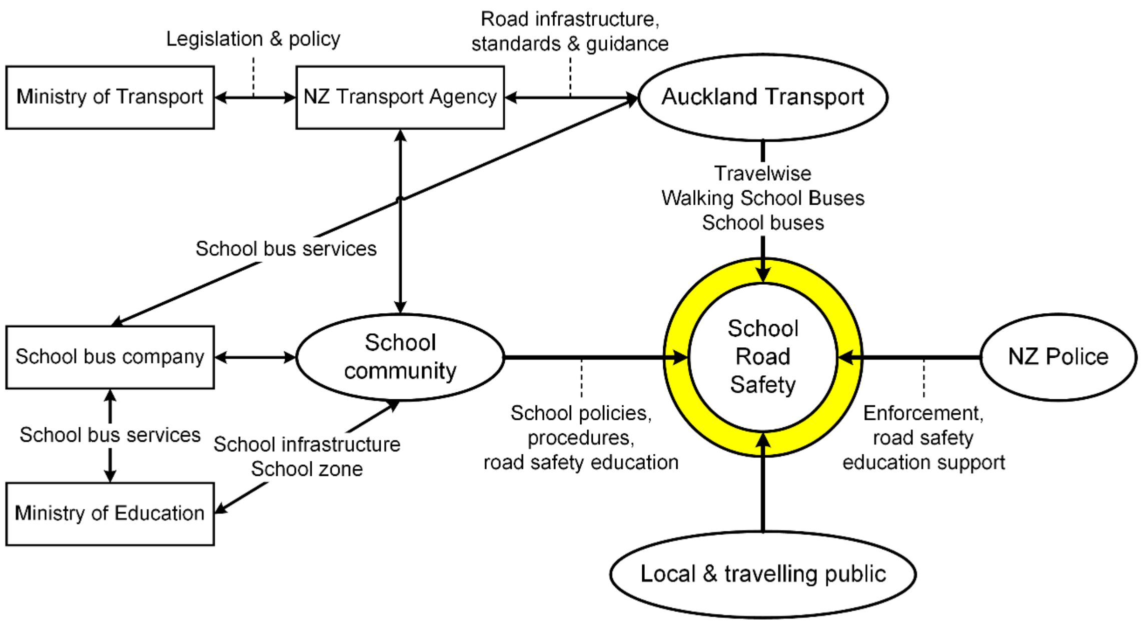


Figure 2. Structure of government agencies and organisations for school road safety in NZ. Adapted from NZ Transport Agency, Auckland Transport, Safer Journeys. Safer journeys for schools: Guidelines for school communities. Wellington, New Zealand: 2014.

At the national level, the Safer Journeys Strategy 2010-2020 and Action Plans (2011-2012, 2013-2015, 2016-2020) were released to guide improvements in road safety from 2010-2020 by the National Road Safety Committee (NRSC) (61). The NRSC is a group of government agencies including the Ministry of Transport, NZ Transport Agency, NZ Police and Accident Compensation Corporation (ACC), and other government partners (61). The vision of this strategy is "a safe road system increasingly free of death and serious injury", and the Safe System focuses on creating safe roads and roadsides, safe speeds, safe vehicles, and safe road use (62). Actions through the Safe System encompass increasing coverage of temporary lower speed limits around schools, cycle skills training in schools, and effective road user education for safe walking and cycling (62).

As part of the Safe System, the NZ Transport Agency released guidelines for school road safety and provided technical guidance for road controlling authorities (i.e., NZ Transport Agency, Auckland Transport) and consultant engineers to enhance road safety in local communities (63). In NZ, the state highway network has been managed by the NZ Transport Agency, and local agencies (e.g., Auckland Transport) are responsible for managing local roads. Commonly recognised road safety risks include but are not limited to (62):

- Unsafe crossing facilities and intersections;
- Poorly designed drop-off/pick-up or parking zones and lack of cycle ways and footpaths;
- Lack of explicit school policy and procedures, and unsafe and illegal parking near the school; and
- Unsafe pedestrian activity to and from school buses, and unsafe bus stopping locations.

Furthermore, this guideline provides some of the techniques that schools can apply to eliminate the risks listed above (62). Examples regarding school policy and procedures include clear and regularly enforced expectations about parking behaviour (with NZ Police involvement), a policy of parents and teachers modelling safe behaviour, and regularly checking compliance with policies and procedures and reviewing them as needed (62).

The NZ Ministry of Education provides guidelines for the development and operation of school enrolment zones (64, 65), and school bus services (66). In Auckland, school buses and scheduled public transport which travel near schools have been operated by Auckland Transport (67).

The Energy Efficiency and Conservation Authority (EECA) initiated walk to school programmes in 2001, and actively supported and were involved in walking school buses (68). In July 2006, the NZ Transport Agency took over national coordination of travel behavioural change programmes including school travel plans (68). The NZ Transport Agency has updated resources for schools to develop safe school travel plans (i.e., an action plan for road safety and active transport) nationwide (69).

At the regional and local level in Auckland, safe school travel plans have been operated by Auckland Transport, the agency responsible for all of the regional and local transport services from roads and footpaths, to cycling, parking, and public transport. These plans have been developed in collaboration with the school community, Auckland Council, NZ Police, NZ Transport Agency, and other organisations (70). Safe school travel plans in Auckland fall under the 'Travelwise' programmes, a behavioural change programme managed by the Auckland Transport (71). A total of 408 primary (elementary), intermediate (middle/junior high), secondary and special needs schools (76.2% of schools in Auckland) had become Travelwise Schools at the end of 2015 (72). The programme adopted a whole school approach supported by three pillars (71):

- Curriculum (e.g., providing student-centred, curriculum based road safety, and active transport education programmes)
- Ethos and organisation (e.g., reviewing policies, guidelines, and school traffic environment)
- Parents and community (e.g., providing parents with information and engaging school community and stakeholders)

Along with the Travelwise programme, walking school buses and the Bike Safe programme have been run by Auckland Transport. There were 341 active walking school buses across 148 schools in the Auckland region between 2014 and 2015 (72). The Bike Safe programme is cycle control skills training delivered to Years 5 and 6 students (approximate ages 9-11 years) within the school playground focusing on bike handling, confidence, and safety using the NZ Transport Agency Cyclist Skills Training Guidelines (72, 73). In partnership with NZ Police School Community Officers or Regional Sports Trusts, a total of 113 schools (31% of all primary schools in NZ) received the programme from 2014 to 2015 (72). Auckland Transport has undertaken various evaluations to review and develop the programme. In 2015-2018, their focus shifted from expanding the number of schools on the programmes to developing a comprehensive approach to working with wider school communities with greatest need to reduce road safety risk.

With partnership between government agencies and organisations, several policy and practices about children's AST have been conducted in Auckland and nationwide. Yet, the prevalence of children's AST in NZ is low, and there is a need for research thoroughly identifying what factors influence children's AST and how these factors are interrelated in the NZ context. The heterogeneity in methodology and interventions have hindered providing conclusive evidence for the most effective intervention strategy, and theory utilisation and specificity for children's AST interventions is limited (28, 40, 41). Environments and socio-cultural factors differ substantially across countries and context-specific information is needed to develop efficacious interventions.

In order to address these research gaps and contribute new knowledge to children's AST, the current research aims to assess the associations between children's AST and environmental attributes in the Auckland, NZ context.

Chapter 2 Systematic Literature Review

Chapter 2 reviewed a growing body of evidence from international studies to critically assess areas of common ground addressing evidence on associations between children's AST and social and perceived physical environments. Coupled with Appendix A (a systematic meta-analysis review on associations between AST and objectively measured built environment attributes in NZ children and youth), this systematic review provides comprehensive and harmonised evidence of factors related to children's AST which built on existing knowledge, and identifies existing research gaps which offer a rationale for the following study chapters (Chapters 4 and 5). The assessment of measurement including a child-centred method (e.g., a child versus parent self-reports) is beyond the scope of this chapter. However, descriptive results (i.e., number of studies) were summarised in 2.3.2 Study characteristics.

2.1 Background

A global epidemic of physical inactivity has contributed to increased prevalence of non-communicable diseases and a worsening of health and associated economic burden (74). Sufficient physical activity can boost physical, psychological, social, and cognitive health and wellbeing in children and youth (4, 75, 76). Physical activity can be accumulated in various ways such as sports, play, active travel, and at different settings (e.g., schools, home, and the neighbourhood built environment (4, 77)). AST can be a key form of habitual physical activity in children and youth (22, 78). Previous systematic reviews proved positive associations of AST with overall physical activity and cardiorespiratory fitness in children and youth (21, 23, 79). However, despite the clear benefits of physical activity and AST, recent evidence across 38 countries from six continents showed that only 20-39% of children and youth were adequately physically active for health (77). Overall, about half of the population successfully engaged in sports, play, and active travel, and lived in supportive school, community, and built environments (77). AST is also low and declining in developed countries (80-84).

Socio-ecological models have been advocated to better understand the multifaceted influences on physical activity and AST (33, 85-87). These models encompass attributes of the individual, and social/cultural, physical (i.e., natural and built), and policy environments (33, 85, 86). Physical and social environments can substantially and broadly impact on children's school travel behaviour directly and indirectly (24, 32, 88). It is evident that perceptions of the physical environment may have at least an equal association with children's school travel behaviour compared to objective measures of physical environments (25, 87, 89, 90). Previous systematic reviews have investigated correlates of AST with perceived physical environment barriers (87), or a combination of objective and perceived physical environments (24-26, 91). Apart from the considerable influence of distance to school (24, 26, 87), AST has also been positively associated with walkability, safety, traffic calming, walking and cycling infrastructure, and recreational facilities (24, 25, 87, 91). Sociodemographic correlates include parental education, household income and car ownership, and ethnicity were also demonstrated (24, 26).

Gaps remain in this evidence base. Social interactions in the neighbourhood may enhance perceptions of safety and sense of community, thus potentially facilitating children's active travel (42, 43). However, aspects of the neighbourhood social environment (e.g., social relationships, social support) have not been thoroughly explored in previous systematic reviews (24). Furthermore, quality assessment of the existing evidence to ensure the rigour of systematic reviews is warranted (92, 93). Although a variety of quality assessment tools have been utilised to appraise risk of bias or the methodological strength of relevant studies (24, 41, 79, 87, 94), quality assessment has been insufficiently reported in many published systematic reviews.

Variance in conceptualisation and measurement of variables across different studies adds complexity in aggregating findings for systematic reviews (26, 87). In this context, meta-analyses are not possible, and alternative robust methods for data synthesis are required (26). Reviews are further hampered when individual studies do not allow for disentangling physical and social environments (e.g., 'neighbourhood safety' can encompass safety from traffic and stranger danger). There is also a need for systematic reviews that have comprehensively examined and summarised the strength and direction of relationships with school travel behaviour. To date, only one systematic review has undertaken this process, with findings indicating individual (e.g., child age and ethnicity, parental education), and social (e.g., household income, car ownership) factors had moderately positive associations with AST (26).

Therefore, the aims of this systematic review are: (i) to summarise associations of school travel mode in children aged 5-13 years with perceived physical environment attributes and social and sociodemographic characteristics; and (ii) to assess the robustness of the evidence and synthesis in relation to quality of the studies included, and the consistency of these results. This review adds to and builds on existing systematic reviews by summarising and evaluating the evidence for social factors, conducting quality appraisal, reassessing and reassigning individual variables to well-defined categories, and identifying the strength and direction of associations.

2.2 Methods

The review presents the highest level of evidence possible by utilising Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) protocols as a reporting guideline of methodology (95), and the implementation of rigorous study quality assessment (96). The systematic review protocol was published following the PROSPERO criteria (97).

2.2.1 Eligibility criteria

Studies were selected according to the eligibility criteria of study designs, participants, and outcome measures. Inclusion criteria were:

- Descriptive and observational studies (i.e., cohort and prospective studies, case-control studies, case series, cross-sectional studies, longitudinal studies).
- Children aged 5-13 years at the commencement of the study and/or their parents/caregivers. Studies with mixed child age groups were included if over 50% of the participants were so defined and findings for the age group included in the review were reported separately.
- Objectively or subjectively measured modes of travel to/from school reported as a dependent variable.
- Subjectively measured (i.e., survey, scale) physical environment attributes AND objectively or subjectively measured social environment variables reported as independent variables.
- Associations of school travel mode with perceived physical environments AND social environments reported.

Exclusion criteria were:

- Experimental studies (e.g., natural and quasi experiments) and interventions (due to a variety of environmental and/or behavioural changes involved (98-100), and the complexity of determining the true effect of each intervention); qualitative studies (due to the different quality assessment criteria required (93, 101, 102)); and other study designs (i.e., systematic reviews, expert opinions, and conference proceedings).

- Other age groups that could not be separated; and children with medical conditions or physical or intellectual disabilities that could restrict AST.
- No objectively or subjectively measured modes of travel to/from school reported.
- Subjectively measured physical environment attributes OR/NOR objectively or subjectively measured social environment variables reported.
- Only objectively measured (e.g., GIS) physical environment attributes reported.
- No associations of school travel mode with perceived physical environments AND/OR social environments reported.

All composite and individual outcomes as reported in the included studies were considered. Outcomes measured at the individual (e.g., child, parent, household) and group (i.e., school, neighbourhood) levels were included. In this review, the physical environment was defined as natural (non-man-made physical features) and built (man-made physical attributes) environments in which children live and spend their time (e.g., neighbourhood, school, home) (24, 60, 103). Built environment referred to urban design, transportation systems, and recreation settings (34, 35, 104). The term 'social environment' was used to encompass social (e.g., social cohesion, social interaction, social support) and sociodemographic (e.g., socioeconomic status, ethnicity) characteristics. Test statistics and significance for associations between dependent and independent variables were included.

This systematic review was limited to peer-reviewed articles, available in full-text, written in English, and published from January 2000 to July 2017. This time period was chosen as most of the relevant literature was published during the last decade. Moreover, it is essential to study only the most recent literature as environments are constantly changing.

2.2.2 Information sources and search terms

Between October 2016 and July 2017, the first review author (EI) conducted literature searches in Scopus, Web of Science, MEDLINE (EBSCO, Ovid and PubMed Interfaces), CINAHL (EBSCO

Interface), SportDiscus (EBSCO Interface), PsycINFO (Ovid Interface), ERIC (Education Resources Information Center, Ovid and ProQuest Interfaces), TRID (Transportation Research International Documentation), and Cochrane Library. The information sources and search strategy were elaborated in consultation with a subject-specific research librarian.

Search terms were identified from previous related reviews (25, 105, 106) and the knowledge and expertise of the authors using four categories (Table 1): (i) population, (ii) travel mode, (iii) physical environment, and (iv) social environment. An example of a full electronic search strategy is available in figshare (97).

Table 1 Search terms

Population	child* OR (boy or girl) OR (pupil or student) AND school
Travel mode	((travel* or transport* or commut*) AND school) OR (walk or (bike or biking) OR (cycle or cycling) OR (bicycle or bicycling) OR scooter OR (skate or skating or skateboard) OR (car or automobile or motor or drive or driving or chauffeur) AND school
Physical environment	"physical environment*" OR "built environment*" OR "neighbo*rhood environment*" OR (urban and neighbo*rhood) OR "residential density" OR "dwelling density" OR "population density" OR connectivity OR "land use" OR pedestrian OR (bicyclist or cyclist) OR (street or path or road or track or trail or pavement) OR route OR (facility or facilities or equipment or infrastructure) OR safe* OR crime OR traffic OR (aesthetic or esthetic) OR (park or "open space" or playground)
Social environment	social OR culture OR cultural

2.2.3 Study selection

A Cochrane data collection form tailored to the requirements of this review (e.g., excluding intervention components) was used to extract and manage data (97). An initial screening of titles and abstracts was undertaken by the first review author (EI), and 10% of the randomly selected titles and abstracts were screened by a co-author (MS) (107, 108). Full texts were obtained for all titles and abstracts that appeared to meet the inclusion criteria. Review authors (EI and MS) then independently screened the full text reports and assessed their eligibility for inclusion. Discrepancies between the review authors were resolved through discussion. The reasons for excluding studies were recorded. Neither of the review authors was blinded to the journal titles or to the study authors or institutions.

2.2.4 Data collection process

Using the modified Cochrane data collection form, data for all the eligible studies were extracted by the first review author (EI), and then checked by a research assistant to reduce bias and errors in data extraction. Data extracted included sociodemographic information, methodology, and all reported important outcomes related to school travel mode, perceived physical environments, and social environments.

To make all variables comparable across studies included, the first author (EI) categorised each item and construct into four domains (i.e., perceived physical environment, social characteristics, sociodemographic characteristics, or others) within which three to four subdomains were identified (i.e., child, parent/household, school, or neighbourhood) (Table 2, pp. 21-28; Appendix H, pp. 268-301). Consequently, some of the items and constructs were categorised into a different domain from the original study (e.g., an item was characterised as the social environment in this review but was perceived as physical environment in the original study). The domain of 'others' included demographics (e.g., age, gender), objective physical environments (e.g., GIS), independent mobility, and psychological characteristics (e.g., attitudes, skills/abilities/confidence, preference/enjoyment). This strategy was adopted to improve the consistency of results and provided more precise insights into the findings.

All reported (i.e., statistically significant and non-significant) results of associations (i.e., odds ratios (OR) and regression coefficients (β)) of children's school travel mode (i.e., dependent variable) with perceived physical environment, and social and sociodemographic characteristics (i.e., independent variables) were included. Statistical methods, confounders, and clustering (schools and neighbourhoods) were identified and summarised with quality assessment.

Table 2 Characteristics of included studies

Author (Year)	**Study location**	**Study design [Project]**	**Participants**	**Self-reported school travel***		**Perceived physical environment**			**Social environment**						
									Social characteristics			**Sociodemographic characteristics**			
	City/State; Country		*N; Gender; Age/Grade*	*Child*	*Parent*	*Child*	*Parent*	*School*	*Child*	*Parent*	*School*	*Child*	*Parent*	*School*	*Neighbourhood*
Aarts et al. (2013) (109)	N/R; The Netherlands	CS	5963; 3001 boys, 2950 girls; 7.8 ± 2.4 years old	-	Travel mode: walking, bicycling, inactive	-		✓	-	✓	-	-	✓	-	✓
Bringolf-Isler et al. (2008) (110)	Bern, Payerne, Biel/Bienne; Switzerland	CS [SCARPOL]	1031; 503 boys, 528 girls; 6-7 years old/Kindergarten-Grade 1, 9-10 years old/Grade 4, 13-14 years old/Grade 8	-	Travel mode: active (to & from school in winter & summer), non-active; Regular car trips to school (≥ 1 trips/week)	-	✓	-	-	-	-	-	✓	-	-
Carver et al. (2005) (111)	Sydney; Australia	CS [Nepean Kids Growing Up Study]	347; 172 boys, 175 girls; 13.0 ± 0.2 years old	Travel mode: walk, cycle; Travel frequency	-	✓	✓	-	✓	-	-	-	✓	-	-
Carver et al. (2013) (112)	Victoria; Australia	CS	688; 340 boys, 348 girls; 10.4 ± 1.2 years old/Years 3-6, 13.7 ± 1.0 years old/Years 7-10	Travel mode: car	-	-	✓	-	-	✓	-	-	✓	✓	-

Author (Year)	Study location *City/State; Country*	Study design [Project]	Participants *N; Gender; Age/Grade*	Self-reported school travel*		Perceived physical environment			Social environment						
									Social characteristics			Sociodemographic characteristics			
				Child	*Parent*	*Child*	*Parent*	*School*	*Child*	*Parent*	*School*	*Child*	*Parent*	*School*	*Neighbourhood*
Chillón et al. (2014) (113)	Florida, North Carolina, Texas, Colorado, California, Alaska, Minnesota, Pennsylvania, New Jersey; U.S.	CS [National Evaluation of Walk to School Project]	8376; N/R; Grades 4-5	Travel mode: active (≥ 4 trips/week)	-	✓	✓	-	✓	✓	-	-	-	✓	-
Christiansen et al. (2014) (114)	N/R; Denmark	CS [SPACE for physical activity]	1250; 646 boys, 604 girls; 12.5 years old	Travel mode: active, passive; Active trips/week (binomial: 0-1)	-	✓	-	-	✓	-	-	-	✓	-	-
Curriero et al. (2013) (115)	Baltimore; U.S.	CS [MORE]	362; 167 boys, 195 girls; 9.60 ± 1.04 years old/Grades 2-5	Travel mode: walk	Travel mode: walk	✓	✓	-	-	-	-	✓	✓	✓	✓
Cutumisu et al. (2014) (116)	Quebec; Canada	CS [Opération Wixx]	809; 411 boys, 398 girls; Grades 3-6, Grade ≥ 7	Travel mode: active, passive	Travel mode: active (3-7 days/week), passive	✓	✓	-	-	-	-	-	✓	✓	✓

Author (Year)	**Study location** *City/State; Country*	**Study design [Project]**	**Participants** *N; Gender; Age/Grade*	**Self-reported school travel***		**Perceived physical environment**			**Social environment**						
									Social characteristics			**Sociodemographic characteristics**			
				Child	*Parent*	*Child*	*Parent*	*School*	*Child*	*Parent*	*School*	*Child*	*Parent*	*School*	*Neighbourhood*
Ducheyne et al. (2012) (117)	Flanders; Belgium	CS	850; 432 boys, 418 girls; 10.38 ± 0.95 years old	-	Travel mode: cycle ('never' = 0 trips/week, 'always' = 10 trips/week)	-	✓	-	-	✓	-	-	✓	-	-
Durand et al. (2012) (118)	San Bernardino; U.S.	CS	365; 186 boys, 179 girls; 11.7 ± 1.49 years old	Travel mode: active, non-active	-	-	✓	-	-	✓	-	✓	-	✓	-
Hume et al. (2009) (119)	Melbourne; Australia	Pros (2 years) [CLAN]	309; 145 boys, 164 girls; 9.1 ± 0.34 years old (children), 14.5 ± 0.65 years old (adolescents)	[Adolescents ONLY] Travel mode: walk, cycle; Frequency: never, 1-5 trips/week, daily (6-10 trips/week)	[Children ONLY] Travel mode: walk, cycle; Frequency: never, 1-5 trips/week, daily (6-10 trips/week)	✓	✓	-	-	✓	-	-	✓	-	-
Kim et al. (2016) (120)	Manhattan, Austin; U.S.	CC	842 (Manhattan (case): N = 171, Austin (comparison): N = 671); N/R; Grade 4	-	Travel mode: walk	-	✓	-	-	✓	-	✓	✓	✓	-
Larouche et al. (2014) (22)	Ottawa; Canada	CS [ISCOLE, Canada]	567; 239 boys, 328 girls; 9-11 years old/Grade 5	Travel mode: active, inactive	-	✓	-	✓	-	-	✓	-	✓	✓	-

Author (Year)	Study location *City/State; Country*	Study design [Project]	Participants *N; Gender; Age/Grade*	Self-reported school travel*		Perceived physical environment			Social environment						
									Social characteristics			Sociodemographic characteristics			
				Child	*Parent*	*Child*	*Parent*	*School*	*Child*	*Parent*	*School*	*Child*	*Parent*	*School*	*Neighbourhood*
Leslie et al. (2010) (121)	Victoria, Queensland, Western Australia; Australia	CS [Healthy Neighbourhoods]	2961; 1441 boys, 1520 girls; 11.4 ± 0.8 years old/Years 6 & 8	Travel mode: active, non-active	-	✓	✓	-	✓	-	-	✓	✓	-	✓
McMillan (2007) (90)	California; U.S.	CS [Safe Routes to School, California]	1128; N/R; Grades 3-5	-	Travel mode: walk, bike, car, carpool	-	✓	-	-	✓	-	-	✓	✓	-
Moran et al. (2016) (122)	Rishon LeZion; Israel	CS	573; 287 boys, 286 girls; 10-12 years old/Grades 5-6	Travel mode: walk ($\geq$ 4 times/week)	-	✓	-	-	✓	-	-	-	✓	-	-
Muthuri et al. (2016) (123)	Nairobi; Kenya	CS [ISCOLE, Kenya]	563; 262 boys, 301 girls; 9.0-11.9 years old	Travel mode: active, motorised	-	-	✓	-	-	✓	-	-	✓	✓	-
Page et al. (2010) (124)	N/R; UK	CS [PEACH]	1300; 639 boys, 661 girls; 10-11 years old/Year 6	Travel mode: walk/cycle, car	-	✓	-	-	✓	-	-	-	-	-	✓
Panter et al. (2010) (125)	Norfolk; UK	CS [SPEEDY]	2012; 899 boys, 1113 girls; 9-10 years old	Travel mode: on foot, by bicycle, motorised travel	-	✓	✓	-	✓	✓	-	-	✓	-	✓

Author (Year)	**Study location** *City/State; Country*	**Study design [Project]**	**Participants** *N; Gender; Age/Grade*	**Self-reported school travel***		**Perceived physical environment**			**Social environment**						
									Social characteristics			**Sociodemographic characteristics**			
				Child	*Parent*	*Child*	*Parent*	*School*	*Child*	*Parent*	*School*	*Child*	*Parent*	*School*	*Neighbourhood*
Panter et al. (2013) (126)	Norfolk; UK	Pros (12 months) [SPEEDY]	912; 373 boys, 539 girls; 10.23 ± 0.30 years old	Travel mode: active, passive; Change in travel modes: maintained/took up active, maintained/took up passive	-	✓	✓	-	✓	✓	✓	-	✓	-	✓
Pont et al. (2013) (127)	Logan, Brisbane; Australia	CS	206; 99 boys, 107 girls; 10.26 ± 0.96 years old	-	Travel mode: active (≥ 1 trips in the past week)	-	✓	-	-	✓	-	-	✓	✓	-
Ross et al. (2017) (128)	Phoenix; U.S.	CS [Safe Routes to School, Arizona]	217; 81 boys, 132 girls, 4 N/R; 10.3 ± 1.65 years old	-	Travel mode: active (≥ 3 trips/week), non-active	-	✓	-	-	✓	-	-	✓	-	-
Rossen et al. (2011) (129)	Baltimore; U.S.	CS [MORE]	365; 168 boys, 197 girls; 9.60 ± 1.04 years old	Travel mode: active, non-active	Travel mode: active, non-active	✓	-	-	-	-	-	✓	✓	✓	✓
Rothman et al. (2015) (130)	Toronto; Canada	CS	733; 350 boys, 383 girls; Grades 4-6	-	Travel mode: frequent walker (4-5 times/week)	-	✓	-	-	-	-	-	✓	✓	-
Salahuddin et al. (2016) (131)	Texas; U.S.	CS [T-COPPE]	857; 422 boys, 431 girls, 4 N/R; 9.6 ± 0.6 years old/Grade 4	-	Travel mode: active, non-active	-	✓	-	-	✓	-	-	✓	✓	-

Author (Year)	Study location *City/State; Country*	Study design [Project]	Participants *N; Gender; Age/Grade*	Self-reported school travel*		Perceived physical environment			Social environment						
									Social characteristics			Sociodemographic characteristics			
				Child	*Parent*	*Child*	*Parent*	*School*	*Child*	*Parent*	*School*	*Child*	*Parent*	*School*	*Neighbourhood*
Salmon et al. (2007) (132)	N/R; Australia	CS [Pedestrian Council of Australia's National Walk Safely to School Day]	720; 354 boys, 366 girls; 4-9 years old, 10-13 years old	-	Travel mode: active (≥ 1 trips/week)	-	✓	-	-	✓	✓	-	✓	-	-
Sidharthan et al. (2011) (133)	Los Angeles, Riverside, Orange; U.S.	CS	1192; N/R; 5-15 years old	-	Travel mode: car, school bus, bicycle, walk, car + school bus, car + walk	-	✓	-	-	✓	-	-	✓	-	-
Timperio et al. (2006) (134)	Melbourne; Australia	CS	912; 435 boys, 477 girls; 5-6 years old, 10-12 years old	-	Travel mode: walk, cycle; Frequency: never, infrequent/occasional (1-4 times/week), frequent (≥ 5 times/week)	✓	✓	-	-	✓	-	-	✓	✓	✓
Trang et al. (2012) (135)	Ho Chi Minh City; Vietnam	Pros (5 years)	759; 364 boys, 395 girls; 11.8 (IQR: 11.2, 12.3) years old/Grades 6-7	Travel mode: active (≥ 4 days/week), passive	-	-	✓	-	-	-	-	-	✓	✓	✓
Trapp et al.	Perth; Australia	CS [TREK]	1197; 573 boys, 624	Travel mode: cycle (≥ 1 trip/week)	-	✓	✓	-	✓	✓	-	-	✓	✓	-

Author (Year)	Study location *City/State; Country*	Study design [Project]	Participants *N; Gender; Age/Grade*	Self-reported school travel*		Perceived physical environment			Social environment						
									Social characteristics			Sociodemographic characteristics			
				Child	*Parent*	*Child*	*Parent*	*School*	*Child*	*Parent*	*School*	*Child*	*Parent*	*School*	*Neighbourhood*
(2011) (136)			girls; Grades 5-7												
Trapp et al. (2012) (137)	Perth; Australia	CS [TREK]	1298; 617 boys, 681 girls; 10.99 ± 0.80 years old/Years 5-7	Travel mode: walk (≥ 6 trips/week)	-	✓	✓	-	✓	✓	✓	-	✓	✓	-
Vanwolleghem et al. (2016) (138)	Flanders; Belgium	Pros (2 years)	313; 160 boys, 153 girls; 11.0 ± 0.5 years old	Travel mode: active, passive; Change in travel modes (primary - secondary school): maintained/switched to active, maintained/switched to passive	-	-	✓	-	-	✓	-	-	✓	-	-
Veitch et al. (2017) (139)	Victoria; Australia	Pros (2 years) [READI]	184; 83 boys, 101 girls; 12.0 ± 2.1 years old	Travel mode: active (≥ 3 trips/week)	-	-	✓	-	-	✓	-	-	✓	-	-
Yu et al. (2015) (140)	Austin; U.S.	CS	2597; 1202 boys, 1395 girls; Grades 1.84 ± 1.76	-	Travel mode: walk	-	✓	-	-	✓	-	✓	✓	✓	-
Yu et al. (2016) (141)	Austin; U.S.	CS	2597; 1202 boys, 1395 girls; Grades 1.84 ± 1.76	-	Travel mode: walk	-	✓	-	-	✓	-	✓	✓	✓	-

Author (Year)	Study location *City/State; Country*	Study design [Project]	Participants *N; Gender; Age/Grade*	Self-reported school travel*		Perceived physical environment			Social environment						
									Social characteristics			Sociodemographic characteristics			
				Child	*Parent*	*Child*	*Parent*	*School*	*Child*	*Parent*	*School*	*Child*	*Parent*	*School*	*Neighbourhood*
Zhu et al. (2008) (142)	Austin; U.S.	CS [Safe Routes to School, Texas]	1281; N/R; N/R	-	Travel mode: walk	-	✓	-	-	✓	-	✓	✓	✓	-
Zhu et al. (2009) (143)	Austin; U.S.	CS [Safe Routes to School, Texas]	2695; 1245 boys, 1450 girls; Grades 1.837 ± 1.739	-	Travel mode: walk	-	✓	-	-	✓	-	✓	✓	✓	-

CC = case-control; CLAN = Children Living in Active Neighbourhoods; CS = cross-sectional; IQR = interquartile range; ISCOLE = International Study of Childhood Obesity, Lifestyle and the Environment; MORE = Multiple Opportunities to Reach Excellence; N = number; N/R = not reported; PEACH = Personal and Environmental Associations with Children's Health; Pros = prospective; READI = Resilience for Eating and Activity Despite Inequality; SCARPOL = Swiss Study on Childhood Allergy and Respiratory Symptoms with respect to Air Pollution, Climate and Pollen; SPEEDY = Sport, Physical activity and Eating behaviour: Environmental Determinants in Young people; T-COPPE = Texas Childhood Obesity Prevention Policy Evaluation; TREK = Travel, Environment and Kids.
*Travel modes included for analyses.

2.2.5 Quality assessment and risk of bias in individual studies

The strength of evidence, quality, and risk of bias for each included study were assessed at the study level using the quality assessment checklist of Pont et al. (24). Rating scales were retrieved from the Effective Public Health Practice Project Quality Assessment Tool (EPHPP) (28, 40, 144-146). The grading system, comprising six components and a composite global rating are available in Appendices I (pp. 302-308) and J (p. 309). The six domains of bias and methodological quality are: description of the sample, sampling methods, study methodology, measurement, external validity of measurement tools, and bias from blinding and follow-up (24). The original quality assessment checklist of Pont et al. (24) was modified to increase the suitability for evaluating studies included in this review, and to generate an overall appraisal of each study (Appendices I and J). Given the importance of assessment in confounders and analyses (40, 99, 144-147), an additional domain of analyses (i.e., statistical methods, confounders, clustering and model fit) was included in the assessment but reported separately from the overall rating of the other six domains. Two review authors (EI and EH) independently assessed the quality of each study included. Reviewers resolved disagreements by discussion, and an arbitrator (KW) adjudicated unresolved disagreements.

2.2.6 Summary measures, synthesis of results, and quality assessment and risk of bias across studies

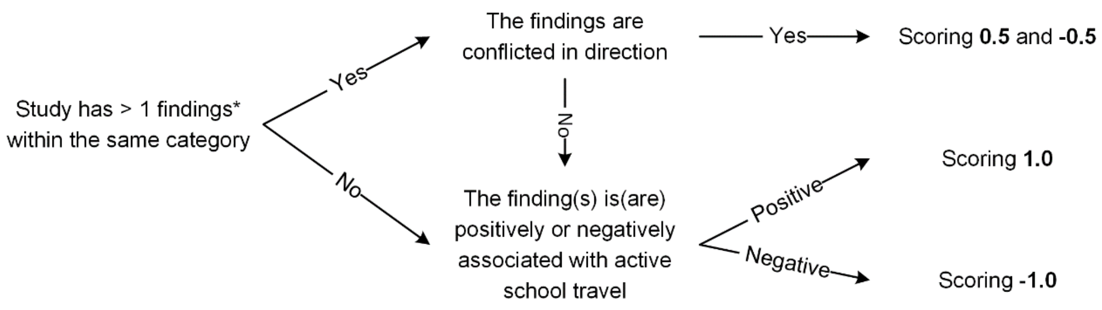
A systematic narrative synthesis was performed to summarise the characteristics (i.e., study location, study design, research project, participants, school travel mode, perceived physical environment attributes, and social and sociodemographic variables) and significant and non-significant findings (i.e., ORs and β) in the final statistical model of the included studies. In order to identify the direction of associations, findings were classified as positive (i.e., OR > 1, β > 0) or negative (i.e., OR < 1, β < 0). Reverse-coding of the original direction of associations (i.e., positive to negative or vice versa) was performed depending on the wording of the original question items (e.g., 'too far' versus 'distance close enough'). Findings were collated separately by statistical significance (i.e., significant versus non-significant findings) and independent variables (i.e., perceived physical environment, and social and sociodemographic characteristics). Results from each independent variable were integrated into categories (Table 3). Findings were also identified by the level of study quality (i.e., low and moderate) to assess the robustness of the synthesis by considering risk of bias and strength of evidence.

Table 3 The categories of perceived physical environment attributes and social environment variables, and the direction of their associations with active school travel

	Direction	
	Positive	**Negative**
Perceived physical environment:		
Travel distance & time	Shorter distance / time	Longer distance / time
Walkability	More walkable	Less walkable
Land use mix - diversity	Presence of business or facilities	Absence of business or facilities
Land use mix - access	More accessible to services	Less accessible to services
Walking & cycling infrastructure	More infrastructure	Less infrastructure
Traffic & route safety	Safer (less traffic)	More dangerous (more traffic)
Neighbourhood safety	Safer	More dangerous
Personal safety	Safer	More dangerous
Aesthetics	More aesthetic	Less aesthetic
Social environment:		
Social characteristics		
Neighbourhood social capital / cohesion	Stronger social capital / cohesion	Weaker social capital / cohesion
Neighbourhood social interaction	More social interaction	Less social interaction
Social norms of active travel	Stronger social norms	Weaker social norms
Family & friends support / encouragement for active school travel	More support / encouragement	Less support / encouragement
Family/parents support / encouragement for active school travel	More support / encouragement	Less support / encouragement
Friends/other children support / encouragement for active school travel	More support / encouragement	Less support / encouragement
School support / encouragement for active school travel	More support / encouragement	Less support / encouragement
Sociodemographic characteristics		
Neighbourhood socioeconomic status	Higher socioeconomic status	Lower socioeconomic status
Household income	Higher income	Lower income
Household parent education	Higher education	Lower education
Household parental employment	Unemployed / Part-time	Employed / Full-time
Family structures	More adults (dual parent) / family members	Less adults (single parent) / family members
Number of children	More children / siblings	Less children / siblings
Car ownership/access	More cars	Less cars
Ethnicity/race	*Not specified*	*Not specified*
School bus	Availability of school bus	Unavailability of school bus
School administration	*Not specified*	*Not specified*
School level	Higher level (secondary)	Lower level (primary)

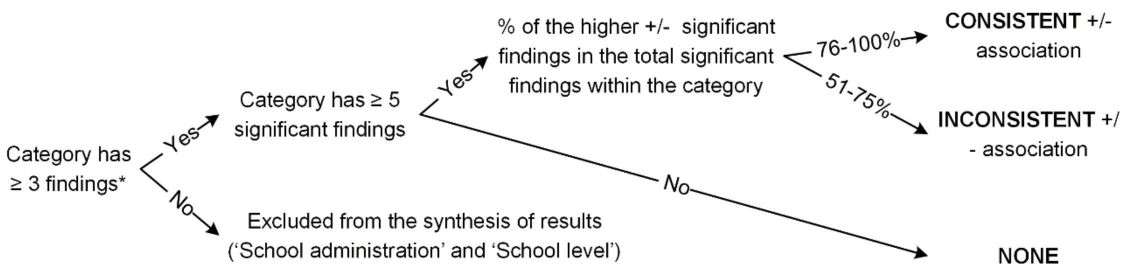
Vote counting was applied for significant and non-significant findings separately to summarise the number of studies reporting positive and/or negative associations with school travel modes in each category (Table 3) (26, 148). School travel modes were classified from individual studies as being concerned with active travel (i.e., walk, cycle) or passive travel (i.e., car, school bus, public transport). Key findings were summarised only for studies investigating AST due to a small number of studies reporting results for passive school travel (N = 3). Studies were counted once per category (Table 3) by scoring either ‘1’ for positive or ‘-1’ for negative associations with AST. If the study reported more than one finding for the category, and these findings were conflicted in direction (i.e., positive AND negative associations), the studies were scored as ‘0.5’ AND ‘-0.5’ for both directions (Figure 3).

STEP 1: How to score a study in each category



**Significant and non-significant findings separately*

STEP 2: How to assess the consistency of positive/negative associations in each category



**Combined significant and non-significant findings.* + = positive, - = negative.

Figure 3. Vote counting: how to score a study in each category and how to assess the consistency of positive or negative associations in each category.

The categories (Table 3, p. 30) wherein three or more studies reported significant and non-significant findings were included in the synthesis of results (i.e., the categories of school administration (two studies) and school level (one study) were excluded using this criterion). The consistency of positive or negative associations was examined in the categories with five or more studies reporting significant findings to sufficiently indicate consensus (26) (i.e., the categories with < 5 studies were classified as '*none*'). '*Consistent associations*' were defined as 76-100% (i.e., more than three quarters) of the significant results reporting the same direction within each category (c.f., 51-75%: '*inconsistent association'*) (Figure 3, p. 31).

2.3 Results

2.3.1 Study selection

Figure 4 (p. 33) depicts the flow diagram of studies included and excluded from the review. From the six databases, 1,777 articles were identified. After discarding 694 duplicates and adding hand searching (N = 6), 1,007 were excluded at the title or abstract screening stage with excellent agreement with the first author (K = 0.91) (148). The remaining 82 full-text articles were assessed for eligibility. In total 37 of these studies met the inclusion criteria for this review with good agreement with the first author (K = 0.68) (148).

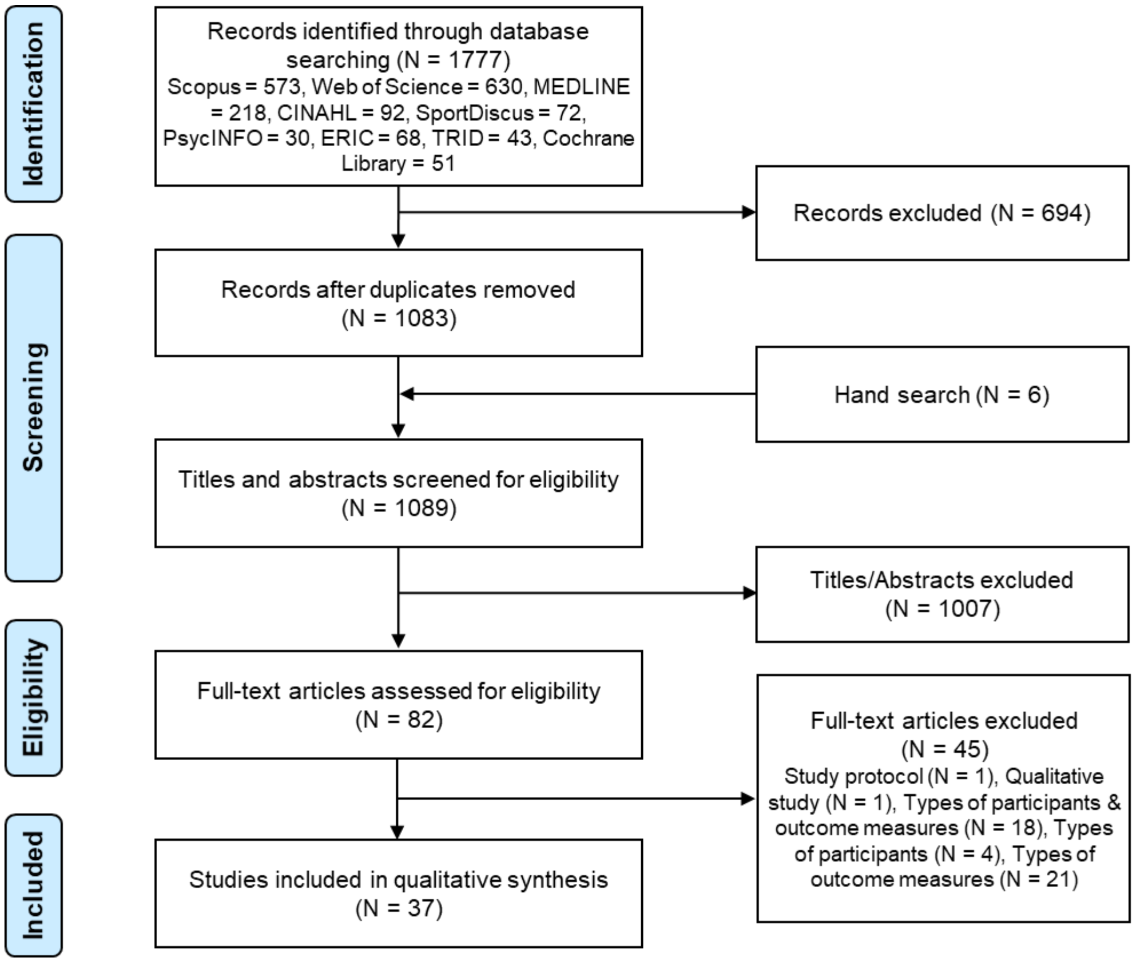


Figure 4. Flow of identification, screening, eligibility, and study inclusion of previously published studies.

2.3.2 Study characteristics

Key characteristics of the included studies are presented in Table 2 (pp. 21-28) and Appendix H (pp. 268-301). Most of the studies were cross-sectional (N = 31), with the remainder being prospective (N = 5) or case-control (N = 1) studies. The majority of the studies were conducted in the United States (N = 13) and Australia (N = 10). Five pairs of studies were categorised as the same research projects or identified as having matching data (e.g., repetitive cross-sectional studies in different years or locations, and use of different measures) (115, 125, 126, 129, 136, 137, 140-143). As variables included and/or statistical analyses used between the paired studies were different, to some extent, the paired studies were treated independently.

The average (standard deviation) sample size of all 37 studies was 1333 (1613), with sample sizes ranging from 184 to 8376 participants. The mean (standard deviation) percentage of male participants was 47.5% (3.10%; range: 37.3-51.7%) across 32 studies, excluding five studies in which values were not reported. Modes of school travel were self-reported by children in 17 studies, by parents in 16 studies, or by both parents and children in four studies. For assessment of perceived physical environments, a majority of studies (N = 20) administered parent self-reports only as opposed to five studies using child questionnaire only, and 10 studies used the combination of child and parent measures. The social environment was assessed using characteristics and/or perceptions of parents/households in all studies included, and children and/or schools in 29 of these studies.

The Neighbourhood Environment Walkability Scale (NEWS) including adapted (ANEWS) and youth (NEWS-Y) versions was the most popular measure for perceived physical environment (117, 118, 123, 125, 126, 138). Various individual or composite measures were used to assess social and sociodemographic characteristics.

2.3.3 Quality assessment and risk of bias within studies

Results of study quality assessment are presented in Table 4 (pp. 35-37). Seven studies were rated as moderate quality and a majority were rated as weak. No studies were identified as strong. The quality component most frequently rated as weak was risk of bias (N = 33) and, subsequently, sampling methods (N = 23) and external validity (N = 21). This was mainly because of unclear or inappropriate blinding methods (e.g., interviews) and lower response rates (less than 40%) in the bias category. Most studies were graded as strong in the measurement category (N = 31). Sample description (N = 26) and study methodology (N = 30) were most commonly rated as moderate quality.

Statistical analyses were classified into 11 methods based on the type and number of independent and dependent variables, and whether clustering was considered in the final statistical model. A mixed effects multivariable logistic regression (N = 13) which is a series of logistic regressions with multiple independent variables and clustering was the most often used statistical method. Confounders were considered in 27 studies, and model fit was tested in 10 studies. The effect of clustering (e.g., school) was adjusted for in 26 studies.

1 Table 4 Quality assessment of studies included

Author (Year)	Sample description	Sampling methods	Study methodology	Measurement	External validity	Bias	Analyses				Overall rating
							Statistical method†	*Confounders**	*Clustering*	*Model fit*	
Aarts et al. (2013) (109)	Strong	Weak	Moderate	Strong	Moderate	Moderate	E	YES	School	-	MODERATE
Christiansen et al. (2014) (114)	Moderate	Weak	Moderate	Strong	Strong	Moderate	F	YES	School	YES	MODERATE
Ducheyne et al. (2012) (117)	Moderate	Strong	Moderate	Strong	Weak	Moderate	F	YES	School	-	MODERATE
Rothman et al. (2015) (130)	Strong	Strong	Moderate	Strong	Strong	Weak	F	YES	School	-	MODERATE
Zhu et al. (2009) (143)	Moderate	Strong	Moderate	Strong	Strong	Weak	F	-	School; Time	YES	MODERATE
Salmon et al. (2007) (132)	Moderate	Strong	Moderate	Strong	Strong	Weak	H	YES	-	-	MODERATE
Leslie et al. (2010) (121)	Moderate	Strong	Moderate	Strong	Strong	Weak	K	YES	-	-	MODERATE
Yu et al. (2015) (140)	Moderate	Weak	Moderate	Strong	Strong	Weak	A	-	-	YES	WEAK
Yu et al. (2016) (141)	Moderate	Strong	Moderate	Strong	Weak	Weak	A	YES	School	YES	WEAK
Chillón et al. (2014) (113)	Weak	Strong	Moderate	Strong	Strong	Weak	B	YES	School; Time	-	WEAK
Larouche et al. (2014) (22)	Moderate	Weak	Moderate	Strong	Strong	Weak	B	YES	School	-	WEAK
Trang et al. (2012) (135)	Strong	Strong	Strong	Weak	Strong	Weak	B	YES	School; Time	-	WEAK
Curriero et al. (2013) (115)	Moderate	Strong	Moderate	Weak	Weak	Weak	C	-	Neighbourhood statistical area	-	WEAK
Rossen et al. (2011) (129)	Moderate	Weak	Moderate	Strong	Weak	Weak	C	YES	School; Census tract	-	WEAK
Sidharthan et al. (2011) (133)	Weak	Weak	Weak	Weak	Weak	Weak	D	-	-	YES	WEAK
Panter et al. (2010) (125)	Moderate	Weak	Moderate	Strong	Moderate	Weak	E	YES	School	-	WEAK

Author (Year)	Sample description	Sampling methods	Study methodology	Measurement	External validity	Bias	Analyses				Overall rating
							Statistical method†	*Confounders**	*Clustering*	*Model fit*	
Panter et al. (2013) (126)	Moderate	Weak	Strong	Strong	Weak	Weak	E	YES	School	-	WEAK
Carver et al. (2013) (112)	Moderate	Weak	Moderate	Strong	Weak	Weak	F	-	School	-	WEAK
Durand et al. (2012) (118)	Moderate	Weak	Moderate	Strong	Strong	Weak	F	YES	Community	YES	WEAK
McMillan (2007) (90)	Weak	Weak	Moderate	Strong	Weak	Weak	F	-	School	YES	WEAK
Pont et al. (2013) (127)	Strong	Weak	Moderate	Strong	Weak	Weak	F	YES	Census collection district	-	WEAK
Timperio et al. (2006) (134)	Moderate	Strong	Moderate	Strong	Weak	Weak	F	YES	School	-	WEAK
Trapp et al. (2011) (136)	Moderate	Weak	Moderate	Strong	Weak	Weak	F	YES	School	-	WEAK
Trapp et al. (2012) (137)	Moderate	Strong	Moderate	Weak	Weak	Weak	F	YES	School	-	WEAK
Veitch et al. (2017) (139)	Moderate	Strong	Strong	Strong	Weak	Weak	F	YES	Suburb	-	WEAK
Zhu et al. (2008) (142)	Weak	Weak	Moderate	Strong	Strong	Weak	F	-	School	YES	WEAK
Carver et al. (2005) (111)	Moderate	Weak	Moderate	Strong	Weak	Weak	G	YES	-	-	WEAK
Bringolf-Isler et al. (2008) (110)	Moderate	Weak	Moderate	Strong	Weak	Moderate	H	-	-	-	WEAK
Cutumisu et al. (2014) (116)	Weak	Moderate	Moderate	Strong	Weak	Weak	H	YES	-	-	WEAK
Kim et al. (2016) (120)	Weak	Weak	Strong	Weak	Weak	Weak	H	YES	-	YES	WEAK
Moran et al. (2016) (122)	Moderate	Weak	Moderate	Strong	Weak	Weak	H	YES	-	-	WEAK
Muthuri et al. (2016) (123)	Moderate	Weak	Moderate	Strong	Strong	Weak	H	-	-	-	WEAK
Ross et al. (2017) (128)	Weak	Weak	Moderate	Weak	Strong	Weak	H	-	-	YES	WEAK
Vanwolleghem et al. (2016) (138)	Moderate	Weak	Strong	Strong	Weak	Weak	I	YES	School	-	WEAK

Author (Year)	Sample description	Sampling methods	Study methodology	Measurement	External validity	Bias	Analyses				Overall rating
							Statistical method†	*Confounders**	*Clustering*	*Model fit*	
Hume et al. (2009) (119)	Moderate	Strong	Strong	Strong	Weak	Weak	J	YES	School	-	WEAK
Page et al. (2010) (124)	Moderate	Weak	Moderate	Strong	Strong	Weak	J	YES	School	-	WEAK
Salahuddin et al. (2016) (131)	Moderate	Weak	Moderate	Strong	Weak	Weak	J	YES	School	-	WEAK

A = Structural equation model (SEM, weighted least square); B = Generalised linear mixed model (GLMM); C = Generalised estimating equation (GEE); D = Maximum approximated composite marginal likelihood (MACML); E = Mixed effects multivariable multinomial regression; F = Mixed effects multivariable logistic regression; G = Multivariable linear regression; H = Multivariable logistic regression; I = Multivariable logistic regression; J = Mixed effects logistic regression; K = Logistic regression.

†Statistical methods from each study were categorised into A - K (N = 11) based on the type and number of independent and dependent variables, and clustering included in the final statistical model.

*Relevant confounders including: child's age/grade/year; child's gender; child's/parental race/ethnicity; household socioeconomic status: annual income, receiving government assistance, parental/maternal education, parental/maternal employment; marital/family status; household car ownership/access; number of children; child receiving free/reduced lunch; area socioeconomic status: median income, education, poverty level, deprivation indices; child's weight status/BMI; child's pubertal stage; distance to school; location of residence; neighbourhood walkability; school location; school walkability; hours of daylight; maternal travel mode to work; change of schools.

2

2.3.4 Results of individual studies

All results from both active and passive travel were reported as ORs and coefficients except one study in which ORs were calculated using probabilities (131). Composite items which encompassed multiple categories were utilised in six studies assessing the perceived physical environment (113, 126, 128, 133, 138, 139), and five studies measuring the social environment (109, 126, 140, 142, 143). For instance, 'suitability of the route to school' consists of six single items encompassing categories of land use mix – access, walking and cycling infrastructure, traffic safety, as well as components of the natural environment (i.e., hills and weather) (113). Six single items comprise 'social cohesion' in which categories of neighbourhood social capital/cohesion and social interaction were identified (109). The item 'working situation of parents' involved measures of family structure (i.e., dual/single parent family) and employment status (i.e., > 36 or 12-36 hours/week work) (109).

Three studies reported findings related to passive travel (110, 112, 133). Passive travel was correlated negatively with travel distance under two miles (school bus: $\beta = -0.521$, car plus school bus: $\beta = -1.725$) (133), and positively with safety concerns (slightly unsafe: OR = 3.1, 95% CI 2.0-5.1, very unsafe: OR = 4.8, 95% CI 1.8-2.9) (110). Weaker social trust (OR = 0.77, 95% CI 0.64-0.93), part-time employment status (OR = 1.55, 95% CI 1.03-2.34) (112), and higher car ownership in the household (110, 133) were also found to be related to passive travel.

2.3.5 Synthesis of results and quality assessment across studies

The summary of significant and non-significant findings in AST in relation to perceived physical environment, and social and sociodemographic characteristics are provided in Figures 5-10 (pp. 39-44). Findings from the case-control study were not included in the synthesis of results because the study only reported differences in walking to school behaviour between Manhattan and Austin, and the results were not comparable to the other studies (e.g., the odds of AST) (120).

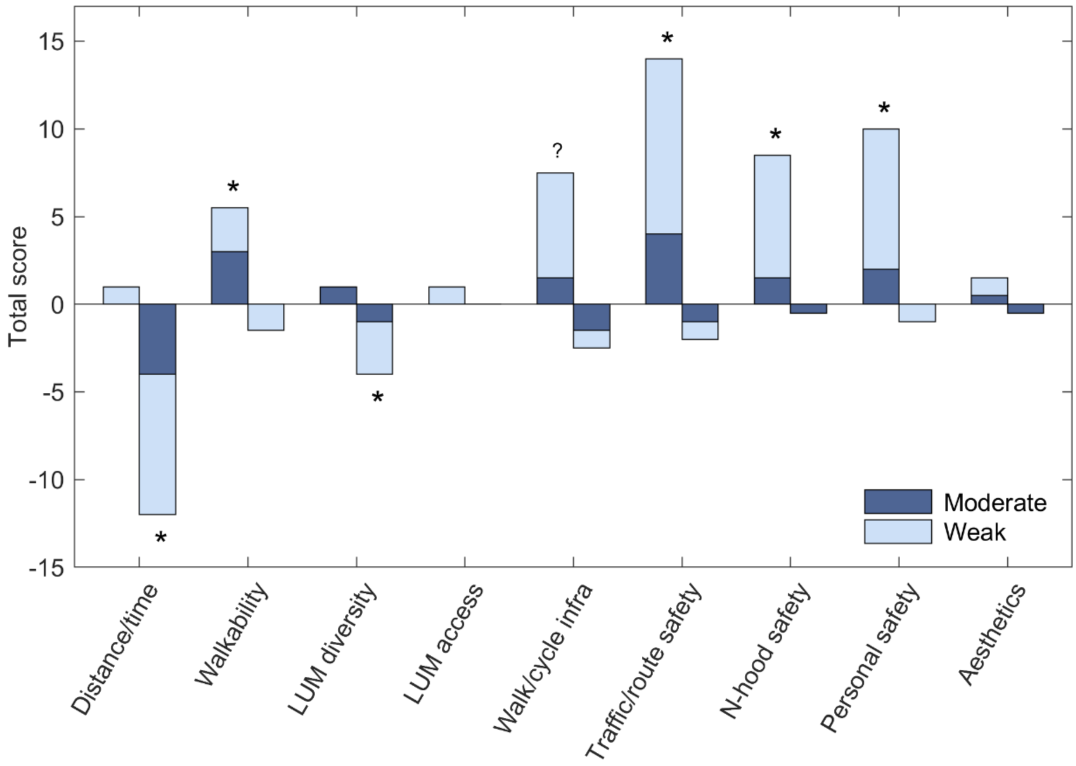


Figure 5. Significant associations between perceived physical environment attributes and active school travel. X-axis represents the category of perceived physical environment attributes. Y-axis denotes the total score of studies (each study was scored as 1 = a finding(s) was (were) agreed in positive direction; -1 = a finding(s) was (were) agreed in negative direction; or 0.5 and -0.5 = findings were disagreed in direction). * = Consistent association (i.e., 76-100% of significant findings are in positive/negative direction). ? = Inconsistent association (i.e., 51-75% of significant findings are in positive/negative direction). LUM = land use mix. Infra = infrastructure. N-hood = neighbourhood.

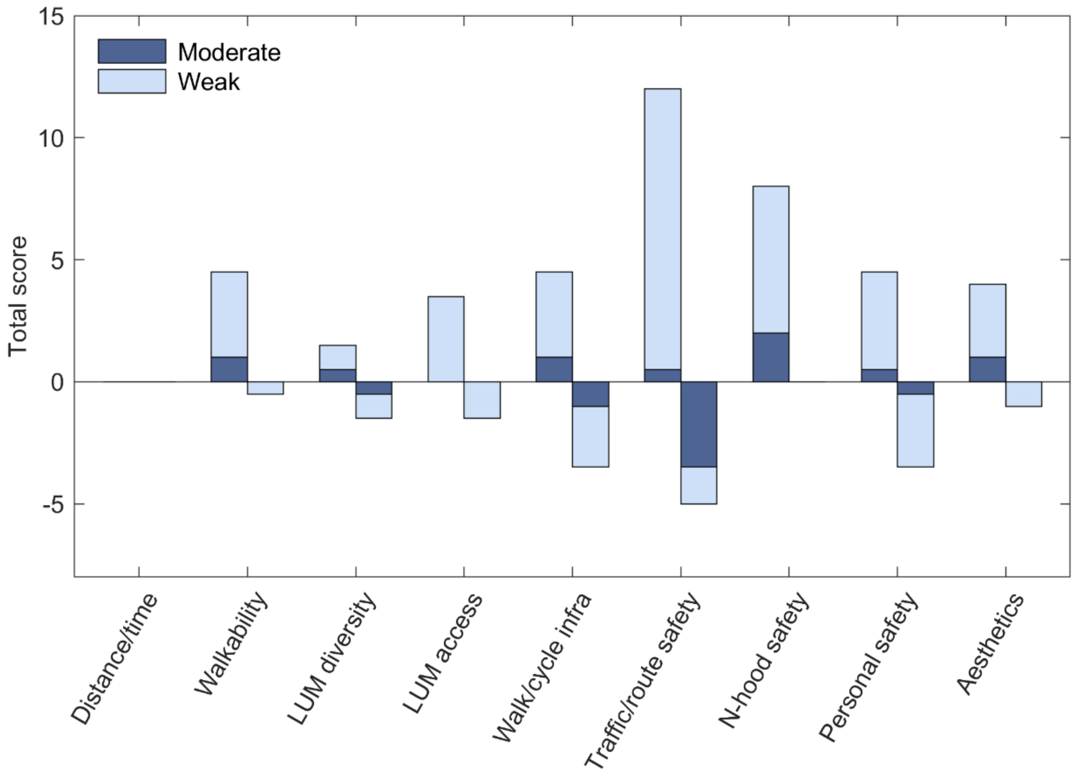


Figure 6. Non-significant associations between perceived physical environment attributes and active school travel. X-axis represents the category of perceived physical environment attributes. Y-axis denotes the total score of studies (each study was scored as 1 = a finding(s) was (were) agreed in positive direction; -1 = a finding(s) was (were) agreed in negative direction; or 0.5 and -0.5 = findings were disagreed in direction). LUM = land use mix. Infra = infrastructure. N-hood = neighbourhood.

With respect to the association between AST and the perceived physical environment a total of 128 significant and 115 non-significant outcomes from 31 studies were included to draw inferences for each category. Traffic and route safety were the most often studied (N = 23), followed by walking and cycling infrastructure (N = 16) (Figures 5-6). Consistent significant associations were found in travel distance and time and land use mix – diversity in negative direction, and walkability, traffic and route safety, neighbourhood safety, and personal safety in positive direction (Figure 5). Walking and cycling infrastructure was categorised as an inconsistently positive association (Figure 5). A higher percentage of moderate quality studies with significant findings were observed for walkability (42.9% in positive direction), travel distance, and time (30.8% in negative direction), and traffic and route safety (25.0% in positive direction).

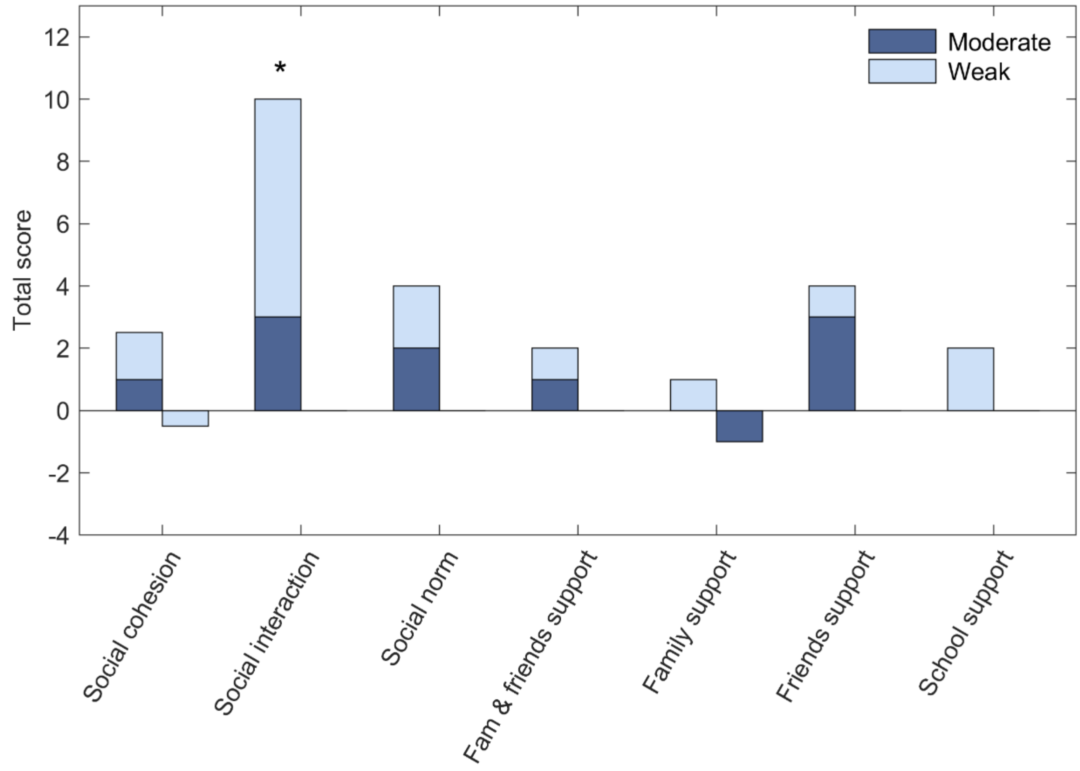


Figure 7. Significant associations between social characteristics and active school travel. X-axis represents the category of social characteristics. Y-axis denotes the total score of studies (each study was scored as 1 = a finding(s) was (were) agreed in positive direction; -1 = a finding(s) was (were) agreed in negative direction; or 0.5 and -0.5 = findings were disagreed in direction). * = Consistent association (i.e., 76-100% of significant findings are in positive/negative direction). Fam = family.

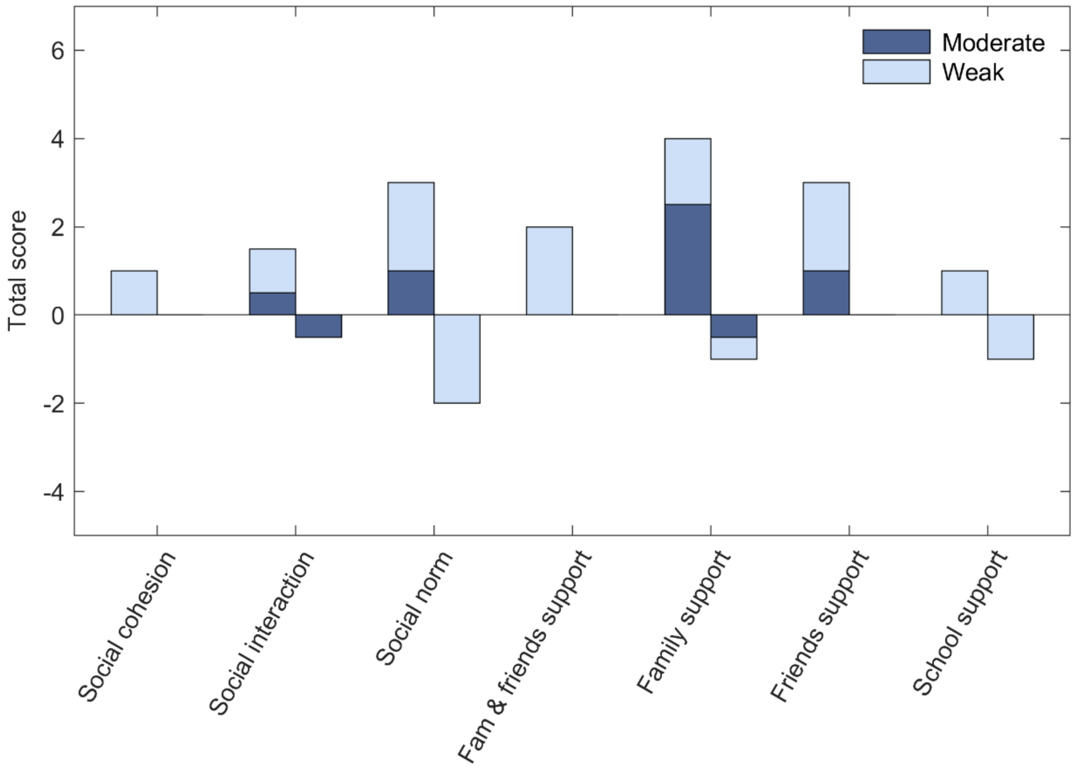


Figure 8. Non-significant associations between social characteristics and active school travel. X-axis represents the category of social characteristics. Y-axis denotes the total score of studies (each study was scored as 1 = a finding(s) was (were) agreed in positive direction; -1 = a finding(s) was (were) agreed in negative direction; or 0.5 and -0.5 = findings were disagreed in direction). Fam = family.

The social environment involved 40 significant and 48 non-significant outcomes from 23 studies of the social characteristic, and 56 significant and 66 non-significant outcomes from 21 studies of the sociodemographic characteristic. AST was consistently and significantly associated with neighbourhood social interaction in positive direction, and with household education and car ownership in negative direction (Figures 7 and 9). Neighbourhood socioeconomic status inconsistently had a positive association with AST (Figure 9). Thirty percent of moderate quality studies reported significantly positive associations with neighbourhood social interaction and significantly negative associations with household car ownership were reported in 42.9% of moderate quality studies.

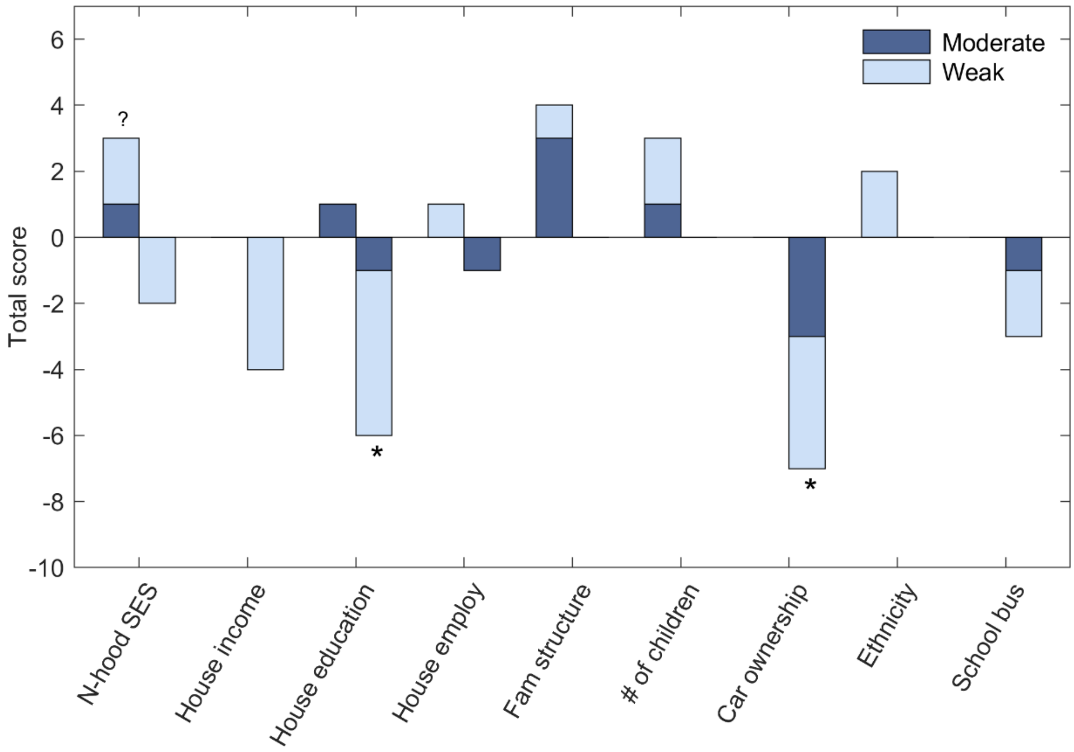


Figure 9. Significant associations between sociodemographic characteristics and active school travel. X-axis represents the category of sociodemographic characteristics. Y-axis denotes the total score of studies (each study was scored as 1 = a finding(s) was (were) agreed in positive direction; -1 = a finding(s) was (were) agreed in negative direction; or 0.5 and -0.5 = findings were disagreed in direction). * = Consistent association (i.e., 76-100% of significant findings are in positive/negative direction). ? = Inconsistent association (i.e., 51-75% of significant findings are in positive/negative direction). N-hood SES = neighbourhood socioeconomic status. Fam = family. # = number.

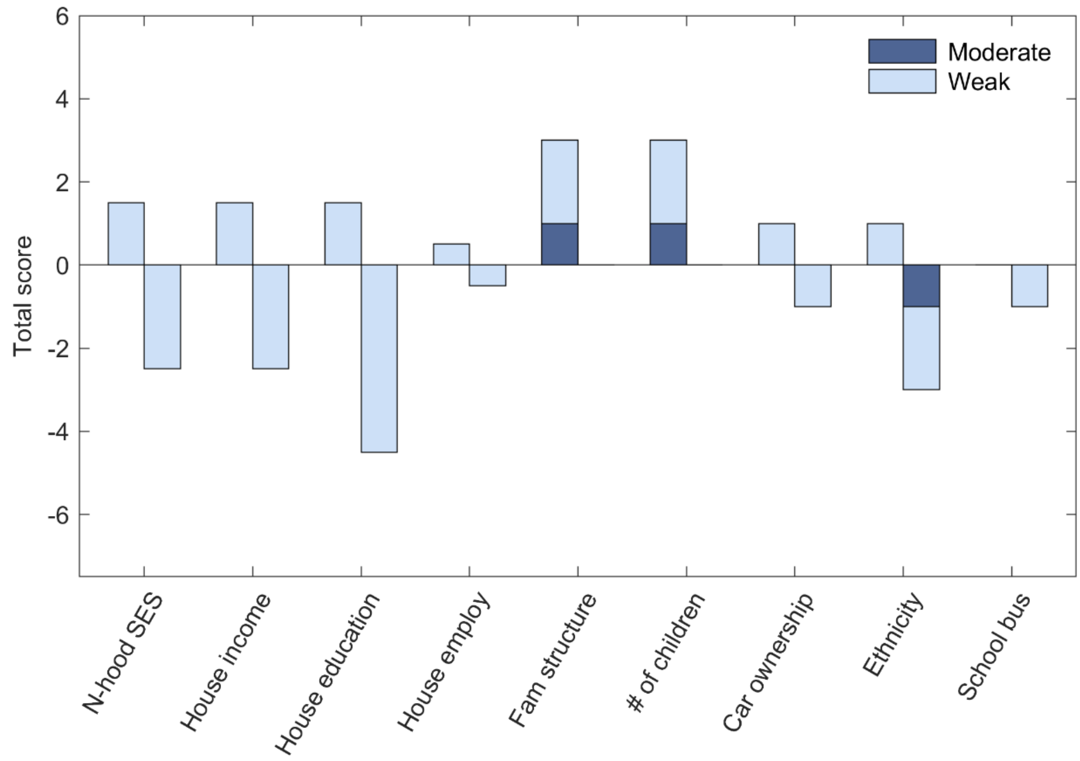


Figure 10. Non-significant associations between sociodemographic characteristics and active school travel. X-axis represents the category of sociodemographic characteristics. Y-axis denotes the total score of studies (each study was scored as 1 = a finding(s) was (were) agreed in positive direction; -1 = a finding(s) was (were) agreed in negative direction; or 0.5 and -0.5 = findings were disagreed in direction). N-hood SES = neighbourhood socioeconomic status. Fam = family. # = number.

2.4 Discussion

This systematic review aimed to summarise and assess the evidence for associations between school travel modes in children aged 5-13 years and perceived physical environments, as well as social and sociodemographic characteristics. With the application of the PRISMA protocols, a systematic approach was utilised for identification, screening, eligibility, data extraction, and quality assessment of relevant literature. As a result, 37 studies were included in quantitative synthesis and assessment using a vote-counting technique. This systematic review provides a rigorous descriptive appraisal of the existing evidence relating to associations of children's active travel with the perceived physical as well as social environments by integrating assessments of study quality and directions of the associations.

Safety perceptions, particularly of traffic and travel routes, strongly and consistently predicted children's AST. These findings reflect parental concern about child traffic safety (24, 25). Three studies rated as moderate quality (114, 117, 132) paradoxically reported AST had positively significant and negatively non-significant associations with traffic safety, in which the importance of reporting non-significant results was emphasised.

For instance, the score of family support calculated from non-significant findings (Figure 8) was four times as high as that calculated from significant findings (Figure 7). Negative associations between AST and ethnicity were only reported from non-significant findings (Figure 10; cf., Figure 9). In fact, all included studies reported significant results compared to 28 of 37 for non-significant results. One study only reported significant results where non-significant results also existed, indicating possible publication bias (25). Although the evidence base was generally clear and consistent, bias and errors (e.g., publication bias, measurement errors) should be eliminated to gain a comprehensive understanding of 'true effects'.

Regarding travel distance and time, 12 out of 13 studies demonstrated negative associations with AST wherein all reported findings were statistically significant. The category of walkability had consistently positive associations with AST. This measure incorporated measures of neighbourhood walkability scores (e.g., NEWS, ANEWS, NEWS-Y), street connectivity, cul-de-sac connectivity, directness and diversity of routes, and hilliness. The diversity of land use mix, a subscale of neighbourhood walkability score, indicated associations with AST in the opposite direction to walkability. Given that three out of four papers (140, 142, 143) were based on the same study population and measures (e.g., presence of convenience, presence of office building), the results of land use mix – diversity – might have selection bias and lack generalisability. Further investigation of associations between AST and land use mix (diversity and access) may be required for future studies particularly outside North America (25). There also remains insufficient evidence and substantial variance in associations for aesthetics. The conflicting evidence may be partly due to children's exposure to positive and negative aesthetics in their neighbourhood environment as they actively travel.

Activity-friendly built environments can potentially lead to long-term and population-wide improvements in physical activity behaviours (4, 99). The current review found that walking and cycling infrastructure was associated with children's AST. Smith et al. (41) reported that streetscape features (i.e., two or more of crossing walk/sidewalk, cycle parking, traffic calming, safe pedestrian paths) can benefit children's active travel (to school and other destinations). There was some indication of a socio-economic gradient in that more advantaged communities were more likely to benefit from infrastructure improvements. As a possible reflection of this finding, the current review showed that the presence of walking and cycling infrastructure and higher neighbourhood socioeconomic status was associated with children's AST. Children living in a wealthy neighbourhood in the Netherlands were more likely to actively travel to school (109). Similarly, children from the least deprived neighbourhoods in two UK studies were more liable to actively travel to/from school than children from the most deprived neighbourhoods (124, 126).

In contrast to the findings for neighbourhood-level socioeconomic status (e.g., deprivation index), household socioeconomic status including car ownership and education were negatively associated with AST in the current review. These conflicting findings (between neighbourhood-level and individual level factors) may be due to varying definitions and delineations of a geographic area, with scale ultimately affecting sensitivity and specificity of the measure. A growing body of literature shows neighbourhoods have been defined in various ways (i.e., modifiable area unit problem; MAUP) including census tract boundaries based on participants' home locations, researcher-defined buffers around participants' home using GIS, and self-determined/perceived neighbourhoods by participants (149-153). These varying neighbourhood definitions can influence outcomes. Neighbourhood sociodemographic characteristics in all six studies included were derived from census tract (109, 115, 116, 124, 129, 135).

In this review, outcomes of the perceived physical environment were predominantly obtained using questionnaires in which the concept of 'neighbourhoods' was self-defined by the participants. The NEWS, for example, indicates a 'neighbourhood' to respondents by providing approximate walking time from their home (e.g., within a 10-15 minute) (117, 118, 123, 125, 126, 138). GIS-based buffers were used for objective physical environments which were not reported in this review (110, 114, 122, 126, 131, 134, 136, 137, 139). Hence, the variability in measurement of geographic areas across studies included should be considered when inferring the evidence. The specificity of geographic areas for AST such as around school and along route should be highlighted as an important consideration to increase the sensitivity of environmental exposure and perceptions during children's school travel (154).

Even with sufficient evidence supporting positive influences of neighbourhood social interaction, there is still a dearth of evidence on the other social factors considered in this review. Children who walked to school had relatively positive attitudes towards their neighbourhood community which were related to their social interactions, social network, and sense of community (43). Evidence suggests effective interventions to increase AST require involvement of, and collaboration with, parents, stakeholders, school, and community to create positive attitudes towards AST (40, 155). Positive peer influence can be a moderator of associations between walking to/from school and attitudes towards and enjoyment of walking (141). Associations between AST and social factors can be mediated by safety perceptions (128). Thus, social factors can potentially facilitate children's AST; however, further evidence is required to confirm these associations.

The current review developed and tailored the qualitative assessment checklist of Pont et al. (24), in conjunction with the EPHPP's grading system, to be more suitable for and sensitive to the included studies. In line with the position of Humphreys et al. (100), results of the quality assessment were treated as a 'benchmark', and used to identify and interpret limitations of the evidence and methodological weakness. The primary limitations of studies reviewed were risk of bias, poor sampling methods, and lack of external validity. To reduce the impact of bias due to lack of researcher blinding and control over the questionnaire, further research could consider the use of self-administration methods without the presence of assessors during data collection process and the assurance of confidentiality or anonymity which can improve data quality (156). In view of designing a study practically and feasibly, purposive sampling was most commonly used in the observational studies. However, use of randomisation is recommended to minimise risk of bias and confounding (157). The application of measures designed and validated specifically for the target population is required to ensure external validity. Likewise, choosing appropriate instruments (e.g., questionnaire and/or interviews), modes of administration (e.g., self- and/or proxy reports) and respondents (e.g., child and/or parent) corresponding to the research purpose is critical for designing a robust study (158). With a view to minimising potential errors (e.g., poorly worded questions, the way questions are asked) and self-report bias (e.g., social desirability, comprehension, inability to recall activities with accuracy), conducting a pilot study for a self-administration questionnaire and testing the reliability and validity of measures are recommended (159-161).

In addition to the six components of the quality assessment (24), in this review additional work was undertaken to extract details on the statistical analyses performed in each study. Eleven categories of statistical methods, and adjustments of confounders, clustering and model fit were identified. Overall, robust and comprehensive statistical analyses were used (114, 118, 141). It has been recognised that a conceptual model of school travel behaviour drawing from the socio-ecological model encompasses multifaceted and multi-level factors (32, 49, 60, 87, 88, 162, 163). In this regard SEM, a multivariate analysis technique combining aspects of factor analysis and multiple regression, can throw light on the appropriateness of the theories. This is achieved by examining a series of interrelated dependence relationships among the observed variables and latent constructs as well as between several latent constructs. (140, 141, 164-166). Yu and Zhu (140, 141) applied SEM to test two different conceptual models for children's walking to/from school behaviours. One investigated relative impacts of residential self-selection and built environment factors (140); and another focused on mediating effects of parental attitudes (i.e., attitudinal barriers, enjoyment of walking) in relation to social and built environment factors (141). Distance to school had the stronger impact on walking to/from school behaviour than residential self-selection, and an inverse relationship was observed between neighbourhood walking environment and residential self-selection (140). An impact of positive peer influence on walking to/from school behaviour was mediated by parental attitudes (141). Accordingly, the level of significance and the direction of associations between AST and physical and social environments can alter depending on conceptual models utilised and variables included in analyses.

2.4.1 Strengths and limitations

This systematic review aimed to summarise and evaluate the evidence for associations of children's AST with perceived physical environments and social and sociodemographic characteristics; therefore, only observational studies were included. Petticrew (93) referred to 'fitness for purpose' in which systematic reviews should consider meaningful evidence on the topic of interest. Observational studies are informative and can provide additional knowledge in this field of research (93, 100). It is acknowledged that experimental studies (e.g., natural and quasi-experiments) and interventions may have higher quality of evidence and infer causal mechanisms. However, due to a wide range of factors involved in experimental studies and interventions (e.g., impact of individuals' lifestyles, duration of interventions), as well as variation in their methods (e.g., 'soft' interventions including general awareness and promotion; 'hard' interventions such as upgradation and production infrastructure; and involvement of school, parents and communities) (98-100), causal assumptions and true effects are often hard to be determined by synthesising results from these studies (e.g., (40, 144, 167)).

Despite these limitations, this review met rigorous systematic standards by following best practice using PRISMA. It strengthens the existing evidence by conducting quality assessment, considering study quality when summarising results, and analysing the direction and strength of findings (96). In conjunction with perceived physical environments and sociodemographic characteristics, social factors were examined. The current review also re-identified the domain and category (Table 3, p. 30) of each finding from the original studies. This approach may result in refining the synthesis and consistency of findings across studies reviewed.

2.5 Conclusions

This review builds on existing systematic reviews by providing additional evidence for social factors, implementing quality appraisal, summarising individual variables to well-defined categories, and highlighting findings in view of study quality and directions. Most of the studies included were cross-sectional and conducted in the Unites States and Australia. Approximately 19% of the studies were rated as moderate quality and the remaining were rated as weak. There is a need for the improvement of study quality by using robust sampling methods, validated measures for the specific population, and blinding methods. Appropriate statistical analyses with adequate controlling for confounders and clustering are essential. Positive associations were found for AST with perceptions of safety, walkability, and neighbourhood social interaction. Inverse relationships were found for perceived travel distance and time, the diversity of land use mix, and household education and car ownership. Inconsistent findings were identified for walking and cycling infrastructure and neighbourhood socioeconomic status. Generally insufficient findings were reported in the domain of social characteristics. Future research should consider the importance of perceptions of the physical environment and elements of the social environment associated with school travel behaviour. Furthermore, the application of a socio-ecological model with a multidisciplinary approach can bring new insights into the complex structure of school travel behaviour.

Chapter 3 Research Philosophy, Theory, Methodology and Methods

Findings from Chapter 2 and Appendix A provided the platform for developing the empirical chapters of this thesis, including the identification of key constructs, variables, measures, and analyses. This chapter describes the research philosophy, theory, methodology and methods employed in subsequent chapters. First, philosophical foundations of the research, including theoretical elements and definition of terminology, are described and linked with the methodology (3.1 Research Philosophy and Paradigm). Next, theoretical elements adopted in the research are outlined (3.2 Objectivism and Post-positivism: How I See the World as a Researcher). Thereafter, existing theories, models, and frameworks for children's school travel behaviour are explored to establish a new theoretical basis that underpins the research, entitled the C-STBM (3.3 Theoretical Approaches to Children's School Travel Behaviour). The principles of survey methodology and quantitative research methods are then outlined (3.4.1 Survey research, questionnaires and structured interviews). Finally, research design (3.4.2 Research design), sampling methods (3.4.3 Sampling), the choice of data collection methods (3.4.4 Data collection methods) and statistical analyses (3.4.5 Data analysis) in relation to the NfAK study (the dataset used for this research) and the C-STBM are detailed. A novel child-centred approach of online participatory mapping (softGIS) survey for use to measure chldren's school travel behaviour are highlighted in 3.4.4 Data collection methods.

3.1 Research Philosophy and Paradigm

Any research process embraces four elements: *epistemology*, *theoretical perspective*, *methodology*, and *methods* (168). *Epistemology* refers to "the theory of knowledge embedded in the theoretical perspective and thereby in the methodology"; *theoretical perspective* means "the philosophical stance informing the methodology and thus providing a context for the process and grounding its logic and criteria"; *methodology* is defined as "the strategy, plan of action, process or design lying behind the choice and use of particular methods and linking the choice and use of methods to the desired outcomes"; and *methods* indicate "the techniques or procedures used to gather and analyse data related to some research question or hypothesis" (p. 3) (168). These four elements are related to each other, as illustrated in Figure 11 (p. 51). Although conceptual differences exist between ontology (i.e., the nature of existence, *what is*) and epistemology (i.e., the nature of knowledge, *how we know what we know*), ontology is not expressively discussed in Figure 11. Ontology often implies epistemology, and therefore ontological issues can be explained by the epistemological stance.

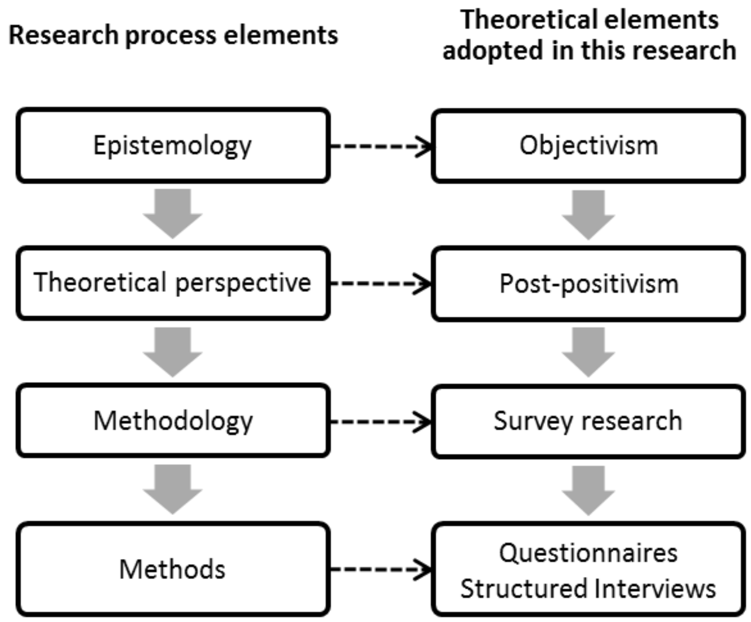


Figure 11. Structure of how this thesis fits with the four research process elements. Adapted from "The Foundations of Social Research: Meaning and Perspective in the Research Process," by M. Crotty, 1998, p. 4, 6.

3.2 Objectivism and Post-positivism: How I See the World as a Researcher

My epistemological stance is objectivism which views the non-peopled world as a meaningful reality independent of any human consciousness, and so the researcher discovers objective truth (168). Positivism, a term coined by Auguste Comte, is a theoretical perspective which underpins objectivism (168, 169). Positivism grounds two assumptions. First, knowledge (e.g., facts, evidence) is built on through methodologies, such as evidence-based practice (i.e., Chapter 2 and Appendix A) (169). Second, research is theory-driven and aims to test theory using the data (i.e., a deductive approach) rather than developing new theory emerged from the data (i.e., an inductive approach), where social reality is assumed to follow pre-existing patterns or order (i.e., Chapter 5) (159, 169). Post-positivism advocated by Karl Popper, Thomas Kuhn, and Paul Feyerabend holds these positivist fundamental assumptions ('the absoluteness of objectivity'), but recognised the value of subjective perceptions (168, 169). The methodology employed in the current research is non-experimental survey research (3.4.1 Survey research, questionnaires and structured interviews). Given that survey research embraces, to some extent, 'subjective' aspects of the experiences of people, post-positivism is an appropriate theoretical perspective for this research. In survey research, questionnaires and structured interviews are utilised to collect and analyse data. Further detail of the research methodology and methods is provided in 3.4 Methodology and Methods.

3.3 Theoretical Approaches to Children's School Travel Behaviour

"The best theory is informed by practice; the best practice should be grounded in theory" (170). The post-positivist view of research is deductive and driven by theory (159). A deductive approach involves the process of identifying theory, defining hypotheses, collecting data, discovering findings, confirming or rejecting hypotheses, and revising theory (159). The terms theory, model, and framework are often used interchangeably regardless of their distinctive meanings (171). In this research, the term *conceptual model* was used to denote a model explaining a phenomenon by describing the relationship between constructs/domains (i.e., a collective form of variables; e.g., physical/built environment) and variables (i.e., items constituting a construct; e.g., distance to school) (171). Numerous conceptual models for active travel among adults and children have been developed across different fields of research including transportation/urban planning, environmental psychology, and physical activity/public health (32).

Main conceptual models for active travel in the field of transportation and urban planning involve the economic consumer theory (32, 172, 173), the 3Ds (i.e., density, diversity, design) (174) and the 3Ds+R (i.e., destinations, distance, density, route) (175), the human activity framework (176-178), and the theory of planned behaviour (179). The economic consumer theory in which a mode choice is viewed as the economic choice process has been commonly utilised in transportation engineering (32). This theory solely focuses on the generalised costs related to a trip and the characteristics of the origins and destinations (32). The 3Ds and the 3Ds+R have been introduced in urban planning, and incorporate built environment attributes (e.g., density) into the value of travel mode (174, 175). The human activity framework conceptualises activity-travel patterns and interactions of the child and household in space and time (e.g., trip-chaining) in relation to built environment attributes and the child's/household characteristics, environmental preferences and constraints (176-178). Despite the potential methodological challenges of measuring a child's/household's activity-travel patterns and interactions (32), a few studies have investigated the impact of the household activity-travel patterns and interactions on children's AST (177, 180, 181). To understand the linkage of an individual's beliefs and travel behaviour, the theory of planned behaviour (i.e., reasoned action approach) hypothesises that the individual's attitudes, subjective norms and self-efficacy (i.e., perceived behavioural control) predict his/her travel behaviour through intention. The theory of planned behaviour has been broadly applied across different disciplines such as environmental psychology and physical activity/public health (32).

In environmental psychology, the human-environment interaction explains travel behaviour through the basic emotional process from a neuropsychological lens (182, 183). The basic emotional process involves four steps: activation, orientation, evaluation and control which is influenced by physical and social environment as well as individual characteristics (182, 183). All the above conceptual models are designed for active travel among adults and children from various angles in transportation/urban planning and environmental psychology. This research broadly aims to promote children's health including physical, psychological and social wellbeing, and to contribute to environmental and policy changes and population-wide improvement of children's AST. Therefore, the most appropriate conceptual model for understanding children's school travel behaviour was determined from a body of empirical research in the field of physical activity and public health as described below.

3.3.1 Socio-ecological model

A large number of conceptual models have been identified through review and research articles within the scope of understanding children's travel behaviour including the behavioural economics, the social cognitive theory and the socio-ecological model, as outlined in Table 5 (pp. 56-62) (24, 32, 49, 60, 88, 119, 140, 141, 163, 184-195). Behavioural economics, compared with the economic consumer theory, outlines the decision-making of travel behaviour in response to the circumstances of a given situation, for instance, the availability of alternatives, the behavioural cost, the involvement of reinforcer or reward, and the time of choosing and receiving the alternative or reinforcer/reward (32, 188, 196). Social cognitive theory conceptualises reciprocal relationships between personal factors, environmental influences and travel behaviour in which an individual learns through observing others' travel behaviour (i.e., observational learning) (197). Both behavioural economics and social cognitive theory (as well as theory of planned behaviour), however, do not incorporate a broader range of influences on children's travel behaviour at multiple levels. The most commonly used conceptual model is a socio-ecological model which identifies multiple layers of constructs that may have a direct or indirect effect on a particular behaviour (e.g., Figure 12, p. 54) (29). However, variance exists among socio-ecological models in terms of conceptualisation of the constructs (e.g., Chapter 2, Ikeda et al. (44)).

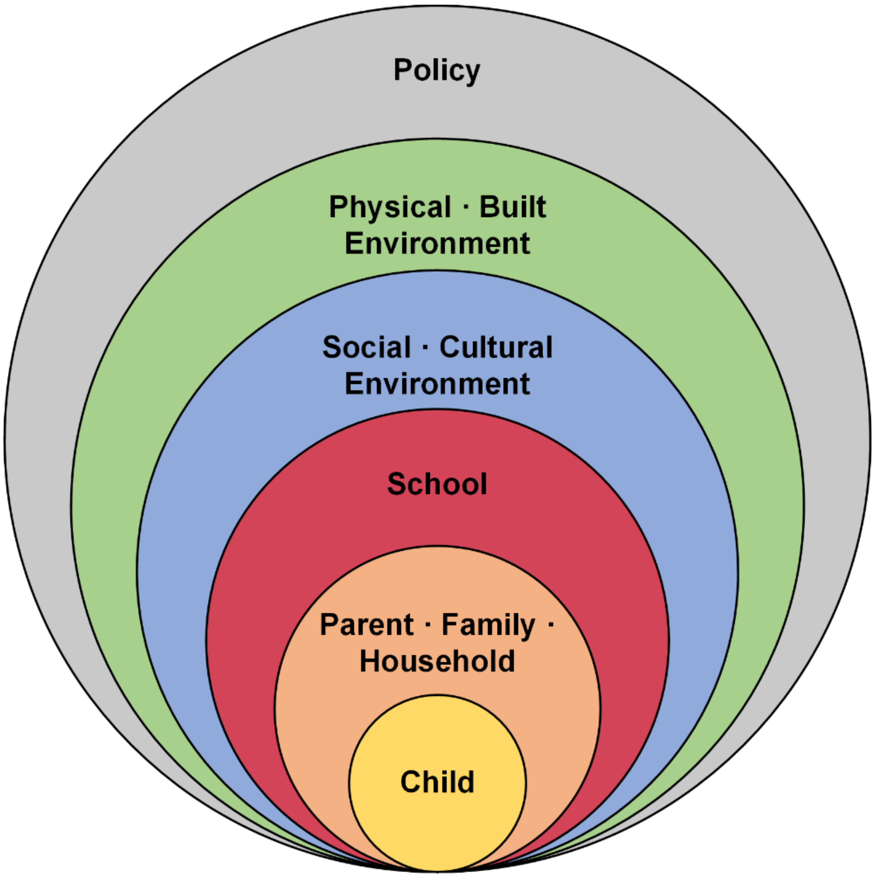


Figure 12. Socio-ecological model.

A number of conceptual models based on a socio-ecological model exist that are: (i) designed for children and youth as target populations, (ii) have active travel (e.g., walking and cycling) as a target behaviour, and (iii) include school as a destination (e.g., travel to school) (32, 49, 60, 88, 119, 163, 184-187, 189, 190, 194, 198). Key established conceptual models that encompass these three factors are detailed below (32, 49, 60, 163).

Table 5 Summary of conceptual models for children's school travel behaviour

Author	Conceptual Model [specified in the article]			Construct/Domain [specified in the current research]							
	Name	*Source*	*Construct/Domain*	*Child*	*Parent/Family/ Household*	*School*	*Social/Cultural Environment*	*Physical/Built Environment*	*Policy*	*Mediation*	*Moderation*
				Construct/Domain (examples of subcategories and/or variables) [specified in the article]							
Review											
Garrard (189)	Socio-ecological model*	(199)	Intra-individual factors; Physical (natural and built) environment; Social/cultural environment; Policy/regulatory environment	Intra-individual factors (age, sex)	Intra-individual factors (travel behaviour)	-	Social/cultural environment (economic equality, social norms)	Built environment (residential density, infrastructure, walkability index)	Policy/regulatory environment	-	-
Ginja et al. (195)	Behavioural Ecological Model (BEM)*	(200, 201)	Individual level; Local level; Community level; Social/cultural level	Individual level (independent mobility)	Individual level (car ownership, encouragement)	Local/community level (school encouragement, AT initiatives)	Social/cultural level (social encouragement, equality)	Local/community level (walkability index, urban areas)	Local/community level (policy, laws, media)	-	-
McMillan (49)	Conceptual framework of a child's travel behaviour*	(202, 203)	Parental decision making; Mediating factors (psychosocial factors: real/perceived neighbourhood safety, real/perceived traffic safety, socioeconomic factors: household travel options); Moderating factors (social/cultural norms, parental attitudes, sociodemographics); Urban form	-	Parental decision making	-	-	Urban form (block length, street lighting)	-	Neighbourhood safety, traffic safety, household travel options	Social/cultural norms, parental attitudes, sociodemographics

Author	Conceptual Model [specified in the article]			Construct/Domain [specified in the current research]							
	Name	*Source*	*Construct/Domain*	*Child*	*Parent/Family/ Household*	*School*	*Social/Cultural Environment*	*Physical/Built Environment*	*Policy*	*Mediation*	*Moderation*
				Construct/Domain (examples of subcategories and/or variables) [specified in the article]							
Mitra (32)	Behavioural model of school transportation (BMST)*	(49, 197, 204, 205)	Child (self-efficacy, attitudes, physical and cognitive developments); Household (travel behaviour, attitudes, sociodemographics); Urban environment (urban spatial structure, built environment, social environment); External influences (natural environment, policy); Mediators (proximity to school, traffic/personal safety, street connectivity, pedestrian comfort/attractiveness, social capital)	Child (self-efficacy, attitudes, physical and cognitive developments)	Household (sociodemographics, travel behaviour, attitudes)	External influences (school policy)	Urban environment (social environment)	Urban environment (urban spatial structure, built environment)	External influences (national/regional policy)	Proximity to school, traffic/personal safety, street connectivity, pedestrian comfort/attractiveness, social capital	-
Panter et al. (88)	Conceptual framework for the environmental determinants of active travel in children*	(49)	Individual factors (youth characteristics and attitudes, parental characteristics and attitudes); Moderating factors (age, sex, distance to school); Physical environment factors (attitudes of neighbourhood, school and surroundings, and route); External	Individual factors (youth characteristics, youth attitudes)	Individual factors (parental characteristics, parental attitudes)	-	Physical environment factors (social interaction)	Physical environment factors (urban form, AT facilities)	External factors (government policy)	-	Age, sex, distance to school

Author	Conceptual Model [specified in the article]			Construct/Domain [specified in the current research]							
	Name	*Source*	*Construct/Domain*	*Child*	*Parent/Family/ Household*	*School*	*Social/Cultural Environment*	*Physical/Built Environment*	*Policy*	*Mediation*	*Moderation*
				Construct/Domain (examples of subcategories and/or variables) [specified in the article]							
			factors (weather, cost, policy);								
Pont et al. (24)	Analysis grid for environments linked to obesity (ANGELO) framework	(206)	Social/cultural environment (community/societal attitudes/values/beliefs); Physical (natural and built) environment; Political environment (power structures, laws, rules, regulations); Economic environment (direct/indirect cost)	-	-	-	Socio-cultural environment (community/societal attitudes, values or beliefs)	Physical environment (footpaths/cycle ways, weather)	Political environment (laws, rules, regulations)	-	-
Pont et al. (60)	Model of children's active travel (M-CAT)*	(24, 205, 207)	Objective (child, parent and family) characteristics; Child perceptions (parent, attitudes/beliefs/values, environment); Parental perceptions (child, attitudes/beliefs/values, environment); Objective (physical, economic, political-socio-cultural) environment	Child characteristics (age, sex, ethnicity, self-efficacy)	Parent/family characteristics (marital status, income, family size)	Political-socio-cultural environment (school policy)	Political-socio-cultural environment (friend/peer/community/societal attitudes, values or beliefs)	Physical environment (street connectivity, distance, topography)	Political-socio-cultural environment (local/state /national policies)	-	-
Sirard and Slater (163)	Ecological and cognitive active commuting	(49, 197)	Parent level (perceived physical environment, perceived social context, children's	Parent/family level (children's influence, sociodemographics)	Parent/family level (sociodemographics, resources)	Policy level (school policy)	Neighbourhood level (perceived social context)	Neighbourhood level (objective/perceived physical environment)	-	Psychosocial mediators (self-efficacy)	-

Author	Conceptual Model [specified in the article]			Construct/Domain [specified in the current research]							
	Name	*Source*	*Construct/Domain*	*Child*	*Parent/Family/ Household*	*School*	*Social/Cultural Environment*	*Physical/Built Environment*	*Policy*	*Mediation*	*Moderation*
				Construct/Domain (examples of subcategories and/or variables) [specified in the article]							
	(ECAC) framework*		influence, sociodemographics, resources, psychosocial mediators); Neighbourhood level (objective physical environment, objective social context); Policy level (transportation and urban planning, school)								
Study											
Broberg and Sarjala (184)	Behavioural model of school transportatio n (BMST)*	(32)	-	(independent mobility, age, sex)	(car ownership)	-	(social capital)	(distance to school, traffic/personal safety, connectivity, comfort/attractiven ess)	-	-	-
Carlson et al. (185)	Ecological models of behaviour*	(208)	-	Demographics (age, sex, ethnicity); Psychosocial constructs (self-efficacy, rules)	Demographics (education, employment)	-	Psychosocial constructs (peer/parent social support, parent modelling)	Psychosocial constructs (perceived barriers); Objective/perceive d neighbourhood environment (distance to school, residential density, street connectivity, safety)	-	-	-

Author	Conceptual Model [specified in the article]			Construct/Domain [specified in the current research]							
	Name	*Source*	*Construct/Domain*	*Child*	*Parent/Family/ Household*	*School*	*Social/Cultural Environment*	*Physical/Built Environment*	*Policy*	*Mediation*	*Moderation*
				Construct/Domain (examples of subcategories and/or variables) [specified in the article]							
Curtis et al. (186)	Socio-ecological model*	(32, 88, 209)	-	Sociodemographics (age, sex)	Independent mobility (parental licence)	-	Independent mobility (social norms)	Built environment (distance to school, residential density, street connectivity)	-	-	-
D'Haese et al. (187)	Socio-ecological model*	(88)	-	-	Sociodemographics (age, sex, education)	-	-	Environment perceptions (residential density, street connectivity, accessibility)	-	-	-
Faulkner et al. (188)	Behavioural economics	(196)	Availability of alternatives; Behavioural cost/work of access; Reinforcement/rewards of behaviour	-	-	-	-	-	-	-	-
Guliani (190)	Behavioural model of school transportation (BMST)*	(32)	-	Household composition (age, sex)	Household composition (car ownership, employment, income)	-	-	Urban environment (distance to school, street connectivity)	-	Parental perceptions (traffic safety, neighbourhood walking environment)	-
Hume et al. (119)	Socio-ecological model*	(208)	-	Individual level factors (height, weight, attitudes)	Sociodemographics (education)	-	Social factors (neighbourhood social environment)	Physical environment factors (safety, crossings, footpaths)	-	-	-

Author	Conceptual Model [specified in the article]			Construct/Domain [specified in the current research]							
	Name	*Source*	*Construct/Domain*	*Child*	*Parent/Family/ Household*	*School*	*Social/Cultural Environment*	*Physical/Built Environment*	*Policy*	*Mediation*	*Moderation*
				Construct/Domain (examples of subcategories and/or variables) [specified in the article]							
Kemperman and Timmermans (191)	Conceptual framework of active travel behaviour of children*	(210)	-	Individual characteristics (age, sex)	Household characteristics (socioeconomic status, car ownership, household size)	-	Social environment (social cohesion)	Physical environment (infrastructure, urbanisation); Social environment (safety)	-	-	-
Lu et al. (211)	Social cognitive theory (SCT)	(50)	-	Previous experience, emotional states, social persuasion, social modelling	Parent self-efficacy	-	Social economic disadvantage	Environment constraints	-	Child self-efficacy	-
Murtagh et al. (193)	Theory of planned behaviour	(212)	Intention; Attitude; Subjective norm; Perceived behavioural control	-	-	-	-	-	-	-	-
Murtagh et al. (192)	Bio-ecological model	(213)	-	Individual level (sex, exercise)	Family level (income, education)	School level (enrolment size)	-	School level (distance to school); Neighbourhood level (neighbourhood safety, urban/rural status)	-	-	-
Robertson-Wilson et al. (194)	Socio-ecological model*	(208)	-	Demographics (age, sex, height, weight); Behavioural (physical activity); Psychological	-	-	Psychological (parent encouragement)	School level (rural/urban/suburban status, weather)	-	-	-

Author	Conceptual Model [specified in the article]			Construct/Domain [specified in the current research]							
	Name	*Source*	*Construct/Domain*	*Child*	*Parent/Family/ Household*	*School*	*Social/Cultural Environment*	*Physical/Built Environment*	*Policy*	*Mediation*	*Moderation*
				Construct/Domain (examples of subcategories and/or variables) [specified in the article]							
				(perceived athletic ability)							
Yu and Zhu (140)	Socio-ecological model*	(134, 142, 143, 214, 215)	-	Personal factors (age, sex, ethnicity)	Personal factors (education, car ownership, walking barriers, positive attitudes)	Social factors (school bus availability)	Social factors (positive peer influence)	Personal factors (residential self-selection); Social factors (safety concern); Built environment factors (distance to school, sidewalk quality)	-	-	-
Yu and Zhu (141)	Socio-ecological model*	(134, 140, 215-217)	-	Personal factors (age, sex, ethnicity)	Personal factors (education, car ownership)	Social factors (school bus availability)	Social factors (positive peer influence)	Social factors (safety); Built environment factors (distance to school, traffic safety, walkability)	-	Parental attitude (barriers, enjoyment)	-

AT = active travel. *Based on socio-ecological model.

3.3.2 McMillan's conceptual model, Ecological and Cognitive Active Commuting (ECAC) framework, and Model of Children's Active Travel (M-CAT)

McMillan (49) conceptualised a child's travel behaviour as a result of parental decision making processes. McMillan's conceptual model posits that psychosocial and socioeconomic factors are considered as mediators, and the built environment indirectly influences parental decision making around their child's school travel modes through these mediators (49) (see Table 5). The strength of the association between the mediators and parental decision making can vary depending on moderating factors such as parental attitudes, social norms, and sociodemographic variables (e.g., age, sex) (49). McMillan's conceptual model, however, does not incorporate a child's role in the travel mode decision making process. Although parents and caregivers play a vital role in decision making around children's school travel, it is also important to consider the child's viewpoints. Based on McMillan's conceptual model, Sirard and Slater (163) developed the Ecological and Cognitive Active Commuting (ECAC) framework which also incorporates constructs commonly included in the socio-ecological model, such as policy, physical environment, and social context. The ECAC postulates that all constructs, including children's perceptions, are indirectly associated with children's school travel through parents' cognitions (i.e., psychosocial mediators). In contrast, Pont et al. (60) proposed the Model of Children's Active Travel (M-CAT) in which objective and perceived elements interactively affect the decision making process of the parent and child. Despite the M-CAT's consideration of child-centred constructs, the explanation of directions and relationships between constructs (i.e., physical, economic, and political-socio-cultural environments, characteristics of child and parent, and child and parent perceptions) and relationships between variables (e.g., perceptions of environment and child, and attitude) are indefinite. While the M-CAT is thorough, the structure of children's behavioural processes, particularly child-household dynamics, and the influence of policy and social environments remain unclear. Panter et al. (88) provided a more detailed conceptual model by incorporating child characteristics and attitudes as well as household environment factors, calling these "individual factors". The built environment (e.g., neighbourhood, destination and travel route), external factors (e.g., weather, cost, and policy), and moderators (e.g., age, sex, and distance to destination) are also identified as main constructs (88). More recently Mitra (32) outlined a conceptual model for children's school travel behaviour, entitled the Behavioural Model of School Transportation (BMST). The BMST filled gaps in the previous four conceptual models

(49, 60, 88, 163) by incorporating child and household characteristics and insights, and comprehensively and explicitly detailing direct and indirect relationships with children's school travel behaviour.

3.3.3 Behavioural Model of School Transportation (BMST)

The BMST combines a socio-ecological model (i.e., policy, natural, built and social environments, household, child), a household active-travel approach (218), and McMillan's conceptual model (e.g., correlates between neighbourhood built environment and children's school travel behaviour) (49). In the BMST, school travel behaviour is conceptualised as having two components: travel mode and accompaniment (i.e., independent versus escorted) (32). To predict, explain and change school travel behaviour, Mitra (32) identified four domains: external influences, the urban environment, the household, and the child (see Figure 13).

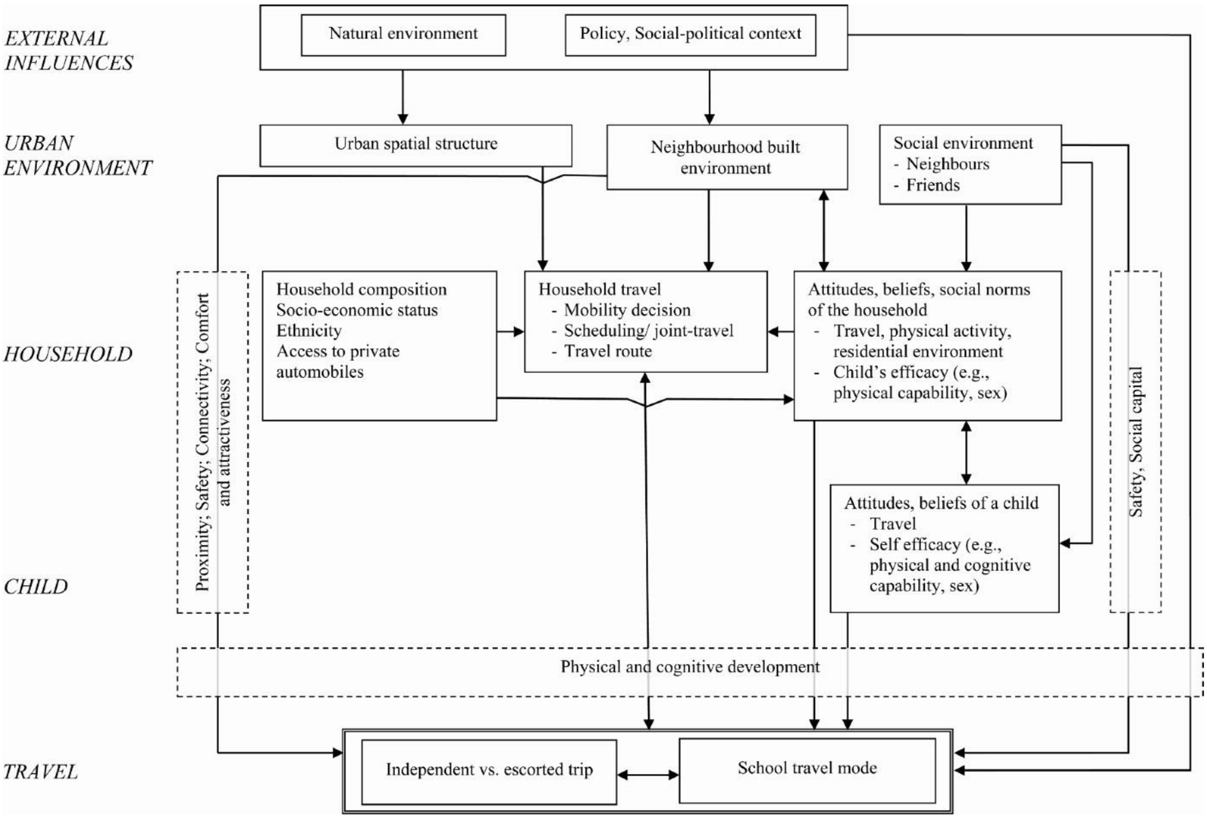


Figure 13. Behavioural Model of School Transportation (BMST). Mitra R. Independent mobility and mode choice for school transportation: A review and framework for future research. Transp Rev. 2013;33(1):21-43. Figure 1, A behavioural model of school transportation; p. 33. Copyright 2013 by Taylor & Francis.

External influences denote the natural environment (e.g., topography/slope and weather) and policy (e.g., national/local government and school policies and programmes) which are directly linked with school travel behaviour and the neighbourhood environment (32, 88, 163). The urban environment refers to urban spatial structure (i.e., regional distribution of destinations), neighbourhood built environment (i.e., land use mix, transportation network, and urban design), and the social environment (i.e., sense of community, social cohesion) (32). The urban spatial structure and the neighbourhood built environment directly influence a household's travel patterns (32). The neighbourhood built and social environments indirectly impact on school travel behaviour through five mediators: (i) proximity to school, (ii) street connectivity, (iii) comfort and attractiveness of the travel route, (iv) traffic and personal safety, and (v) social capital (32). Proximity, connectivity, comfort and attractiveness, and safety are associated with the neighbourhood built environment; whereas the social environment is conceptualised as being related to safety and social capital. Within the household, three factors (i.e., socio-demographic characteristics, travel and activity patterns, and beliefs, attitudes and norms) are interrelated and influence school travel behaviour. Household beliefs, attitudes, and norms towards the child's school travel behaviour (e.g., child's autonomy and capability, perceived benefits and barriers, and neighbourhood self-selection) interact with the neighbourhood built environment and children's motivational factors such as beliefs and attitudes (e.g., self-efficacy and norms) towards their school travel behaviour. Both household factors and children's beliefs, attitudes, and norms are influenced by the social environment. In the BMST, a child's physical and cognitive development moderates the associations between various domains of influences and school travel behaviour.

Given the thorough contextualisation of, and systematic approach to, children's school travel behaviour, including multilevel influences (i.e., external influences, urban environment, household and child), the BMST can provide a comprehensive and appropriate conceptual model for children's school travel behaviour (see Table 5, pp. 56-62). The following section addresses how the BMST was developed and applied in the current research.

3.3.4 Modification of the Behavioural Model of School Transportation: Children's School Travel Behaviour Model (C-STBM)

In this research, a study-specific conceptual model was developed that drew from the BMST and the conceptual models designed by McMillan (49) and Panter et al. (88), namely the C-STBM, as depicted in Figure 14 (p. 67). Adaptations to the BMST were made based on the literature presented in Table 5, the systematic literature review presented in Chapter 2, and the systematic meta-analysis presented in Appendix A. Travel accompaniment (e.g., independent versus escorted) was not explicitly conceptualised in the C-STBM where instead the mode of travel to school was considered as the sole outcome of interest. Instead, independent mobility was considered as an independent variable as well as a potential mediator in the C-STBM. The word *beliefs* was used to denote cognitive constructs including attitudes, perceived norms, and self-efficacy (60, 88, 193). Children's school travel behaviour was considered to be directly and indirectly influenced by the school environment (i.e., school policies, AST programmes), the physical (i.e., natural and built) environment, the social environment, the household (i.e., characteristics and beliefs) and the child (i.e., characteristics and beliefs). The school environment was incorporated as an additional new construct to the C-STBM because of its significant and distinctive impact on the behaviour (32, 68, 155, 163, 198, 219-222). Despite its importance, the C-STBM tested in Chapter 5 was not able to incorporate the school environment in SEM due to the small number of schools (N = 19) (see 5.4.6 Strengths and limitations and 6.6.2 Limitations and possible solutions for future research directions). Along with child socio-demographics (e.g., age, sex, ethnicity), physical and cognitive development factors in the BMST were categorised as child characteristics in the C-STBM. Child characteristics were included as predictors of school travel behaviour as well as household and child beliefs (32, 49). Moreover, five mediators (i.e., proximity to school, street connectivity, comfort and attractiveness of the travel route, traffic and personal safety, and social capital) were incorporated in the physical and social environments.

The following null hypothesis was tested using the C-STBM: "There is no direct and/or indirect relationship between children's school travel mode and the school, physical and social environments, and the characteristics and beliefs of the household and the child". In the post-positivist view, the current research was undertaken based on a deductive approach in which the C-STBM was tested in terms of its applicability and practicality. The next section discusses the choice of methodology and methods, precisely how constructs of the C-STBM were measured and how the hypothesis was tested.

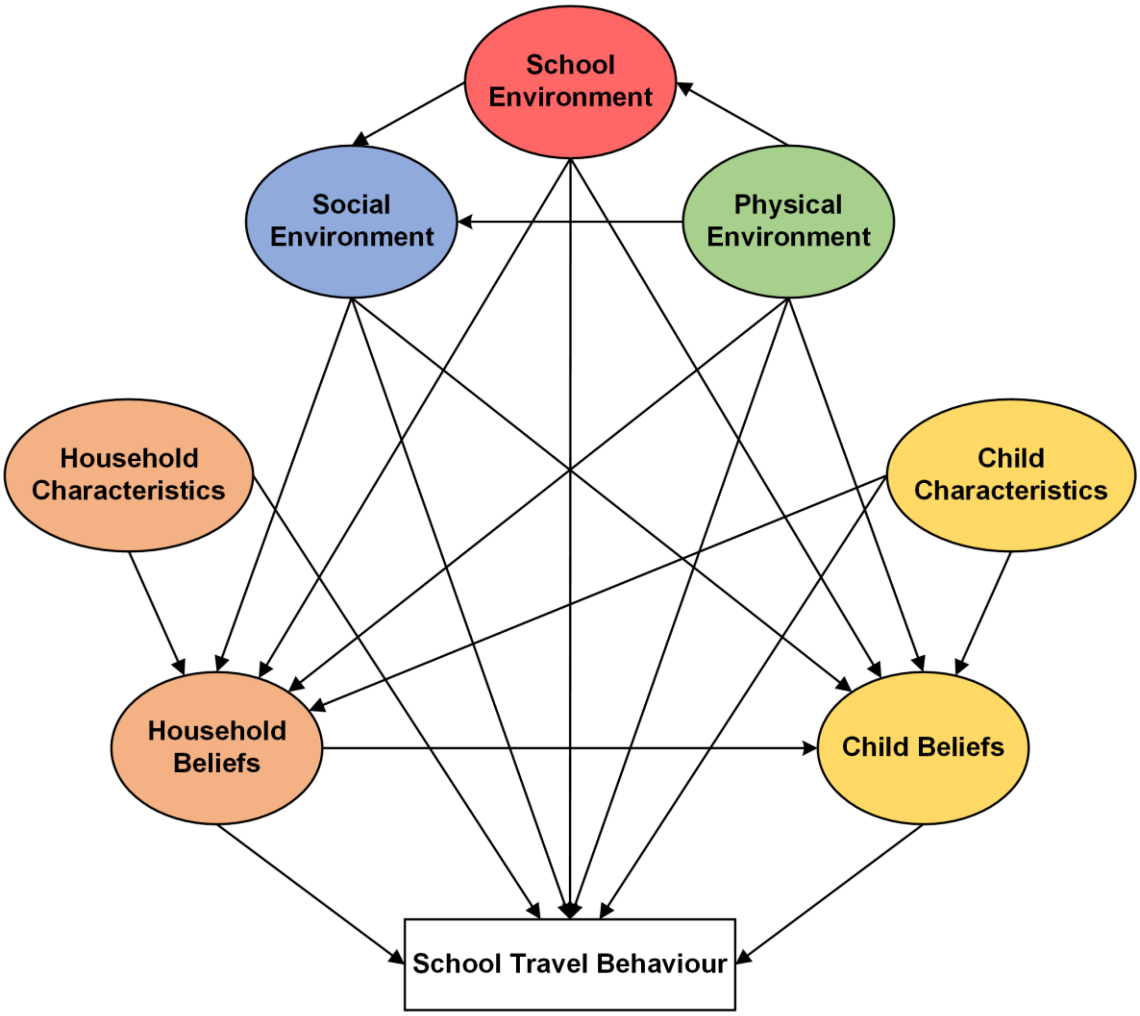


Figure 14. Children's School Travel Behaviour Model (C-STBM).

3.4 Methodology and Methods

The following section outlines the principles of survey methodology and quantitative research methods (3.4.1 Survey research, questionnaires and structured interviews). Next, a detailed account of the research design (3.4.2 Research design), sampling technique (3.4.3 Sampling), data collection methods (3.4.4 Data collection methods) and data analysis (3.4.5 Data analysis) utilised in the current research is provided. In Chapters 4 and 5, the description of the methods is briefly repeated.

3.4.1 Survey research, questionnaires and structured interviews

Survey research is generally concerned with an individual's characteristics, beliefs, experiences, and/or behaviours (223). In survey research, information is collected mainly by questionnaires or structured interviews, and analysed descriptively and statistically to examine patterns of associations between variables (159). The nature of survey research, therefore, leads to the choice of quantitative research methods as techniques to collect and analyse quantifiable data.

Survey research often employs self-completion questionnaires and structured interviews as research instruments (159, 223). Self-completion questionnaires are typically administered in person, by post, or through the internet (159). Structured interviews are commonly administered face to face or by telephone (e.g., computer-assisted telephone interview) (159).

Over the last few decades, the application of online surveys, including Web and email surveys, has flourished (159). Compared to their traditional counterparts (e.g., paper-and-pencil questionnaires), online surveys can be conducted economically with large sample sizes, and their design and structure can be made more attractive and efficient (159). Despite these advantages, issues of internet access, accessing representative samples, and participants' online skills remain challenges (159). If a standardised approach is used in survey interviews, whereby all interviewees are asked the same questions using the same modality, all individual replies can be aggregated (159).

Potential pitfalls of survey research include poorly worded questions, inconsistency in the way questions are asked, and the way data are recorded and processed (159). Self-report bias can also occur through issues with social desirability, comprehension, or inability to recall activities with accuracy (160, 161). With a view to minimising these errors, conducting a pilot study, particularly for a self-completion questionnaire, and testing the reliability and validity of measures are recommended (159). Along with quality control in measurement, limitations of causality and generalisation in survey research should be acknowledged (159). In a cross-sectional design, survey data are collected at a single point in time (159). Cross-sectional designs, compared to experimental designs, can imply relationships between variables but cannot infer causality between variables (159). In terms of generalisation, sampling error, whereby the selected sample does not represent the target population, can jeopardise external validity and the findings cannot be generalised beyond the specific research context (159).

Accordingly, issues of measurement, causality, and generalisation, as well as different sources of errors, in survey research are acknowledged and minimised as much as possible in the current research. To diminish the influence of bias and maximise the replicability of the research, the design, methods, and procedure of data collection and analyses employed in the current research are explicitly described in the following sections.

3.4.2 Research design

Neighbourhoods for Active Kids (NfAK)

The NfAK is a cross-sectional study taking a child-centred approach to measuring and describing relationships between the built environment and a range of children's activity behaviours and health outcomes (224). This study defined a 'neighbourhood' as the catchment area around a contributing primary (elementary) school (years/grades 1-6 where children were aged approximately 5-10 years) and a state co-education intermediate (middle/junior high) school (years/grades 7-8 where children were aged approximately 11-12 years). Schools were selected based on a matrix of school decile (i.e., a neighbourhood-level measure of socioeconomic status) (225), child-specific school walkability (39), and child-specific neighbourhood destination accessibility (NDAI-C) (226). Children aged 8-13 years (years 5-8), their parents/caregivers, and school representatives from 10 primary and nine intermediate schools across nine neighbourhoods were invited to participate. Information was collected using an online participatory mapping (softGIS) survey with children, a computer-assisted telephone interviewing (CATI) survey with parents/caregivers, GIS for physical environment attributes, and school stakeholder semi-structured interviews for school environment characteristics. Data collection was conducted between February 2015 and December 2016.

The role of the candidate (EI) in the Neighbourhoods for Active Kids study

The candidate (EI)'s main contributions to the NfAK study involved:

- Contributing to developing and testing the softGIS and CATI surveys and their protocols
- Developing questions relating to children's beliefs on traffic and neighbourhood safety relating to AST
- Pilot testing of the softGIS survey

- Leading and managing data collection at all 19 schools (including creating a data collection manual and training all research assistants for data collection)
- Cleaning the softGIS data, in particular checking visibly incorrect route to school data (e.g., incomplete routes, routes ended at non-school locations), calculating differences in distance between child's home location and the start point of their route to school, and identifying school entrance locations
- Testing and comparing route to school data

Current research in relation to the Neighbourhoods for Active Kids study

The current research is partially nested within the NfAK study with respect to research design, sampling techniques, and data collection methods. Therefore, part of the same data collected throughout the NfAK study was used for this research. This research, however, stood alone in terms of the research methodology (e.g., based on the C-STBM instead of a socio-ecological model for the NfAK study), the primary outcome (i.e., children's active travel to school, rather than active travel to neighbourhood destinations (i.e., to school and all other neighbourhood destinations, independent mobility and physical activity for the NfAK study), measures (traffic and neighbourhood safety) and the data analyses (e.g., SEM). In addition, the candidate (EI) led independent research comparing school travel route characteristics (i.e., special overlaps, physical environment attributes) between softGIS routes and the more common method of GIS-modelled shortest routes (Chapter 4).

3.4.3 Sampling

Selection criteria and sampling design

A two-stage cluster sampling method was employed: the sampling of neighbourhoods (as clusters) and the sampling of individuals (as population units). The first stage of the sampling procedure was stratified sampling of neighbourhoods. To increase the diversity in the population sample in terms of neighbourhood-level deprivation and geographic characteristics, a matrix encompassing intermediate (junior high) school decile (225), school walkability (39), and NDAI-C (226) was utilised. School deciles are an index of the neighbourhood socio-economic position calculated based on students' household income and crowding, and parents' occupation, educational qualification, and income support (225). Child-specific school walkability (39) and

NDAI-C (226) were calculated within a buffer of 2 km around each intermediate school using ArcGIS 10.2 (Environmental Systems Research Institute (ESRI), Redlands, California, USA). The indices of school walkability and NDAI-C were then divided into tertiles (high, medium, low). School deciles were reported as 1-10 (low deciles/high deprivation = 1-3, medium deciles = 4-7, high deciles/low deprivation = 8-10) (225). Primary schools were then selected based on the proximity to each intermediate school (Figure 15, p. 72). School representatives of each school were provided with information sheets for the principal and teachers, and their school invited to participate in the study (see Figure 15). In total, 19 schools (i.e., 10 primary and nine intermediate schools) across nine neighbourhoods were selected (one of the neighbourhoods included two primary schools due to the small sample size from each school).

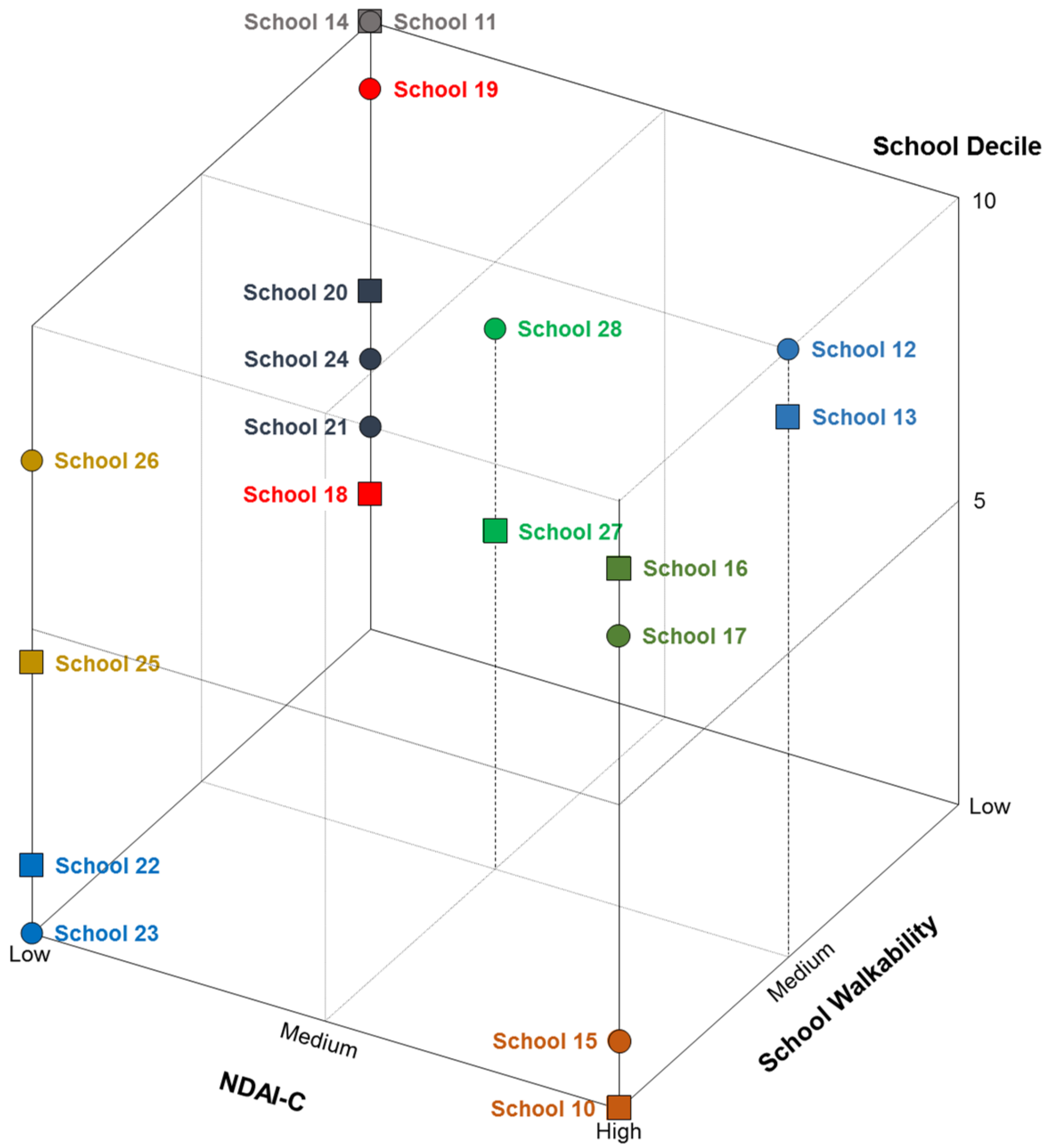


Figure 15. A matrix of school walkability, child-specific neighbourhood destination accessibility index (NDAI-C), and school decile in the stratified sampling of contributing primary and intermediate schools in Auckland, NZ. School walkability (x-axis) and NDAI-C (y-axis) are shown in tertiles (high, medium, low). School deciles (z-axis) are shown in 1-10 (low decile/high deprivation = 1-3, medium decile = 4-7, high decile/low deprivation = 8-10). Shapes represent school type (i.e., square = intermediate school, circle = contributing primary), and neighbourhoods are presented by different colour (N = 9).

In the second stage of the sampling, members of the NfAK research team visited students from years 5-6 in primary schools and years 7-8 in intermediate schools following consent from the school representatives. Verbal information about the study was given to students during class time, and written participant information sheets, child assent forms and parent consent forms were provided to students (Appendices C, pp. 258-260; D, pp. 261-262; E, pp. 263-264; F, p. 265). Students and teachers were given the opportunity to have any questions answered in person by the researchers at this time or by phone or email thereafter. The students were asked to return their signed assent and parent consent forms to the school within two weeks if they wished to participate in the study.

Sample size

The process of the school selection, participant recruitment and data collection is presented in Figure 16 (p. 74). A total of 2534 students from years 5-8 across 19 schools were invited. Excluding 1407 (55.5%) who did not assent/consent and 25 (1.0%) who were ineligible due to their absence during the data collection, 1102 (43.5%) students participated in the study. Data were also collected from 946 parents/caregivers of the students (85.8%). Sample size calculations showed that this research was able to detect meaningful and significant differences in school travel behaviour (i.e., active versus passive school travel) with power of 0.8 and significance level at $\alpha = 0.05$.

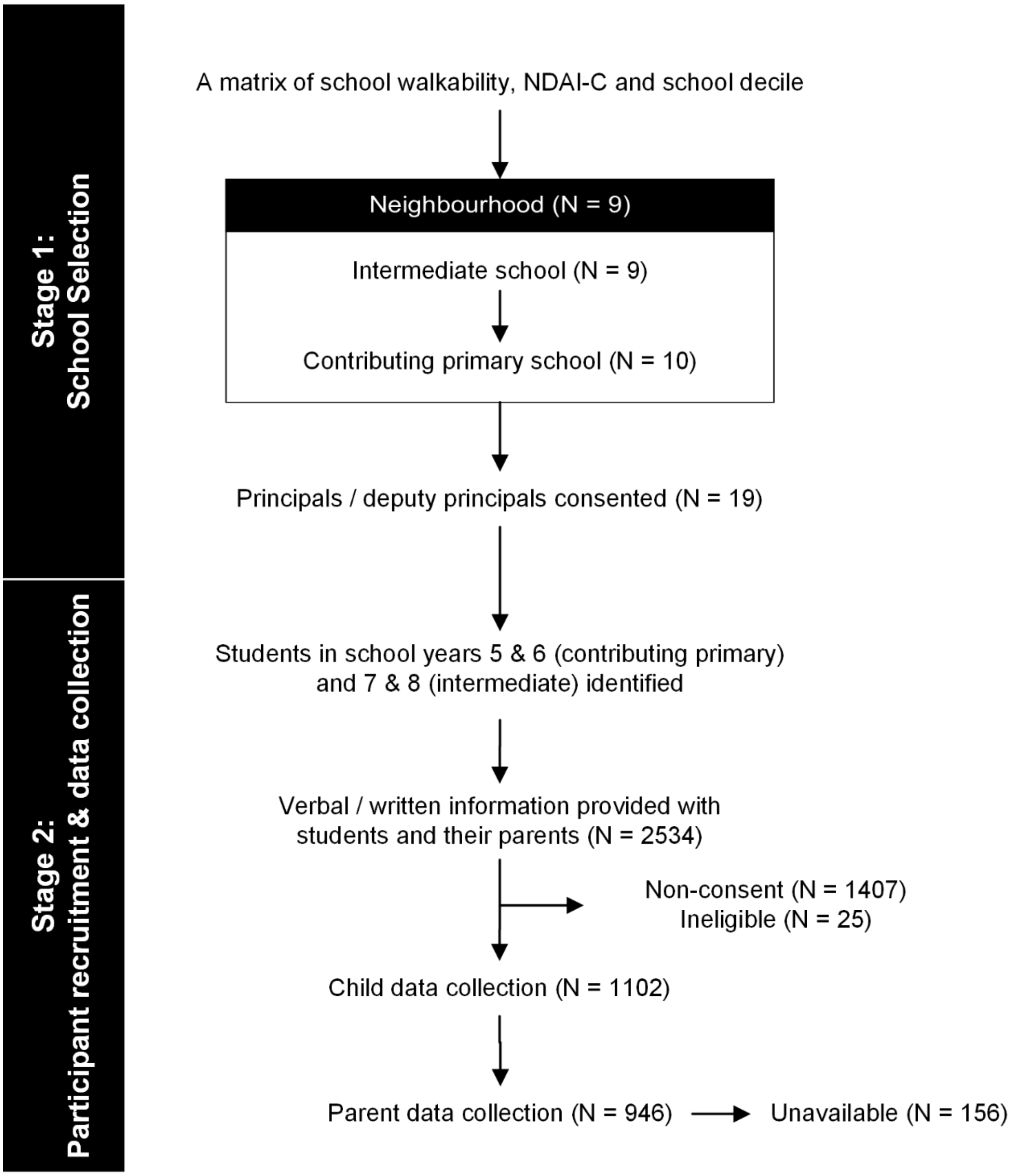


Figure 16. A flow chart of the school selection, participant recruitment, and data collection process. N = number. NDAI-C = child-specific neighbourhood destination accessibility index (NDAI-C).

Ethical considerations

Ethics approval to conduct the NfAK study was granted by the Auckland University of Technology Ethics Committee (AUTEC) on 3 September 2014, AUTEC Reference number 14/263 (Appendices B, pp. 256-257; C, pp. 258-260; D, pp. 261-262; E, pp. 263-264; F, p. 265; G, pp. 266-267).

3.4.4 Data collection methods

The current research under the NfAK study utilised four data collection methods to measure children's school travel behaviour to cover six of the seven constructs identified in the C-STBM (i.e., physical environments, social environments, household and child characteristics, and household and child beliefs), as illustrated in Figure 17. The seventh, the school environment (i.e., school policy, AST programmes) in the context of Auckland, NZ was described in Chapter 1 (1.4.1 Policy and practice). Each data collection method is described sequentially in order from the child to the physical environment as follows.

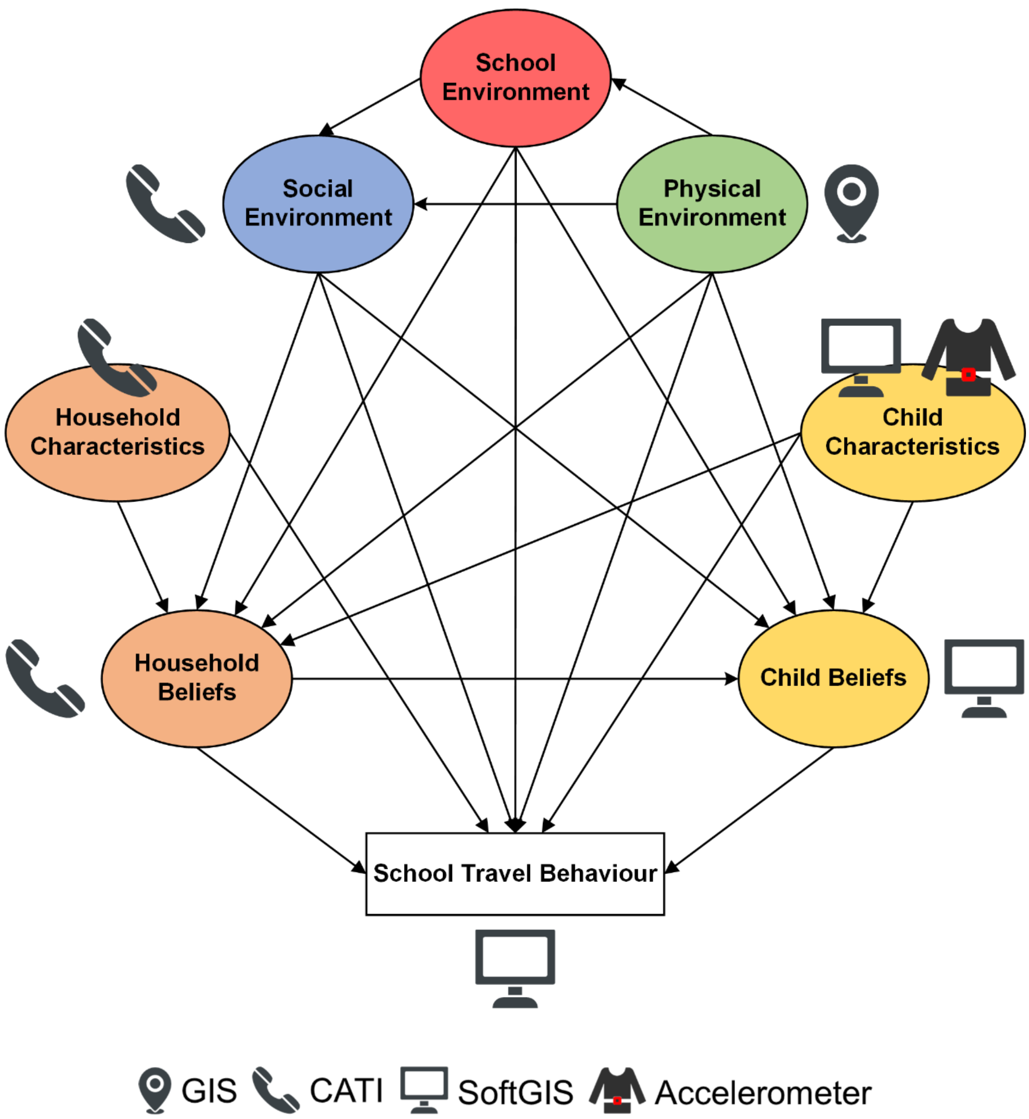


Figure 17. Methods of data collection utilised to measure each construct of the children's school travel behaviour model (C-STBM). CATI = computer-assisted telephone interview. GIS = geographic information systems.

Child measures

Protocols. Trained researchers visited the school during the school hours for up to four consecutive days to collect data with child participants. During this time, children completed the softGIS (i.e., online participatory mapping) survey with one-to-one researcher support, and were fitted with their accelerometer around their waist. Children were asked to wear the accelerometer during waking hours for the next seven consecutive days. A printed compliance log was provided to the children to record attachment and removal of the accelerometers daily. Researchers returned to the school to collect the accelerometers and compliance logs approximately eight days after they were distributed to the children. Children were provided with a small koha (gift; NZ$20 shopping mall vouchers) to acknowledge their contribution to the NfAK study.

Online participatory mapping (softGIS) survey. A softGIS survey (https://maptionnaire.com) which was developed at Aalto University in Finland by Professor Marketta Kyttä was utilised to measure children's home location, school travel behaviour (i.e., school travel mode and route), perceived safety of their neighbourhoods and traffic around their school, and independent mobility (see Figure 18, p. 78, for snapshots of the softGIS survey) (227). Compared to 'hard' (i.e., objective) GIS, the softGIS methodology is a type of public participation GIS which enables 'soft' (i.e., qualitative) characteristics of the mapping of environmental and social experiences at specific locations, as well as routes to destinations (e.g., school) (184, 227, 228). For example, this place-based approach using a softGIS survey was performed in Finland and Japan to explore children's urban experiences through identifying their meaningful places (i.e., affordances) and travel modes and accompaniment to these places (229). The methodology has been employed successfully in numerous studies with children and youth internationally (184, 229-231). Prior to implementation in the NfAK study, the softGIS survey was pilot tested with children across a range of ages, levels of cognitive abilities, and technical skill. Subsequently, adaptations to the survey and methods were made including: reducing or rewording items; adding an item to assess the confidence of children who used passive travel modes to map their route to school (due to difficulties of describing their route to school – where children felt they were unable to do this, this stage of the survey was skipped); and changing the researcher-student ratio from 1:4 to 1:1 (to aid comprehension and engagement). Better spatial mapping skills were also observed among children who walked or cycled to school (particularly without adult accompaniment) than those who were driven to school (232). Children were allowed to zoom in/out and change map view styles (‘Bing satellite’, ‘Roads and Terrain’ and ‘Google Hybrid’) in the online map. Specific measures relevant to the research presented in this thesis were:

- School travel mode: Children’s usual mode of travel to school was measured by asking “*How do you usually get to school?*” with responses being ‘walk’, ‘bike’, ‘scooter (non-motorised)’, ‘public bus, train or ferry’, ‘car, motorbike, scooter or taxi’, and ‘another way (e.g., skateboard)’.
- Home location: Children were asked to indicate, on the online map, their home. If a child had more than one home (e.g., separated parents, living part time with grandparents, etc.), they were asked to choose the house where they spent more time living or which was closer to the school (if spending their time living equally between the houses).
- School travel route: Children were asked to draw their usual route from home to school on the online map. If any shortcuts through parks or buildings were taken by the children, they were asked to go along these shortcuts to accurately capture their usual route to school. If any mistakes occurred during the mapping (e.g., missed a turn, took a wrong street), children were asked to restart a new route. Route data were manually cleaned and obviously incorrect routes were excluded from further analyses.
- Traffic safety: Children’s perceptions of traffic safety around their school was measured using two items (“*The roads around my school are busy with traffic before and after school*”, and “*The roads around my school are full of parked cars before and after school*”) with a 4-point Likert scale for responses (‘all of the time’, ‘most of the time’, ‘sometimes’, and ‘hardly ever/never’) (233). These two items were summed to the total traffic safety perception (Spearman’s $\rho = 0.29$, $p < 0.001$, indicating ‘weak’ correlation).
- Neighbourhood safety: Children’s perceived safety in their neighbourhoods was measured by two items (“*If I am out with an adult, I feel safe in my neighbourhood*” and “*If I am out without an adult, I feel safe in my neighbourhood*”) with a 5-point Likert scale for responses (‘all of the time’, ‘most of the time’, ‘sometimes’, ‘hardly ever/never’, and ‘do not go out with/without an adult in the neighbourhood’) (233). The summed score of two items was calculated for neighbourhood safety perception (Spearman’s $\rho = 0.18$, $p < 0.001$, indicating a ‘very weak’ correlation).

- Independent mobility: Children's independent mobility was assessed by three items ("*Are you allowed to cross main roads on your own?*", "*Are you allowed to go on local buses or trains or ferries on your own?*", and "*If you have a bicycle, are you allowed to ride it to go to places?*") with a dichotomous response ('yes' and 'no', including 'do not have a bicycle') (Cronbach's α = 0.85, indicating 'good' internal consistency) (234).

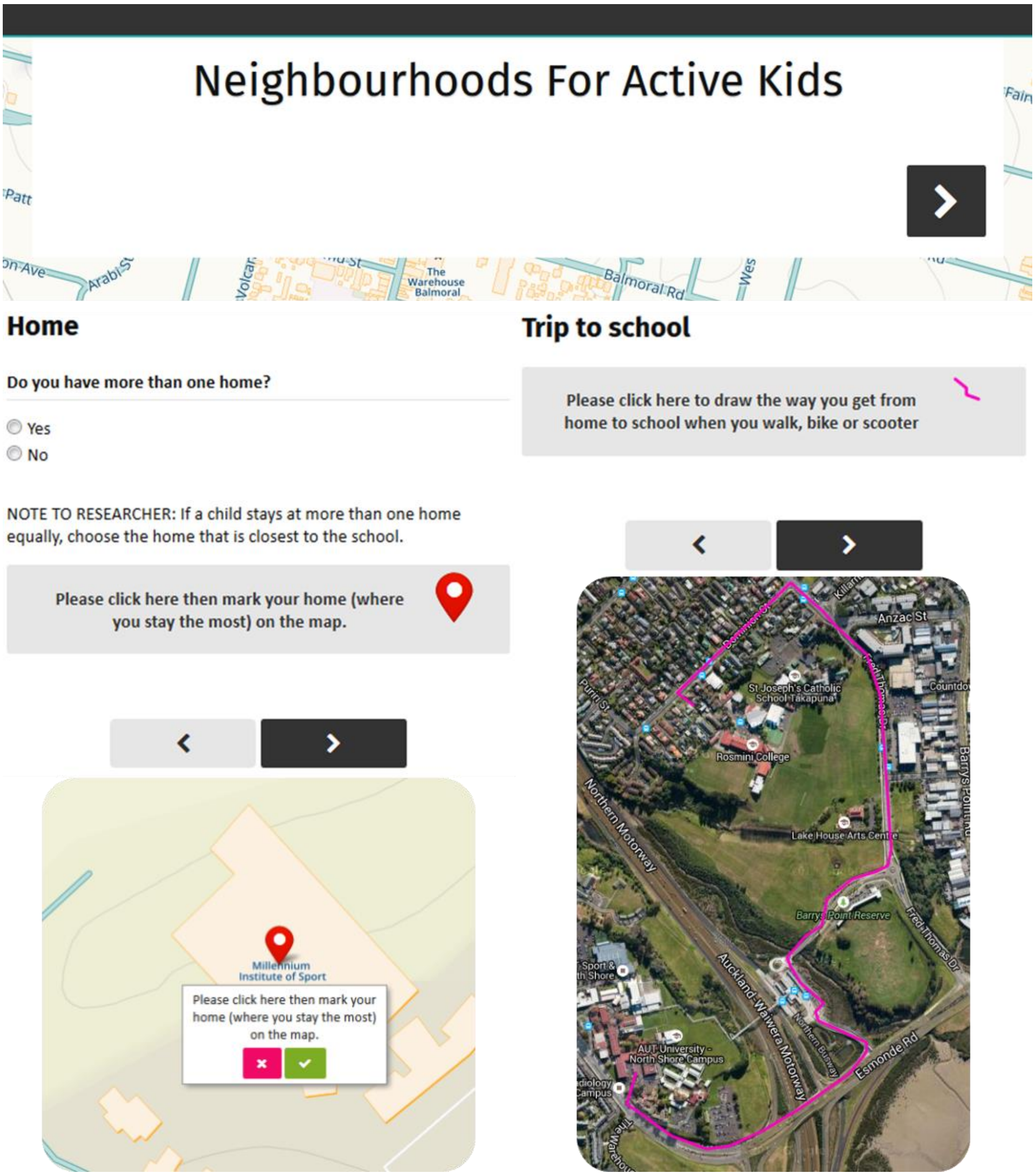


Figure 18. The softGIS survey platform utilised in the NfAK study.

Accelerometer. Physical activity was measured using Actigraph GT3X+ accelerometers (Actigraph, Pensacola, FL). In order to assess the level of physical activity during children's travel to school, the current research specifically utilised physical activity data during the 8:00am-9:00am commuting period on weekdays (Monday-Friday, excluding public holidays) (235). Raw data were collected at frequency of 30 Hz, and aggregated to a 30 second epoch using Actilife v6 (Actigraph, Pensacola, FL). Accelerometer cut-points (vertical counts/minute) provided by Evenson et al. (236) were utilised to classify time spent (in minutes) in sedentary and light, moderate, and vigorous physical activity. Non-wear time was classified as 60 minutes or more of consecutive zero counts (237).

A two-stage process was applied for inclusion in analyses. First, participants were included if they had at least three valid days; with a valid day having a minimum of seven hours of wear time (N = 1071) (238). Of these, participants with different numbers of valid mornings (i.e., 2, 3, 4, ≥ 5 days with at least 60 minutes of data between 8:00am-9:00am on each day) were compared in terms of characteristics of participants included and internal consistency. There were no statistically significant differences in children's school year, sex, and school travel mode between those having two, three, four, or five or more valid mornings (Table 6, pp. 80-81). Differences were found by ethnicity ($\chi^2 = 35.58$, $p < 0.01$), especially in NZ European and Pacific children ($p < 0.01$, data were not shown in Table 6) when ethnicity variables were dummy coded. Irrespective of the number of valid mornings, time spent in sedentary and physical activity (i.e., light, moderate and vigorous) between two randomly selected days were significantly correlated, indicating good internal consistency (Table 7, p. 81). Consequently, participants were required to have at least two weekdays with 60 minutes of data between 8:00am-9:00am for inclusion in analyses (N = 994) (Figure 19).

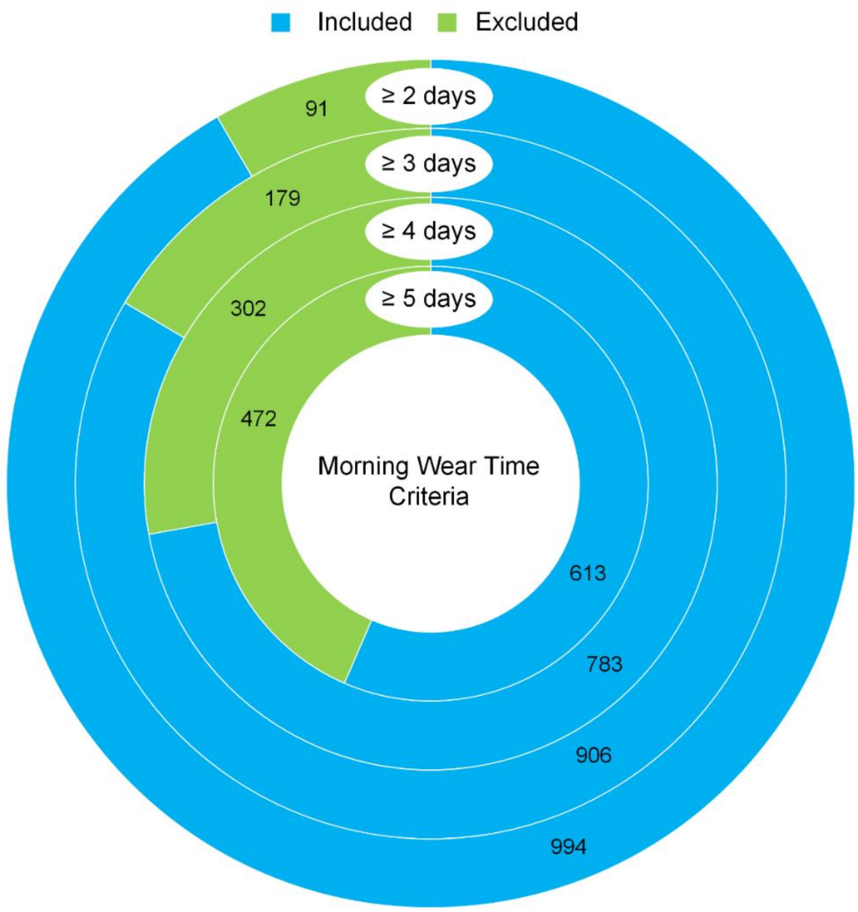


Figure 19. Number of child participants included and excluded for morning wear time criteria (N = 1085).

Table 6 Differences in child characteristics between two, three, four, and five or more valid mornings using chi-square tests (N = 969)

			Number of valid mornings*				Total	Chi-square tests
			2	3	4	≥ 5		
School year	Year 5	N	29	38	55	113	235	χ^2 = 11.14, df = 9, p = 0.27
		%	12.3	16.2	23.4	48.1	100.0	
	Year 6	N	37	47	73	97	254	
		%	14.6	18.5	28.7	38.2	100.0	
	Year 7	N	23	34	60	124	241	
		%	9.5	14.1	24.9	51.5	100.0	
	Year 8	N	26	42	62	109	239	
		%	10.9	17.6	25.9	45.7	100.0	
Sex	Male	N	67	72	112	215	466	χ^2 = 6.62, df = 3, p = 0.09
		%	14.4	15.5	24.0	46.1	100.0	
	Female	N	48	89	138	228	503	
		%	9.5	17.7	27.4	45.3	100.0	
Ethnicity	NZ European	N	32	59	107	221	419	
		%	7.6	14.1	25.5	52.7	100.0	

	Māori	N	17	24	25	55	121	$\chi^2 = 35.58$, df = 12, $p < 0.01$
		%	14.0	19.8	20.7	45.5	100.0	
	Pacific	N	27	25	46	43	141	
		%	19.1	17.7	32.6	30.5	100.0	
	Asian	N	12	19	34	54	119	
		%	10.1	16.0	28.6	45.4	100.0	
	Other	N	5	6	5	8	24	
		%	20.8	25.0	20.8	33.3	100.0	
School travel mode	Walk	N	44	49	86	155	334	$\chi^2 = 18.90$, df = 15, $p = 0.22$
		%	13.2	14.7	25.7	46.4	100.0	
	Bike	N	3	9	9	18	39	
		%	7.7	23.1	23.1	46.2	100.0	
	Scooter	N	5	5	4	16	30	
		%	16.7	16.7	13.3	53.3	100.0	
	Skateboard	N	2	1	1	1	5	
		%	40.0	20.0	20.0	20.0	100.0	
	Car	N	50	85	112	190	437	
		%	11.4	19.5	25.6	43.5	100.0	
	Public transport	N	11	12	38	63	124	
		%	8.9	9.7	30.6	50.8	100.0	

N = number. df = degrees of freedom. *60 minutes of data between 8:00am-9:00am on weekdays

Demographics. Child's school year (i.e. 5-8), sex (i.e., male, female) and ethnicity (e.g., NZ European, Māori, Pacific, Asian, Other) were reported by schools or their parents/caregivers via CATI.

Table 7 Correlations between randomly selected two days of time spent in sedentary and light, moderate, and vigorous physical activity across two, three, four, and five or more valid mornings using Spearman's rho (N = 969)

	Number of valid mornings*											
	2			3			4			≥ 5		
	N	*ρ*‡	*p*	N	*ρ*‡	*p*	N	*ρ*‡	*p*	N	*ρ*‡	*p*
Sedentary	115	0.40	<0.01	161	0.41	<0.01	250	0.42	<0.01	443	0.40	<0.01
Light	115	0.43	<0.01	161	0.36	<0.01	250	0.45	<0.01	443	0.48	<0.01
Moderate	115	0.48	<0.01	161	0.43	<0.01	250	0.37	<0.01	443	0.36	<0.01
Vigorous	115	0.47	<0.01	161	0.18	0.02	250	0.40	<0.01	443	0.31	<0.01

N = number. *60 minutes of data between 8:00 am - 9:00 am on weekdays.
‡Spearman's rho (correlation coefficient).

Household measures

Computer-assisted telephone interviewing (CATI) survey. A CATI survey was conducted with parents/caregivers of participating children approximately 1-2 weeks after the completion of data collection with the children at schools. The survey was delivered mainly in English (N = 935, 98.8%), but also in Chinese (N = 10, 1.1%) and Korean (N = 1, 0.1%) (other languages such as Samoan and Tongan were also available).

- Household characteristics: Parents/caregivers reported their highest academic qualification, employment status, and number of adults, children aged under 18 years and working cars in their household.
- Importance of reasons for decision-making on school travel mode: Two items were employed to assess the importance of reasons when parents make decisions on their children's school travel mode: "*What are the main reasons your child gets to school by respective school travel mode?*" with a dichotomous response ('not main reason' and 'main reason'), and "*How important would you say this reason when deciding how your child gets to school?*" with a 4-point Likert scale for responses ('not important', 'a little bit important', 'important', and 'very important'). Reasons mainly comprised variables that could be categorised into 'distance to school', 'traffic safety', 'stranger danger', 'convenience' and 'social interaction'. Other minor categories included 'health/fitness', 'independent mobility', 'weather', and 'preference'.
- Neighbourhood safety, cohesion and connection: Neighbourhood social environment was appraised by neighbourhood safety (nine items; Cronbach's α = 0.76), neighbourhood cohesion (nine items; Cronbach's α = 0.80), and neighbourhood connection (five items; Cronbach's α = 0.85), which indicated 'good' internal consistency (239). A 5-point Likert scale ('strongly agree', 'agree', 'neither agree nor disagree', 'disagree', and 'strongly disagree') was used for responses, and scales were reverse coded where appropriate.

  Neighbourhood safety:

  1. There are safe places for children to play in our neighbourhood;
  2. It's a good place to bring up children;
  3. I feel safe walking down my street after dark;
  4. I worry about the number of crimes committed in our neighbourhood;
  5. Graffiti and vandalism are problems;

6. Roaming dogs are a problem in our neighbourhood;
7. It's a good place to buy a home;
8. Bullying is a problem in our neighbourhood; and
9. There are a lot of families with young children living in our neighbourhood.

Neighbourhood cohesion:

1. People are willing to help;
2. Neighbours watch out for kids;
3. It's a close knit neighbourhood;
4. I could borrow $10 from a neighbour;
5. If there is a problem with neighbours, we can deal with it;
6. The neighbours cannot be trusted;
7. People will take advantage of you;
8. People you don't know will greet you or say hello to you; and
9. People of different backgrounds don't talk to each other.

Neighbourhood connection:

1. Parents in this neighbourhood know their children's friends;
2. Adults in this neighbourhood know who the local children are;
3. There are adults in this neighbourhood that the children can look up to;
4. Parents in this neighbourhood generally know each other; and
5. You can count on adults in this neighbourhood to watch out that children are safe and don't get in trouble.

Physical environment measures

Geographic information systems (GIS). GIS measures of the physical (i.e., natural and built) environment were derived around each child-drawn route to school via the softGIS survey (see Chapter 4 for comparisons between child-drawn (softGIS) routes and GIS-modelled shortest routes in terms of spatial overlaps and built environment attributes). The flow of softGIS survey data processing is illustrated in Figure 20 (p. 84). SoftGIS home location (point) and school travel route (polyline) data were downloaded from the softGIS survey and imported into ArcGIS 10.2 (Environmental Systems Research Institute (ESRI), Redlands, CA). All softGIS routes were manually cleaned and obviously incorrect softGIS routes (e.g., incomplete routes, routes ended at non-school locations) were excluded from further analyses. School entrances of each school were manually identified by the candidate (EI), and converted into points in ArcGIS. SoftGIS routes inside the school polygon were trimmed. To examine the variability of start and end points of each softGIS route, two Euclidean (straight-line) distances between (i) each participant's softGIS home location and the start point of his/her softGIS route, and (ii) the end point of his/her softGIS route and the school polygon attended by the participant were calculated. Nine softGIS routes were classified as 'invalid' because:

- Distance between the softGIS home location and the route start point was longer or almost equal to (> 90%) distance of the softGIS route
- Distance between the school polygon and the softGIS route end point was more than 1 km (ranging 1502.0 m – 2156.5 m).

Excluding these nine participants, means and standard deviations of the distances were 13.6 ± 18.4 m (home location and route start point) and 4.5 ± 20.3 m (school polygon and route end point).

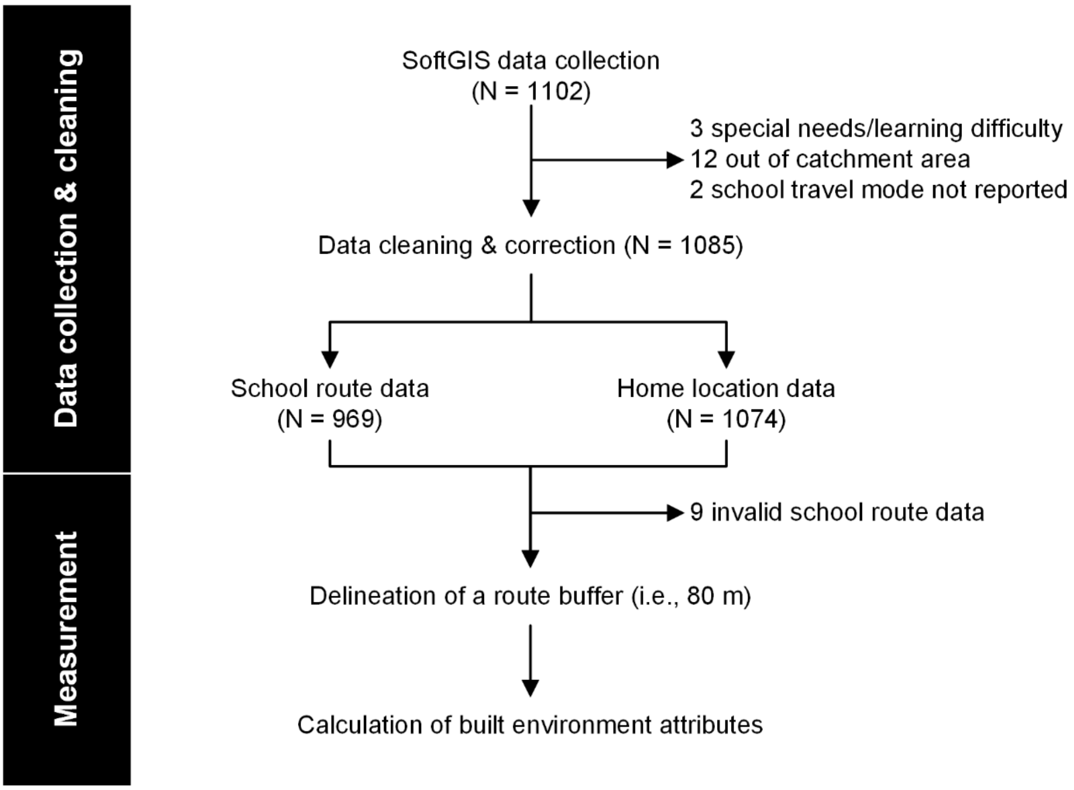


Figure 20. The flow of softGIS survey data processing.

SoftGIS routes were buffered using an 80 m radius on each side of the street centre line. Previous studies utilised different buffer sizes around school travel routes including 25 m (240, 241), 50 m (242, 243), 100m (244, 245), or 200 m (110, 246). The current research considered the importance of destinations often accessed by children along the route to school (e.g., shops, parks), and ensured that these destinations were captured by the buffer (247-249). Straight-line proximity to the closest land parcels of these destinations along 95 randomly selected softGIS routes (10% of the dataset) was visually inspected. An 80 m buffer would capture 75% of these destinations; whereas a 50 m buffer captured just over 15%. Considering a child's average walking speed (e.g., 80 m/min (250), 82.7 ± 14.53 m/min (251)) and cycling speed (e.g., 133.3 m/min (240)), 80 m was identified as a reasonable buffer size to characterise a directly accessible environment along a child's usual school route by active travel.

Built environment attributes were then calculated within softGIS 80 m route buffers (residential density, street network connectivity, traffic exposure, traffic lights, child-specific neighbourhood destination accessibility) or at softGIS route line (distance to school, route directness, slope) as detailed below.

- Net residential density: Meshblock level data on the number of private occupied dwellings at the 2013 Census was downloaded from the Statistics NZ website and linked to the meshblock boundaries derived from land use and zoning data at the 2014 Territorial Local Authority. The number of dwellings in the meshblocks that intersect the route buffers was counted, and the area of meshblocks that intersect the route buffers was calculated.
- Street network connectivity: Road centreline data were obtained from the 2015 CoreLogic Transport dataset. Each intersection point (i.e., node) was buffered by 15 m and dissolved into a single intersection polygon (i.e., creation of new centroids) (252). The total of the valences of nodes within the polygon buffer were counted, and centroids of the polygon buffers which function as three or more way intersections were extracted to produce a new data layer in subsequent analyses. The centroid data layer of the three or more way intersections was spatially joined to all route buffers to count the number of intersections in each route buffer.
- Traffic exposure: Road classification derived from the 2015 CoreLogic Transport dataset was employed as a proxy for traffic volume and speed limit. Arterial rural/urban, major rural/urban, and medium rural/urban were categorised as high traffic roads. Low traffic

roads included the classification of access rural/urban, minor rural/urban and foot path/track. A higher ratio indicated a higher exposure to vehicular traffic.

- Traffic lights: Traffic light data were obtained from the 2015 CoreLogic Transport dataset.
- Child-specific neighbourhood destination accessibility (NDAI-C): The NDAI-C index accounts for 28 destinations in eight domains (excluding airport and other destinations) that are weighted based on the frequency of trips taken to the destinations by children (226). The NDAI-C index consists of a binary (i.e., absent = 0, present = 1) and tertile scoring systems (226). The tertile scoring system was calculated by summing the number of destinations or proportion of area within the defined buffer and stratifying it by tertiles (74). The weights and scores for each subdomain were multiplied together, and summed to generate a continuous NDAI-C value ranging from 0 to 100 (226).
- Distance to school: Distance to school from home (in metres) was calculated along the softGIS route.
- Route directness: Route directness was calculated as the softGIS route distance divided by the Euclidean (straight-line) distance between softGIS home location and the nearest school entrance. An index value closer to "1" indicates a more direct route and the larger the value the worse the directness (253, 254).
- Slope: The Path Slope tool from the ArcGIS Military Analyst toolbox was used to calculate the slope of each route using a Digital Elevation Model at 1-metre resolution derived from the 2014 Auckland City Council dataset. The proportion of each route with a slope of less than or equal to 8% (i.e., 4.57 degrees, gradient 1:12.5) was calculated. This slope threshold was based on previous research (242, 251, 255, 256) and inspection of slope data around the schools where the participants perceived slope as a barrier in the softGIS survey (Figure 21).

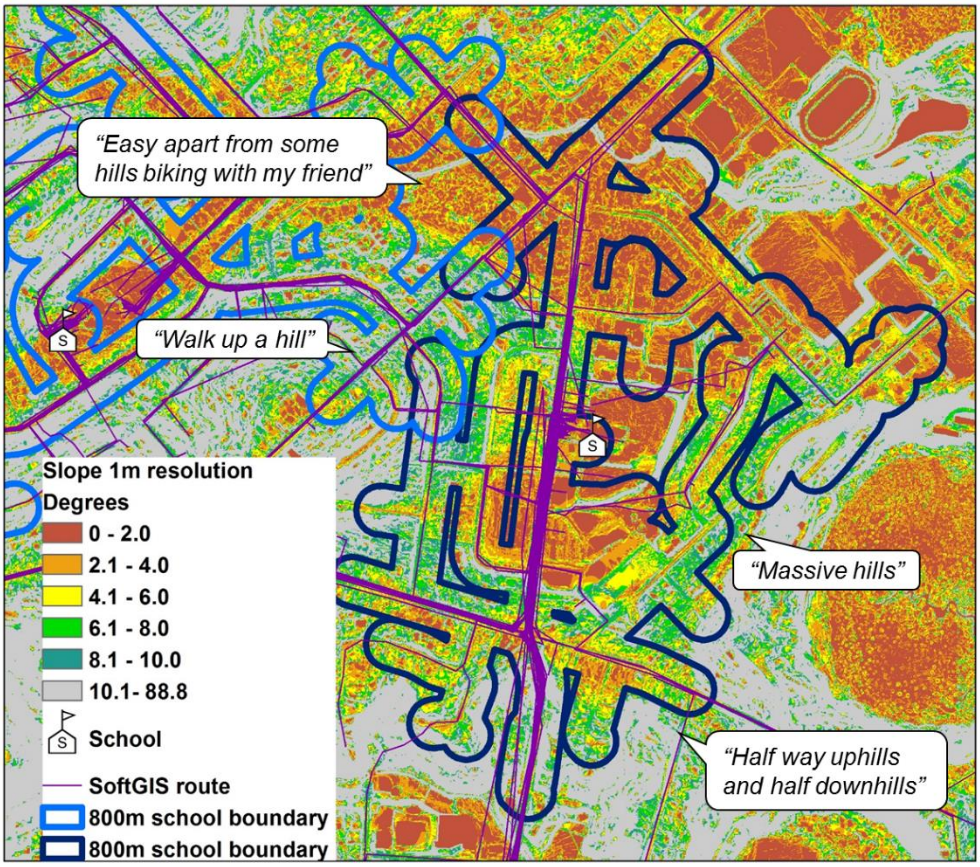


Figure 21. Inspection of slope data around one of the schools where the participants perceived slope as a barrier in the softGIS survey.

3.4.5 Data analysis

Figure 22 presents a flow chart of children, parents, and school representatives participating in the current research and those retained in analyses. Children with special needs and learning difficulty, which were reported by teachers during the data collection, were excluded for further analyses. Twelve children from School 19 living in a rural area (within the school zone) were excluded because the area was recognised as 'out of catchment area' in the current research (approximately 20 km away from the school) and those living in this area used school buses as their mode of travel. Information and descriptive statistics of all variables (except school measures) are reported in Table 8 (pp. 89-96) including frequencies or means and standard deviations where applicable. Distributions of dependent and independent variables were examined to determine the most appropriate statistical techniques for Chapters 4 and 5. Detailed descriptions for analytical approaches employed are provided in Chapters 4 and 5.

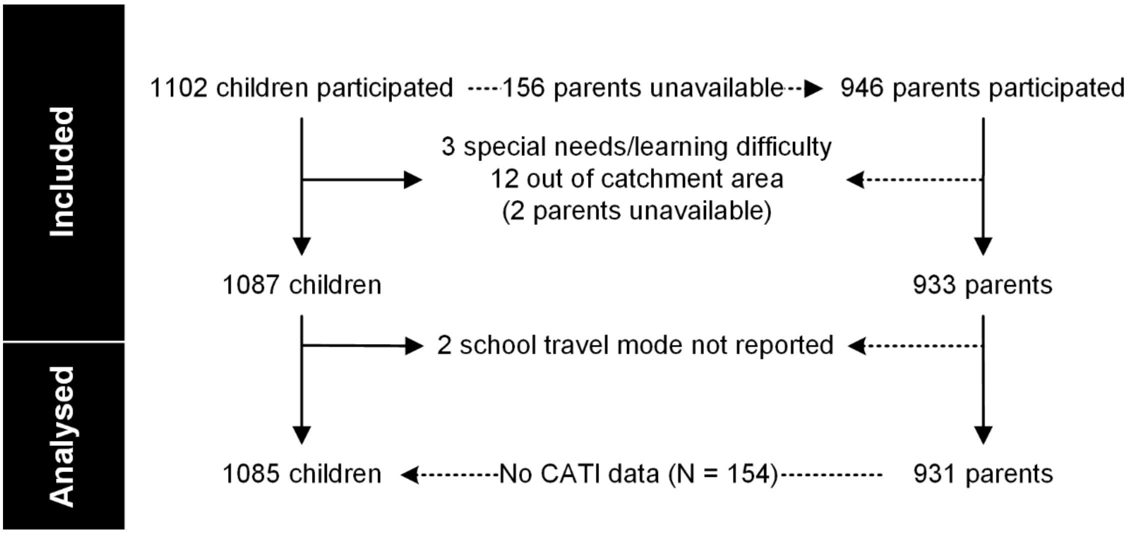


Figure 22. Flow of data collection and analyses.

In Chapter 4, non-parametric Wilcoxon signed-rank tests and Friedman tests were conducted using IBM SPSS Statistics version 24 (IBM Cooperation, USA) to compare spatial overlaps between buffers around softGIS route against GIS-modelled shortest routes, and to examine differences in built environment attributes derived from these buffers.

In Chapter 5, SEM using Mplus version 8.1 (257) was employed to test the hypothesised conceptual model, C-STBM (Figure 14, p. 67). SEM is a multivariate technique involving factor analysis (i.e., a measurement model) and multiple regression (i.e., a structural model). Further details of these statistical analyses are described in Chapters 4 and 5.

Table 8 Information of variables and their descriptive statistics (N = 1085)

Variable	Description	Data source	Number	Missing (%)	Measurement scale	Descriptive statistics†
Child measures						
School travel mode	How do you usually get to school?	SoftGIS	1085	0.0	Walk	34.4%
					Bike	3.9%
					Scooter	3.2%
					Skateboard	0.6%
					Car	46.1%
					Public transport	11.9%
Home location	Please mark your home on the map	SoftGIS	1074	1.0	-	-
School travel route	Please draw your usual route from home to school	SoftGIS	969	10.7	-	-
Traffic safety	1. The roads around my school are busy with traffic before and after school.	SoftGIS	1083	0.2	All of the time	13.0%
					Most of the time	40.7%
					Sometimes	37.2%
					Hardly ever/never	8.8%
	2. The roads around my school are full of parked cars before and after school.	SoftGIS	1081	0.4	All of the time	17.1%
					Most of the time	36.2%
					Sometimes	35.9%
					Hardly ever/never	10.3%
Neighbourhood safety	1. If I am out with an adult, I feel safe in my neighbourhood.	SoftGIS	1081	0.4	Hardly ever/never/do not go out with an adult in the neighbourhood	2.0%
					Sometimes	8.0%
					Most of the time	21.2%
					All of the time	68.4%
	2. If I go out without an adult, I feel safe in my neighbourhood.	SoftGIS	1082	0.3	Hardly ever/never/do not go out without an adult in the neighbourhood	17.9%
					Sometimes	27.3%
					Most of the time	33.2%
					All of the time	21.4%
Independent mobility		SoftGIS	1081	0.4	No	32.3%

Variable	Description	Data source	Number	Missing (%)	Measurement scale	Descriptive statistics†
	1. Are you allowed to cross main roads on your own?				Yes	67.4%
	2. Are you allowed to go on local buses or trains or ferries on your own?	SoftGIS	1076	0.8	No	71.2%
					Yes	27.9%
	3. If you have a bicycle, are you allowed to ride it to go to places?	SoftGIS	1078	0.6	No/do not have a bicycle	40.5%
					Yes	58.9%
Physical activity	Percentage of time spent in overall (light + moderate + vigorous) physical activity during the morning (8:00-9:00 am) commute	Accelerometer	994	8.4	-	8.8 ± 3.0
Year	Child's school year	School/Parent consent form	1085	0.0	Year 5	24.5%
					Year 6	26.4%
					Year 7	24.2%
					Year 8	24.9%
Sex	Child's sex	School/Parent consent form	1085	0.0	Male	49.0%
					Female	51.0%
Ethnicity	Child's ethnicity	School/CATI	1072	1.2	NZ European	52.7%
					Māori	12.9%
					Pacific	15.3%
					Asian	15.0%
					Other	2.9%
Household measures						
Education	What is your highest academic qualification?	CATI	881	18.8	Certificate (levels 1-6), Diploma or lower	51.2%
					Bachelor's degree or higher	30.0%
Employment	Which one best describes your main current employment situation?	CATI	887	18.2	Full-time	40.0%
					Part-time	25.0%
					Other	16.8%
Number of adults	How many adults, including yourself, live in your household?	CATI	888	18.2	1 adult	9.1%
					2 adults	56.5%
					3 adults	9.2%

Variable	Description	Data source	Number	Missing (%)	Measurement scale	Descriptive statistics†
					4 adults	4.7%
					Greater than or equal to 5 adults	2.3%
Number of children	How many other children under 18 live in your household?	CATI	888	18.2	No other children	12.1%
					1 child	36.2%
					2 children	21.8%
					3 children	7.6%
					Greater than or equal to 4 children	4.1%
Car ownership	How many working cars are available to your household?	CATI	888	18.2	Less than or equal to 1 car	18.1%
					Greater than or equal to 2 cars	63.8%
Distance to school	What are the main reasons your child gets to school by (travel mode to school)? How important would you say this reason (i.e., distance to school) when deciding how your child gets to school?	CATI	850	21.7	Not main reason	35.0%
					Main reason, but not important	0.6%
					Main reason, and a little bit important	0.8%
					Main reason, and important	6.3%
					Main reason, and very important	35.6%
Traffic safety	What are the main reasons your child gets to school by (travel mode to school)? How important would you say this reason (i.e., traffic safety) when deciding how your child gets to school?	CATI	923	14.9	Not main reason	78.5%
					Main reason, but not important	0.1%
					Main reason, and a little bit important	0.1%
					Main reason, and important	0.6%
					Main reason, and very important	5.7%
Stranger danger	What are the main reasons your child gets to school by (travel mode to school)? How important would you say this reason (i.e., stranger danger) when deciding how your child gets to school?	CATI	927	14.6	Not main reason	79.6%
					Main reason, but not important	0.0%
					Main reason, and a little bit important	0.2%
					Main reason, and important	0.6%
					Main reason, and very important	5.0%
Convenience	What are the main reasons your child gets to school by (travel mode to school)? How important would you say this reason (i.e., convenience) when deciding how your child gets to school?	CATI	898	17.2	Not main reason	56.0%
					Main reason, but not important	0.6%
					Main reason, and a little bit important	2.8%
					Main reason, and important	7.9%
					Main reason, and very important	15.4%
Social interaction	What are the main reasons your child gets to school by (travel mode to school)? How	CATI	930	14.3	Not main reason	80.8%
					Main reason, but not important	0.0%

Variable	Description	Data source	Number	Missing (%)	Measurement scale	Descriptive statistics†
	important would you say this reason (i.e., social interaction) when deciding how your child gets to school?				Main reason, and a little bit important	0.7%
					Main reason, and important	1.8%
					Main reason, and very important	2.4%
Neighbourhood safety	1. There are safe places for children to play in our neighbourhood.	CATI	877	19.2	Strongly disagree	1.0%
					Disagree	11.7%
					Neither agree nor disagree	5.9%
					Agree	47.7%
					Strongly agree	14.5%
	2. It's a good place to bring up children.	CATI	881	18.8	Strongly disagree	0.6%
					Disagree	2.7%
					Neither agree nor disagree	5.1%
					Agree	48.3%
					Strongly agree	24.6%
	3. I feel safe walking down my street after dark.	CATI	873	19.5	Strongly disagree	3.6%
					Disagree	18.4%
					Neither agree nor disagree	7.0%
					Agree	41.6%
					Strongly agree	9.9%
	4. I worry about the number of crimes committed in our neighbourhood.	CATI	876	19.3	Strongly agree	6.0%
					Agree	25.4%
					Neither agree nor disagree	11.2%
					Disagree	34.1%
					Strongly disagree	4.1%
	5. Graffiti and vandalism are problems.	CATI	882	18.7	Strongly agree	2.9%
					Agree	14.4%
					Neither agree nor disagree	5.3%
					Disagree	52.7%
					Strongly disagree	6.1%
	6. Roaming dogs are a problem in our neighbourhood.	CATI	882	18.7	Strongly agree	3.1%
					Agree	11.7%
					Neither agree nor disagree	4.1%

Variable	Description	Data source	Number	Missing (%)	Measurement scale	Descriptive statistics†
					Disagree	55.0%
					Strongly disagree	7.3%
	7. It's a good place to buy a home.	CATI	874	19.4	Strongly disagree	1.2%
					Disagree	5.5%
					Neither agree nor disagree	3.5%
					Agree	54.8%
					Strongly agree	15.5%
	8. Bullying is a problem in our neighbourhood.	CATI	839	22.7	Strongly agree	1.9%
					Agree	8.9%
					Neither agree nor disagree	5.6%
					Disagree	54.5%
					Strongly disagree	6.4%
	9. There are a lot of families with young children living in our neighbourhood.	CATI	864	20.4	Strongly disagree	0.1%
					Disagree	6.0%
					Neither agree nor disagree	4.5%
					Agree	54.8%
					Strongly agree	14.2%
Neighbourhood cohesion	1. People are willing to help.	CATI	843	22.3	Strongly disagree	0.4%
					Disagree	5.1%
					Neither agree nor disagree	7.7%
					Agree	55.3%
					Strongly agree	9.2%
	2. Neighbours watch out for kids.	CATI	836	22.9	Strongly disagree	0.5%
					Disagree	6.5%
					Neither agree nor disagree	7.4%
					Agree	53.5%
					Strongly agree	9.1%
	3. It's a close knit neighbourhood.	CATI	859	20.8	Strongly disagree	0.7%
					Disagree	18.7%
					Neither agree nor disagree	15.3%

Variable	Description	Data source	Number	Missing (%)	Measurement scale	Descriptive statistics†
					Agree	39.2%
					Strongly agree	5.3%
	4. I could borrow $10 from a neighbour.	CATI	810	25.3	Strongly disagree	2.3%
					Disagree	20.4%
					Neither agree nor disagree	5.1%
					Agree	39.4%
					Strongly agree	7.5%
	5. If there is a problem with neighbours, we can deal with it.	CATI	850	21.7	Strongly disagree	0.3%
					Disagree	5.1%
					Neither agree nor disagree	5.1%
					Agree	62.0%
					Strongly agree	5.9%
	6. The neighbours cannot be trusted.	CATI	850	21.7	Strongly agree	0.4%
					Agree	6.6%
					Neither agree nor disagree	6.0%
					Disagree	54.2%
					Strongly disagree	11.2%
	7. People will take advantage of you.	CATI	842	22.4	Strongly agree	0.9%
					Agree	6.7%
					Neither agree nor disagree	5.3%
					Disagree	55.6%
					Strongly disagree	9.0%
	8. People you don't know will greet you or say hello to you.	CATI	877	19.2	Strongly disagree	0.3%
					Disagree	6.6%
					Neither agree nor disagree	5.9%
					Agree	61.4%
					Strongly agree	6.6%
	9. People of different backgrounds don't talk to each other.	CATI	850	21.7	Strongly agree	0.9%
					Agree	17.0%
					Neither agree nor disagree	7.6%
					Disagree	49.3%

Variable	Description	Data source	Number	Missing (%)	Measurement scale	Descriptive statistics†
					Strongly disagree	3.6%
Neighbourhood connection	1. Parents in this neighbourhood know their children's friends.	CATI	816	24.8	Strongly disagree	0.4%
					Disagree	7.6%
					Neither agree nor disagree	6.1%
					Agree	53.7%
					Strongly agree	7.4%
	2. Adults in this neighbourhood know who the local children are.	CATI	808	25.5	Strongly disagree	0.7%
					Disagree	10.3%
					Neither agree nor disagree	10.6%
					Agree	48.2%
					Strongly agree	4.6%
	3. There are adults in this neighbourhood that the children can look up to.	CATI	778	28.3	Strongly disagree	0.5%
					Disagree	9.3%
					Neither agree nor disagree	10.0%
					Agree	46.6%
					Strongly agree	5.3%
	4. Parents in this neighbourhood generally know each other.	CATI	840	22.6	Strongly disagree	0.5%
					Disagree	12.5%
					Neither agree nor disagree	10.9%
					Agree	48.2%
					Strongly agree	5.3%
	5. You can count on adults in this neighbourhood to watch out that children are safe and don't get in trouble.	CATI	815	24.9	Strongly disagree	0.5%
					Disagree	8.1%
					Neither agree nor disagree	10.2%
					Agree	50.3%
					Strongly agree	6.0%
Physical environment measures						
Residential density	Ratio of residential dwellings to the residential land area (i.e., without water) of 80 m softGIS route buffer	GIS	959	11.6	-	28.8 ± 10.8

Variable	Description	Data source	Number	Missing (%)	Measurement scale	Descriptive statistics†
Street connectivity	Ratio of number of intersections with three or more intersecting streets to the land area of 80 m softGIS route buffer	GIS	959	11.6	-	56.6 ± 19.2
High traffic exposure	Length of high traffic roads (in metres) within 80 m softGIS route buffer	GIS	959	11.6	-	48217.8 ± 62526.8
Low traffic exposure	Length of low traffic roads (in metres) within 80 m softGIS route buffer	GIS	959	11.6	-	78312.5 ± 96100.9
Traffic lights	Number of traffic lights within the 80 m route buffer	GIS	959	11.6	-	2.6 ± 6.8
NDAI-C	Child-specific neighbourhood destination accessibility (NDAI-C)	GIS	959	11.6	-	29.1 ± 26.9
Distance to school	Distance to school (in metres) along softGIS routes	GIS	960	11.5	-	2783.7 ± 3557.7
Route directness	SoftGIS route distance dividing by Euclidean distance	GIS	936	13.7	-	3.2 ± 23.4
Slope	Proportion of the softGIS route with a slope of less than and equal to 8%	GIS	959	11.6	-	0.6 ± 0.3

CATI = computer-assisted telephone interview. GIS = geographic information systems. †Frequencies (%) for categorical variables; mean ± standard deviation for continuous variables.

Chapter 4 School Travel Route Characteristics

Chapter 2 and Appendix A identified key objective and perceived physical environment attributes that might influence children's AST, and addressed the importance of geographic areas to measure the physical environment which were relevant to children's actual travel routes to school. Findings also highlighted the need for improved sensitivity and specificity in environmental measures (e.g., residential density, street connectivity). Accordingly, before undertaking modelling of factors related to AST, there was a need to evaluate methods for characterising environments for children's school travel behaviour to identify the most appropriate approach. This chapter demonstrates a practical application of internet-based child-drawn routes using the softGIS survey and an evidence-supported route buffer generation method to increase in sensitivity and specificity of objective built environment measures using GIS. Furthermore, geographical and environmental differences between child-drawn school travel routes and estimated shortest school travel routes using GIS are identified.

4.1 Background

Physical activity can be accumulated in many ways including through active travel (e.g., walking or cycling to destinations) and can occur in different settings (e.g., home, schools, and neighbourhood environments) (4, 77, 258). Adequate physical activity can enhance children's physical, psychological, and social wellbeing (4, 74-76). Despite these advantages, recent global estimates showed only 20-39% of children and youth were classified as sufficiently physically active for health (77). In New Zealand, approximately one third of children are insufficiently active for health, and less than half of children actively travel to school (14, 259).

Activity-friendly built environments (i.e., through urban design, transportation systems, and provision of parks and recreation settings) can encourage active school travel and physical activity behaviours in the short term and long term across a range of population groups (4, 24-27, 32, 41, 87, 99). Objective measurement of the physical environment (i.e., natural and built) provides a robust, accurate, and replicable assessment of environmental features in relation to school travel behaviour in a language that is translatable to policy-makers and practitioners. Predominantly this objective measurement has been achieved through use of GIS software (24, 27) to analyse, store, manipulate, and visualise spatial and geographic data. Wong et al. (27) identified several theoretical and methodological limitations of GIS measures in this field including (i) inaccurate estimation of the school travel route; (ii) absence and imprecision of pedestrian and street network data; and (iii) inconsistent buffer methods and sizes.

There is potential to solve the first issue with global positioning systems (GPS) or participatory mapping activities with children by identifying actual school travel routes between home and school. Previous studies have reported that the magnitude of spatial overlap (244) and consistency in route characteristics (e.g., the physical environment) between GIS-modelled and GPS-measured school travel routes can vary significantly (240, 244, 260). Notwithstanding its high quality of spatial and temporal information, the time and cost of GPS data collection, processing, and management are substantial, making this method unfeasible for many large epidemiological studies (241, 243, 261, 262). Paper-based participatory mapping involves participants drawing their route to and from school on a printed paper map or an aerial photomap (263-265). This process can be costly and labour intensive, requiring printing of maps and manual data entry by researchers.

Online participatory mapping, on the other hand, can minimise participant and researcher burden, with data entered online and in real time by participants. Maptionnaire (184) and Visualisation and Evaluation of Route Itineraries, Travel Destinations, and Activity Spaces (VERITAS) (242, 262, 266) are emerging methods to capture location-based active travel information. Compared to paper-based mapping, these web-based and cloud-based software systems allow participants to interact with maps such as zooming in/out and changing map view styles. These functionalities may stimulate participant recall and aid the accuracy of mapping (242). Online mapping surveys can be practical and cost-effective methods to measure actual school travel routes for large population groups (262).

Secondly, the discordance in school travel routes between GIS and GPS or participatory mapping might be because of incomplete pedestrian network data for active travellers within GIS datasets (240, 263, 267, 268). Another reason could be inappropriate use of street network data for passive travellers within GIS (e.g., turn and directional restrictions, and including or excluding motorways, freeways and highways) (263, 269). Even with complete pedestrian and street network data, GIS is limited to capturing actual children’s travel behaviour occurring outside these networks, for example using shortcuts through private properties, public buildings, public open spaces, or vacant lots (268, 270).

Thirdly, methods of buffer generation (i.e., contextual units or geographic areas), for the most part, have been arbitrary. A growing body of literature has investigated the utility of different buffer development methods in physical activity and active travel research including circular, standard deviational ellipse, street network, and sausage buffers (241, 243, 267, 271, 272). In the area of school travel behaviour, buffers have been delineated around participants' homes, schools, and travel routes, with physical environment attributes calculated within the buffers (27). The specification of the buffer method and size is subject to two key methodological complications: the Modifiable Areal Unit Problem (MAUP) and the Uncertain Geographic Context Problem (UGCoP) (261). MAUP indicates scale (i.e., size) and zoning (i.e., aggregation) effects which cause the variation and inconsistency of results in the physical environment (27, 261, 273). UGCoP refers to the uncertainty about the spatial and temporal configuration of children's school travel behaviour, and where, when, and how long children are exposed to the physical environment (261). To minimise these potential confounders and consequently inferential errors, it is important to carefully select buffer generation methods and sizes that capture children's school travel behaviour spatially and temporally (261).

To address current research gaps and contribute new knowledge to measurement of school travel routes, the current study aimed to inform methodological decision making around measurement of travel routes to school by comparing two measurement approaches. The first phase of the study aimed to describe and compare the spatial overlaps between buffers around child-drawn routes to school using online participatory mapping against GIS-modelled shortest routes in the street network (including and excluding motorways/freeways/highways) and in the pedestrian network. The second phase of the study aimed to examine differences in physical environment attributes derived from child-drawn routes using online participatory mapping with those derived from GIS-modelled shortest routes in the street and pedestrian networks. To achieve the second aim, exposure to physical environment attributes that were hypothesised to be related to children's school travel were identified, calculated for each method (see Measures of the physical environment), and results compared.

4.2 Methods

4.2.1 Protocol

The NfAK is a cross-sectional study that aims to use a child-centred approach to measuring and describing relationships between the physical environment and a range of children's activity behaviours and health outcomes. Using an online participatory mapping survey (i.e., softGIS), information was collected from children on their travel and independent mobility, as well as their neighbourhood perceptions, experiences, and engagement. Pilot testing the softGIS survey was conducted within children across a range of ages and levels of cognitive abilities and technical skills. Design and methods of the full study are described in detail elsewhere (224).

In brief, data were collected from 1102 children aged 8-13 years (school years 5-8) from nine intermediate (middle/junior high) and 10 primary (elementary) schools across nine neighbourhoods in Auckland, NZ between February 2015 and September 2016. Schools were selected based on a matrix of school decile (i.e., a neighbourhood-level measure of socioeconomic status; high, medium, low), child-specific school walkability (high, medium, low) (39) and the NDAI-C (high, medium, low) (226). Trained researchers visited schools during school hours to collect data with participants. During this time, participants completed a softGIS survey with one-on-one researcher support. Ethical approval to conduct the research was granted by the Auckland University of Technology Ethics Committee (AUTEC, 14/263, 3 September 2014).

4.2.2 SoftGIS survey

A softGIS survey (227-229) was used to measure children's school travel mode(s) and routes. The softGIS method has been established as a valid and reliable method for recording travel mode use and route data among children (184, 230, 231). Pilot testing with primary school children of different ages was conducted, and refinement (e.g., rewording of items) of the survey made prior to implementation in the current study (224). Participants' usual travel mode to school was self-reported by asking "*How do you usually get to school?*" with responses being 'walk', 'bike', 'scooter (non-motorised)', 'public bus, train or ferry', 'car, motorbike, scooter or taxi', and 'another way (e.g., skateboard)'. School travel mode was categorised as either active travel (i.e., walk, bike, scooter, skateboard) or passive travel (i.e., car, public transport). Public transport, including school bus, was considered as passive travel due to a theorised majority of time spent being physically inactive (e.g., sitting) regardless of the amount of time spent travelling actively (e.g., walking from home to a bus stop or from a bus stop to school). It was also hypothesised that important differences may exist between motorised vehicles and active travel. Therein, school travel routes and their characteristics may be more likely to be similar between car and bus travel than between bus and active travel, which is an important distinction for the purpose of this study. Participants were also asked to map online their usual route from home to school.

4.2.3 GIS measures

Route buffer development

SoftGIS home location (point) and school travel route (polyline) data were downloaded from the softGIS survey and imported into ArcGIS 10.2 (Environmental Systems Research Institute (ESRI), Redlands, California, USA). SoftGIS routes inside the school polygon were trimmed. All softGIS routes were manually cleaned and obviously incorrect softGIS routes (e.g., incomplete routes, routes ended at non-school locations) were excluded from further analyses.

Access to schools is more accurately modelled using school entrance locations than a single centroid (244). Accordingly, entrances of each school were manually identified by the first author (EI), and converted to points in ArcGIS. The shortest route from the softGIS home location to the nearest school entrance attended by each participant was modelled using the Closest Facility function in ArcGIS Network Analyst based on three different road networks: (i) street network including motorways (SNm), (ii) street network excluding motorways (SN), and (iii) pedestrian network including footpaths (PN) (Table 9, p. 102). All road networks were derived from the 2015 CoreLogic Transport dataset. SN and PN were used to calculate route distances and buffers for active travellers (i.e., walk, bike, scooter, and skateboard) as it is not possible to actively travel along motorways. SNm and SN were used to calculate route distances and buffers for passive travellers (i.e., car and public transport) as it is not possible to drive along footpaths.

The four types of routes (i.e., softGIS, SNm, SN and PN) were then buffered using an 80 m radius on each side of the street centre line. Previous studies utilised buffer scales of 25 m (240, 241), 50 m (242, 243, 269, 271), 100 m (112, 244, 245, 253, 274), or 200 m (110, 246) along travel routes. In selecting a buffer distance an important consideration was ensuring common childhood destinations (e.g., shops, parks), often accessed by children along the route to school, fell within the buffer (247-249). A visual inspection of Euclidean (straight-line) proximity to the closest land parcels along 95 randomly selected softGIS routes (10% of the dataset) indicated that an 80 m buffer would capture 75% of these destinations; whereas a 50 m buffer captured just over 15%. In light of a child's average walking speed (i.e., 65 m/min (240), 80 m/min (250), 83.3 m/min (275), 82.7 ± 14.53 m/min (251)) and cycling speed (i.e., 133.3 m/min (240)), 80 m was considered a reasonable buffer distance to characterise a directly accessible environment within a one minute walk along a child's usual school travel route.

Table 9 Classification and criteria of road networks used in calculating GIS-modelled shortest routes

Category	Street network including motorways	Street network excluding motorways	Pedestrian network
Abbreviation	SNm	SN	PN
Application to	Passive travellers	Active / Passive travellers	Active travellers
Classification			
Access rural	✓	✓	✓
Access urban	✓	✓	✓
Arterial rural	✓	✓	✓
Arterial urban	✓	✓	✓
Ferry car	−	−	−
Ferry passenger	−	−	−
Foot path	−	−	✓
Foot track	−	−	✓
Major rural	✓	✓	✓
Major urban	✓	✓	✓
Medium rural	✓	✓	✓
Medium urban	✓	✓	✓
Minor rural	✓	✓	✓
Minor urban	✓	✓	✓
Motorway	✓	−	−
Vehicle track	✓	−	−
Water route	−	−	−
Other criteria			
State highway	✓	−	−
Motorway exit	✓	−	−
Use type: vehicle only	✓	−	−

✓ = included, − = excluded.

Spatial overlap measures

The first phase of the study aimed to describe and compare the spatial overlaps between child-drawn route buffers and GIS-modelled shortest route buffers. Assessment of spatial overlap provides the level of accuracy in geographical space, where the point of reference (i.e., 80 m buffers around softGIS routes) against which 80 m buffers around GIS-modelled shortest routes were compared. The overlap between softGIS and SNm, SN or PN buffers were compared for each participant by calculating seven measures of spatial overlap. These seven measures were: (i) overlap area (m^2); (ii) percentage of overlap area in the softGIS buffer; (iii) percentage of overlap in the SNm, SN or PN buffer; (iv) percentage of total overlap area; (v) percentage of disjunctive area in the softGIS buffer; (vi) percentage of disjunctive area in the SNm, SN or PN buffer; and (vii) percentage of total disjunctive area (Table 10, p. 104; Figure 23, p. 105) (270). Using the 'Clip' and 'Calculate Geometry' functions in ArcGIS, overlap area was calculated for paired route buffers for each participant (270). The disjunctive areas were calculated using the 'Erase' and 'Calculate Geometry' functions (270).

Table 10 Description of spatial overlap measures

Measure	Description	Formula
Overlap area	The overlap area (m^2) between 80 m buffers around child-drawn routes using softGIS *AND* GIS-modelled shortest routes.	SoftGIS ∩ SNm SoftGIS ∩ SN SoftGIS ∩ PN
Percentage of overlap area in the softGIS buffer	The percentage of overlap area in the 80 m buffer around child-drawn routes using softGIS.	(SoftGIS ∩ SNm / SoftGIS)*100 (SoftGIS ∩ SN / SoftGIS)*100 (SoftGIS ∩ PN / SoftGIS)*100
Percentage of overlap area in the SNm, SN or PN buffer	The percentage of overlap area in the 80 m buffer around GIS-modelled shortest routes.	(SoftGIS ∩ SNm / SNm)*100 (SoftGIS ∩ SN / SN)*100 (SoftGIS ∩ PN / PN)*100
Percentage of total overlap area	The percentage of overlap area in the total buffers around child-drawn routes using softGIS *AND* GIS-modelled shortest routes.	(SoftGIS ∩ SNm) / {SoftGIS + SNm - (SoftGIS ∩ SNm)}*100 (SoftGIS ∩ SN) / {SoftGIS + SN - (SoftGIS ∩ SN)}*100 (SoftGIS ∩ PN) / {SoftGIS + PN - (SoftGIS ∩ PN)}*100
Percentage of disjunctive area in the softGIS buffer	The percentage of disjunctive (nonoverlap) area in the 80 m buffer around child-drawn routes using softGIS.	{SoftGIS - (SoftGIS ∩ SNm)} / SoftGIS*100 {SoftGIS - (SoftGIS ∩ SN)} / SoftGIS*100 {SoftGIS - (SoftGIS ∩ PN)} / SoftGIS*100
Percentage of disjunctive area in the SNm, SN or PN buffer	The percentage of disjunctive (nonoverlap) area in the 80 m buffer around GIS-modelled shortest routes.	{SNm - (SoftGIS ∩ SNm)} / SNm*100 {SN - (SoftGIS ∩ SN)} / SN*100 {PN - (SoftGIS ∩ PN)} / PN*100
Percentage of total disjunctive area	The percentage of disjunctive (nonoverlap) area in the total buffers around child-drawn routes using softGIS *AND* GIS-modelled shortest routes.	SoftGIS Δ SNm / {SoftGIS + SNm - (SoftGIS ∩ SNm)}*100 SoftGIS Δ SN / {SoftGIS + SN - (SoftGIS ∩ SN)}*100 SoftGIS Δ PN / {SoftGIS + PN - (SoftGIS ∩ PN)}*100

Δ = symmetric difference, ∩ = intersection, PN = a GIS-modelled shortest route in the pedestrian network including footpaths, SN = a GIS-modelled shortest route in the street network excluding motorway, SNm = a GIS-modelled shortest route in the street network including motorways, SoftGIS = child-drawn routes using softGIS.

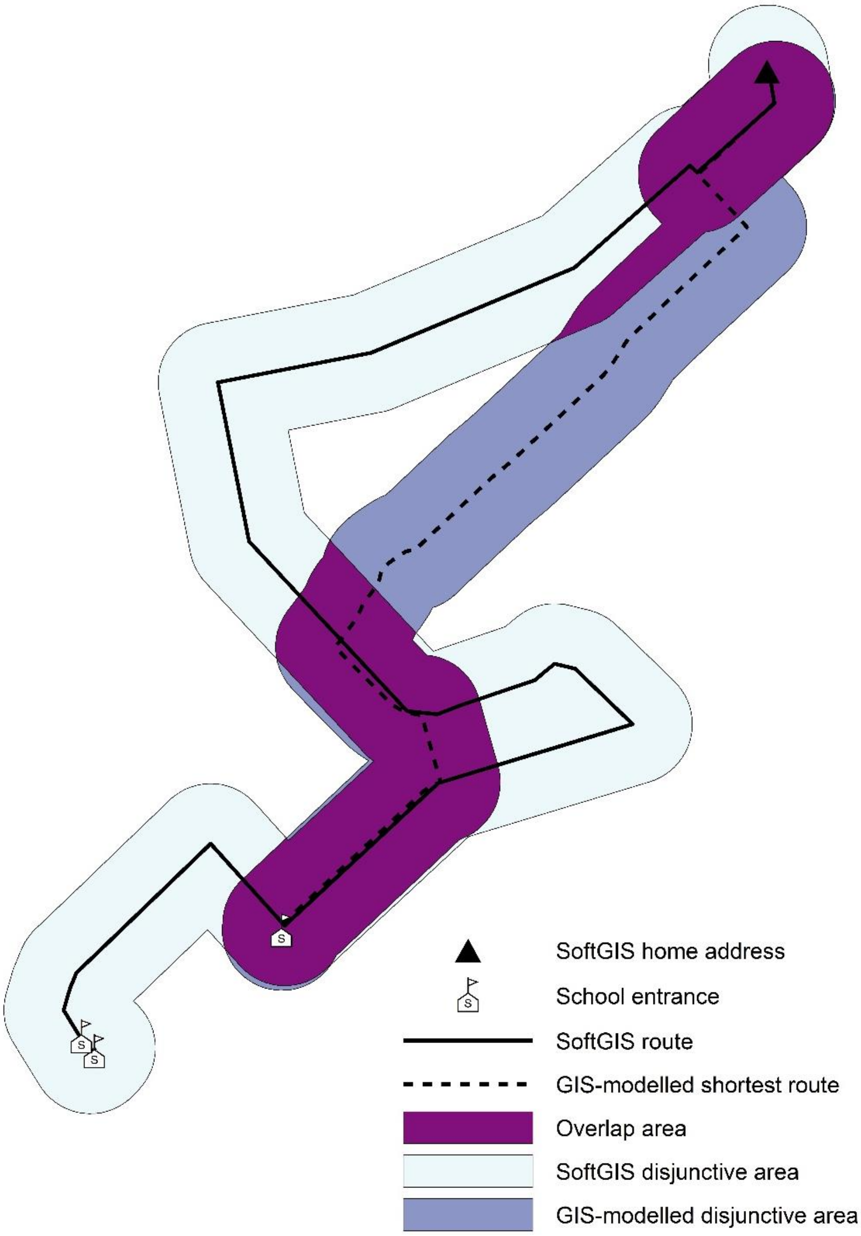


Figure 23. Example of spatial overlap measures between softGIS and GIS-modelled shortest route buffers.

Measures of the physical environment

The second phase of the study aimed to contextualise and compare the environments around child-drawn routes to school against GIS-modelled shortest routes to school. Physical environment attributes were calculated within four different (i.e., softGIS, SNm, SN and PN) 80 m route buffers or at four different route lines as detailed in Table 11 (pp. 106-107). Data sources are summarised in Table 12 (p. 107).

Table 11 Description of physical environment attributes

Attributes	Description
Net residential density	Ratio of residential dwellings to the residential land area (i.e., without water) of 80 m route buffer. Meshblock level data on the number of private occupied dwellings at the 2013 Census was downloaded from the Statistics New Zealand website and linked to the meshblock boundaries. The number of dwellings in the meshblocks that intersect the route buffers was counted, and the area of meshblocks that intersect the route buffers was calculated.
Street network connectivity	Ratio of number of intersections with three or more intersecting streets to the land area of 80 m route buffer. Road centreline data were obtained from the 2015 CoreLogic Transport dataset. Each intersection point (i.e., node) was buffered by 15 m and dissolved into a single intersection polygon (i.e., creation of new centroids) (252). The total of the valences of nodes within the polygon buffer were counted, and centroids of the polygon buffers which function as three or more way intersections were extracted to produce a new data layer in subsequent analyses. The centroid data layer of the three or more way intersections was spatially joined to all route buffers to count the number of intersections in each route buffer.
Traffic exposure	Length of high and low traffic roads, and ratio of the length of high to low traffic roads (39, 235). Road classification derived from the 2015 CoreLogic Transport dataset was employed as a proxy for traffic volume. Arterial rural/urban, major rural/urban, and medium rural/urban are categorised as high traffic roads. Low traffic roads included the classification of access rural/urban, minor rural/urban and foot path/track. A higher ratio indicates a higher exposure to vehicular traffic.
Traffic lights	Number of traffic lights, and density of number of traffic lights within each buffer (240, 276). Traffic light data were obtained from the 2015 CoreLogic Transport dataset.
Child-specific neighbourhood destination accessibility (NDAI-C)	The NDAI-C index accounts for 28 destinations in eight domains (excluding airport and other destinations) that are weighted based on the frequency of trips taken to the destinations by children (226). The NDAI-C index consists of a binary (i.e., absent = 0, present = 1) and tertile scoring systems (226). The tertile scoring system was calculated by summing the number of destinations or proportion of area within the defined buffer and stratifying it by tertiles (74). The weights and scores for each subdomain were multiplied together, and summed to generate a continuous NDAI-C value ranging from 0 to 100 for each defined boundary (Appendix K, p. 310) (226).
Distance to school	Route distance between softGIS home location and the nearest entrance of the school attended by each participant along (i) softGIS, (ii) SNm, (iii) SN, and (iv) PN. For the SNm, SN and PN, the Closest Facility function in ArcGIS Network Analyst was used to calculate the shortest distance (in metres).
Route directness	Ratio of the route distance (i.e., softGIS, SNm, SN and PN) to the Euclidean (i.e., straight-line) distance. Route directness is calculated as RDI = R / E, where R is the route distance and E is the Euclidean distance between softGIS home location and the nearest school entrance. An index value closer to “1” indicates a more direct route and the larger the value the worse the directness (253, 254).

Slope	The Path Slope tool from the ArcGIS Military Analyst toolbox was used to calculate the slope of each route using a Digital Elevation Model at 1-metre resolution. The proportion of each route with a slope of less than or equal to 8% (i.e., 4.57 degrees, gradient 1:12.5) was calculated. This slope threshold was based on previous research (242, 251, 255, 256) and inspection of slope data around the schools where the participants perceived slope as a barrier.

Table 12 GIS data sources used to calculate physical environment attributes

Measure	**Database**	**Data source**	**Year**
Net residential density	New Zealand Census	Statistics New Zealand	2013
	Land use and zoning	Territorial Local Authority	2014
Street connectivity	Road centre line	CoreLogic Transport	2015
Traffic exposure	Road classification	CoreLogic Transport	2015
Traffic lights	Traffic lights	CoreLogic Transport	2015
Slope	Digital Elevation Model (1-metre resolution)	Auckland City Council	2014

4.2.4 Statistical analyses

All statistical analyses were conducted using IBM SPSS Statistics v24 (IBM Cooperation, USA). Chi-square tests were performed to compare the proportion of participants' characteristics (i.e., sex, school year, school type, ethnicity, and school socio-economic position) between active (as a reference group) and passive travellers. Two approaches to compare the four route types (i.e., softGIS, SNm, SN and PN) were employed. In Phase One, spatial overlap between softGIS and SNm, SN or PN was calculated. In Phase Two, physical environment attributes generated using each route buffer and line type (i.e. softGIS and SNm, SN or PN) were compared. Analyses were conducted separately by travel mode (i.e., active versus passive).

Phase One: Spatial overlap between softGIS and GIS-modelled shortest route buffers

Descriptive statistics of seven measures (i.e., overlap area; percentage of overlap area in the softGIS buffer; percentage of overlap area in the SNm, SN or PN buffer; percentage of total overlap area; percentage of disjunctive area in the softGIS buffer; percentage of disjunctive area in the SNm, SN or PN buffer; and percentage of total disjunctive area) were calculated. It is plausible that differences in spatial overlaps between softGIS and GIS-modelled shortest route buffers could exist where children report travelling shorter or longer distances (because an increased distance proffers more opportunity for deviation between the two measures). Therefore, the percentage of total overlap area weighted by softGIS route distance was also calculated:

$$Weight = \delta r \div \sum_r \delta r$$

where δr is the distance of an individual softGIS route, $\sum_r \delta r$ is the sum of softGIS route distances from active and passive travellers (i.e., a longer softGIS route distance had a higher weight) (277). The unweighted and weighted percentages of overlap area were compared using non-parametric Wilcoxon signed-rank tests with statistical significance at $p < 0.05$, paired-groups between softGIS and SN versus softGIS and PN (for active travel), and softGIS and SNm versus softGIS and SN (for passive travel).

Phase Two: Differences in physical environment attributes between route types

Separate non-parametric Friedman tests were conducted to determine whether the four route buffer and line types were significantly different from each other in terms of the following physical environment attributes: residential density, street connectivity, traffic exposure, traffic lights, NDAI-C, distance to school, route directness, and slope. Post-hoc testing using Wilcoxon Signed Rank tests with a Bonferonni adjusted alpha value was employed to identify any pairwise differences between specific route buffer types. For active travel, only softGIS, SN, and PN were compared. For passive travel, only softGIS, SNm and SN were compared.

4.3 Results

Seventeen out of 1102 children were excluded due to having special needs or learning difficulty (N = 3), living out of catchment zone (N = 12), or missing school travel mode (N = 2). SoftGIS and GIS data from 1085 participants were included in analyses (Figure 24, p. 110). Overall, 99.1% of children who reported usually travelling to school by active modes completed the softGIS mapping activity (452 of 456 children), compared with 80.8% (508 of 629 children) of passive travellers (Figure 24). The active travel group (N = 456) comprised more males ($\chi^2 = 26.59$, $p < 0.001$), and more children of New Zealand European ethnicity and less children of Māori, Pacific, or Asian ethnicity ($\chi^2 = 23.47$, $p < 0.001$) than the passive travel group (N = 629). Children living in neighbourhoods of higher socio-economic status were more likely to actively travel to school than those living in more deprived areas ($\chi^2 = 14.66$, $p = 0.001$) (

Table 13, p. 111).

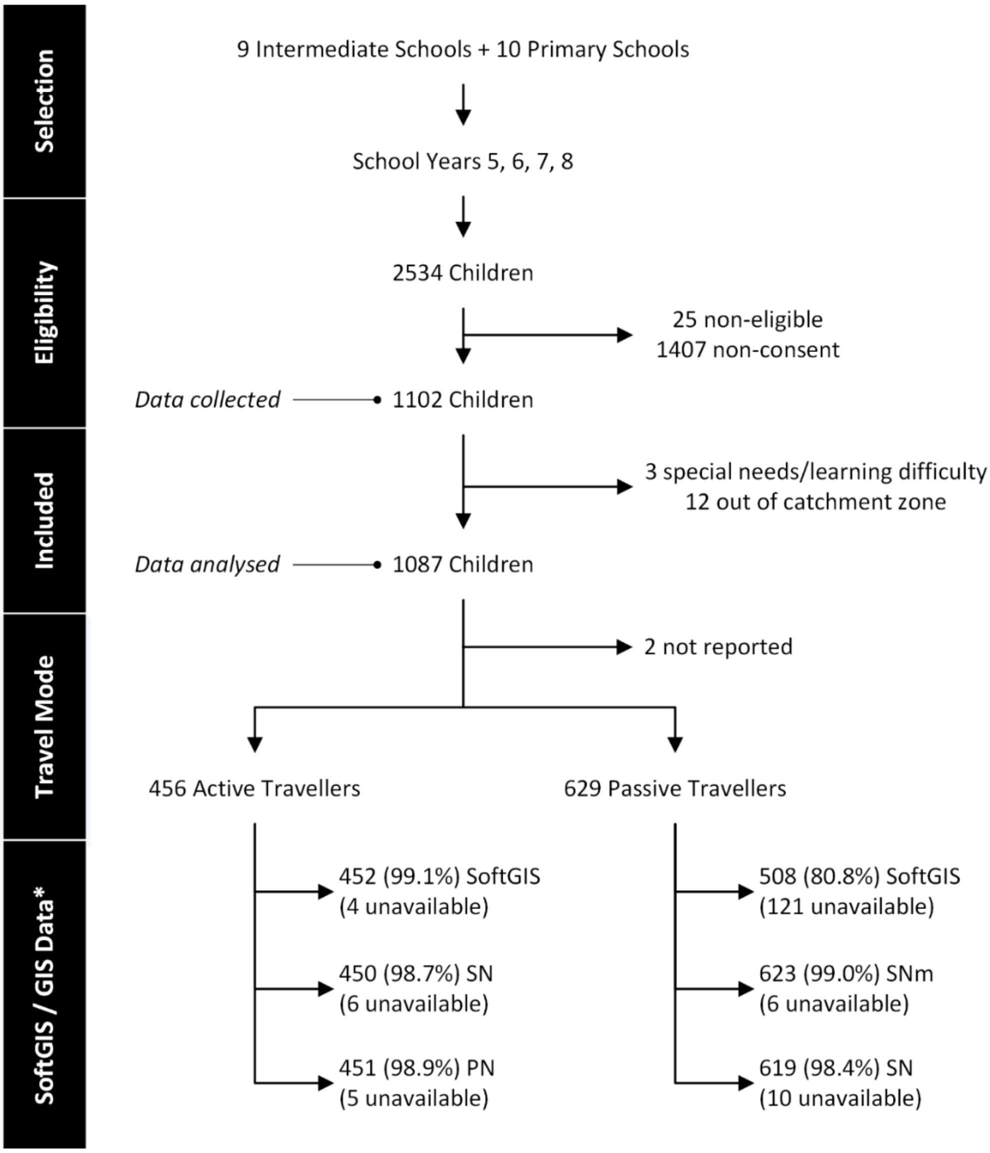


Figure 24. Flow of recruitment and data process. *Numbers are based on available distance to school data.

Table 13 Characteristics of participants included in analyses (N = 1085)

Variable	Category	Active Travel		Passive Travel		Total		Chi-Square*	
		N	%	N	%	N	%	χ^2	*p*
Sex	Male	266	58.3	266	42.3	532	49.0	26.59	**<0.001**
	Female	190	41.7	363	57.7	553	51.0		
School year	5	105	23.0	161	25.6	266	24.5	2.92	0.403
	6	122	26.8	164	26.1	286	26.4		
	7	121	26.5	142	22.6	263	24.2		
	8	108	23.7	162	25.8	270	24.9		
School type	Primary	227	49.8	325	51.7	552	50.9	0.31	0.580
	Intermediate	229	50.2	304	48.3	533	49.1		
Ethnicity†	NZ European	226	56.9	218	41.5	444	48.2	23.47	**<0.001**
	Māori	51	12.8	87	16.6	138	15.0		
	Pacific peoples	64	16.1	101	19.2	165	17.9		
	Asian	48	12.1	98	18.7	146	15.8		
	Other	8	2.0	21	4.0	29	3.1		
Neighbourhood SES	Low	114	25.0	202	32.1	316	29.1	14.66	**0.001**
	Middle	92	20.2	156	24.8	248	22.9		
	High	250	54.8	271	43.1	521	48.0		

N = number, SES = socio-economic status, NZ = New Zealand. †Missing data (N = 163).
*Reference group = active travel.

4.3.1 Phase One: Spatial overlap

For active travel, a higher unweighted and weighted percentage of total overlap area (median: 75.2%; weighted: 0.019%) and a smaller percentage of total disjunctive area (24.8%) was observed for the PN buffer than for the SN buffer (68.8%; weighted: 0.018% and 31.2%) (Table 14, pp. 112-113). For passive travel, SN buffer had a higher unweighted and weighted percentage of total overlap area (55.4%; weighted: 0.046%) and a smaller percentage of total disjunctive area (44.6%) compared to SNm buffer (41.8%; weighted: 0.038% and 58.2%). Differences in unweighted and weighted percentage of total overlap area were statistically significant in both active (unweighted: Z = -2.97, p = 0.003, r = 0.10; weighted: Z = -1.99, p = 0.047, r = -0.07) and passive (unweighted: Z = -2.99, p = 0.003, r = 0.09; weighted: Z = -3.46, p = 0.001, r = -0.11) travel (Figure 25, p. 114). These results indicate that PN (active travel) and SN (passive travel) buffers were spatially more comparable to softGIS buffers than SN (active travel) and SNm (passive travel). Furthermore, when distance was taken into account, active travellers were less likely to travel the same routes as GIS-modelled shortest routes (SN: 0.018%, PN: 0.019%) compared to passive travellers (SNm: 0.038%, SN: 0.046%).

Table 14 Descriptive characteristics of the overlap and disjunctive areas between softGIS and GIS-modelled shortest route buffers

Variable	N	Median (IQR)
Active Travel		
Area of 80 m route buffer (m^2)		
SoftGIS	451	161541.4 (91280.9 - 242957.0)
SN	447	170826.1 (93647.6 - 252137.8)
PN	448	143511.2 (83870.0 - 222563.8)
Overlap area (m^2)		
SN	445	96829.5 (56549.6 - 177053.4)
PN	446	97685.4 (60583.1 - 168905.8)
Percentage of overlap area in the softGIS buffer (%)		
SN	445	80.1 (53.0 - 93.2)
PN	446	81.5 (54.9 - 93.5)
Percentage of overlap area in the SN or PN buffer (%)		
SN	445	86.2 (51.4 - 97.7)
PN	446	90.2 (62.0 - 97.5)
Unweighted percentage of total overlap area (%)		
SN	445	68.8 (35.9 - 89.4)
PN	446	75.2 (40.7 - 89.4)
Weighted percentage of total overlap area (%)		
SN	445	0.018 (0.009 - 0.036)
PN	446	0.019 (0.011 - 0.034)
Percentage of disjunctive area in the softGIS buffer (%)		
SN	445	19.9 (6.8 - 47.0)
PN	446	18.5 (6.5 - 45.1)
Percentage of disjunctive area in the SN or PN buffer (%)		
SN	445	13.8 (2.3 - 48.6)
PN	446	9.8 (2.5 - 38.0)
Percentage of total disjunctive area (%)		
SN	445	31.2 (10.6 - 64.1)
PN	446	24.8 (10.6 - 59.3)
Passive Travel		
Area of 80 m route buffer (m^2)		
SoftGIS	508	468098.6 (265781.9 - 763601.0)
SNm	510	386177.5 (221220.5 - 607758.0)
SN	508	413194.7 (237343.7 - 638394.3)
Overlap area (m^2)		
SNm	504	206508.2 (113956.3 - 371266.1)
SN	502	234655.5 (139243.8 - 400354.6)
Percentage of overlap area in the softGIS buffer (%)		
SNm	504	54.9 (27.4 - 82.8)
SN	502	67.4 (31.7 - 90.0)
Percentage of overlap area in the SNm or SN buffer (%)		
SNm	504	67.0 (38.9 - 94.0)
SN	502	76.6 (41.1 - 96.0)
Unweighted percentage of total overlap area (%)		
SNm	504	41.8 (18.9 - 76.1)
SN	502	55.4 (20.6 - 86.6)
Weighted percentage of total overlap area (%)		
SNm	504	0.038 (0.021 - 0.071)
SN	502	0.046 (0.025 - 0.081)
Percentage of disjunctive area in the softGIS buffer (%)		
SNm	504	45.1 (17.2 - 72.6)

Variable	N	Median (IQR)
SN	502	32.6 (10.0 - 68.3)
Percentage of disjunctive area in the SN or PN buffer (%)		
SNm	504	33.0 (6.0 - 61.1)
SN	502	23.4 (4.0 - 58.9)
Percentage of total disjunctive area (%)		
SNm	504	58.2 (23.9 - 81.1)
SN	502	44.6 (13.4 - 79.4)

IQR = interquartile range, N = number, PN = pedestrian network including footpaths 80 m route buffer, SN = street network excluding motorway 80 m route buffer, SNm = street network including motorways 80 m route buffer, SoftGIS = softGIS 80 m route buffer. Weights were calculated based on softGIS route distance.

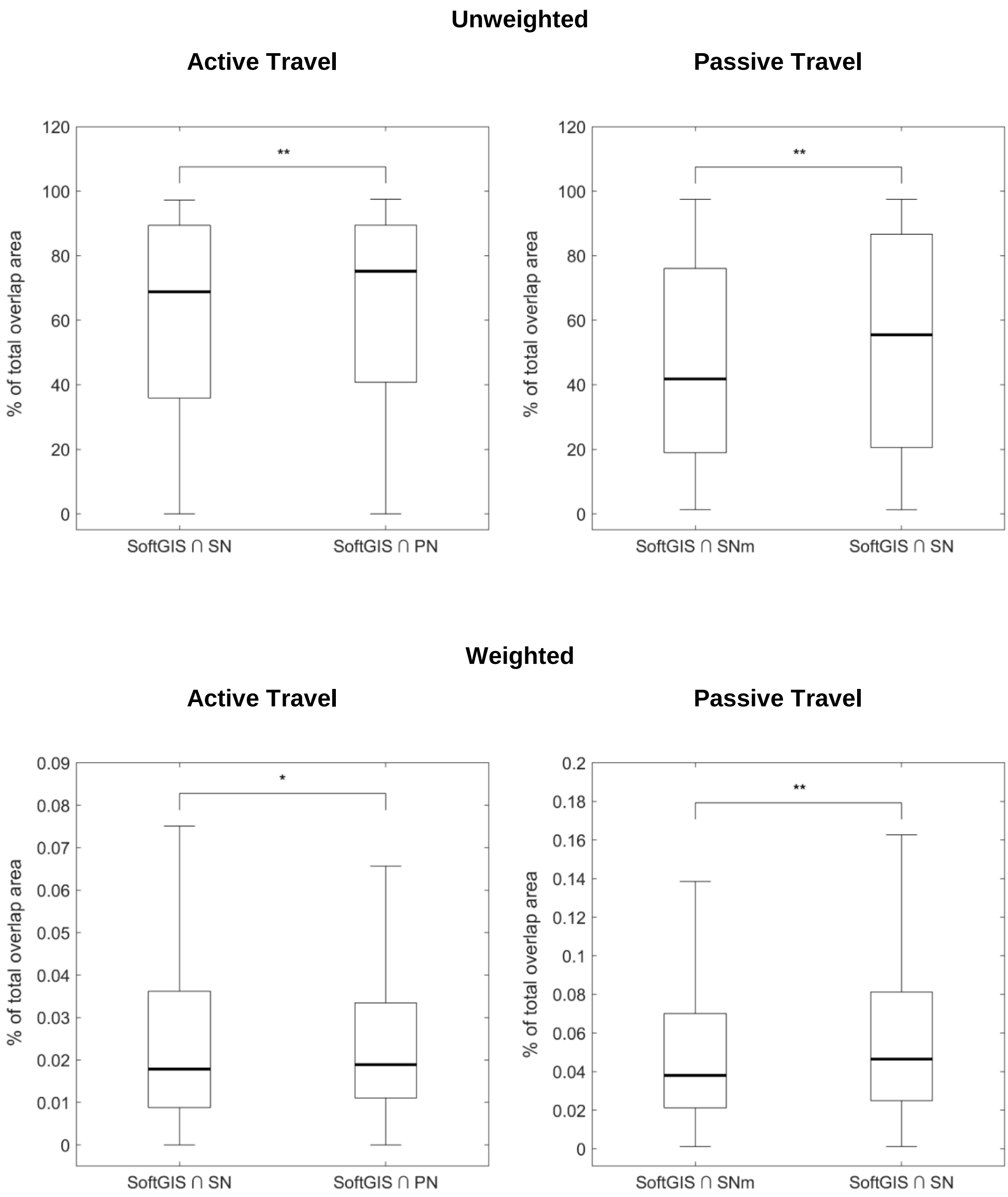


Figure 25. Differences in unweighted and weighted percentages of overlap area by travel mode. Weights were calculated based on softGIS route distance. *$p < 0.05$, **$p < 0.01$.

4.3.2 Phase Two: Physical environment attributes

Overall, density of traffic lights and NDAI-C within the softGIS buffer were not significantly different from GIS-modelled shortest route buffers. Traffic exposure, distance to school and route directness in GIS-modelled shortest routes were consistently and significantly different from those in softGIS routes. Effect sizes were large for traffic exposure, and medium-to-large for distance to school and route directness.

Active travel

Compared to SN and PN, the softGIS routes had lower residential density and street connectivity, higher traffic exposure, higher NDAI-C, longer distance to school, were less direct, and were less hilly (Table 15, pp. 116-117). Differences in the physical environment between three routes were statistically significant for all attributes except traffic light density ($\chi^2 = 3.50$, $p = 0.174$) and NDAI-C ($\chi^2 = 3.36$, $p = 0.186$) (Table 16, p. 118). Post-hoc pairwise comparisons ($\alpha = 0.017$) between three routes showed that softGIS was significantly different from SN and PN in street connectivity ($p < 0.001$), high traffic length (SN: $p < 0.001$, PN: $p = 0.004$), high to low traffic ratio ($p < 0.001$), distance to school ($p < 0.001$), and route directness ($p < 0.001$) (Figure 26, pp. 119-122).

Table 15 Descriptive characteristics of built environment attributes calculated within softGIS and GIS-modelled shortest route buffers and at route lines by travel mode

Variable	SoftGIS		SN		PN	
	N	Median (IQR)	N	Median (IQR)	N	Median (IQR)
Active Travel						
Net residential density	451	31.8 (27.0 - 37.9)	451	32.2 (26.6 - 38.8)	451	33.0 (28.0 - 39.6)
Street network connectivity	451	56.8 (45.3 - 67.7)	451	57.8 (47.2 - 68.1)	451	58.3 (47.8 - 69.2)
Traffic exposure:						
High traffic length (m)	451	15846.8 (8535.5 - 32261.5)	451	1417.6 (755.8 - 2388.8)	451	14281.1 (7413.5 - 27329.6)
Low traffic length (m)	451	32464.6 (21482.1 - 49428.0)	451	41298.5 (22557.7 - 57585.3)	451	32094.9 (20637.3 - 49597.5)
High to low traffic ratio	451	0.6 (0.4 - 0.7)	451	0.0 (0.0 - 0.1)	451	0.5 (0.3 - 0.6)
Traffic lights:						
Number*	451	0.0 (0.0 - 0.0)	451	0.0 (0.0 - 0.0)	451	0.0 (0.0 - 0.0)
Density*	451	0.0 (0.0 - 0.0)	451	0.0 (0.0 - 0.0)	451	0.0 (0.0 - 0.0)
NDAI-C	451	16.3 (7.4 - 58.1)	451	12.6 (7.4 - 58.3)	451	14.2 (7.4 - 52.6)
Distance to school (m)	452	979.0 (502.0 - 1489.2)	450	974.0 (465.7 - 1472.6)	451	800.3 (405.0 - 1295.3)
Route directness	442	1.6 (1.4 - 1.9)	440	1.4 (1.2 - 1.7)	441	1.3 (1.2 - 1.5)
Slope ≤ 8%	451	0.6 (0.3 - 1.0)	450	0.6 (0.3 - 1.0)	451	0.6 (0.3 - 1.0)
Variable	**SoftGIS**		**SNm**		**SN**	
	N	**Median (IQR)**	**N**	**Median (IQR)**	**N**	**Median (IQR)**
Passive Travel						
Net residential density	508	25.8 (20.2 - 29.5)	619	25.9 (18.8 - 30.6)	624	25.4 (19.0 - 30.0)
Street network connectivity	508	57.6 (47.5 - 67.5)	619	88.1 (66.8 - 111.1)	624	59.2 (47.8 - 70.9)
Traffic exposure:						
High traffic length (m)	508	50648.1 (31733.5 - 80762.8)	619	50726.6 (22431.2 - 81904.2)	624	4327.6 (2214.2 - 7452.5)
Low traffic length (m)	508	80283.3 (50724.5 - 128386.9)	619	35846.7 (19152.1 - 58296.3)	624	95181.5 (51368.8 - 145187.9)
High to low traffic ratio	508	0.6 (0.6 - 0.7)	619	1.5 (1.0 - 1.9)	624	0.0 (0.0 - 0.1)
Traffic lights:						
Number	508	1.0 (0.0 - 4.0)	619	1.0 (0.0 - 4.0)	624	0.1 (0.0 - 4.0)
Density	508	2.6 (0.0 - 8.2)	619	1.3 (0.0 - 8.0)	624	1.7 (0.0 - 8.3)
NDAI-C	508	16.7 (8.3 - 61.2)	619	11.8 (4.6 - 57.8)	624	20.1 (11.8 - 67.7)
Distance to school (m)	508	2933.0 (1600.1 - 4877.7)	623	2760.9 (1393.8 - 4433.8)	619	2822.0 (1465.2 - 4534.0)

Route directness	494	1.6 (1.4 - 2.0)	602	1.3 (1.2 - 1.4)	598	1.3 (1.2 - 1.5)
Slope ≤ 8%	508	0.6 (0.3 - 0.9)	623	0.6 (0.3 - 1.0)	619	0.6 (0.3 - 1.0)

IQR = interquartile range, n = number, PN = pedestrian network including footpaths 80 m route buffer, SN = street network excluding motorway 80 m route buffer, SNm = street network including motorways 80 m route buffer, SoftGIS = softGIS 80 m route buffer. *Number (mean ± standard deviation) = 0.5 ± 1.5 (SoftGIS), 0.5 ± 1.3 (SN), 0.5 ± 1.6 (PN); Density = 2.0 ± 4.9 (SoftGIS), 2.1 ± 5.7 (SN), 2.0 ± 5.6 (PN)

Table 16 Differences in built environment attributes between softGIS and GIS-modelled shortest route buffers and lines by travel mode using Friedman tests

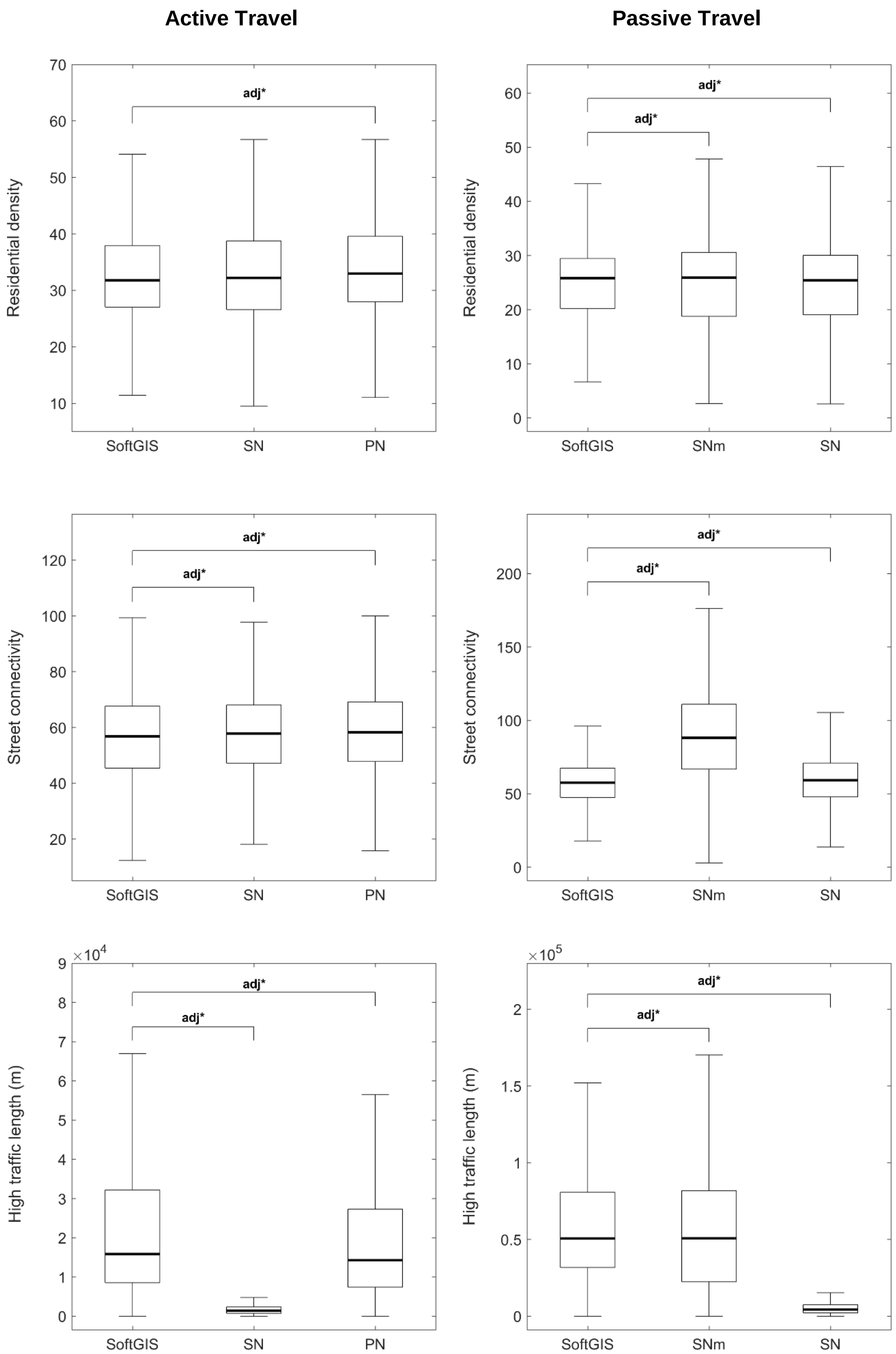
Variable	N	Median			Friedman	
		SoftGIS	SN	PN	χ^2	*p*
Active Travel						
Net residential density	446	31.75	32.15	32.92	28.74	**< 0.001**
Street network connectivity	446	56.77	57.62	58.19	85.39	**< 0.001**
Traffic exposure:						
High traffic length (m)	446	15836.30	1424.84	14371.67	590.03	**< 0.001**
Low traffic length (m)	446	32479.96	41446.66	32026.28	41.62	**< 0.001**
High to low traffic ratio	446	0.55	0.03	0.49	610.39	**< 0.001**
Traffic lights:						
Number	446	0.00	0.00	0.00	8.82	**0.012**
Density	446	0.00	0.00	0.00	3.50	0.174
NDAI-C	446	16.51	12.63	13.92	3.36	0.186
Distance to school (m)	446	974.10	976.85	801.92	348.96	**< 0.001**
Route directness	436	1.56	1.37	1.33	339.02	**< 0.001**
Slope ≤ 8%	445	0.64	0.61	0.59	12.63	**0.002**
Variable	**N**	**Median**			**Friedman**	
		SoftGIS	**SNm**	**SN**	χ^2	***p***
Passive Travel						
Net residential density	502	25.84	26.34	25.96	51.45	**< 0.001**
Street network connectivity	502	57.64	86.95	58.64	568.57	**< 0.001**
Traffic exposure:						
High traffic length (m)	502	50599.42	46985.88	3834.03	735.44	**< 0.001**
Low traffic length (m)	502	79972.61	33158.99	89367.45	697.55	**< 0.001**
High to low traffic ratio	502	0.63	1.40	0.04	923.34	**< 0.001**
Traffic lights:						
Number	502	1.00	0.00	1.00	109.26	**< 0.001**
Density	502	2.58	0.00	1.42	34.47	**< 0.001**
NDAI-C	502	16.69	11.63	18.92	153.81	**< 0.001**
Distance to school (m)	502	2917.81	2287.94	2471.67	721.78	**< 0.001**
Route directness	488	1.59	1.28	1.32	700.50	**< 0.001**
Slope ≤ 8%	502	0.61	0.59	0.60	10.05	**0.007**

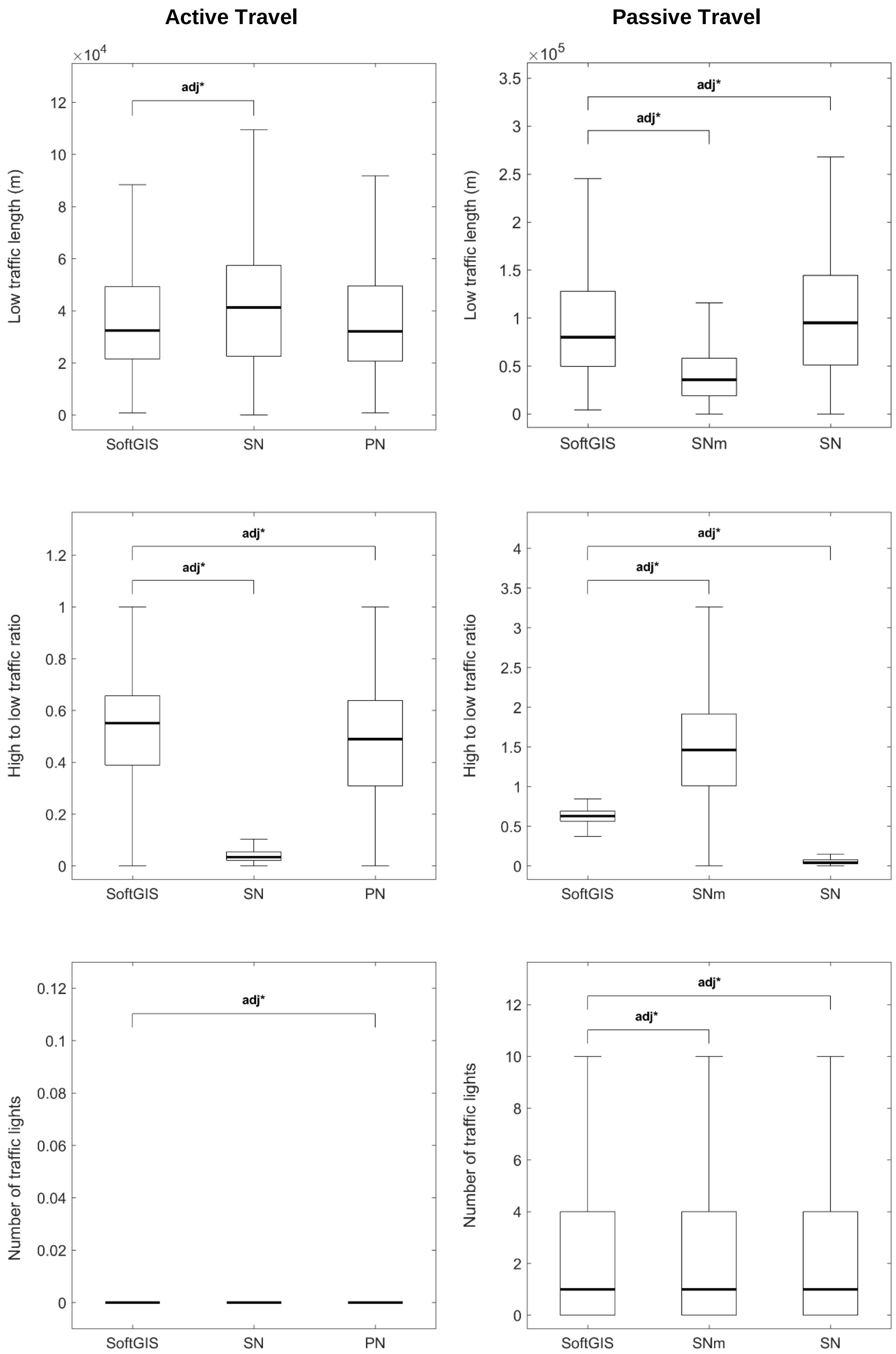
N = number, NDAI-C = child-specific neighbourhood destination accessibility, PN = pedestrian network including footpaths 80 m route buffer, SN = street network excluding motorway 80 m route buffer, SNm = street network including motorways 80 m route buffer, SoftGIS = softGIS 80 m route buffer.

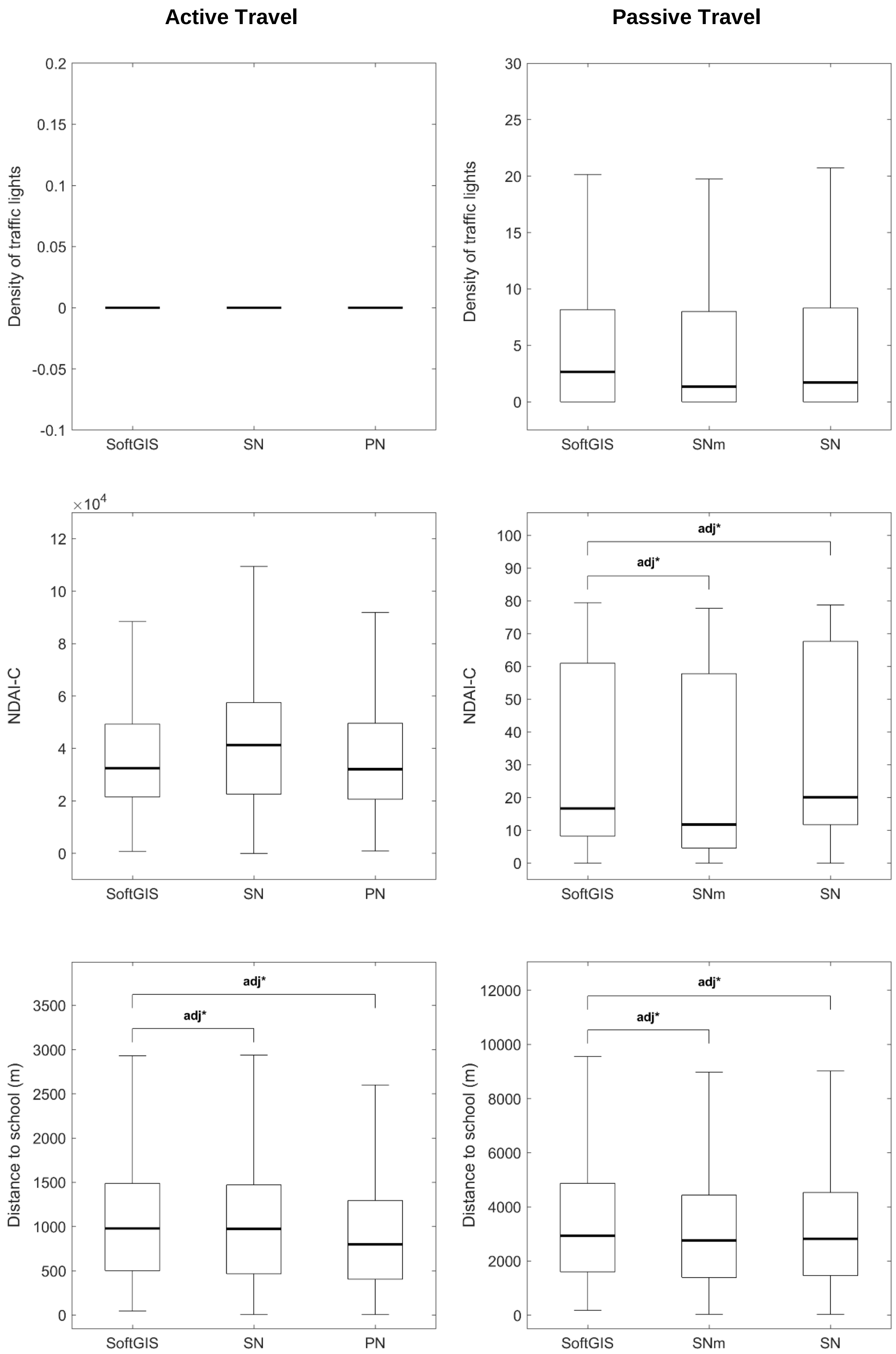
Passive travel

Across all physical environment attributes, there were statistically significant differences between softGIS, SNm, and SN (Table 16). In post-hoc pairwise comparisons with softGIS, there were statistically significant differences in residential density (SNm: $p < 0.001$, SN: $p = 0.006$), street connectivity ($p < 0.001$, $p = 0.008$), high traffic length (SNm: $p = 0.014$, SN: $p < 0.001$), low traffic length ($p < 0.001$), high to low traffic ratio ($p < 0.001$), number of traffic lights ($p < 0.001$), NDAI-C (SNm: $p < 0.001$, SN: $p = 0.016$), distance to school ($p < 0.001$) and route directness ($p < 0.001$)

(Figure 26). Similar to active travel, no differences were observed between softGIS and SN in term of traffic light density (p = 0.969) and ≤ 8% slope (p = 0.141).




Active Travel
Passive Travel
×10^4
×10^5
adj*
Low traffic length (m)
High to low traffic ratio
Number of traffic lights
SoftGIS
SN
PN
SNm
0
2
4
6
8
10
12
0.5
1
1.5
2
2.5
3
3.5
0.2
0.4
0.6
0.8
1
1.2
4
0.02
0.04
0.06
0.08
0.1
0.12



Active Travel
Passive Travel
Density of traffic lights
NDAI-C
Distance to school (m)
SoftGIS
SN
PN
SNm
adj*
×10^4

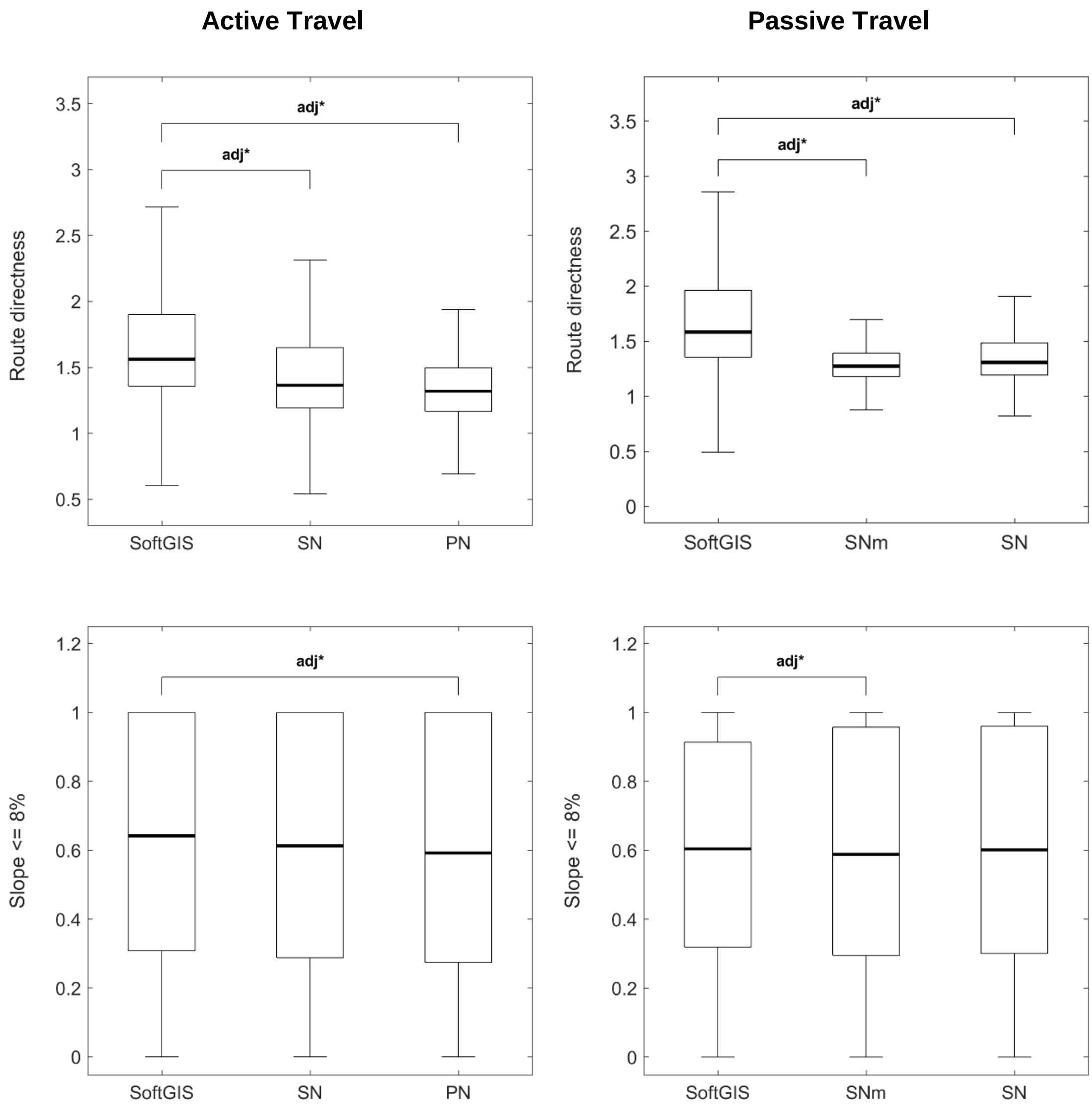


Figure 26. Pairwise comparison in built environment attributes between softGIS and GIS-modelled shortest route buffers and lines by travel mode using post-hoc Wilcoxon Signed Rank tests. adj*Adjusted *p*-value using the Bonferroni correction (α = 0.017).

4.4 Discussion

This is the first study to investigate spatial and physical environment differences in child-drawn routes using online participatory mapping and GIS-modelled shortest routes using distinct network datasets for active and passive travellers. The level of spatial overlap between softGIS and PN buffers was higher than those between softGIS and SN buffers for active travel. Except for traffic light density and NDAI-C, physical environment attributes were significantly different across the three routes types (i.e., softGIS, SN, PN). For passive travel, SN route buffers had more spatial overlap with the softGIS buffer than with the SNm buffer. All physical environment attributes differed statistically between three routes (i.e., softGIS, SNm, SN). For both active and passive travel, no significant differences in traffic light density and ≤ 8% slope were observed between softGIS and SN routes.

Considerable disagreements observed in spatial overlap between children's mapped routes (i.e., softGIS) and GIS-modelled shortest routes were consistent with a previous study comparing school travel routes calculated using GIS with those measured by GPS (244). On average, just over 60% of the routes areas between softGIS and SN or PN in active travel, and around 50% between softGIS and SNm or SN in passive travel overlapped. Furthermore, variances existed between different network datasets. When comparing GIS-modelled shortest routes to assess spatial similarity to softGIS routes, spatial overlap was higher for PN than SN in active travel suggesting children who actively travelled to school may have used pedestrian and cycling paths or trails which were included in PN (267). Footpaths were considered in PN which may have increased the availability of potential routes for active travellers and the walkability of the neighbourhood, but shortcuts through parks and buildings could not be captured by PN (but were captured using softGIS).

Among passive travellers, discrepancies in route areas between softGIS and SNm were higher. It is hypothesised that motorways may have been avoided due to high traffic volume in motorways during the morning peak hour in the Auckland region (278, 279). Decisions on travel routes for passive travellers is often made by parents as drivers based on convenience and scheduling of other activities, resulting in 'trip-chaining' between several neighbourhood destinations (45, 188, 280). Interestingly, when adjusted for distance, spatial overlaps between softGIS and GIS-modelled shortest route buffers were lower for active travellers than for passive travellers in contrast to unadjusted spatial overlaps (i.e., active travel > passive travel). When assessing active travellers' routes, child-drawn routes may be more meaningful than GIS-modelled shortest routes regardless of their travel distances.

Moreover, route characteristics, including physical environment attributes, can influence the choice of children's school travel route (240, 242, 244, 260, 263). SoftGIS routes were significantly longer and less direct than GIS-modelled shortest routes. These findings support previous studies comparing GIS-modelled routes with GPS-measured or self-drawn (online or paper-based mapping) routes in both active and passive travel (240, 242, 244, 263). Children and parents may prefer to choose a route which is faster, safer, easier, and more enjoyable rather than shorter routes (i.e., the concept of distance) due to speed limits, risks of dangers, crossings, and hills (43, 270). GIS cannot explain child and parent preferences for, and perceptions of, the environments around the routes children take. However, environmental exposures may influence their route choice. This study demonstrated the importance of geographic space specifically identified and delineated for children's school travel behaviour, which can be directly and indirectly associated with preferences for and perceptions of children's school travel modes and routes. Likewise, variation in physical environment attributes may explain a greater preference for these attributes.

Surprisingly, the current study found that child-drawn active travel routes (i.e., softGIS) compared to GIS-modelled shortest routes (i.e., SN or PN) were more likely to go along higher traffic roads, main roads with more traffic lights, and through areas with more access to destinations such as commercial rather than residential areas. Similarly, children living in San Diego, California perceived busy commercial areas with more traffic as safer walking environments than quiet and remote residential roads with less traffic (43). However, contrasting results have been found in earlier research whereby GIS-modelled shortest routes went along more high traffic roads (240, 244) and through less residential areas (240) compared to GPS-measured routes. It is important to note that the majority of schools recruited in the current study were located on main roads or near busy streets, meaning that at least some portion of all children's routes would have been characterised as having higher traffic exposure. Moreover, the length of high traffic roads calculated within SN buffers can be underestimated because the SN approach disregarded the presence of motorways and freeways which, on the contrary, were recognised as high traffic roads in SNm and PN (several motorways/freeways in Auckland have footpaths). Further investigation into the relationships between residential density, traffic exposure, road safety, and active school travel is warranted (e.g., Rothman et al. (91)).

4.4.1 Strengths and limitations

Given existing theoretical and methodological limitations of GIS to calculate children's school travel route, there is a need for research that critically examines the applicability of GIS to measure environmental exposure (i.e., potential and actual) en-route to school. To date, only one study has employed different network datasets to estimate shortest school travel routes depending on travel mode (i.e., walking and being driven) (263).

Use of a valid and reliable measure of children's school travel routes, such as online participatory mapping, can provide a relatively accurate and reliable method. Yet, self-report bias can occur through issues with participant recall, spatial knowledge and online map navigation skills, and cognitive abilities (242, 260). These differences were pronounced among adolescents using passive travel modes (i.e., motorised vehicles) (242). Children who actively travelled to school were 17.6% more likely to complete the softGIS mapping exercise than those who passively travelled to school. Moran et al. (281) reported that children aged 10-12 years who walked to school were more likely to draw sketch maps with accurate orientation and structure, suggesting greater spatial knowledge and mapping capabilities in those who actively travelled. Moreover, children who regularly walked in the neighbourhood en-route to school had a more elaborate mental and cognitive presentation of their settings (43). It is possible this was also the case in the children participating in the current study.

Importantly, myriads of decisions on the process of GIS measurement were made including data sources, spatial units, and buffering methods and sizes, which all significantly impacted on the outcomes. It is also acknowledged that available GIS data collected from different sources may vary in terms of consistency, accuracy, and time (282). The current study exploited a combination of techniques (i.e., a visual inspection of land parcels along softGIS routes and walking speed) to determine the size of school travel route buffer (i.e., 80 m) within which children were (actually and potentially) exposed to the physical environment. Despite this thorough approach, the effects of spatial scale and zoning (i.e., Modifiable Area Unit Problem (MAUP)), and spatial and temporal uncertainty of the contextual influences (i.e., UGCoP) should be considered as methodological limitations. Furthermore, even with GPS, capturing 100% accurate children's 'usual' routes to school may be challenging due to daily or weekly variations in travel modes and routes. GPS can only provide a snapshot of mobility patterns over a research defined period of time.

Due to a small sample size of cyclists (N = 42, 3.9%) in the current study, walking and cycling were combined as active travel in which children were more likely to be physically active and exposed to the physical environment during their school travel compared to those who were driven or used public transport (i.e. passive travel). Route characteristics can differ depending on travel modes including between walking and cycling, and the orientation of travel 'to' and 'from' school. For example, Dessing et al. (240) found walking and cycling routes were at variance with the physical environment, and Harrison et al. (244) reported differences in distance and high traffic road use among adolescents who travelled on foot, by bicycle, by car, and by bus. Further research is needed to untangle the differences in physical environment attributes of importance for walking and cycling to school.

The cross-sectional study design limited the causal interpretation of the findings. Though school travel behaviour can be a regular behaviour (193), the influence of the physical environment on this behaviour can vary spatially and temporally (261). However, the current findings can be applied to describe the characteristics of children's school travel routes. They also suggest that GIS-modelled shortest routes should be used cautiously to assess spatial and environmental influence on children's school travel in future research. What is more, this method can potentially allow for the quantification and collation of the individual usage of roads that children take as part of their school travel routes. The information can benefit the planning and development of activity-friendly and safe neighbourhoods (e.g., Ryan et al. (283)).

4.5 Conclusions

This study utilised self-drawn routes using softGIS and various GIS-modelled shortest routes and examined the spatial and environmental differences between these route types. Overall, none of the GIS-modelled shortest routes were comparable to softGIS routes for active or passive travellers in terms of spatial overlap and the physical environment. The spatial overlap between softGIS and GIS-modelled shortest routes ranged from 46.9-64.4%, and traffic exposure, distance to school and route directness were significantly different between softGIS and GIS-modelled shortest routes. GIS-modelled shortest routes to school may not represent actual routes taken; therefore, physical environment attributes calculated for these estimated routes may not accurately reflect the environment to which a child is actually exposed.

Chapter 5 Structural Equation Modelling

Chapter 5 is the heart of the current research in which findings from Chapter 2, Appendix A, and Chapter 4 are integrated to inform and develop the C-STBM and, consequently, to answer the research question. In this chapter, SEM is an analytical technique to comprehensively examine the mechanism of children's AST, including its direct and indirect relationships with multiple environmental (i.e., physical, social, household, child) factors. For brevity, only significant results are only described and discussed in 5.3.3 Structural model and Indirect (mediating) effects

Specific indirect (mediating) effects from the observed/latent variables to AST are shown in Figure 32 (p. 153).A full mediation was observed in the pathway from *Active Mobility Environment* to AST through distance to school ($p < 0.01$). All indicators of *Active Mobility Environment* (i.e., residential density, street connectivity, high and low traffic exposure) were negatively correlated with distance to school (r = -0.61, -0.06, -0.42, and -0.52, respectively; standard errors for the correlation matrix were not available in Mplus). The pathway from importance of stranger danger to AST was fully mediated by importance of traffic safety ($p < 0.05$).

Independent mobility partially mediated the pathways from school year ($p < 0.01$), sex ($p < 0.05$), and *Neighbourhood Social Environment* ($p < 0.05$) to AST. The pathways from school year ($p < 0.05$) or sex ($p < 0.05$) to AST were also partially mediated by independent mobility through neighbourhood safety. Distance to school was a partial mediator of the pathway from school year to AST ($p < 0.01$).

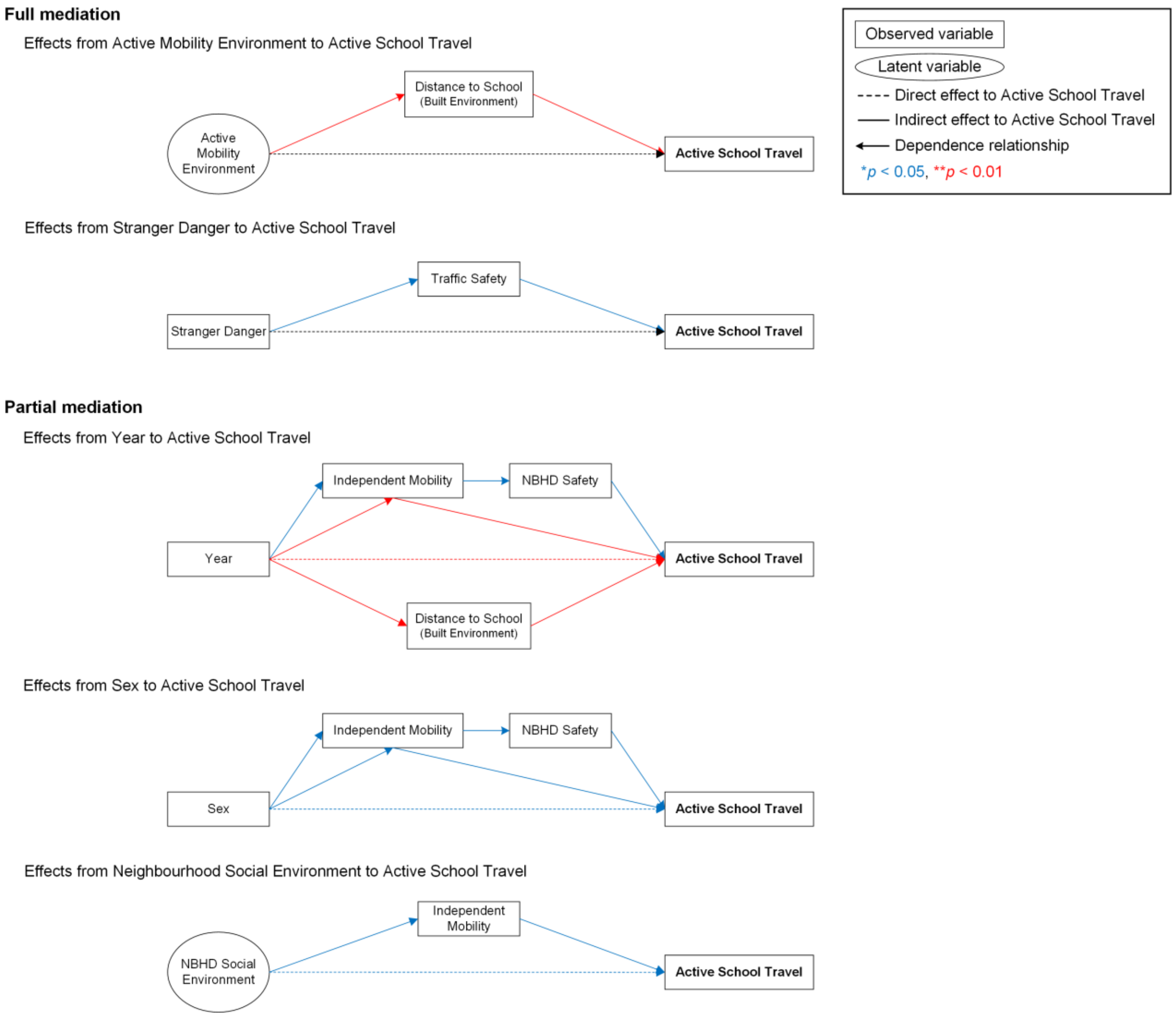


Figure 32. Standardised specific indirect effects on children’s active travel to school.

5.4 Discussion. The further discussion of key findings are provided in Chapter 6 Discussion and Conclusion.

5.1 Background

Active travel (e.g., walking or cycling to destinations) can be a convenient and regular way for children to accumulate physical activity. Children's physical, psychological and social health, and cognitive development benefit from active travel through opportunities to accumulate physical activity, interact with friends and nature, and spatially navigate their neighbourhood (4, 189, 284). In more broad terms, active travel can also be economically beneficial and contribute to environmental sustainability via reducing traffic congestion and emissions due to motorised transportation. Gross greenhouse emissions in NZ have increased by 20% between 1990 and 2016 (19). Road transport has contributed to this increase particularly in terms of carbon dioxide emissions (19).

There is a clear need for reducing the use of motorised transportation in favour of active travel. The school trip is one area where such changes could be achieved. In NZ a majority of schools have zoning regulations, providing children who live inside the zone an absolute right to enrol at the school (64, 285, 286). This means that many children might live close enough to the school they attend to actively travel to/from school. Yet, recent data show less than half of NZ children aged 5-14 years get to school actively (15). Demographic differences were also observed, with older youth (ages 10-14 years) and males more likely to report AST (15).

A wealth of studies have collectively demonstrated the complex nature of children's AST (24, 26, 27, 44, 87, 284). The diverse range of factors that can promote or inhibit children's AST includes physical (i.e., natural and built) and social environment factors as well as household and individual child factors. For the most part, these factors have been assessed using objective (e.g., GIS) and/or subjective (e.g., survey) measures (25-27, 44, 284). The socio-ecological model has been the most commonly used to structure multiple layers of influence on AST (32, 49, 60, 88, 163).

A conceptual model specifically for children's school travel behaviour, the BMST was developed by Mitra (32). The BMST is a comprehensive conceptual model that combines the socio-ecological model, a household active-travel approach (218), and McMillan's framework (49) in which school travel behaviour is conceptualised as having two components: travel mode and accompaniment (i.e., independent versus escorted) (32). Mitra identified four domains (external influences, urban environment, household, child) and five mediators (proximity to school, street connectivity, comfort and attractiveness of the travel route, traffic and personal safety, social capital) that influence children’s school travel behaviour. Previous studies have empirically tested the BMST; however, they were unable to examine indirect (mediated) relationships to AST (184) or missed integrating the social environment and children’s perceptions (190).

The application of theories such as BMST can highlight the structure of mediated relationships between variables such as physical environments and safety (32, 49, 128). Opportunities exist to improve the knowledge base through robust application of conceptual models to guide analytical techniques (87). Given the complicated interrelationships of influences on AST, SEM is an appropriate multivariate technique, for testing theories and elucidating respective dependent relationships. The strength of SEM is the ability to combine analyses of linear and logistic regressions including direct and indirect (i.e., mediating) effects among observed and latent (i.e., unobserved) variables.

Yu and Zhu (140, 141) utilised SEM to evaluate two conceptual models for children’s walking to/from school. The first consisted of personal (including residential self-selection), social factors, and built environment factors (as a mediator of residential self-selection) (140). The second considered personal, social and built environment factors, and parental attitudes (as a mediator) (141). Both models had acceptable/adequate fit. Children’s walking to/from school was negatively associated with attitudinal and walking barriers (e.g., too much to carry, too hot and sweaty) and safety concerns, and positively correlated with perceived proximity to school, enjoyment of walking, and residential self-selection (140, 141). These studies, however, did not incorporate objective built environment measures or children’s perspectives. Lu et al. (87) examined associations between children’s AST and child and parent self-efficacy using SEM based on Bandura’s social cognitive theory. This study examined relationships between children’s AST and psychological (i.e., self-efficacy), social, and environmental factors. However, unlike Mitra’s BMST, or other socio-ecological models (32, 49, 60, 88, 163), indirect relationships among these factors were not explicitly demonstrated. Mehdizadeh et al. (166) developed a more comprehensive conceptual model based on the social cognitive theory, the theory of planned behaviour and the prototype willingness model in which direct and indirect associations between children’s AST and built and social environments as well as parent attitudes were conceptualised and tested using SEM. This model, however, did not integrate children’s perspectives.

The purpose of this chapter is to assess direct and indirect associations between children's AST and environmental, household, and child factors based on Mitra's BMST (32) using SEM. It is informed by a conceptual model developed from the BMST and the conceptual models designed by McMillan (49) and Panter et al. (88), entitled the C-STBM, as presented in Figure 27 (p. 130). Six of the seven domains identified in the model (physical environment, social environment, household characteristics, household beliefs, child characteristics, and child beliefs) were included in the current analysis. The seventh, the school environment (i.e., school policies, AST programmes) was not included due to an inadequate number of participating schools (see 5.4.6 Strengths and limitations). It was hypothesised that (i) the physical environment, the social environment, household and child characteristics, and household and child beliefs were directly associated with children's AST (Appendix L, pp. 311-315); and (ii) all the domains, except child beliefs, were indirectly related to children's AST (Appendix M, pp. 316-321).

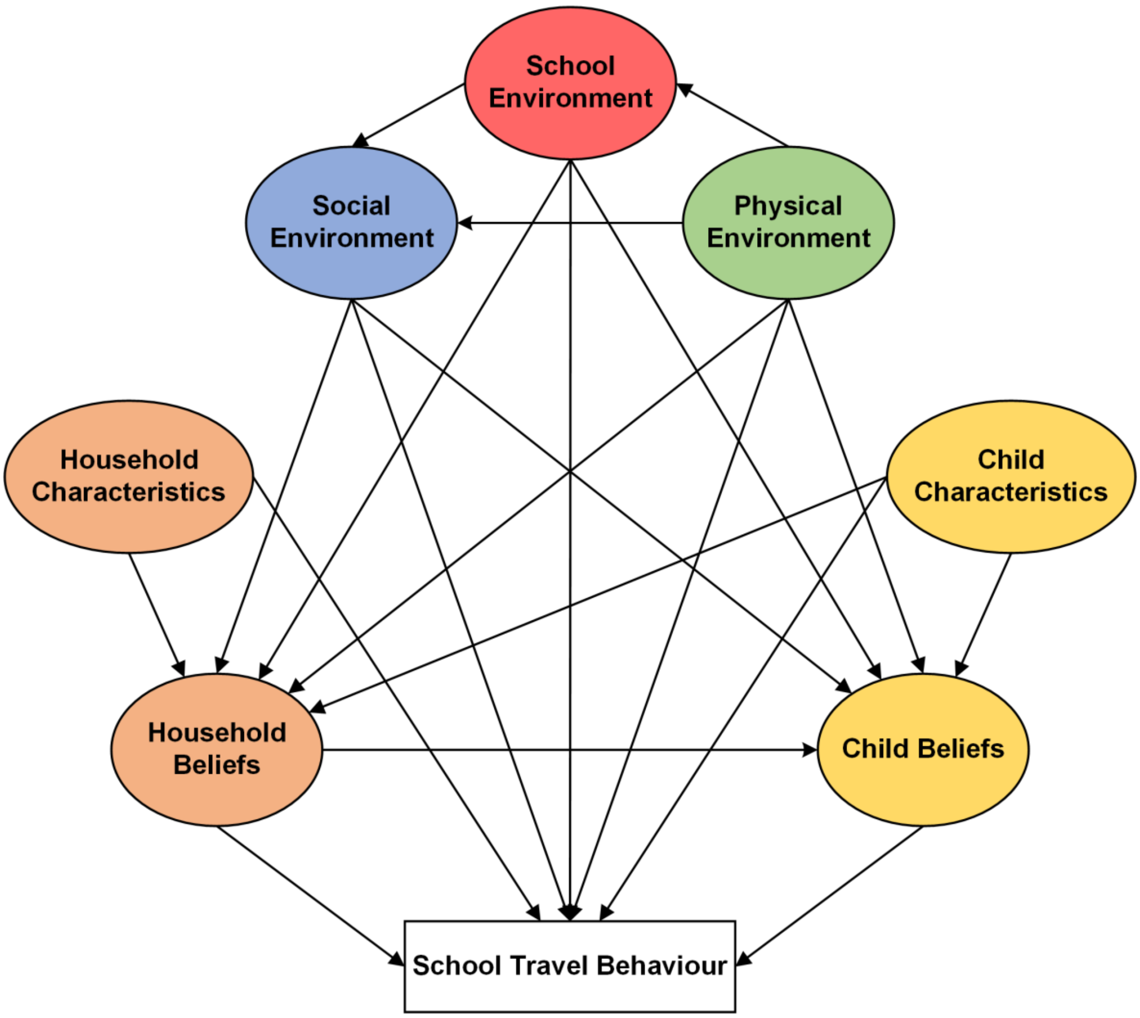


Figure 27. Children's School Travel Behaviour Model (C-STBM).

5.2 Methods

5.2.1 Study design, setting, participants and protocol

New Zealand is characterised as a highly suburbanised nation with a total population of 4.9 million in 2018 of which 13% were children aged 5-14 years (56). Auckland is NZ's largest urban area (1.7 million in 2017) located in the North Island where the population has sprawled and shifted towards automobile dependency due to urban developments (287).

The NfAK is a cross-sectional study conducted in Auckland that uses a child-centred approach to measuring and describing relationships between the physical environment and a range of children's activity behaviours and health outcomes. Information was collected using an online participatory mapping survey (i.e., softGIS) with children, the CATI with parents, and GIS for physical environment attributes. Design and methods of the full study are described in detail elsewhere (224).

Briefly, children aged 8-13 years (school years 5-8) and their parents from nine intermediate (middle/junior high) and 10 primary (elementary) schools across nine neighbourhoods in Auckland, NZ participated in the study between February 2015 and December 2016. Schools were selected based on a matrix of school decile (i.e., a neighbourhood-level measure of socioeconomic status; high, medium, low), child-specific school walkability (high, medium, low) (39) and the NDAI-C (high, medium, low) (226). This recruitment approach was applied to increase heterogeneity in neighbourhood deprivation and geographic characteristics.

A softGIS survey (227-229) was used to measure children's mode of travel and route to school, perceived neighbourhood and traffic safety, and independent mobility. Trained researchers visited schools during school hours at which time children completed a softGIS survey with one-on-one researcher support. Children were then asked to wear Actigraph GT3X+ accelerometers (Actigraph, Pensacola, FL) around their waist over seven consecutive days. A CATI survey was conducted with parents/caregivers of participating children to measure household sociodemographics, and reasons for decision-making on children's school travel mode and relative importance of the reasons. Ethical approval to conduct the study was granted by the host institution ethics committees (AUTEC, 14/263, 3 September 2014).

5.2.2 Measures

Information about observed variables including description of variables, type of variables (i.e., continuous, binary, ordinal, nominal), code or scale of variables, and descriptive statistics is summarised in Table 17 (pp. 135-142).

School travel mode

Children's usual mode of travel to school was self-reported using softGIS by asking "*How do you usually get to school?*" with responses being 'walk', 'bike', 'scooter (non-motorised)', 'public bus, train or ferry', 'car, motorbike, scooter or taxi', and 'another way (e.g., skateboard)'. School travel mode was dichotomised to active travel (i.e., walk, bike, scooter, skateboard) and passive travel (i.e., car, public transport).

Child characteristics

Child's school year (grade), sex, and ethnicity were reported by schools or their parents/caregivers, and included in analyses as covariates. School-travel-related physical activity was assessed using Actigraph GT3X+ accelerometers (Actigraph, Pensacola, FL) during the 8:00am-9:00am commuting period on weekdays (Monday-Friday, excluding public holidays) (235). Raw data were collected at frequency of 30 Hz, and aggregated to a 30 second epoch using Actilife v6 (Actigraph, Pensacola, FL). Accelerometer cut-points (vertical counts/min) provided by Evenson et al. (236) were utilised to classify time spent in sedentary and in light, moderate, and vigorous physical activity. Non-wear time was classified as 60 minutes or more of consecutive zeros counts (237). Inclusion in analyses was a two-stage process. First, participants were required to have at least three valid days with a minimum of seven hours of wear time (238). Of these, participants with at least two valid weekdays with 60 minutes of data between 8:00am-9:00am were included. The percentage of time spent (in minutes) in overall (i.e., light + moderate + vigorous) physical activity (PA) during the morning commute was calculated as:

$$Physical\ activity = \left(\sum morning\ overall\ PA \div \sum allday\ overall\ PA\right) \times 100$$

Child beliefs

Traffic safety perception was measured by the summed score of two items with a 4-point Likert scale (Spearman's $\rho = 0.29$, $p < 0.001$) (233). Neighbourhood safety perception was measured by the summed score of two items with a 4-point Likert scale after combining responses of ‘hardly ever/never’ and ‘do not go out with/without an adult in the neighbourhood’ ($\rho = 0.18$, $p < 0.001$) (233). Independent mobility (i.e., unaccompanied/unsupervised travel) was assessed by the summed score of three items with a dichotomous response indicating whether the child had independent mobility or not (Cronbach’s $\alpha = 0.85$) (234).

Household characteristics

Parents/caregivers reported their highest academic qualification, their current employment situation, and number of adults, children aged under 18 years, and working cars in their household.

Household beliefs

Importance of parent reasons for decision-making on children’s school travel mode was assessed by two items: “*What are the main reasons your child gets to school by respective school travel mode?*”, and “*How important would you say this reason when deciding how your child gets to school?*” Reasons were categorised into ‘distance to school’, ‘traffic safety’, ’stranger danger’, ‘convenience’ and ‘social interaction’. Each reason was first dummy coded as ‘not main reason’ and ‘main reason’. ‘Main reason’ was then rated as ‘not important’, ‘a little bit important’, ‘important’, or ‘very important’.

Social environment

Neighbourhood Social Environment was a first-order factor (latent variable) which was collectively measured by three observed variables: neighbourhood safety, neighbourhood cohesion, and neighbourhood connection (239). Neighbourhood safety was measured by the summed score of nine items (Cronbach’s $\alpha = 0.76$). Neighbourhood cohesion was measured by the summed score of nine items (Cronbach’s $\alpha = 0.80$). Neighbourhood connection was measured by the summed score of five items (Cronbach’s $\alpha = 0.85$). A 5-point Likert scale was used, and scales were reverse coded where appropriate.

Physical environment

SoftGIS home location (point) and child-drawn school travel route (polyline) data were downloaded from the softGIS survey, and imported into ArcGIS 10.2 (Environmental Systems Research Institute (ESRI), Redlands, CA). SoftGIS routes inside the school polygon were trimmed.

All softGIS routes were manually cleaned and obviously incorrect softGIS routes (e.g., incomplete routes, routes ended at non-school locations) were excluded from further analyses. Distance to school (in metres) along softGIS routes was calculated, and log-transformed. SoftGIS routes were then buffered using an 80 m radius on each side of the street centre line to measure physical environment attributes (288).

Active Mobility Environment was a first-order factor (latent variable) which was collectively assessed by four observed variables: residential density, street connectivity, high traffic exposure, and low traffic exposure. Residential density was calculated as the ratio of residential dwellings to the residential land area (i.e., without water) of 80 m softGIS route buffer (288). Meshblock level data on the number of private occupied dwellings at the 2013 Census was downloaded from the Statistics New Zealand website and linked to the meshblock boundaries. Street connectivity was calculated as the ratio of number of intersections with three or more intersecting streets to the land area of 80 m softGIS route buffer (288). Road centreline data were obtained from the 2015 CoreLogic Transport dataset. High or low traffic exposure was measured by length of high or low traffic roads within an 80 m softGIS route buffer weighted by an inverse softGIS route distance:

$$High\ (Low)\ traffic\ exposure = \frac{1}{\delta r \div \sum_r \delta r \times 10^6} \times length\ of\ high\ (low)\ traffic\ roads$$

where δr is the distance of an individual softGIS route, $\sum_r \delta r$ is the sum of softGIS route distances (i.e., a shorter softGIS route distance had a higher weight) (277). Road classification derived from the 2015 CoreLogic Transport dataset was employed as a proxy for traffic volume (288).

Table 17 Information about observed variables and their descriptive statistics (N = 1085)

Observed variable	Latent variable	Description	Data source	Variable type	Missing (%)	Measurement scale	Descriptive statistics†
School Travel Mode							
Active school travel	-	How do you usually get to school?	SoftGIS	Binary	0.0	0 = passive travel (i.e., car, public transport)	58.0%
						Car	46.1%
						Public transport	11.9%
					0.0	1 = active travel (i.e., walk, bike, scooter, skateboard)	42.0%
						Walk	34.4%
						Bike	3.9%
						Scooter, skateboard	3.8%
Child Characteristics							
Year	-	Child's school year	School/Parent consent form	Continuous	0.0	5 = Year 5	24.5%
						6 = Year 6	26.4%
						7 = Year 7	24.2%
						8 = Year 8	24.9%
Sex	-	Child's sex	School/Parent consent form	Binary	0.0	0 = male	49.0%
						1 = female	51.0%
Ethnicity	-	New Zealand (NZ) European	School/CATI	Binary*	1.2	0 = Māori/Pacific/Asian/other	46.1%
						1 = NZ European	52.7%
		Māori	School/CATI	Binary*	1.2	0 = NZ European/Pacific/Asian/other	85.9%
						1 = Māori	12.9%
		Pacific	School/CATI	Binary*	1.2	0 = NZ European/Māori/Asian/other	84.5%
						1 = Pacific	15.3%
		Asian	School/CATI	Binary*	1.2	0 = NZ European/Māori/Pacific/other	83.8%
						1 = Asian	15.0%
Physical activity	-	Percentage of time spent in overall (light + moderate + vigorous) physical activity during the morning (8:00-9:00 am) commute	Accelerometer	Continuous	8.4	-	8.8 ± 3.0

Observed variable	Latent variable	Description	Data source	Variable type	Missing (%)	Measurement scale	Descriptive statistics†
Child Beliefs							
Traffic safety	-	Summed scores of 2 items:	SoftGIS	Continuous	0.4	-	4.8 ± 1.4
		1. The roads around my school are busy with traffic before and after school.	SoftGIS	Ordinal	0.2	1 = all of the time	13.0%
						2 = most of the time	40.7%
						3 = sometimes	37.2%
						4 = hardly ever/never	8.8%
		2. The roads around my school are full of parked cars before and after school.	SoftGIS	Ordinal	0.4	1 = all of the time	17.1%
						2 = most of the time	36.2%
						3 = sometimes	35.9%
						4 = hardly ever/never	10.3%
Neighbourhood safety	-	Summed scores of 2 items:	SoftGIS	Continuous	0.4	-	6.2 ± 1.3
		1. If I am out with an adult, I feel safe in my neighbourhood.	SoftGIS	Ordinal	0.4	1 = hardly ever/never/do not go out with an adult in the neighbourhood	2.0%
						2 = sometimes	8.0%
						3 = most of the time	21.2%
						4 = all of the time	68.4%
		2. If I go out without an adult, I feel safe in my neighbourhood.	SoftGIS	Ordinal	0.3	1 = hardly ever/never/do not go out without an adult in the neighbourhood	17.9%
						2 = sometimes	27.3%
						3 = most of the time	33.2%
						4 = all of the time	21.4%
Independent mobility	-	Summed scores of 3 items:	SoftGIS	Continuous	1.0	-	4.6 ± 1.0
		1. Are you allowed to cross main roads on your own?	SoftGIS	Binary	0.4	1 = no	32.3%
						2 = yes	67.4%
		2. Are you allowed to go on local buses or trains or ferries on your own?	SoftGIS	Binary	0.8	1 = no	71.2%
						2 = yes	27.9%
		3. If you have a bicycle, are you allowed to ride it to go to places?	SoftGIS	Binary	0.6	1 = no/do not have a bicycle	40.5%
						2 = yes	58.9%
Household Characteristics							
Education	-	What is your highest academic qualification?	CATI	Binary	18.8	0 = Certificate (levels 1-6), Diploma or lower	51.2%

Observed variable	Latent variable	Description	Data source	Variable type	Missing (%)	Measurement scale	Descriptive statistics†
						1 = Bachelor's degree or higher	30.0%
Employment	-	Which one best describes your main current employment situation? Full-time paid work.	CATI	Binary*	18.2	0 = part-time/other	41.8%
						1 = full-time	40.0%
		Which one best describes your main current employment situation? Part-time paid work.	CATI	Binary*	18.2	0 = full-time/other	56.8%
						1 = part-time	25.0%
Number of adults	-	How many adults, including yourself, live in your household?	CATI	Ordinal	18.2	1 = 1 adult	9.1%
						2 = 2 adults	56.5%
						3 = 3 adults	9.2%
						4 = 4 adults	4.7%
						5 = greater than or equal to 5 adults	2.3%
Number of children	-	How many other children under 18 live in your household?	CATI	Ordinal	18.2	0 = no other children	12.1%
						1 = 1 child	36.2%
						2 = 2 children	21.8%
						3 = 3 children	7.6%
						4 = greater than or equal to 4 children	4.1%
Car ownership	-	How many working cars are available to your household?	CATI	Binary	18.2	0 = less than or equal to 1 car	18.1%
						1 = greater than or equal to 2 cars	63.8%
Household Beliefs							
Distance to school	-	What are the main reasons your child gets to school by (travel mode to school)? How important would you say this reason (i.e., distance to school) when deciding how your child gets to school?	CATI	Ordinal	21.7	1 = not main reason	35.0%
						2 = main reason, but not important	0.6%
						3 = main reason, and a little bit important	0.8%
						4 = main reason, and important	6.3%
						5 = main reason, and very important	35.6%
Traffic safety	-	What are the main reasons your child gets to school by (travel mode to school)? How important would you say	CATI	Ordinal	14.9	1 = not main reason	78.5%
						2 = main reason, but not important	0.1%

Observed variable	Latent variable	Description	Data source	Variable type	Missing (%)	Measurement scale	Descriptive statistics†
		this reason (i.e., traffic safety) when deciding how your child gets to school?				3 = main reason, and a little bit important	0.1%
						4 = main reason, and important	0.6%
						5 = main reason, and very important	5.7%
Stranger danger	-	What are the main reasons your child gets to school by (travel mode to school)? How important would you say this reason (i.e., stranger danger) when deciding how your child gets to school?	CATI	Ordinal	14.6	1 = not main reason	79.6%
						2 = main reason, but not important	0.0%
						3 = main reason, and a little bit important	0.2%
						4 = main reason, and important	0.6%
						5 = main reason, and very important	5.0%
Convenience	-	What are the main reasons your child gets to school by (travel mode to school)? How important would you say this reason (i.e., convenience) when deciding how your child gets to school?	CATI	Ordinal	17.2	1 = not main reason	56.0%
						2 = main reason, but not important	0.6%
						3 = main reason, and a little bit important	2.8%
						4 = main reason, and important	7.9%
						5 = main reason, and very important	15.4%
Social interaction	-	What are the main reasons your child gets to school by (travel mode to school)? How important would you say this reason (i.e., social interaction) when deciding how your child gets to school?	CATI	Ordinal	14.3	1 = not main reason	80.8%
						2 = main reason, but not important	0.0%
						3 = main reason, and a little bit important	0.7%
						4 = main reason, and important	1.8%
						5 = main reason, and very important	2.4%
Social environment							
Neighbourhood safety	Neighbourhood social environment	Summed scores of 9 items:	CATI	Continuous	27.6	-	33.4 ± 4.8
		1. There are safe places for children to play in our neighbourhood.	CATI	Ordinal	19.2	1 = strongly disagree	1.0%
						2 = disagree	11.7%
						3 = neither agree nor disagree	5.9%

Observed variable	Latent variable	Description	Data source	Variable type	Missing (%)	Measurement scale	Descriptive statistics†
						4 = agree	47.7%
						5 = strongly agree	14.5%
		2. It's a good place to bring up children.	CATI	Ordinal	18.8	1 = strongly disagree	0.6%
						2 = disagree	2.7%
						3 = neither agree nor disagree	5.1%
						4 = agree	48.3%
						5 = strongly agree	24.6%
		3. I feel safe walking down my street after dark.	CATI	Ordinal	19.5	1 = strongly disagree	3.6%
						2 = disagree	18.4%
						3 = neither agree nor disagree	7.0%
						4 = agree	41.6%
						5 = strongly agree	9.9%
		4. I worry about the number of crimes committed in our neighbourhood.	CATI	Ordinal	19.3	1 = strongly agree	6.0%
						2 = agree	25.4%
						3 = neither agree nor disagree	11.2%
						4 = disagree	34.1%
						5 = strongly disagree	4.1%
		5. Graffiti and vandalism are problems.	CATI	Ordinal	18.7	1 = strongly agree	2.9%
						2 = agree	14.4%
						3 = neither agree nor disagree	5.3%
						4 = disagree	52.7%
						5 = strongly disagree	6.1%
		6. Roaming dogs are a problem in our neighbourhood.	CATI	Ordinal	18.7	1 = strongly agree	3.1%
						2 = agree	11.7%
						3 = neither agree nor disagree	4.1%
						4 = disagree	55.0%
						5 = strongly disagree	7.3%
		7. It's a good place to buy a home.	CATI	Ordinal	19.4	1 = strongly disagree	1.2%
						2 = disagree	5.5%
						3 = neither agree nor disagree	3.5%
						4 = agree	54.8%
						5 = strongly agree	15.5%
		8. Bullying is a problem in our neighbourhood.	CATI	Ordinal	22.7	1 = strongly agree	1.9%
						2 = agree	8.9%

Observed variable	Latent variable	Description	Data source	Variable type	Missing (%)	Measurement scale	Descriptive statistics†
						3 = neither agree nor disagree	5.6%
						4 = disagree	54.5%
						5 = strongly disagree	6.4%
		9. There are a lot of families with young children living in our neighbourhood.	CATI	Ordinal	20.4	1 = strongly disagree	0.1%
						2 = disagree	6.0%
						3 = neither agree nor disagree	4.5%
						4 = agree	54.8%
						5 = strongly agree	14.2%
Neighbourhood cohesion	Neighbourhood social environment	Summed scores of 9 items:	CATI	Continuous	36.7	-	33.8 ± 4.5
		1. People are willing to help.	CATI	Ordinal	22.3	1 = strongly disagree	0.4%
						2 = disagree	5.1%
						3 = neither agree nor disagree	7.7%
						4 = agree	55.3%
						5 = strongly agree	9.2%
		2. Neighbours watch out for kids.	CATI	Ordinal	22.9	1 = strongly disagree	0.5%
						2 = disagree	6.5%
						3 = neither agree nor disagree	7.4%
						4 = agree	53.5%
						5 = strongly agree	9.1%
		3. It's a close knit neighbourhood.	CATI	Ordinal	20.8	1 = strongly disagree	0.7%
						2 = disagree	18.7%
						3 = neither agree nor disagree	15.3%
						4 = agree	39.2%
						5 = strongly agree	5.3%
		4. I could borrow $10 from a neighbour.	CATI	Ordinal	25.3	1 = strongly disagree	2.3%
						2 = disagree	20.4%
						3 = neither agree nor disagree	5.1%
						4 = agree	39.4%
						5 = strongly agree	7.5%
		5. If there is a problem with neighbours, we can deal with it.	CATI	Ordinal	21.7	1 = strongly disagree	0.3%
						2 = disagree	5.1%
						3 = neither agree nor disagree	5.1%
						4 = agree	62.0%

Observed variable	Latent variable	Description	Data source	Variable type	Missing (%)	Measurement scale	Descriptive statistics†
						5 = strongly agree	5.9%
		6. The neighbours cannot be trusted.	CATI	Ordinal	21.7	1 = strongly agree	0.4%
						2 = agree	6.6%
						3 = neither agree nor disagree	6.0%
						4 = disagree	54.2%
						5 = strongly disagree	11.2%
		7. People will take advantage of you.	CATI	Ordinal	22.4	1 = strongly agree	0.9%
						2 = agree	6.7%
						3 = neither agree nor disagree	5.3%
						4 = disagree	55.6%
						5 = strongly disagree	9.0%
		8. People you don't know will greet you or say hello to you.	CATI	Ordinal	19.2	1 = strongly disagree	0.3%
						2 = disagree	6.6%
						3 = neither agree nor disagree	5.9%
						4 = agree	61.4%
						5 = strongly agree	6.6%
		9. People of different backgrounds don't talk to each other.	CATI	Ordinal	21.7	1 = strongly agree	0.9%
						2 = agree	17.0%
						3 = neither agree nor disagree	7.6%
						4 = disagree	49.3%
						5 = strongly disagree	3.6%
Neighbourhood connection	Neighbourhood social environment	Summed scores of 5 items:	CATI	Continuous	35.9	-	18.6 ± 3.2
		1. Parents in this neighbourhood know their children's friends.	CATI	Ordinal	24.8	1 = strongly disagree	0.4%
						2 = disagree	7.6%
						3 = neither agree nor disagree	6.1%
						4 = agree	53.7%
						5 = strongly agree	7.4%
		2. Adults in this neighbourhood know who the local children are.	CATI	Ordinal	25.5	1 = strongly disagree	0.7%
						2 = disagree	10.3%
						3 = neither agree nor disagree	10.6%
						4 = agree	48.2%
						5 = strongly agree	4.6%
			CATI	Ordinal	28.3	1 = strongly disagree	0.5%

Observed variable	Latent variable	Description	Data source	Variable type	Missing (%)	Measurement scale	Descriptive statistics†
						2 = disagree	9.3%
		3. There are adults in this neighbourhood that the children can look up to.				3 = neither agree nor disagree	10.0%
						4 = agree	46.6%
						5 = strongly agree	5.3%
		4. Parents in this neighbourhood generally know each other.	CATI	Ordinal	22.6	1 = strongly disagree	0.5%
						2 = disagree	12.5%
						3 = neither agree nor disagree	10.9%
						4 = agree	48.2%
						5 = strongly agree	5.3%
		5. You can count on adults in this neighbourhood to watch out that children are safe and don't get in trouble.	CATI	Ordinal	24.9	1 = strongly disagree	0.5%
						2 = disagree	8.1%
						3 = neither agree nor disagree	10.2%
						4 = agree	50.3%
						5 = strongly agree	6.0%
Physical environment							
Distance to school	-	Distance to school (in metres) along softGIS routes	GIS	Continuous	11.5	-	2783.7 ± 3557.7
		Distance to school (log-transformed) along softGIS routes	GIS	Continuous	11.5	-	7.4 ± 1.0
Residential density	Active mobility environment	Ratio of residential dwellings to the residential land area (i.e., without water) of 80 m softGIS route buffer	GIS	Continuous	11.6	-	28.8 ± 10.8
Street connectivity	Active mobility environment	Ratio of number of intersections with three or more intersecting streets to the land area of 80 m softGIS route buffer	GIS	Continuous	11.6	-	56.6 ± 19.2
High traffic exposure	Active mobility environment	Length of high traffic roads within 80 m softGIS route buffer weighted by inverse softGIS route distance	GIS	Continuous	11.6	-	5.9 ± 4.9
Low traffic exposure	Active mobility environment	Length of low traffic roads within 80 m softGIS route buffer weighted by inverse softGIS route distance	GIS	Continuous	11.6	-	10.5 ± 8.2

CATI = computer-assisted telephone interview. GIS = geographic information systems. *Dummy variable. †Frequencies (%) for binary or ordinal variables; mean ± standard deviation for continuous variables.

5.2.3 Statistical analysis

Structural equation modelling

Structural equation modelling using Mplus version 8.1 (257) was employed to test the hypothesised conceptual model (Figure 28, p. 145). SEM is a multivariate technique combining factor analysis and multiple regression, which can encompass two components: a measurement model (i.e., confirmatory factor analysis) and a structural model (289, 290). Benefits of SEM are (i) to represent theoretical concepts which cannot be directly observed, (ii) to improve the statistical estimation of relationships between the concepts by considering the measurement error, (iii) to estimate multiple and interrelated dependent relationships, and (iv) to define a model to elucidate the complete set of relationships between variables (290).

Mplus can estimate mixture modelling with cross-sectional data including combinations of continuous, binary, ordinal, and nominal observed variables, and can handle missing data (257). Multiple imputation using Bayesian analysis was performed for a set of observed variables with missing values (100 replications) (257). As the children were nested within their schools, the data might have a multilevel hierarchical structure (i.e., a multilevel model) (291). Intraclass correlation coefficients (ICCs) were performed to examine the clustered data structure (i.e., the variability in observed variables can be explained by schools). The ICCs indicated cluster effects might exist in AST (ICC = 0.13), year (ICC = 0.81), ethnicity (NZ European: ICC = 0.39, Pacific: ICC = 0.30), independent mobility (ICC = 0.22), education (ICC = 0.15), neighbourhood safety (ICC = 0.19), and GIS measures (ICC = 0.15-0.44). However, due to the small size of school clusters (N = 19), a multilevel model was deemed inappropriate.

A measurement model specified observed variables for each latent variable (i.e., *Active Mobility Environment* and *Neighbourhood Social Environment*). The construct validity including convergent validity, discriminant validity, and reliability of the measurement model was assessed. Convergent validity was assessed using factor loadings (λ; ≥ 0.5), average variance extracted (AVE; ≥ 0.5), and construct reliability (CR; ≥ 0.7). Discriminant validity was assessed by a correlation between the latent variables being significantly smaller than 1.0.

A structural model was specified based on the hypothesised conceptual model by assigning direct and indirect (mediating) dependent relationships to AST (Appendices L, p. 311-315; M, p. 316-321). The indirect (mediating) effect represents a pathway from an independent variable to AST through a mediator and can be classified as full (100% mediation and no direct effects on AST) or partial (some mediation and some remaining direct effect on AST) (292). Individual estimates of each hypothesised structural relationship were examined by the significance (i.e., $p < 0.05$, $p < 0.01$) and direction (i.e., positive, negative; Appendix L) of the standardised associations.

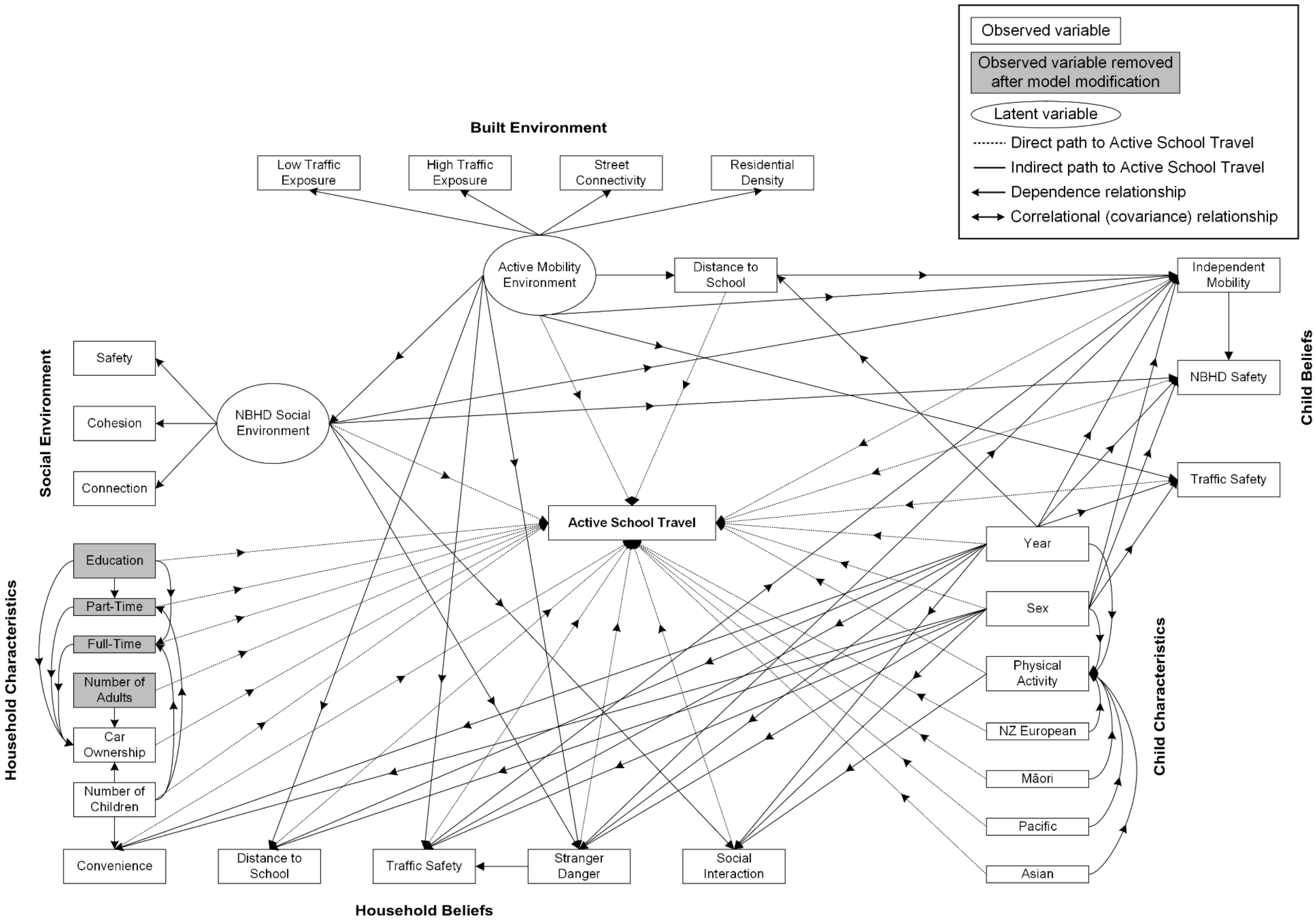


Figure 28. The hypothesised full structural equation modelling.

Modelling strategy

A model development strategy was applied to improve the conceptual model of children's school travel behaviour. Two stages were involved: (i) testing the hypothesised SEM, and (ii) developing the SEM through modifications of the measurement or structural models (290). The SEM developed through the second stage should be tested with an independent sample from the first stage (290). Therefore, the current sample (N = 1085) was randomly divided into two groups (Stage 1: N = 543 and Stage 2: N = 542). Chi-square tests and t-tests were conducted using IBM SPSS Statistics v24 (IBM Cooperation, USA) to test for differences in observed variables between the two groups. No significant differences were observed between the Stage 1 and Stage 2 groups.

Estimation and goodness-of-fit

The weighted least squares means and variance adjusted (WLSMV) estimation was used for analysis of categorical outcomes (e.g., school travel mode) (257, 293). To assess how well the specified model reproduced the observed covariance matrix, four (two absolute and two incremental) fit indices were employed: standardised root mean residual (SRMR), root mean square error of approximation (RMSEA), comparative fit index (CFI), and Tucker-Lewis index (TLI) (289, 290, 294, 295). The two-index presentation strategy with at least one absolute (e.g., SRMR, RMSEA) and one incremental (e.g., CFI, TLI) fit indices were recommended (290, 295). The SRMR was only reported for the measurement model because Mplus did not produce the SRMR for binary outcomes in the structural model where the RMSEA was reported (291). Cut-off criteria for a 'good' fit were defined as SRMR ≤ 0.08, RMSEA ≤ 0.06, CFI ≥ 0.95, and TLI ≥ 0.95 (295). SRMR ≤ 0.08, RMSEA ≤ 0.08, CFI ≥ 0.90, and TLI ≥ 0.90 were considered as an 'acceptable/adequate' fit (290, 296).

5.3 Results

Figure 29 (p. 147) presents a flow chart of children recruited into the current study and those retained in analyses. Seventeen out of the 1102 study participants were excluded due to having special needs or a learning difficulty (N = 3), living out of the school catchment zone (N = 12), or having missing data for school travel mode (N = 2). Data from 1085 participants were included in analyses. Descriptive statistics for observed variables are presented in Table 17 (pp. 135-142).

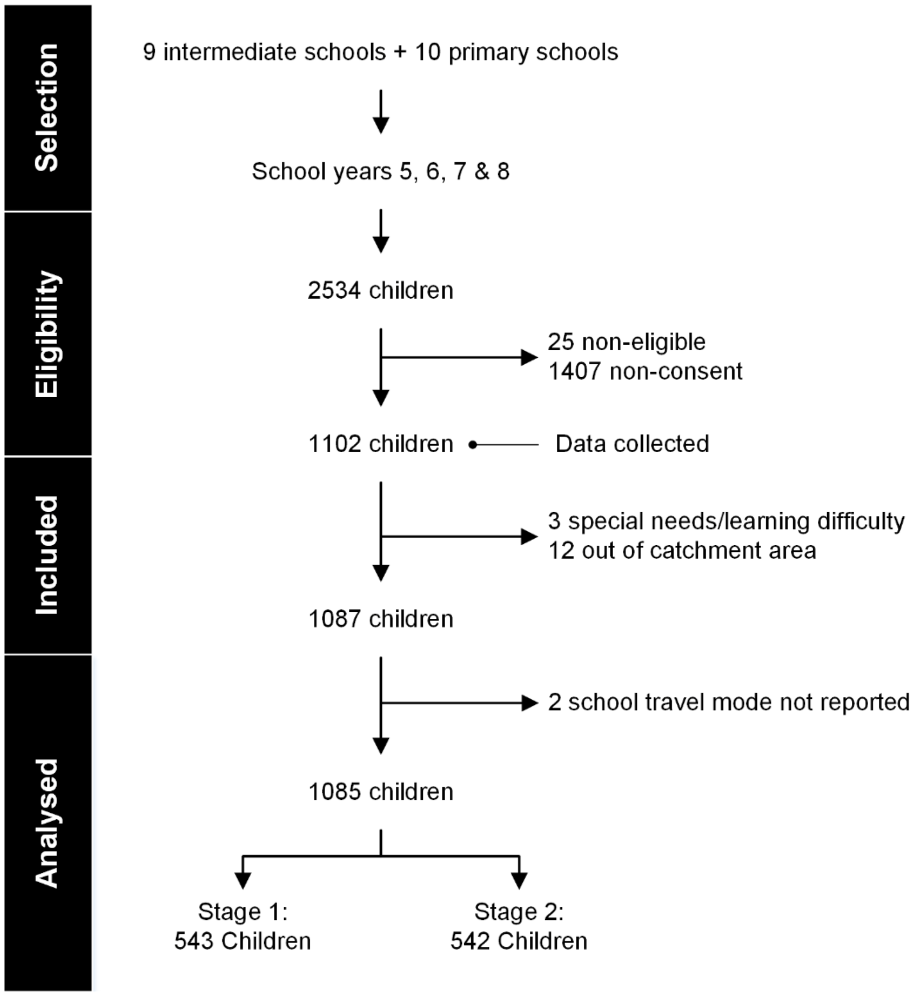


Figure 29. Flow of recruitment and data analyses.

5.3.1 Model modification

A full SEM including the measurement and structural models are illustrated in Figure 28. The hypothesised SEM produced unacceptable/inadequate fit indices with RMSEA = 0.07, CFI = 0.64, and TLI = 0.55 (Stage 1: N = 543). Linear and logistic regressions were conducted to identify non-significant observed variables associated with AST or the other observed variables (141). The results of regressions and theoretical evidence were considered to modify the hypothesised SEM. Parents' highest academic qualification (i.e., education), their employment status (i.e., full-time, part-time), number of adults in their household, and associated dependent relationships with these observed variables were removed through the modification process. A majority of the interviewees for the CATI were mothers of the child (69.2%) followed by fathers of the child

(14.2%), suggesting results of parent education and employment may have been biased towards those of mothers.

5.3.2 Measurement model

Active Mobility Environment was specified by a combination of exploratory factor analysis and theory, comprising four observed variables: residential density, street connectivity, high traffic exposure, and low traffic exposure (Appendix L, pp. 311-315). *Neighbourhood Social Environment* was specified based on theory (239), encompassing three observed variables: neighbourhood safety, neighbourhood cohesion, and neighbourhood connection (Appendix L). Fit indices showed that the measurement model was acceptable with SRMR = 0.06, CFI = 0.93, and TLI = 0.91 (Stage 2: N = 542). Results of the construct validity of the measurement model denoted good validity and reliability with standardised factor loadings (λ) ranging from 0.50 to 1.00; AVEs of 0.59 (*Active Mobility Environment*) and 0.62 (*Neighbourhood Social Environment*); and CRs of 0.84 (*Active Mobility Environment*) and 0.82 (*Neighbourhood Social Environment*). A correlation between *Active Mobility Environment* and *Neighbourhood Social Environment* was significantly smaller than 1.0 (95% confidence interval: -0.17-0.05), indicating good discriminant validity.

5.3.3 Structural model

The overall fit of the modified SEM was acceptable/adequate with RMSEA = 0.04, CFI = 0.94 and TLI = 0.92 (Stage 2: N = 542). The modified SEM accounted for 94.4% of the variance in AST. Standardised and unstandardised results are presented in Figures 30 (p. 149) and 31 (p. 151).

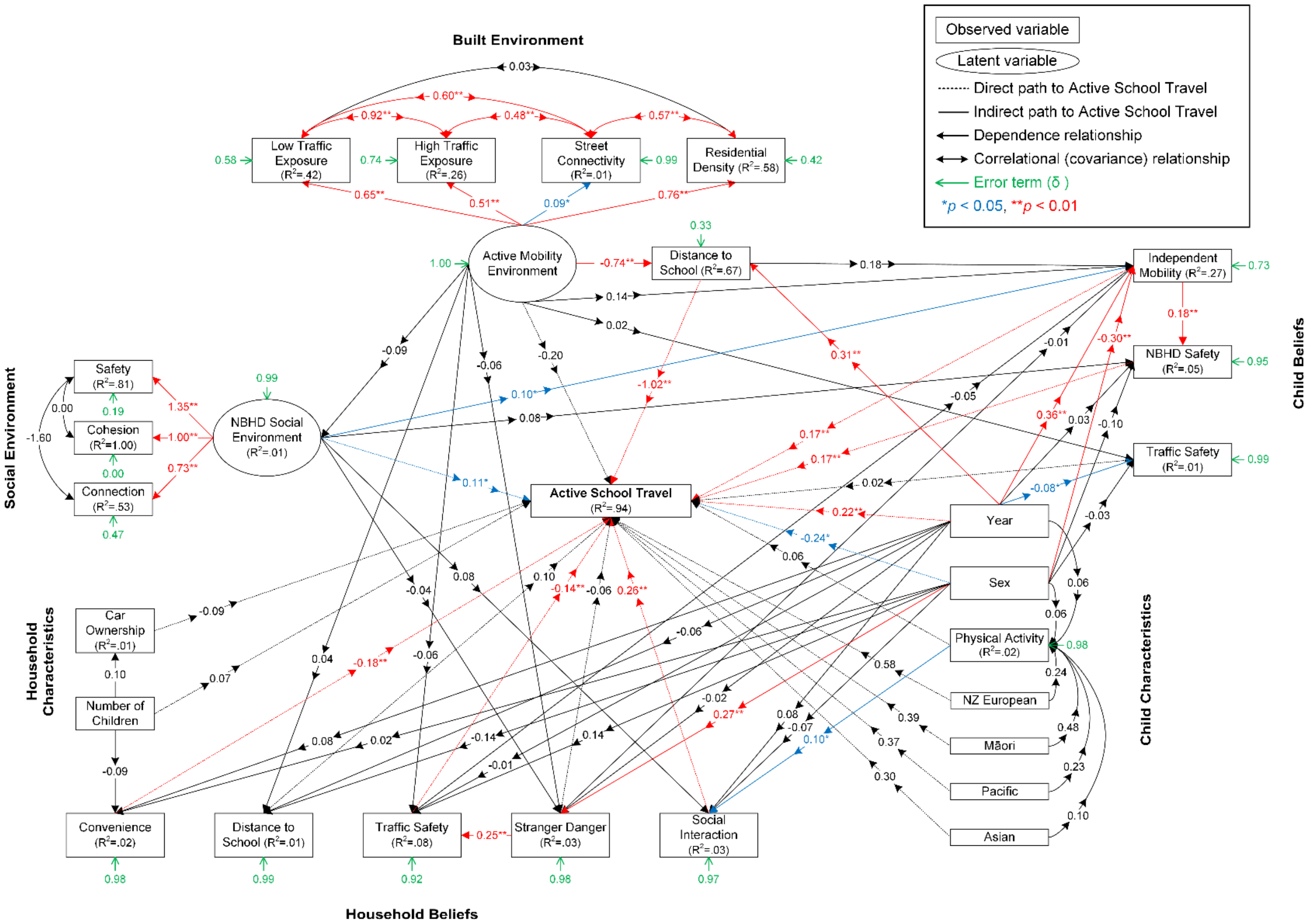


Figure 30. Standardised estimated coefficients of the structural equation model of children's active travel to school. Root mean square error of approximation (RMSEA) = 0.04, comparative fit index (CFI) = 0.94, Tucker-Lewis index (TLI) = 0.92

Direct effects

Children in higher school year (estimate = 0.22, $p < 0.01$) and more males than females (estimate = -0.24, $p < 0.05$) were more likely to actively travel to school. Neighbourhood safety (estimate = 0.17, $p < 0.01$), independent mobility (estimate = 0.17, $p < 0.01$), importance of social interaction (estimate = 0.26, $p < 0.01$), and *Neighbourhood Social Environment* (estimate = 0.11, $p < 0.05$) were significantly and positively associated with AST. Significantly negative associations with AST were found for importance of traffic safety (estimate = -0.14, $p < 0.01$), importance of convenience (estimate = -0.18, $p < 0.01$), and distance to school (estimate= -1.02, $p<0.01$). Distance to school had the strongest direct association with AST among the observed and latent variables.

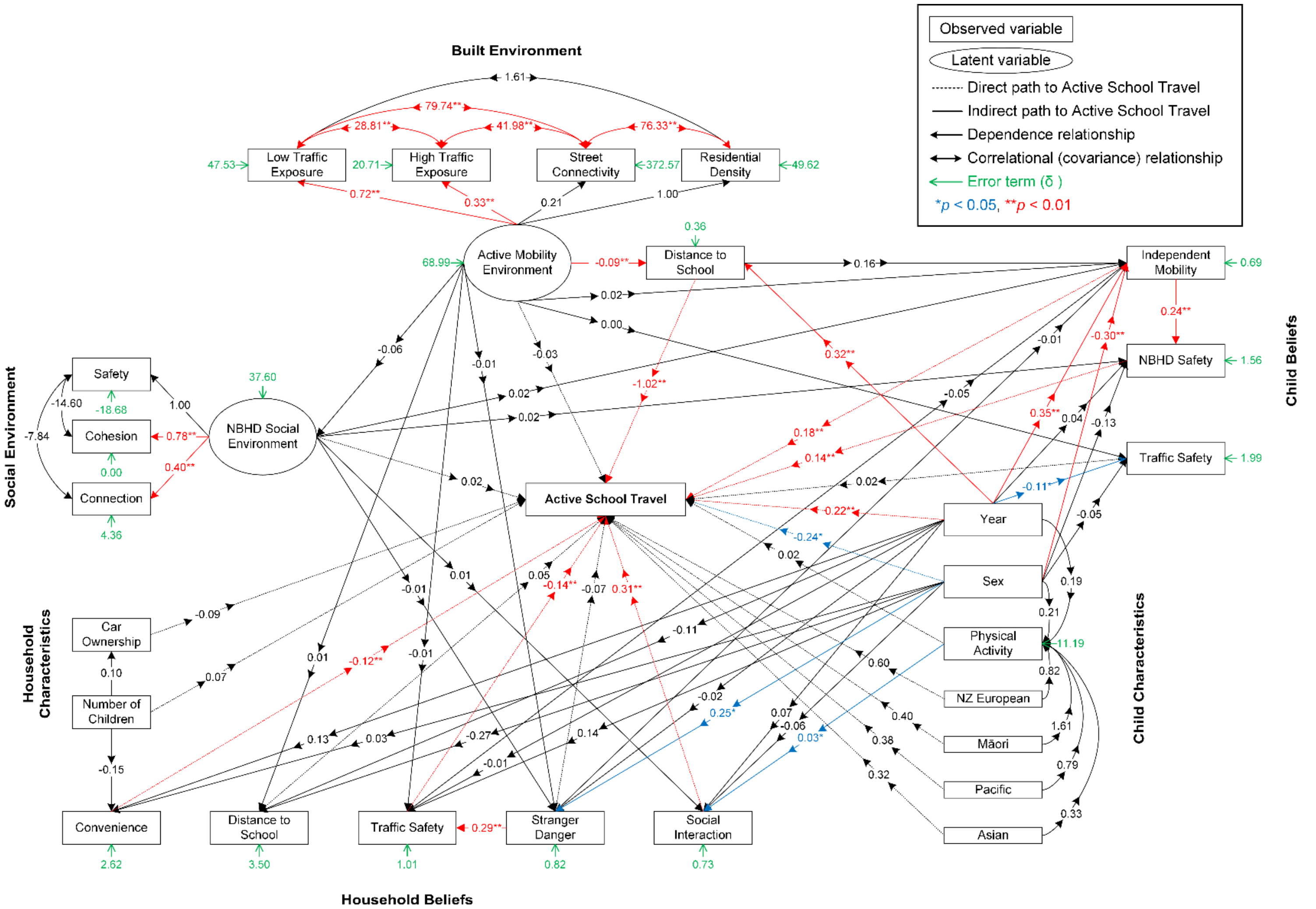


Figure 31. Unstandardised estimated coefficients of the structural equation model of children's active travel to school. Root mean square error of approximation (RMSEA) = 0.04, comparative fit index (CFI) = 0.94, Tucker-Lewis index (TLI) = 0.92.

Indirect (mediating) effects

Specific indirect (mediating) effects from the observed/latent variables to AST are shown in Figure 32 (p. 153).A full mediation was observed in the pathway from *Active Mobility Environment* to AST through distance to school ($p < 0.01$). All indicators of *Active Mobility Environment* (i.e., residential density, street connectivity, high and low traffic exposure) were negatively correlated with distance to school (r = -0.61, -0.06, -0.42, and -0.52, respectively; standard errors for the correlation matrix were not available in Mplus). The pathway from importance of stranger danger to AST was fully mediated by importance of traffic safety ($p < 0.05$).

Independent mobility partially mediated the pathways from school year ($p < 0.01$), sex ($p < 0.05$), and *Neighbourhood Social Environment* ($p < 0.05$) to AST. The pathways from school year ($p < 0.05$) or sex ($p < 0.05$) to AST were also partially mediated by independent mobility through neighbourhood safety. Distance to school was a partial mediator of the pathway from school year to AST ($p < 0.01$).

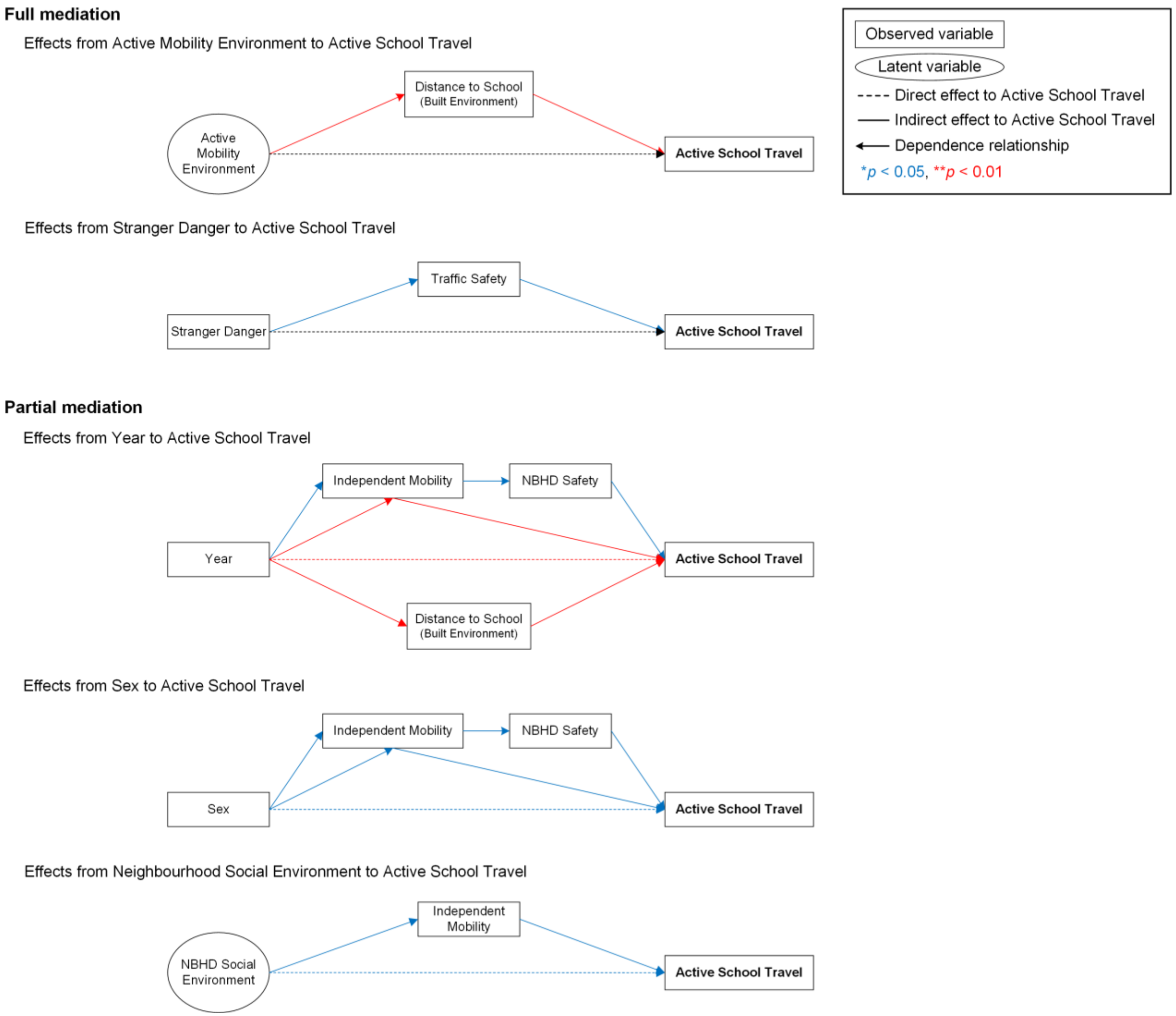


Figure 32. Standardised specific indirect effects on children's active travel to school.

5.4 Discussion

This study assessed direct and indirect associations between children's AST and the physical environment, social environment, household and child characteristics, and household and child beliefs, using SEM. The modified SEM demonstrated acceptable/adequate model fit, explaining 94.4% of the variance in AST. Children's AST had a complex structure in which multiple factors at the individual level were interrelated. Children's AST was mediated by distance to school and independent mobility through child characteristics such as school year and sex. Older (i.e., intermediate school) and male children were more likely to actively travel to school than younger (i.e. primary school) and female children. Parental perceptions of convenience, traffic safety, and social interactions, as well as child perception of neighbourhood safety, were mutually associated with children's AST.

5.4.1 Distance to school

In agreement with findings from previous studies, distance to school was strongly associated with AST and increased by school year (26, 27, 32, 284, 297-300). Although *Active Mobility Environment* on its own did not have a significant direct relationship with AST, distance to school fully mediated its pathway. This finding infers that children travelling through urban environments that support active mobility had shorter distance to school and used active modes of travel to school.

In NZ, parents tend to choose their children's primary school based on the quality of school resources and the overall school reputation rather than the accessibility of school (e.g., within walking distance, accessible public transport) or living within the school zone (i.e., 'reasonably convenient' local schools) (64, 301). This tendency continues into secondary schools where school zoning policies have been 'guidelines', and adolescents and/or parents have freedom of their school choice (222). In fact, less than a third of adolescents chose their school because of proximity to school (222). In this respect, future interventions should consider strategies for children living far from school to encourage them to incorporate active and passive travel rather than only passive travel (e.g., door-to-door chauffeuring). For example, a drop-off/pick-up zone can be arranged away from school entrances so that every child has an opportunity to walk to school within the 'vehicle-free' area (302). This approach can also ease traffic congestion at school and protect active travellers from traffic danger (303).

Public transport is underutilised in NZ for school travel. This study showed 11.2% of the primary and 45.7% of the intermediate children had parental permission to use public transport on their own. However, only 2.9% of the primary and 21.2% of the intermediate school children used public transport to school (cf. car = 56.0% and 35.8%, respectively). Building safe neighbourhoods and supporting parents using a step-by-step approach to improve children's independent mobility can be practical future interventions (44, 45). For instance, potential first steps could be arranging a drop-off point for walking school buses and ensuring safe places to cross in the immediate school vicinity.

5.4.2 Convenience

Children were less likely to actively travel to school if their parents prioritised convenience as a reason for choosing their school travel modes. Research has shown that parents of children who use active travel modes and those who use passive travel modes can both perceive their school travel mode as convenient or easy (188). However, parents of passive travellers more often quoted its convenience or ease in terms of their time, distance, and schedules (188, 195, 299, 304). In addition, trip-chaining by car has been viewed as the best and least stressful way for working parents and/or parents who have more than one child in their household to move around multiple destinations including schools (188, 305-307). Consistent with existing findings, stronger perceptions of convenience was associated with the use of passive travel modes. Paradoxically, if children travel to school independently, parents have less need to juggle their home and work schedules. In this regard, the notion of convenience may not be simply interpreted, and other reasons such as safety can be intermingled. School Travel Plans (e.g., walking school buses, cycle trains) programmes, for instance, can make AST safe, enjoyable, and sociable for children (46), which may balance out parental perceptions of convenience to use cars.

5.4.3 Independent mobility

Independent mobility was positively associated with AST, and acted as a mediator between AST and school year, sex, neighbourhood safety, and *Neighbourhood Social Environment*. These findings supported empirical evidence from previous studies that independent mobility is influenced by child's age, sex, and the quality of neighbourhood environments (e.g., traffic safety) (234, 239, 265, 308-312). Older and male children were more independently mobile and more actively travel to school than younger and female children. The degree of independent mobility was lower in girls than boys due to parental concerns about risk and strangers (265, 313).Community engagement to create child-friendly and safe environments can allow children to be independent in their neighbourhood (314). Social pressure and expectations of being a 'good parent' can make parents anxious about travel practices and the safety of their children (304). Future research should identify parental concerns and investigate community strategies to increase social surveillance and 'eyes' for active travellers in the neighbourhood (45) to help reverse social expectations so that independent mobility becomes associated with 'good parenting'. Policy support for such an approach is needed (234). For example, in NZ, parents are not allowed to leave their children under the age of 14 years without reasonable supervision and care (315); wherein the idea of independent mobility may be questioned by parents. Further, policy-makers and school communities would be wise to take children's needs and views into account using a participatory process, and involve them in decision making and policy implementation.

5.4.4 Safety

If parents reported that traffic safety and stranger danger were important for decision-making regarding their children's school travel mode, children were less likely to actively travel to school. Parental perceptions of traffic safety (e.g., traffic accidents and congestion) and stranger danger (e.g., crime, kidnapping) have been recognised as key obstacles to AST (26, 44, 113, 188). As Safe Routes to School programmes proved, traffic safety can be improved by providing walking and cycling infrastructure (e.g., sidewalks, speed bumps, crosswalks, cycle lanes, traffic signals) (316-318). Educational programmes including the development of motor and cognitive skills can be effective to enhance children's self-efficacy and parents' confidence about their children's abilities to actively travel to school under the traffic environment (32, 318, 319). Despite actual risks of stranger danger happening on rare occasions, the extreme cases were often exaggerated by the media; consequently, parental fear and anxiety of stranger danger were overly stressed (45, 314, 320).

5.4.5 Social interaction and physical activity

The importance of social interaction was positively associated with AST and physical activity specifically during the morning commute (8:00am-9:00am). The findings demonstrated that the choice of AST viewed as an opportunity for social interactions can be coupled with a way to accumulate physical activity. Egli et al. (321) revealed that children enjoyed interacting with their friends and family on the route to school. Tarp et al. (322) reported, irrespective of bout-duration, time spent at higher intensity physical activity (i.e., 3000 counts per minutes, equivalent to walking speed at approximately 66-83 m/min) was inversely associated with cardiometabolic risk factors. In light of a child's average walking speed of 65-83 m/min (240, 250, 275), arguably contributing to 'light to moderate' intensity activity, walking to school for 10 minutes can provide health benefits, and be an achievable goal and a practical intervention for children's regular accumulation of physical activity.

5.4.6 Strengths and limitations

This study used a SEM technique to comprehensively understand the complex interrelationships between children's AST and environmental, household, and child factors. Incorporating voices from children (softGIS), parents (CATI), and objective GIS measures in a model was a novel and holistic approach, and advantageous to test and develop the conceptual model of children's school travel behaviour. Use of child-drawn routes to school using softGIS to generate route environment measures in the current study is likely to have provided greater specificity of the physical environment children actually encounter en-route to school compared to calculating these measures using the more common method of GIS-modelled shortest routes (288).

The absence of school cluster analysis and unavailability of observed variables in analyses were limitations of this study. The use of a multilevel model is recommended for data structured by multiple levels (i.e., individuals and clusters/groups). The effect of clusters (i.e., schools) and group level (i.e., school environment) data such as school policies and AST programmes can influence children's AST. Future research should consider a larger school sample size (at least N > 20 clusters, ideally N > 50) to perform multilevel analyses in SEM.

Though observed variables were cautiously formulated based on the conceptual model, some of the key observed variables were not accessible in this study. Examples include GIS measures of walking/cycling infrastructure (297, 306, 323, 324), household socioeconomic status (26, 44, 211), child/parent attitudes towards AST (183, 193, 325), and child self-efficacy (211, 326). Finally, the findings are applicable only in the context of the urbanised Auckland region in NZ and may not be generalisable to different geographic locations.

5.5 Conclusions

Increasing children's AST requires action on multiple fronts including communities that support independent mobility by providing child friendly social and physical environments, safety from traffic, and policies that promote local schools and safe vehicle-free zones around school.

CHAPTER 6 DISCUSSION AND CONCLUSION

This chapter summarises key findings from Chapters 2, 4 and 5 as well as Appendix A. It provides the overall thesis findings and discusses research strengths and limitations. Implications of the research for future research and advocacy for AST in the Auckland, NZ context are discussed. A comprehensive conclusion is drawn to answer the overarching research question – *"How is children's active school travel associated with multiple environmental attributes?"*

6.1 Systematic reviews

Two complementary systematic reviews were included in the current research: a systematic literature review (Chapter 2) and a systematic meta-analysis (Appendix A). Consolidating findings of these reviews led to thorough identification of existing gaps in knowledge of the associations between environmental attributes and children's AST from different methodological (e.g., subjective and objective measurements) and geographical (e.g., worldwide and NZ) angles. The reviews also identified where the findings have been equivocal and, therefore, further studies are needed to refute evidence. Compared to narrative reviews, systematic reviews employ stringent inclusion and exclusion criteria, and exhaustive and explicit methodologies to identify primary studies (327). Their transparent selection process and interpretative and discursive synthesis of existing literature can clearly highlight the state of knowledge, limitations, and future directions of a topic (327). The following two sections summarise key findings from the systematic reviews (Chapter 2 and Appendix A), which were used to inform the SEM development in Chapter 5.

6.1.1 Systematic literature review: perceived physical environment and social and sociodemographic characteristics

The systematic literature review (Chapter 2) integrated findings from 37 studies and assessed the evidence for associations between school travel behaviour in children aged 5-13 years and perceived physical environment attributes as well as social and sociodemographic characteristics (44). Perceived longer distance and travel time were identified as paramount barriers for children's AST. AST was facilitated if children and/or parents perceived their environments as safer and more walkable. In particular, parents were concerned about child traffic safety, more so than neighbourhood and personal safety. Neighbourhood social interaction could promote children's

AST; however, higher household socioeconomic status, including higher level of parental education and household car ownership, might hinder this behaviour. Thus a systematic meta-analysis review in the context of NZ was conducted to identify key objectively measured built environment attributes and sociodemographic characteristics that were associated with AST.

6.1.2 Systematic meta-analysis review: objective built environment and sociodemographic characteristics

Numerous reviews of associations between the objectively measured built environment and AST exist (26, 27, 88). However, a comprehensive understanding of this relationship with regard to the NZ context did not exist at the inception of this thesis. Thus a systematic meta-analysis review of NZ research was conducted to identify key objectively measured built environment attributes and sociodemographic characteristics associated with AST. The systematic meta-analysis review (Appendix A) examined the association between active travel to school and the neighbourhood built environment in children and youth aged 6-19 years by collating individual data (N = 2844) from five NZ studies (284). Increased distance to school adversely affected active travel to school. Within a 1 km buffered home environment, street connectivity ($p < 0.001$) was positively, and residential density ($p = 0.004$) was negatively, associated with active travel to school. Children and youth who were male and lived in lower neighbourhood-level socioeconomic status were more likely to actively travel to school. A strength of the review was the consistent generation of objective built environment measures across studies.

6.2 School travel route characteristics

Recognising that school travel behaviour may be influenced by the environment that children are exposed to during their journey between home and school, cautious decisions should be made to precisely measure objective physical environment attributes associated with school travel behaviour. In particular, GIS (i.e., 'hard' objective data) is more likely to inaccurately estimate children's school travel route (i.e., GIS-modelled shortest routes) and is subject to arbitrary and inconsistent use of buffer methods and sizes (e.g., street network, sausage buffers) (27). Thus, Chapter 4 built on the systematic meta-analysis review by investigating differences in spatial overlaps and specific physical environment attributes (drawing from the review and other existing evidence) between child-drawn routes using softGIS (i.e., 'soft' subjective data with GIS) and GIS-modelled shortest routes using distinct network datasets for active and passive travellers. A higher level of spatial overlap was observed between softGIS and GIS pedestrian network buffers compared to GIS street network (excluding motorways) buffers for active travel. For passive travel, softGIS buffers had greater spatial overlap with buffers around GIS street network with motorways than those without motorways. Except for traffic light density, NDAI-C, and ≤ 8% slope, all built environment attributes derived within softGIS and GIS street network (excluding motorways) buffers were significantly different from each other. This study provided an important foundation for GIS measurement in which numerous decisions were made with regard to data sources (e.g., CoreLogic Transport, Statistics NZ), spatial units (e.g., meshblocks), and buffer methods (i.e., sausage buffers) and sizes (i.e., 80 m). For instance, a combined technique of a visual inspection of land parcels along softGIS routes and estimated walking speed was used to determine the size of school travel route buffer (i.e., 80 m) within which children were (actually and potentially) exposed to the built environment. Notably, the most commonly used GIS-modelled shortest routes (regardless of pedestrian or street network) in previous studies on school travel routes may not represent actual routes taken by children. Subsequently, objectively measured built environment attributes were calculated within 80 m softGIS route buffers in Chapter 5.

6.3 Structural equation modelling

Chapter 5 is the heart of the current research, assessing direct and indirect associations between children's AST and environmental, household and child factors using SEM. Six of the seven domains identified in the C-STBM (built environment, social environment, household characteristics, household beliefs, child characteristics, child beliefs) (Figure 14, p. 67) were included in the analysis. SoftGIS route distance to school and child independent mobility were directly associated with AST, and indirectly associated with AST through child school year and sex. Older (i.e., intermediate school) and male children were more likely to actively travel to school than younger (i.e., primary school) and female children. Neighbourhood social environment, parental perceptions of convenience, traffic safety, and social interactions as well as child perception of neighbourhood safety were directly associated with AST.

These findings indicated multiple factors are associated with children's AST, and confirmed the utility of the C-STBM for explaining relationships between these factors and children's AST in the context of Auckland, NZ. Consistent with previous studies, distance to school was the strongest indicator for children's AST (26, 27, 44, 284). The role of safety perceptions in determining school travel behaviours was also identified in the SEM. Possible strategies to address distance to school and safety concerns as barriers to AST are discussed in 6.5 Key factors contributing to children's AST.

6.4 Overall thesis findings

Figure 33 (p. 163) illustrates the interrelationships between individual thesis chapters and their findings. The findings demonstrated the complexity of measuring and understanding AST, and the importance of the C-STBM to comprehensively understand the mechanism of children's school travel behaviour. Chapter 2 and Appendix A provided robust evidence for the C-STBM through systematically identifying and examining existing evidence of direct relationships between children's AST and environmental attributes (e.g., distance to school, walkability, safety, social and sociodemographic characteristics). The systematic reviews also recognised gaps and limitations in extant research (e.g., GIS school travel routes estimation and buffer generation methods, linear, and logistic regressions). Chapter 4 highlighted the efficacy of an online participatory mapping (softGIS) method to measure children's school travel routes compared to commonly used GIS-modelled shortest routes. The development of children's school travel behaviour measures based on data collected using softGIS contributed to the robustness and reliability of physical environment data (e.g., distance to school) utilised in Chapter 5. Chapter 5 revealed that the data collected from the Neighbourhoods for Active Kids (NfAK) study adequately fit the C-STBM, and the C-STBM can elucidate multifaceted interrelationships between the physical environment, social environment, and household and child factors. The following section discusses core topics that arose from the body of research and possible solutions for improving children's AST.

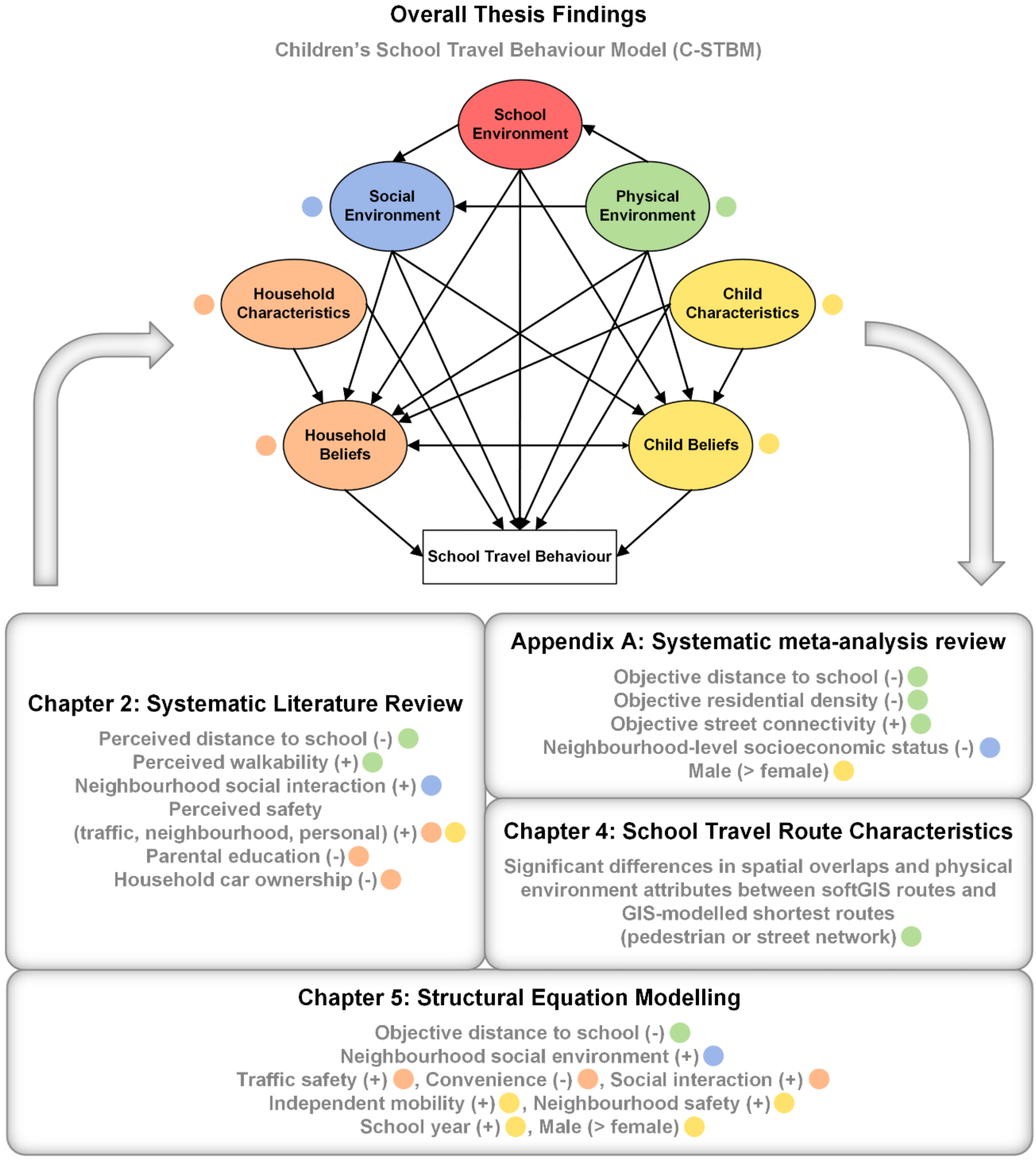


Figure 33. A brief overview of relations between individual studies and their findings. (+) = a positive association with children's active school travel, (-) = a negative association with children's active school travel.

6.5 Key factors contributing to children's AST

6.5.1 Distance to school

Consistent with extant evidence (Chapter 2 and Appendix A) (26, 27, 187, 300), distance to school was one of the strongest indicators for children's AST. An optimal distance threshold of AST was suggested at 1.4 km for NZ children and youth aged 5-16 years using receiver operating characteristic (ROC) curves (300). Among Belgian children aged 11-12 years, criterion distances for walking and cycling (i.e., the distances within which at least 85% of children who walked or cycled to school) were 1.5 km and 3.0 km, respectively (187). In the current research, criterion distances were 1.6 km for walking and 3.0 km for cycling which may be useful to inform geographic boundaries for school enrolment (i.e., school zoning) and to implement AST programmes and interventions by targeting children who live within these walkable and bikeable distances from school (64). Nonetheless, parental freedom to choose among government schools may have contributed to unintended consequences with children no longer living within a walkable or bikeable distance from school (112, 328).

Chapter 4 revealed that child-drawn travel routes to school using softGIS were longer than GIS-modelled shortest routes; meaning that travel routes to school may be chosen based on their proximity and other reasons such as the availability and quality of active travel infrastructure (e.g., crossing) and traffic and neighbourhood safety (e.g., traffic exposure, surveillance) (247, 321). Building new, or improving existing, walking and cycling infrastructure may increase walkability and safety between children's homes and schools as well as in the neighbourhood (114, 329, 330). Children's AST was positively correlated with perceived neighbourhood walkability (Chapter 2); however, it was negatively associated with objectively measured walkability parameters (e.g., residential density in Appendix A, and Active Mobility Environment in Chapter 5). Compared to subjective walkability scales (e.g., Neighbourhood Environment Walkability Scale), objective walkability indices (based on variables such as residential density, street connectivity) may be more sensitive to space (e.g., 80 m route buffers). Additional variables such as topography and crossings potentially improve the specificity of a walkability index for children (110, 329, 331). Further investigation and development of a child-specific objective walkability index may be required to reach consistent and conclusive results.

Strategies to moderate distance to school as a barrier to AST may include enrolment schemes (e.g., school zoning), advocacy of local schools within communities, and construction of new or improvement of existing active travel infrastructure (e.g., pedestrian paths, cycle lanes, crossings). Coupled with these strategies, creating safe environments might have a meaningful impact on children's AST.

6.5.2 Safety

The systematic literature review (Chapter 2) and the SEM (Chapter 5) explicitly demonstrated that safety perceptions are strongly and consistently associated with children's AST. Safety can be characterised as neighbourhood (e.g., disorder, street lighting, surveillance), traffic (e.g., crossings, parking, congestions, speeding, dangerous driving) and personal (e.g., stranger danger, bullying) safety. These components are collectively or discretely as well as directly or indirectly associated with children's AST (26, 54, 306, 326). Fear for safety has been more commonly associated with AST than actual levels of safety (332), despite the recognition that parent perceptions do not always align with statistics (e.g., of crime or accidents) (314, 320). Objective measures such as pedestrian collision rates (91) and crime rates (297) can contribute to understanding children's AST coupled with subjective assessments of safety (49, 297). Parent fears for safety may be mitigated by improving parents' sense of security in their neighbourhood via strategies such as enhancing community connections and increasing neighbourhood surveillance (45). School and community involvement and supports to facilitate social interactions in neighbourhoods may benefit neighbourhood safety and, subsequently, children's AST.

Independent mobility

Children's independent mobility played a mediating role between neighbourhood safety and children's AST. The extent to which children are independently mobile in neighbourhoods could be considered a litmus test for neighbourhood safety and an indicator of likelihood for children's active travel (313, 314). Furthermore, the degree of independent mobility can vary by children's sex (265, 313). Girls tend to be less independently mobile and actively travel than boys as parents are more worried about girls' safety from others (51, 313). Ensuring children's independent mobility and actualising their environmental affordances (i.e., emotional, social, and cultural opportunities that the child perceives, utilises, or shapes the environment) can lead to a child-friendly environment (333). However, levels of independent mobility have decreased internationally, and are low in NZ (234, 239, 308). For example, the proportion of NZ children aged 5-12 years travelling to school as a car passenger increased by 25% in 25 years, indicating a serious decline in independent travel to school by walk (-13%) or bike (-10%) (334). In NZ, negative affordances (i.e., the environment children avoided and disliked) were related to safety concerns among children aged 9-13 years which restricted their independent mobility (308).

Moreover, when parents reported higher neighbourhood cohesion and connection, more independently mobile trips were observed in NZ children aged 8-13 years (239). These positive interactions between neighbourhood social environment, independent mobility, and AST were also observed in Chapters 2 and 5. Recommendations for legal, policy, and practice improvements relating to children's independent mobility are needed to appropriately encourage independent mobility (312, 335). In NZ, parents are not allowed to leave their children aged 14 years and under alone without adequate supervision (315). Anecdotal evidence suggests some parents, particularly new migrants, are uncertain as to whether this legal requirement relates to school travel. A similar debate has occurred in other countries (e.g., Australia (336)). There may be merit in explicitly distinguishing independent mobility from inadequate supervision which is defined as young children being left alone for periods of time without the ability to safely care for themselves (337).

Road safety education and driver behaviour

School road safety has been integrated into policy and practice at both national and regional levels in Auckland, NZ, as described in Chapter 1 (1.4.1 Policy and practice). Evidence suggests that it is not until around the age of 10 years that children have acquired the necessary skills to cross roads and navigate traffic safety (338, 339). Apart from the continuity of safety education and training for children, including use of pedestrian crossings, bike, scooters/skateboards and bus, adults also have a responsibility to behave appropriately to improve the safety of the environment and to act as role models for children. Examples include driving slowly outside schools and parking safely and away from yellow lines (in NZ these are used to indicate no stopping or parking is allowed), intersections, and driveways when picking up or dropping off children. In Auckland, NZ, a reduced 40 km/hour speed limit within school zones is enforced on school days at least 35 minutes before the start of school and 20 minutes at the end of school (340). Continued promotion of safe driving practices is needed through national, regional, and school policies and campaigns, and ideally in society in the long term. Education efforts could also reiterate the paradoxical situation whereby increased chauffeuring of children could endanger the others who use active travel modes; and, conversely, safety is increased where there is a critical mass of children using active travel modes (30, 112).

Safety concerns are one of the biggest barriers to children's AST and independent mobility. Creating supportive built and social environments may increase perceptions of neighbourhood, traffic and personal safety. Improving parent perceptions of neighbourhood safety may lead to increased numbers of children actively travelling to school which, in turn, may reduce traffic danger around schools. Irrespective of child age, girls are less likely to actively travel to school and/or to be independently mobile than boys (Chapter 5 and Appendix A) (26, 265). Targeted approaches for girls to encourage AST and independent mobility might be needed (341). Further research may be required to establish a framework for school travel safety and strengthen evidence-based approaches to ensure the effectiveness of AST programmes and interventions.

6.6 Research strengths and limitations, and future research directions

6.6.1 Strengths

This section summarises strengths of the current research by categorising them into three subsections: theoretical and multimethod approach, data collection and measurement, and statistical analyses.

Theoretical and multi-method approach

As the candidate (EI)'s epistemological stance is objectivism and post-positivism, the current research adopted a deductive approach in which a theory was tested using the data (3.2 Objectivism and Post-positivism: How I See the World as a Researcher). The study-specific conceptual model, the C-STBM was developed that drew from the BMST (32) and a body of empirical research relating to children's school travel behaviour. A multi-method approach (342) was utilised to coherently integrate findings from a series of independent systematic reviews (Chapter 2, Appendix A) and a study (Chapter 4) which established the rationality of constructs and variables included in the C-STBM. In Chapter 5, the C-STBM and interrelationships between constructs and variables were tested using the NfAK data, as presented in Figure 30 (p. 149). The rigorous utilisation of the conceptual model and the multi-method approach are strengths in the current research (28, 87, 342). Other strengths include the methods of data collection (e.g., softGIS) which influenced the quality of the constructs and variables in the C-STBM, and data analyses (e.g., SEM) which affected the interpretation of the C-STBM using the collected data.

Data collection and measurement

The novel online participatory mapping (softGIS) used to measure children's school travel routes, their perceptions of traffic and neighbourhood safety, as well as their levels of independent mobility, reflected a child-centred approach where children's voices were valued. Given differences in perceptions between children and parents, as well as the mechanisms through which their perceptions impact on children's AST, it was important to respect each perspective and incorporate them into a model (32, 54, 343). The current research (as part of the NfAK) used three different data collection methods: softGIS with children, CATI with parents, and GIS for the physical environment. The online-based softGIS is an efficient method for collecting and analysing data which facilitates recruitment of a larger sample compared to paper-based participatory mapping in which participants draw their routes to and from school on a printed paper map or an aerial photomap (263-265).

Furthermore, the development of a buffer method and size for children's school travel behaviour in Chapter 4 improved the specificity and sensitivity of objective physical environment data. Use of different types of routes (i.e., softGIS SNm, SN, PN), a buffer method (i.e., sausage or preferably called 'caterpillar'), size (i.e., a 80 m radius based on visual inspection and children's average walking/cycling speeds), and two different measures (i.e., spatial overlap, physical environment) confirmed the utility of child-drawn routes to school using softGIS

Statistical analyses

SEM, a multivariate analysis combining factor analyses and multiple regressions, was a powerful analytical method to apply to test and confirm the C-STBM. This analytical technique has been increasingly utilised in the field of children's AST (140, 141, 166, 211). To my knowledge, this is the first research to integrate physical and social environments, and household and child factors into the model (C-STBM).

6.6.2 Limitations and possible solutions for future research directions

Despite these theoretical and methodological strengths, this research has limitations. This section acknowledges these limitations, and indicates future research directions of how the limitations can be resolved by categorising them into four subsections: generalisability and causality, sampling, data collection and measurement and statistical analyses.

Generalisability and causality

The implications can be applied only in the context of Auckland, NZ, and may not be generalisable to different geographic locations or populations. Due to the cross-sectional study design, the causality of findings cannot be interpreted. Given a dearth of existing evidence based on longitudinal and (quasi-)experimental studies, future research utilising these study designs are required to determine whether causal relationships exist with children's AST.

Sampling

The use of cluster sampling may have caused sampling error (i.e., error in the findings because of the difference between a sample and the population from which was selected). In this research, multilevel analyses were not performed in SEM to control the effect of clustering (i.e., schools) and to examine school-level variables (e.g., neighbour-level socioeconomic status (school deciles), school policy, and programmes around AST) due to the small school sample size (N = 19). Instead, a relevant individual-level variable (i.e., household car ownership as a proxy of socioeconomic status) was included in SEM, and policies and practices about children's AST in the context of Auckland, NZ were comprehensively reviewed and summarised in Chapter 1 (1.4.1 Policy and practice). Future research should aim to include a minimum number of 20 clusters (ideally 50) to perform multilevel analyses in SEM (344).

Data collection and measurement

The softGIS and CATI methods may have generated self-report (e.g., social desirability) and recall biases (345). Given children's school travel is habitual behaviour and the nature of question items are simple (e.g., 'usual' travel mode and route to school rather than those on specific days), the biases may be minimal (345). One-to-one researcher support during children's completion of the softGIS survey may have minimised recall biases. From a different viewpoint, participants are recognised as having a unique body of knowledge and experience, and responses that are fully informed by participants' own perspectives may be more relevant to their behaviour (rather than 'biases') (346).Conversely, children's reports of 'usual' school travel behaviours (modes and routes) may have not captured variations in behaviours across different weather conditions or seasons. Even with GPS, capturing the variability of children's school travel behaviour can be challenging in cross-sectional research because the information is collected at a certain point in time and place, providing only a snapshot of behaviour. Pontetial differences in school travel modes and routes may exist between the morning (to school) and afternoon (from school) trip (54, 264, 265). However, it was assumed that travel mode and route ‘to’ school may be more habitual and less influential by other activities and trip-chaining. If children were familiarised with using a standardised online survey, it may be possible for children to independently report their school travel behaviour regularly (e.g., seasonally) which would enable researchers to cost-effectively track, and more accurately measure, children’s school travel behaviour (modes and routes) on a regular, long-term basis.

In terms of measurement limitations, children’s traffic safety perceptions (Spearman’s $\rho = 0.29$, $p < 0.001$) and neighbourhood safety perceptions (Spearman’s $\rho = 0.18$, $p < 0.001$) had weak correlations between two items in each measure. Development of these measures (e.g., additional question items to obtain higher internal consistency) may be required in future research.

Future research may also consider including other key measures such as the quantity (e.g., GIS) and quality (e.g., microscale audit of pedestrian streetscapes (MAPS)) (347) of active travel infrastructure (e.g., crossings), the characteristics of household travel (e.g., trip-chaining), and children’s beliefs (e.g., attitudes, subjective norms, self-efficacy, intentions) (87, 181, 193, 195). These measures can be incorporated into the C-STBM in which a model fit needs to be tested using new datasets.

Statistical analyses

Single items in measures of child and household beliefs can create identification problems in SEM where a model is under-identified, and their factor loading and residual variance cannot be estimated. For continuous outcomes, factor loadings would be set to 1.0, and residuals (θ) would be specified as:

$$\theta = (1 - reliability) \times sample\ variance \text{ (348)}$$

However, fixing and correcting residual variance was not recommended for categorical outcomes because residual variances are not parameters in the model. Therefore, it was assumed that there were no measurement errors in the observed values (i.e., the factor loadings were set to 1.0 and the residual variances to 0) because: (i) the single items included in SEM were very simple and easily understood concepts that did not required multiple items, and (ii) can adequately represent their constructs (290). Despite these assumptions, it is recommended for future research to design more than three items to measure one latent variable which may identify a model fit more appropriately.

The next section addresses recommendations for future programmes and interventions for children's AST based on the findings from the current research.

6.7 Recommendations for future programmes and interventions

Programmes and interventions require a strong theoretical basis and the socio-ecological model can provide a holistic approach to integrate multifaceted constructs. Figure 34 (p. 172) summarises the recommendations for future programmes and interventions suggested in this section based on a socio-ecological model and in relation to the C-STBM. From a view of sustainability and efficiency, it is critical to consider the cost and effectiveness of AST programmes and interventions for the targeted population (e.g., children, parents, schools, communities). Improvements in policies are fundamental, and can broadly and indirectly support children's AST through the built environment (e.g., transport), the school (e.g., education system, school zone), and the parent (e.g., independent mobility). Changes in the built environment such as provision of active travel infrastructure may be costly, but is likely to impact children's AST directly and indirectly (i.e., through social environment and household and child beliefs) and have sustained impact. These developments in policy and the built environment will require assistance by policymakers and planners as well as funding from national and regional agencies. Coupled with the wider spread of policy and practices for the built environment in promoting children's AST, an in-depth localised approach can consolidate the quality of effects on children's AST through encouraging community engagement and increasing parents' and children's motivation (146).

The following subsections summarise recommendations for future programmes and interventions in Auckland, NZ, focusing on the domains of policy, built environment, social environment, household, and child. As briefly described in 1.4 Research context, Auckland is a highly suburbanised city, and has greater prevalence of urban sprawl and car dependency. The International Physical Activity and the Environment Network (IPEN) study reported that Auckland (North Shore was merged into Auckland) ranked the worst objectively measured walkability (i.e., residential density, street connectivity, mixed land use) out of 12 countries and 15 cities (349).

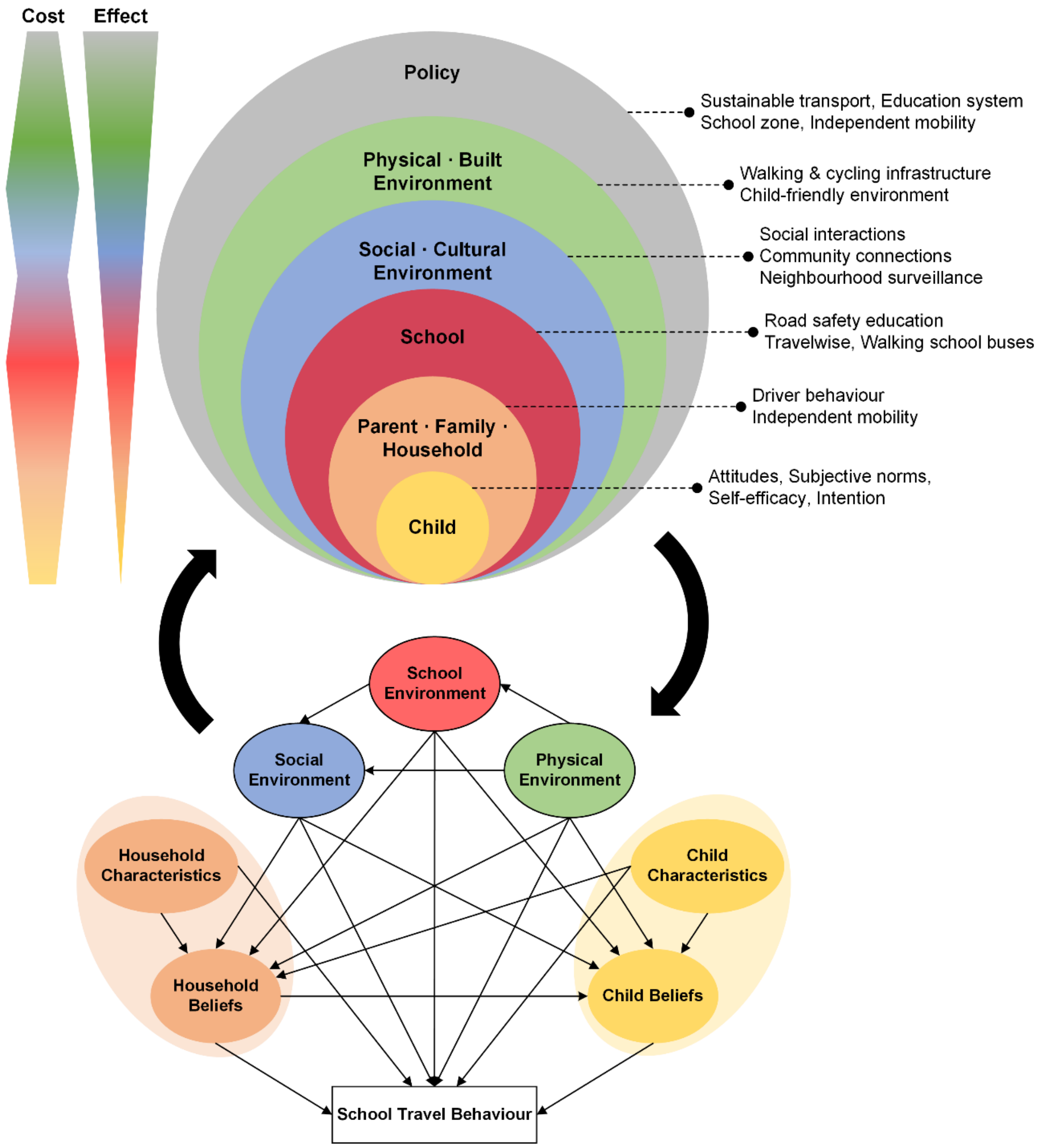


Figure 34. Summary of recommendations for future programmes and interventions based on a socio-ecological model and in relation to the Children's School Travel Behaviour Model (C-STBM).

6.7.1 Policy

Recently a new global action plan on physical activity was launched by the World Health Organization (WHO) which aims to achieve four strategic objectives: (i) create active societies, (ii) create active environments, (iii) create active people, and (iv) create active systems (11). This action plan provides a systems-based approach combining 'upstream' (i.e., policy) and 'downstream' (i.e., individual-focused) implementation tailored to context (11). Guiding principles underpinning the implementation of the action include the “human rights approach” (engaging and empowering individuals and communities to actively participate in the development of solutions) and “proportional universality” (the resourcing and delivery of services at a scale and intensity proportionate to the degree of need) (11). Future programmes and interventions for children’s AST would benefit from incorporating the WHO’s physical activity action plan and guiding principles.

Aligned with the WHO’s guiding principles, Auckland Transport drafted the Auckland Regional Land Transport Plan 2018-2028, and proposed the Safer Communities programme which uses a localised approach to make roads safer and increase opportunities for active travel in selected communities based on safety risks, school locations, neighbourhood accessibility (58, 350). The programme includes physical improvements to the road environment for active travel in the local community, and provides a more consolidated (i.e., creating and improving streets and footpaths for pedestrians, supporting safer driving behaviours) and wider approach (i.e., involving the wider school community) than school-based Travelwise programmes.

Some school policies and practices can facilitate children’s AST; however, others may hinder this behaviour. For example, current NZ school enrolment schemes may allow children living outside the school zone to enrol at the school. Due to fast-growing housing development in Auckland, there may be a risk of overcrowding around development sites and a need of refining the school zones so that schools can accommodate students within the zone. For primary (elementary) and intermediate (middle/junior high) schools, there are opportunities to consider delineation of school zones concurrent with active travel infrastructure (e.g., cycle lanes) that are within a walkable and bikeable distance (e.g., ≤ 3 km), and development of new schools. Promoting local schools will benefit more than just shortening distance to school. Children may have stronger neighbourhood attachment (i.e., affective bonds towards the residential environment) which can strengthen social networks and sense of security in the neighbourhood (351). Nonetheless, NZ parents, especially those of high socioeconomic status, are more likely to choose their children’s primary schools based on the quality of school resources and the overall school reputation rather than the accessibility of school (301, 352). Although overall NZ’s education system is of a high quality standard for most students, educational inequity still remains (352).

Inequity refers to unfair differences arising from socioeconomic status (e.g., household income), living conditions (e.g., safety), and other social (e.g., ethnicity), geographical (e.g., walkability), and environmental (e.g., infrastructure) determinants that can be improved upon by human actions (11). In particular, schools with a higher percentage of Māori and Pasifica students, and those where a substantial portion of students are from low socioeconomic status households, might need ongoing supports and resources by the government to reduce inequities (352). Reducing inequities can be achieved by identifying and prioritising disadvantaged population groups (e.g., Māori and Pacific people, those who are disabled by their environment) (353, 354) and deprived geographical areas (355), and allocating and designing infrastructure and distributing resources and services accordingly to support their AST.

6.7.2 Built environment

Urban planners can consider building spaces that facilitate passive surveillance, encourage people to socialise with each other, and enable children to move safely and independently and to interact with the environment, all of which ultimately lead to creating a child-friendly environment. Participation (i.e., an ongoing process of children's expression and active involvement in decision-making) is a fundamental right of all children and lies at the heart of building a child-friendly environment (346, 356). Children's views as active citizens with rights and capabilities should be respected and recognised (346). Furthermore, it is crucial for Auckland's current transport system to prioritise more sustainable transport and less car-centred transport plans and strategies. Sufficient funding is essential to develop and maintain AST programmes and interventions, particularly with regard to walking and cycling infrastructure improvements such as safer crossings. Emerging evidence shows that investments in these infrastructure is the most cost effective and can largely contribute to reduction in health care costs, air pollution, and traffic congestion in the long term (357-359).

6.7.3 Social environment

Whole-of-community initiatives are the next logical step to engage all stakeholders and empower community members to drive changes in their local environments. Active engagement can be a powerful approach to mobilise communities and create greater community cohesion and safer environments for active travel which may lead to improving children's AST (317, 360). A comprehensive, integrated, and intersectoral approach and the continuity of support and involvement from communities, government agencies and organisations can make a significant impact on the success of such programmes (361). Despite the recognised benefits of such partnerships, collaborating with individuals from diverse disciplines is not always straightforward.

A recent local example is a street redesign intervention study, *Te Ara Mua – Future Streets* which is a researcher-practitioner collaborative project aimed to slow traffic, change driver behaviour, and support active travel in Māngere, a suburban neighbourhood in Auckland, NZ (362, 363). The study demonstrated challenges to work collaboratively between the research team, local community, and Auckland Transport due to differences in the professional norms and practices between researchers and transport engineers, conflicting organisational cultures, and approaches to risk, and lack of organisational readiness and capacity (364). Understanding obstacles to advancing the collaborative processes was seen as an effective catalyst to move the intervention forward. This demonstrates the importance of recognising, understanding, and respecting multidisciplinary perspectives for the development and delivery of effective collaborative interventions for improving AST.

Future AST and active travel programmes and interventions should maintain this localised approach to engage communities and schools, and collaboratively work together towards improving this behaviour. The provision of opportunities such as community activities to increase social interactions and connections may strengthen sense of community and safety perceptions (280).

6.7.4 School

Schools can be an ideal setting in which to deliver several road safety messages as well as education and training as part of the school curriculum. This can include safe road crossings, use of walkways, safe practices in and around cycling, scootering, and buses and other vehicles. To date, AST programmes including Travelwise, walking school buses, and the Bike Safe programme have been successfully implemented by Auckland Transport across a number of schools in the Auckland region. The programmes are school-based interventions in which government agencies and organisations work together collaboratively. A previous study evaluated the effectiveness of the School Travel Plan programme (part of the wider Travelwise programmes) wherein an action plan was developed by incorporating engineering, education, enforcement, encouragement, and policy strategies (365). One of the take-home messages from this study was that programmes and interventions targeting behavioural change may require at least three years to fully implement infrastructure around school environments (e.g., crossings, sidewalks) and for a strong habit of AST to become established (365).

6.7.5 Households

Despite the wider delivery of road safety education, consistent instructions by parents and adults in the community also affect children's behaviour. For example, at drop-off and pick-up times the school gate becomes a parking "war zone" where the road rules are often ignored by parents who drive their children (366). Inappropriate driver behaviour may endanger a child's life. Parents are supposed to model and reinforce good road safety practices, but not to put children at risk. With support from the NZ Police, it is suggested that communities continuously improve driver behaviour and reinforce good driving practice around schools. If parents have time constraints or inflexible work schedules, supporting children to travel to school independently or with siblings and friends could be a viable solution. Walking school buses can be alternative options if parents worry about unsupervised school travel (367). Preferably, if parents are allowed to commute to their workplaces later once or twice a week, parents will be able to actively travel to school with their children and support walking school buses. Parents tend to be decision-makers for children's school travel (49), and their understanding and actions to improve children's AST are imperative as stated in a Japanese proverb – "*Kawaii ko niwa tabi o saseyo (可愛い子には旅をさせよ)*", meaning "*Send the beloved child on a journey*".

6.7.6 Children

Intrapersonal (individual) factors such as children's cognitive processing (e.g., attitudes, subjective norms, self-efficacy, intentions) have been developed and evaluated in some of the children's AST interventions which were commonly based on theory of planned behaviour (i.e., reasoned action approach) and social cognitive theory (87, 193, 195, 212, 368, 369). Interventions designed to change children's school travel behaviour can be directed at parents' and children's attitudes, subjective norms and self-efficacy (i.e., perceived behavioural control) which consequently change their intentions (179, 369). To some extent children's school travel behaviour is habitual due to its characteristics of repetition (i.e., every school day) and situational stability (i.e., almost the same route from home/school to school/home around the same time of day) (193). The dissolution of old habits and formulation of new habits are notoriously difficult, particularly without children's intentions to change their behaviours. Although current Auckland

Transport programmes such as Travelwise, walking school buses, and the Bike Safe programme tend to improve these children's cognitive processing, particularly self-efficacy, they lack underpinning theory (e.g., theory of planned behaviour) and evaluation to understand intention-behaviour relationships. Future programmes and interventions can integrate the mechanism of children's cognitive processing into a wider socio-ecological model (e.g., C-STBM).

6.7.7 Summary

Programmes and interventions focusing on behavioural change, including AST, may require an integrative approach to changing multifaceted constructs (i.e., policy, built environment, social environment, school, household, child), long-term (at least 2-3 years) planning, and funding to make it ongoing and worthwhile. National and regional government policies as well as built environment changes (e.g., active travel infrastructure) are likely to be the most cost-effective and influential strategies to improve children's AST (11, 357, 370). Community engagement and empowerment will be key to encourage and sustain children's AST.

6.8 Conclusions

The current research employed a theory-based holistic approach to assess how children's AST is associated with multiple environmental attributes in the context of Auckland, NZ. The C-STBM was developed by integrating multifaceted evidence-based constructs associated with children's AST and their interrelationships to explain the complex mechanism of children's school travel behaviour. Overall thesis findings indicated the viability of the C-STBM, and the significance of associations between children's AST and the physical environment, the social environment, and household and child factors. Distance to school and safety are key to children's AST, and there is a need to create environments where children are able to move around safely and independently. The development and implementation of community-based programmes and interventions which stimulate engagement by stakeholders and optimise a combination of policy approaches can foster community cohesion and neighbourhood surveillance, and consequently create safe and supportive environments to promote increased children's participation in AST.

The originality of this research includes the application of online participatory mapping (softGIS) to empower children and allow them to provide their voice, and SEM to comprehensively and holistically analyse multifaceted data. The body of research contributes to the international knowledge base on children's AST, provides empirical evidence to establish a conceptual model for children's school travel behaviour, and improves understanding of barriers and enablers of AST in the Auckland context to inform future programmes and interventions.

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APPENDICES

Appendix A

Systematic Meta-Analysis Review:

Built environment associates of active school travel in New Zealand children and youth: a systematic meta-analysis using individual participant data

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Abstract

This systematic review and meta-analysis examined the associations between active travel to school and the neighbourhood built environment in children and youth by systematically identifying and collating data from New Zealand studies. Data from five studies involving 2844 children and youth aged 6-19 years were included in the meta-analysis. Data on participant demographics and school characteristics were obtained from each study, and built environment

features within 400 m and 1 km buffers around home were calculated in a consistent manner using geographic information systems. A one-step individual participant data meta-analysis was performed in SAS. Using stepwise logistic regression, age, school socioeconomic status, distance to school, dwelling density and intersection density (400 m and 1 km buffers) were taken forward from bivariate analyses into a multiple variable model. Active travel to school was positively associated with intersection density ($p<0.001$) (1 km buffer) and negatively associated with school socioeconomic status ($p=0.001$), dwelling density ($p=0.004$) (1 km buffer), and distance to school ($p<0.001$), including age, sex, ethnicity, and number of siblings as fixed effects in the final model. The findings of this meta-analysis can be used to guide and support the development of policies on school location and catchment, and pedestrian and cycling infrastructure for children and youth to actively and safely travel to school.

1. Introduction

The benefits of physical activity in childhood are significant and widely accepted (1). Regular physical activity is associated with improved cognitive (2), cardiometabolic (3), and musculoskeletal health (4), as well as reduced symptoms of depression and anxiety (5). Insufficient physical activity is linked to the significant rise in childhood obesity and comorbidities worldwide (3, 6, 7). It is recommended that all children and young people achieve at least 60 minutes of moderate-to-vigorous intensity physical activity each day (8, 9). Globally, New Zealand fares relatively well in terms of child and youth participation in sufficient levels of physical activity (10). Despite that, a third of New Zealand children and young people remain insufficiently active for health (11), and New Zealand has one of the highest rates of child obesity worldwide (12).

Several systematic reviews show that children and young people who commute actively (e.g., walk or cycle) to school are more likely to attain recommended levels of physical activity than those who travel by motorised vehicle (e.g., public transport, car, or motorcycle) (13, 14). Uptake of active travel in childhood also increases the likelihood of active commuting in later life (15). Active travel to school (ATS) permits children to develop navigational and traffic safety skills, identify and manage risks (16), and gain experience in decision making and social interaction (17, 18). Unsupervised active travel—or independent mobility—can facilitate additional benefits, such as developing and refining resilience and life skills for the adult world, particularly in the context of risk taking (19, 20).

The positive implications of active travel go beyond the physical activity and health of individuals. Wider benefits include less noise and air pollution, climate change mitigation, urban vitality, and reduced traffic congestion. The annual economic cost of traffic congestion is estimated to be up to NZ$1.9 billion in Auckland alone (21). Data from 2015 show that New Zealand's gross greenhouse gas emissions have increased 24% since 1990, and road transportation is one of the main contributors to this increase (77.9% increase) (22). Increased uptake of ATS has the potential to reduce overall traffic volume and air pollution, particularly in urban areas around schools at peak commute times (23).

Despite these benefits, the prevalence of children's ATS is declining worldwide. New Zealand has one of the lowest rates of ATS internationally, with 28-29% of children aged 5-17 years walking and 2-3% cycling to school (10, 24). Understanding the reasons for the low and declining prevalence of ATS has become a priority for governments, urban planners, public health practitioners, and school and community groups. An interaction of multiple factors operating at several levels affects ATS behaviour. Within a socio-ecological framework, these factors are broadly defined as individual (e.g., demographics, perceptions, skills), interpersonal (e.g., family and cultural norms) and broader environmental factors (e.g., built environment and policy) (25). A collective understanding of these influences is crucial to enhance uptake of ATS among children and youth (26, 27).

Both age and sex are key associates of ATS. The 2014/15 New Zealand Health Survey illustrates that in youth aged 10-14 years, a higher proportion of boys travel actively to school compared to girls (46.9% versus 40.6%) (28). No meaningful difference by sex was observed for younger children. In New Zealand, more children aged 10-14 years utilised ATS (43.8%), compared to those aged 5-9 years (38.4%) (28). The relationship between age and ATS is likely to be curvilinear, with an initial age-related increase in ATS among children due to higher degrees of independent mobility, parental allowances, and public transport use. ATS occurs to a small degree; followed by a decrease due to longer distances to secondary (high) schools compared with localised primary (elementary) schools (29-31). There is some evidence of ethnic differences in ATS in New Zealand – with children of Māori, Pacific Island, and "other" ethnicities more likely to walk to primary school in Dunedin than New Zealand European children (32). Household factors such as larger household sizes and having older siblings may also increase the likelihood of ATS (30, 33). There is a trend towards increased ATS in children and youth residing in more socio-economically deprived neighbourhoods (28). Boys residing in areas with the highest levels of socio-economic deprivation are significantly more likely to use ATS than their male peers living in areas with the lowest levels of socioeconomic deprivation (28).

A key principle of socio-ecological theory is that motivating individuals to change behaviour cannot be effective if environments make it difficult or impossible to choose healthy behaviours (34). Rather, creating environments that make it convenient, attractive, safe and economical to make healthy choices (and then motivating and educating people about those choices) will likely be most effective. Built environments comprise all physical surroundings that are constructed through human activity, including buildings, roads, open spaces and infrastructure (35). A number of built environment factors have been associated with ATS, which are discussed briefly below.

A convincing body of research in New Zealand and worldwide has demonstrated that network distance to school is the most consistent built environmental factor associated with the likelihood of ATS (30, 36-42). For example, children living within one mile (1.6 km) of school in the US were at least three times more likely to walk or cycle to school than those living outside the one mile radius (43-46). Similarly, McDonald (47) showed that travel time had the greatest effect on ATS, where a 10% increase in walking time was associated with a 7.5% decline in probability of walking to school in the US. In a sample of 595 New Zealand children and youth aged 8-14 years, a distance of 1.4 km or less best predicted likelihood of ATS (48). However, threshold distances are likely much further for cycling, with some studies from the US and Spain reporting threshold distances of up to 5 km (38, 49, 50).

Connectivity refers to the directness and availability of travel routes between an origin and a destination (51). Street connectivity offers the potential of increased ways to discover direct and shorter travel routes (38). Connectivity is generally measured or assessed using the spacing between streets, the number of three-way or four-way intersections within an area, or the difference between the street and pedestrian network distance and the Euclidean (i.e. 'as the crow flies') distance (41, 51). For adults, grid-design urban environments are associated with significantly greater physical activity levels (52-54). Among the few studies investigating associations between street connectivity and physical activity in children, findings showed both positive (37, 38) and no association (55). Likewise, the latest systematic review showed inconsistent associations between street connectivity and children's ATS (46). One study has shown positive associations between street connectivity and active travel to all destinations in children (37).

Population or residential density refers to the number of individuals or dwellings in a particular area. Density is in turn associated with accessibility and increased rates of active travel because housing is closer to a range of destinations (51). Active travel among children living in urban areas (with high population density) in the US was found to be more common than in their rural or suburban counterparts (with sparse population density) (47). Adolescents living in urban areas have been shown to accumulate most of their physical activity during school travel (56); whereas those in more rural areas achieve the majority of their activity during school hours (57). However, these findings are not consistent in all geographic regions (e.g., Rothman et al. (46)). In the Otago region of New Zealand youth living in rural areas reported higher rates of ATS compared to their urban counterparts (30).

The diversity of land use within a region (e.g., residential, educational, commercial, industrial, and recreational) can have implications for children and young people's active travel. Mixed land uses within a localised area can reduce the distance to destinations, thereby providing more active travel opportunities (51). Higher land use mix has been associated with ATS (58, 59) as well as overall physical activity and total walking trips in youth (60, 61). These studies allude to the importance of destination accessibility and diversity for active travel in children and youth.

In the New Zealand context, differences in geographic information systems (GIS) approaches across studies have hindered an ability to provide a clear and consistent understanding of the built environment associates of ATS in children and youth nationally. Therefore, the aims of this study were: (i) to systematically identify New Zealand research that had measured ATS, distance to school, and the neighbourhood built environment in children and youth, (ii) to collate data from identified studies and combine them in a consistent manner, and (iii) to identify associations between ATS and built environment features across the combined dataset. In doing so, this study provides new, robust evidence that has greater statistical power and is more generalisable than the contributing standalone studies.

2. Methods

2.1 Research context

The total population in New Zealand was estimated at 4.8 million in 2017, and a fifth of the population was children and youth aged 5-19 years (62). New Zealand is also characterised as a highly suburbanised nation. By the end of 20th century, there were 20 main urban areas with a minimum population of 30,000 identified in New Zealand – 16 out of 20 are located in the North Island (e.g., Auckland, Wellington) and the others in the South Island (e.g., Christchurch, Dunedin) (63). Due to changes in urban form, the population has shifted towards car-oriented, low density neighbourhoods over the last few decades (64), which has resulted in greater urban sprawl and a change in children's mode of school travel and mobility. Internationally, New Zealand (e.g., Auckland, Christchurch, Wellington) had lower neighbourhood walkability measured using GIS compared to Australia, Belgium, Brazil, Colombia, the Czech Republic, Denmark, China, Mexico, Spain, the United Kingdom, and the United States (65).

In New Zealand, there are more than 180 different ethnic groups including indigenous Māori and migrants from Europe, Pacific Islands and Asian countries. The distribution of the ethnic groups with the majority of European, Māori and Asian varies across regions and cities (66). In New Zealand, ethnicity is a self-perceived and cultural concept which is considered as a key social factor along with the other demographic characteristics describing the population (66).

2.2 Eligibility criteria

Experimental studies or interventions (i.e., randomised controlled trials, quasi-experimental studies), longitudinal/cohort studies, and cross-sectional studies were eligible for inclusion. Participants in the included studies were school-aged children between 5-19 years living in New Zealand. In order to be eligible, studies needed to have reported participants' mode of travel to school, and collected objective measures of the neighbourhood built environment using GIS. Travel mode could be self-reported by children, their parents, or obtained by observation.

2.3 Information sources and search strategy

Scholarly published journal articles were searched in the following seven academic databases: SPORTDiscus (via EBSCO Host), ABI/Inform (via ProQuest), Web of Science, Scopus, NZResearch.org.nz (New Zealand theses), NewzText (New Zealand newspapers and commentary sources), and Australian/New Zealand Reference Centre (via EBSCO Host) (New Zealand newspapers and commentary from local sources). Unpublished research (i.e., New Zealand Master's and Doctoral theses) was sought through New Zealand Educational Theses Database (via New Zealand Council for Educational Research), Aotearoa New Zealand International Development Studies Network, and Scholarly Commons/Institutional Repository (i.e. Auckland University of Technology, Massey University, University of Auckland, University of Canterbury, University of Otago, University of Waikato, Victoria University of Wellington). Government and local council related reports were sought through major Government agency websites (i.e., Ministry of Health, Ministry of Transport, New Zealand Transport Agency/Land Transport New Zealand) and generally through Google. Combinations of the following search terms were used: "active travel/transport", "mode* travel/transport", "school", "Zealand", "walk*", "bik*", "trip*", "car*". For a full list of search fields refer to Supplementary information 1. The search was limited to English language and year from January 1990 to June 2016. Searches were conducted between May and July 2016.

2.4 Selection of studies

Figure 1 shows a flow chart for article identification and selection. The initial search strategy produced nearly 24,000 articles. An initial screening of titles and abstracts was undertaken by the first review author (EI) to remove those which were outside the scope of the review based on the eligibility criteria. The full text was obtained for articles and reports that passed this initial abstract screening process – 49 were considered potentially eligible and were assessed at the full text stage. Full texts of 12 articles and reports met the inclusion criteria. Finally, multiple publications and reports on the same study were linked together (N = 4), yielding a total of eight studies identified as eligible. Cross-checking of the included articles by a co-author (MS) was only performed at the full text stage. The raw data of primary and secondary outcomes were acquired by contacting the original authors of the included studies. Three authors failed or declined to send raw data and these studies were thus excluded, leaving five studies for inclusion in the meta-analysis.

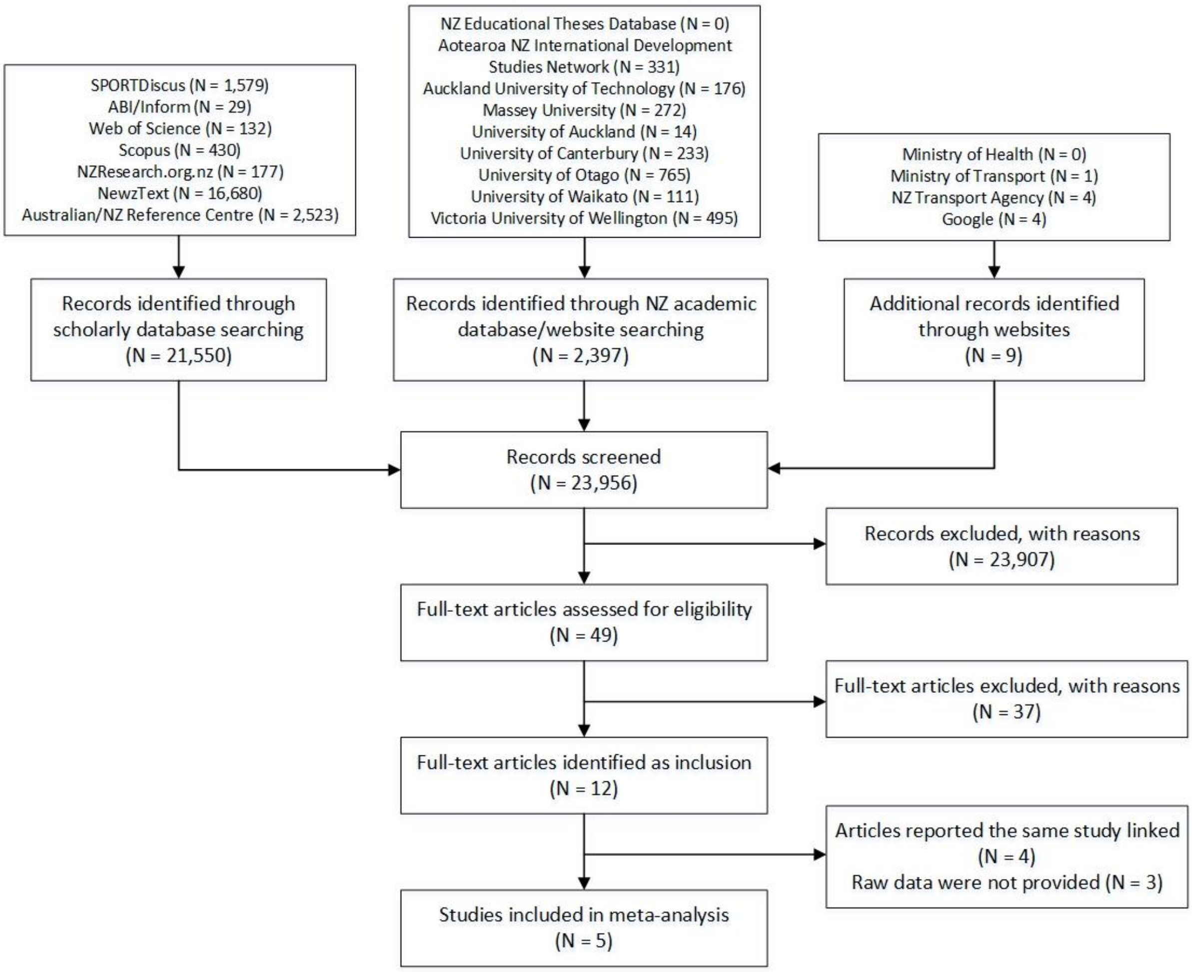

Figure 1. Flow chart of article identification. N = number. Active travel includes walk, bicycle, scooter, and skateboard. Passive travel includes car, bus, and motorbike.

2.5 Data preparation and synthesis

The following variables were obtained (at the individual participant level) from each study author: participant demographics (age, sex, number of siblings, household size, body measurements), mode of travel 'to' school (excluding 'from' school), and GIS-derived distance to school, intersection density, dwelling density, and land use mix using a 400 m and a 1 km street network buffer around each participant's place of residence. Buffers are boundaries placed around areas or points using a predefined scale, and delineated using straight-line (Euclidean) or street network distance (51). In addition, general information about neighbourhood and participant selection, inclusion and exclusion criteria, individual study analyses, and published results and study protocols were requested. TS liaised with all study authors to ensure consistent approaches to generating neighbourhood buffers and built environment variables were undertaken.

2.5.1. Individual characteristics

Participant age was classified into six groups (<13, 13, 14, 15, 16, >17 years): less than 13 years, by age in years between 13 and 16, and more than 17 years in order to detect any possible curvilinearity in relationships, and to ensure sufficient numbers in each age group.

Body mass index (BMI) was calculated from weight and height, and categorised into weight classes (normal, overweight, obese) using growth curve data from the World Health Organization (67). Age was missing for 19 participants, in which case age was imputed using the mean age for the participants from the same school year level.

2.5.2. School characteristics

Data from the Ministry of Education were used to classify each school into contributing (children aged 5-10 years), full primary (5-12 years), intermediate (11-12 years), or secondary (13-17 years), and to identify school decile values. School decile indicates the socio-economic status of households in a school's catchment area. Deciles ranging from 1 (being the 10% of schools with the highest proportion of pupils residing in low socio-economic areas), to 10 (being the 10% of schools with the lowest proportion of these students) (68).

2.5.3. School travel mode

Three studies (36, 69, 70) collected travel mode data across each of the five school days, and one (71) had a 5-scale response for each travel mode ("never", "rarely", "sometimes", "most of the time", "all of the time"). The only school travel information available from the final study (72) pertained to 'usual' travel mode (e.g., "car", "walk", "bike" etc.). For this reason, travel mode data across all studies were dichotomised as 0 or 1, where 0 referred to individuals who used passive modes of travel (i.e., car, bus, motorbike) and 1 represented individuals who used active forms of travel (i.e., walk, bicycle, scooter, skateboard) on three or more school days per week (73, 74), or "most of the time". As ATS was a binary response variable, logistic regression (SAS proc logistic) was performed to test whether each variable was associated with (the odds of) active travel to school. Individuals living further than 10 km from school were excluded from analyses. The rationale for this was two-fold: (i) based on visual inspection of the distance to school data, those living further than 10 km from school were considered outliers, and (ii) previous New Zealand research suggests this threshold would be sufficiently sensitive to capture most ATS (36, 48).

2.5.4. Built environment variables

Dwelling density was calculated as the number of private occupied dwellings per square kilometre. The number of dwellings per meshblock was obtained from the 2013 Census (75), and an area weighted average used to estimate the number of dwellings within each buffer. Parcel-level zoning data were used to calculate land use mix, which is an indicator of the variety of local destinations close to home. Land use was categorised as residential, commercial, public open space, industrial, recreation, or other. An entropy score was used to calculate the extent of land use mix inside each buffer using the equation (76) for four studies (36, 69, 70, 72):

$$Land\ use\ mix = -(\sum_{i=1}^{n} P_i * \ln(P_i)) / \ln(n)$$

where n is the number of different land use categories and Pi is the proportion of land use category i in the region. Entropy scores range from 0, which indicates no mix or homogeneous land use, to 1 which represents heterogeneous land use, or a perfect mix. One study (71) calculated land use mix using a different equation (77):

$$Land\ use\ mix = \{\sum_{k} [\sum_{j} P_{jk} ln(p_{jk})] / ln(J)\} / K$$

where P_{jk} is the proportion of land use category j within a half-mile radius of the developed area surrounding grid-cell k, and K is number of actively developed hectares in each tract. The parcel level land use data used to calculate land use mix was compiled from a variety of sources: territorial authority zoning data, territorial authority points of interest data sourced in 2013/2014 (e.g., parks, libraries), and Zenbu online business directory data extracted in 2014. Lastly, intersection density was calculated as the number of 3 or more-way intersections per square kilometre, using road centreline data obtained from Land Information New Zealand (LINZ; www.linz.govt.nz). The calculation of these variables was consistent with previous work in New Zealand (69, 78).

In the first instance, frequency distributions of categorical data were checked and recategorised if necessary (i.e., if a disproportionately low number of responses was observed in one or more categories). Due to logistic regression assuming an exponential relationship for continuous variables and because non-linear and plateauing effects can exist when examining built environment variables, these variables (dwelling density, intersection density, and land use mix) were organised into quartiles.

2.6 Statistical analysis

A one-step individual participant data (IPD) meta-analysis approach was taken. This differs from more traditional meta-analyses where aggregate data (e.g., effect size estimates) are extracted from individual studies and synthesised. In a one-step approach, the original IPD from all studies is modelled simultaneously. All analyses were performed in SAS (v9.4, SAS Institute, North Carolina, NC).

Using stepwise logistic regression, an initial feature selection step was performed to determine what variables were suitable for inclusion in the final model. A criterion of $p<0.10$ was set for inclusion in the model; and age, sex, ethnicity, and number of siblings were included as fixed effects, being known correlates of ATS behaviour (30, 79-81). The clustering of observations within studies was accounted for by stratifying the analysis by study (i.e., by estimating a separate intercept for each study) using the STRATA statement (82). Individual study results for the full model were also calculated and presented for each outcome variable using forest plots.

3. Results

Overall, five studies involving 2844 children and youth aged 6-19 years were included in this meta-analysis (Figure 1, Table 1) (36, 69-72). In total, there were 988 active travellers, and 1856 passive travellers. Studies were conducted in three of the largest cities in New Zealand, namely Auckland (urban population of 1.495 million, comprising 32% of the total New Zealand population), Wellington (population 405,000), and Christchurch (389,700) (83). Additionally, one study was conducted in Dunedin, New Zealand's seventh largest city, with a population of 118,500. Detailed information about each study is summarised in the Supplementary information 2.

Table 1 Frequency of observations in each study

Study	N	Active Travellers N (%)	Age Range (years)	City
BEANZ (69)	571	254 (44.5)	13-19	Auckland & Wellington
BEATS (71)	1181	384 (32.5)	12-19	Dunedin
KITC (72)	226	120 (53.1)	9-13	Auckland
PIF (70)	657	198 (30.1)	13-15	Auckland

URBAN (36)	209	32 (15.3)	6-19	Auckland, Wellington & Christchurch

BEANZ = Built Environment and Adolescent New Zealanders, BEATS = Built Environment and Active Transport to School, KITC = Kids in the City, N = number, PIF = Pacific Islands Families, URBAN = Understanding the Relationship between Activity and Neighbourhoods.

Participant demographic characteristics, rates of ATS, and the results of the bivariate analyses are presented in Table 2. Descriptive information for the built environment characteristics and results of the bivariate analyses for these variables are presented in Table 3. Age, school decile, dwelling density, intersection density (400 m and 1 km buffer), and distance to school were related to ATS at $p<0.10$ in the bivariate analyses and were taken forward into the multiple variable modelling, along with the aforementioned fixed effects (age, sex, ethnicity and number of siblings).

Table 2 Participant demographic characteristics and results of the bivariate analyses for odds of actively travelling to school for each variable

Variable	**Category**	**N**	**ATS N (%)**	**OR**	**95% CI**	***p*-value**
Sex	Male	1440	509 (35.4)	1.00		0.44
	Female	1471	494 (33.6)	0.94	(0.80, 1.09)	
Age (years)	5-12	363	147 (40.5)	1.00		0.05
	13	258	76 (29.5)	0.68	(0.33, 1.37)	
	14	1026	327 (31.9)	0.78	(0.39, 1.56)	
	15	581	208 (35.8)	0.92	(0.45, 1.82)	
	16	313	126 (40.3)	1.03	(0.51, 2.08)	
	17+	370	118 (31.9)	0.68	(0.33, 1.38)	
Ethnicity	New Zealand European	1438	499 (34.7)	1.00		0.19
	Māori	240	88 (36.7)	1.17	(0.86, 1.58)	
	Pacific	786	238 (30.3)	0.76	(0.55, 1.03)	
	Asian	207	82 (39.6)	0.98	(0.70, 1.35)	
	Other	226	86 (38.1)	1.15	(0.85, 1.54)	
Body mass index (kg/m^2)	Underweight	78	20 (25.6)	1.00		0.61
	Normal	1595	571 (35.8)	1.19	(0.69, 2.02)	
	Overweight	583	193 (33.1)	1.04	(0.59, 1.81)	
	Obese	547	188 (34.4)	1.16	(0.65, 2.05)	
Number of people in a household (n)	<4	611	239 (39.1)	1.00		0.18
	4	873	289 (33.1)	0.82	(0.65, 1.01)	
	5-6	908	294 (32.4)	0.82	(0.65, 1.02)	
	7+	181	65 (35.9)	1.00	(0.69, 1.45)	
Number of siblings (n)	0	308	133 (43.2)	1.00		0.11
	1	894	300 (33.6)	0.80	(0.60, 1.04)	
	2	778	267 (34.3)	0.98	(0.74, 1.30)	
	3	449	133 (29.6)	0.88	(0.63, 1.20)	
	4 +	487	171 (35.1)	1.07	(0.78, 1.45)	
School decile	1-3 (lower SES)	715	247 (34.6)	1.00		<0.001
	4-7	997	388 (38.9)	0.86	(0.62, 1.17)	

	8-10 (higher SES)	1143	357 (31.2)	0.62	(0.44, 0.85)	
School type	Primary/Intermediate	443	161 (36.3)	1.00		0.72
	Secondary	2428	840 (34.6)	0.77	(0.18, 3.22)	

Note. All modelling adjusted for study effects. ATS = active travel to school, CI = confidence interval, N = number, OR = odds ratio, SES = socioeconomic status.

Table 3 Built environment variable characteristics and results of the bivariate analyses for odds of actively travelling to school for each variable

Variable	**Quartile**	**N**	**ATS N (%)**	**OR**	**95% CI**	***p*-value**
1 km buffer:						
Dwellings density (km^2)	Q1 (Low density)	755	185 (24.5)	1.00		<0.001
	Q2	716	233 (32.5)	1.54	(1.21, 1.93)	
	Q3	718	272 (37.9)	2.04	(1.61, 2.56)	
	Q4 (High Density)	727	314 (43.2)	2.14	(1.7, 2.68)	
Intersection density (km^2)	Q1 (Low density)	743	198 (26.7)	1.00		<0.001
	Q2	719	222 (30.9)	1.26	(0.99, 1.60)	
	Q3	718	249 (34.7)	1.67	(1.31, 2.11)	
	Q4 (High Density)	736	335 (45.5)	2.97	(2.33, 3.78)	
Land use mix	Q1 (Low Mix)	764	255 (33.4)	1.00		0.61
	Q2	667	230 (34.5)	0.93	(0.72, 1.18)	
	Q3	738	241 (32.7)	0.84	(0.65, 1.08)	
	Q4 (High Mix)	747	278 (37.2)	0.91	(0.70, 1.17)	
400 m buffer:						
Dwelling density (km^2)	Q1 (Low density)	744	199 (26.8)	1.00		<0.001
	Q2	727	231 (31.8)	1.32	(1.04, 1.66)	
	Q3	716	276 (38.6)	1.73	(1.37, 2.16)	
	Q4 (High Density)	729	298 (40.9)	1.78	(1.42, 2.22)	
Intersection density (km^2)	Q1 (Low density)	751	200 (26.6)	1.00		<0.001
	Q2	715	237 (33.2)	1.43	(1.13, 1.79)	
	Q3	716	247 (34.5)	1.63	(1.29, 2.05)	
	Q4 (High Density)	734	320 (43.6)	2.37	(1.88, 2.97)	
Land use mix	Q1 (Low Mix)	760	256 (33.7)	1.00		0.29
	Q2	728	245 (33.7)	0.90	(0.71, 1.14)	
	Q3	720	234 (32.0)	0.80	(0.62, 1.02)	
	Q4 (High Mix)	708	269 (38.0)	0.95	(0.73, 1.22)	
Distance to school (km)	Q1 (<1.3)	767	482 (62.8)	1.00		<0.001
	Q2 (1.3 to <2.3)	710	341 (48.0)	0.34	(0.26, 0.43)	
	Q3 (2.3 to <4.2)	719	152 (21.1)	0.09	(0.06, 0.11)	
	Q4 (≥4.2)	720	29 (4.0)	0.01	(0.00, 0.02)	

Note. All modelling adjusted for study effects. ATS = active travel to school, CI = confidence interval, N = number, OR = odds ratio.

Table 4 presents the logistic regression results for the final multiple variable model. Accounting for the fixed effects (age, sex, ethnicity, number of siblings) and after removal of non-significant variables at p>0.05, remaining factors in the model were number of siblings, school decile, distance to school, and intersection density and dwelling density within 1 km buffers only. Compared with children who had no siblings, those with one sibling were 30% less likely to use ATS (95% CI 0.48, 0.96, p<0.02). Children and youth attending higher decile (higher socio-economic status) schools were less likely to travel actively compared to those attending lower decile schools (OR 1.18, 95% CI 0.78, 1.79, p = 0.001). The greatest odds for ATS were found for distance to school, with the odds of ATS near zero for those living more than 2.3 km from school. Using the 1 km neighbourhood buffer, a linear increase in odds of ATS was observed for intersection density, with those living in neighbourhoods with the highest intersection density almost three times more likely to use ATS than those living in neighbourhoods with the lowest intersection density (OR 2.86, 95% CI 1.95, 4.17, p<0.001). Conversely (and somewhat counter intuitively), a negative relationship was observed between ATS and dwelling density. Exploratory work was conducted to examine these perplexing results. These examinations suggested a possible level of interaction between dwelling density and distance to school, with a combination of lower housing density and shorter distance to schools linked with ATS (data available on request).

Table 4 Final multiple variable model for odds of using active travel to school

Variable	**Category**	**OR**	**95% CI**	***p*-value**
Age (years)	5-12	1.00		0.26
	13	0.89	(0.39, 2.02)	
	14	0.99	(0.44, 2.19)	
	15	1.20	(0.54, 2.63)	
	16	1.16	(0.51, 2.59)	
	17+	0.81	(0.35, 1.84)	
Sex	Male	1.00		0.01
	Female	0.79	(0.64, 0.95)	
Ethnicity	New Zealand European	1.00		0.15
	Māori	1.04	(0.71, 1.52)	
	Pacific	0.68	(0.46, 1.00)	
	Asian	0.73	(0.49, 1.07)	
	Other	1.05	(0.73, 1.51)	
Number of siblings (n)	0	1.00		0.02
	1	0.69	(0.48, 0.96)	
	2	0.90	(0.62, 1.27)	
	3	0.76	(0.51, 1.13)	
	4+	1.08	(0.72, 1.61)	

School decile	1-3 (lower SES)	1.18	(0.78, 1.79)	0.001
	4-7	1.54	(1.22, 1.95)	
	8-10 (higher SES)	1.00		
Distance to school (km)	Q1 (<1.3)	1.00		<0.001
	Q2 (1.3 to <2.3)	0.29	(0.22, 0.37)	
	Q3 (2.3 to <4.2)	0.07	(0.05, 0.09)	
	Q4 (≥4.2)	0.01	(0.00, 0.01)	
Intersection density (km^2; 1 km buffer)	Q1 (Low density)	1.00		<0.001
	Q2	1.74	(1.27, 2.38)	
	Q3	2.18	(1.57, 3.02)	
	Q4 (High density)	2.86	(1.95, 4.17)	
Dwelling density (km^2; 1 km buffer)	Q1 (Low density)	1.00		0.004
	Q2	0.59	(0.42, 0.81)	
	Q3	0.58	(0.41, 0.80)	
	Q4 (High density)	0.56	(0.39, 0.80)	

Note. All modelling adjusted for study effects. CI = confidence interval, N = number, OR = odds ratio, SES = socioeconomic status.

We further examined distance to school, intersection density and dwelling density as associates of ATS for each individual study. Figure 2 shows the forest plot for individual study results, comparing quartiles 1 with quartiles 2, 3, and 4 for each variable. Distance to school showed significantly negative associations with ATS with all except one comparison from the Understanding the Relationship between Activity and Neighbourhoods (URBAN) study (36). Within many of the individual studies there were no significant findings for dwelling and intersection density. However, studies did show homogeneity in results, which resulted in significant findings overall. With the exception of the Kids in the City (KITC) study (72), individual study findings were relatively consistent with null or negative correlates for dwelling density. For intersection density, greater odds ratios and confidence intervals were observed for the KITC study, and the URBAN study (36).

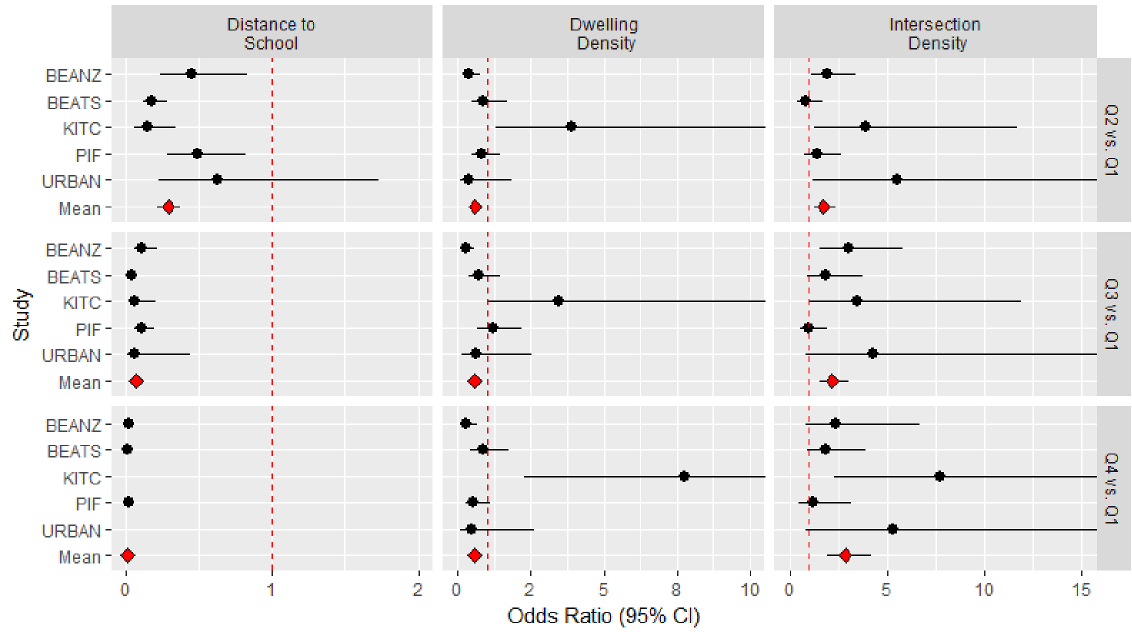

Figure 2. Forest plot comparing quartile 1 with quartiles 2, 3, and 4 for distance to school, dwelling density (1 km buffer), and intersection density (1km buffer) associations with active travel to school. BEANZ = Built Environment and Adolescent New Zealanders, BEATS = Built Environment and Active Transport to School, KITC = Kids in the City, PIF = Pacific Islands Families, URBAN = Understanding the Relationship between Activity and Neighbourhoods.

4. Discussion

The aims of this study were: (i) to systematically identify New Zealand research that had measured ATS, distance to school, and the neighbourhood built environment in children and youth, (ii) to collate data from identified studies and combine them in a consistent manner, and (iii) to identify associations between ATS and built environment features across the combined dataset. In doing so, this study provides new, robust evidence and greater statistical power that is more generalisable than the previous contributing smaller studies. In total, data from 2844 children and young people were obtained from five studies representing four major cities across New Zealand. Approximately a third of the participants used ATS “usually” or “most of the time”. For the most part, associations between environmental variables and ATS were consistent with previous research (40, 41, 84-86) and the individual studies themselves.

4.1 Distance to school

Overall, the relationship between distance to school and odds of ATS had the greatest magnitude of all ATS associations observed even after accounting for all other factors in the final model. This finding is not surprising given the body of existing evidence demonstrating this relationship (30, 38, 43, 48, 86-88). Compared to children living within 1.3 km of school, the odds of ATS were reduced by a third among those residing between 1.3-2.3 km from school. Beyond 2.3 km, the odds of ATS in this combined dataset reduced to near zero. This distance threshold is in line with earlier research indicating significant and substantial reductions in ATS for distances of 1.4-2.0 km (36, 43-45, 89). The results of the individual studies were similar, with the exception of comparing quartile 1 and quartile 2 for the URBAN study whereby the 95% confidence intervals crossed over one, indicating a non-significant association for this comparison only. To some extent, the wider confidence interval may have been a function of the smaller sample size in the URBAN study compared to other included studies (36). Collectively, the evidence shows that shorter school travel distances are significantly associated with increased walking and cycling to school (41). Schools located centrally within communities are likely to facilitate children's ATS. Therefore, location of schools and zoning restrictions are important considerations to optimise travel distances and the likelihood for ATS (36, 89). Distance also varies depending on how children's school travel routes were derived. Previous research identified clear disagreement between school travel routes measured by GIS and Global Positioning Systems (GPS) or participatory mapping (86, 90-93). The absence and imprecision of pedestrian and street network (e.g., including or excluding motorways) data may limit the ability to capture 'actual' school travel routes (41, 94).

4.2 Street connectivity

In line with previous research (38), a clear positive relationship between street connectivity and ATS was observed when using the 1 km neighbourhood buffer. Children and youth living in neighbourhoods with the highest intersection density were almost three times more likely to use ATS than those living in neighbourhoods with the lowest intersection density. This finding was, however, in conflict with other studies from Australia (25), the US (85), and Canada (95) which reported negative associations between intersection density and ATS. Highly connected streets may be more utilised by motorised vehicles. Consequently, children and youth living in those areas, compared to those living in areas with low street connectivity, could be more exposed to high traffic speed and volume and less likely to use ATS (96). Use of pedestrian or walkable networks to calculate intersection density may increase the specificity and sensitivity of results and provide more precise information for active travellers.

4.3 Dwelling density

A somewhat counter intuitive finding emerged in relation to dwelling density, whereby increased dwelling density (using a 1 km buffer only) was associated with reduced rates of ATS in children and youth. With the exception of the KITC study, all studies showed a trend towards reduced ATS with increasing dwelling density. It is possible the differences observed for the KITC study were due to the comparatively smaller sample size (compared to other included studies), and the focus on medium-to-high density neighbourhoods in this project (72). Overall, the findings for dwelling density are in contrast with earlier research showing positive relationships with ATS (59, 85, 97). To investigate this further, interrelationships between the built environment variables were considered in modelling associations with ATS (data available on request). An interesting pattern was observed, whereby there was some evidence for an interaction effect for dwelling density and distance to school. In particular, findings indicated that a combination of low dwelling density and short distance to school may be positively related to ATS. It is likely that the short distance to school overrode the impact of dwelling density on this relationship, so these findings must be interpreted with caution. Further investigation into the links between neighbourhood density, traffic volumes, road safety and ATS is warranted. For example, a neighbourhood with lower dwelling density may represent less traffic and perceptually quieter local streets where parents are more likely to give their children permission to use ATS (e.g., Buliung et al. (98)). It is possible that the relationship for dwelling density is curvilinear, with neighbourhoods of extremely low dwelling density (e.g., in rural areas, also characterised as having low walkability overall (99)) and extremely high dwelling density (e.g., apartment blocks in central city areas) offering little in the way of supporting ATS.

4.4 School characteristics

Neighbourhood-level socio-economic status was associated with ATS, with individuals attending higher decile (higher socio-economic status) schools being significantly less likely to travel actively compared to those attending lower decile schools. Economic factors contributing to ATS can include car ownership (30) and access, and employment status of parents/caregivers (33). It is possible these factors contributed to higher ATS in children and youth residing in lower socio-economic neighbourhoods. However, it was not possible to include these factors in modelling due to differences in measures taken across studies.

4.5 Individual characteristics

Age, sex, ethnicity, and number of siblings were retained in the final model as fixed effects, irrespective of statistical significance. Consistent with previous research (81, 86), females were less likely to use ATS than their male peers. In contrast to our expectations, no significant relationships were observed for the other fixed effects. In the New Zealand context, children of Māori, Pacific Island, and "other" ethnicities have reported higher ATS than their New Zealand European counterparts (32). This was not the case in the current research. It is hypothesised that socio-economic deprivation (as observed with the school decile being one of the significant associations of ATS) may have a greater impact on ATS than ethnicity; meaning that when socio-economic factors are taken into account, the effect of ethnicity could be negligible. Compared with participants with no siblings, those with one sibling were less likely to use ATS, and the relationship was not statistically significant for those with two or more siblings. Earlier New Zealand research has shown a positive impact of having older siblings in the household on children's independent mobility (33). It is likely that a similar pattern existed in the research included here, but it was not possible to account for age of siblings in this analysis as those data were not measured across all studies.

4.6 Limitations and other considerations for active school travel in children and youth

The heterogeneity in study designs and variables measured across included studies limited our ability to consider a range of factors that may have been important in modelling the relationship between ATS and the neighbourhood built environment. Firstly, due to different measures used for mode of travel to school across the studies, only a dichotomous category of active versus passive travel was employed in the meta-analysis, preventing the examination of individual travel modes such as walking versus cycling (31, 100). Furthermore, potential differences may exist in school travel modes between morning (to school) and afternoon (from school) (86, 98). In terms of the objective built environment, pedestrian and cyclist infrastructure and destination accessibility were not able to be examined in the current study. Pedestrian infrastructure and traffic calming along routes to school, such as constructing sidewalks and cycle lanes have shown promise for increasing children's ATS (101, 102). However, conflicting associations exist—particularly for increasing the uptake of cycling (103). Crossing streets can be perceived as a dangerous activity for children, especially when crossing main or busy streets, and particularly for young children. Indeed, an Australian survey showed that parents viewed road crossings to school and traffic calming around the school entrance as major factors influencing their decision about their child's mode of travel to school (104). Children who had to cross a main street on the route to school were more likely to be driven to school than to walk or cycle (105). A recent systematic review found strong evidence for the impact of multiple streetscape components (including two or more of: crosswalk/sidewalk improvements, improved/covered bike parking, traffic calming features and safe places to walk) on children's active travel (to school and other destinations) (106). Other features such as topography may also impact decision-making around school travel modes and routes, but little is known in this area (25, 93). In the New Zealand context, cycling to secondary school is less common than walking, is perceived as less safe, and receives less infrastructure and social support compared to walking (31). However, regional differences exist within New Zealand (107). Further work in this area is needed to identify specific environmental factors that generate the greatest impact on children's walking and cycling to school behaviours and active travel in general.

Collectively, population density, street connectivity, pedestrian and cycling infrastructure, and destination diversity affect overall accessibility to destinations, or how easily a range of destinations can be reached on foot or by bicycle (108). There are a number of objective (e.g., a spatially-derived indices) or subjective (e.g., questionnaires) measures that have been developed and used to assess the walking potential of an area, such as the Walkability Index and Walk Score (108). However, measuring how conducive an environment is for children's walking or cycling is less developed. Most recently a child-specific neighbourhood destination accessibility index (NDAI-C) was developed in New Zealand (109) which has been associated with active travel modes on weekdays (37). To some extent, the measure of land use mix used in the current study provides an indicator of diversity of destination types in the neighbourhood, but this does not capture information about destinations of specific importance to children, or the number of destinations within a region. Future research examining destination accessibility in relation to children's and adolescents' travel behaviours is needed.

A number of social and perceived variables such as encouragement and supports for ATS were not included in this study, but may be important in understanding associations between the built environment and ATS. Firstly, neighbourhood self-selection may impact travel behaviours (110), but was not measured in the current study. In New Zealand, school choice decisions are influenced by social factors and school programmes/facilities rather than proximity to home (111) and have important implications for ATS to secondary schools, particularly in higher socioeconomic status areas. One New Zealand study showed that adolescents who enrolled in the closest school to home had five times higher rates of ATS and lower rates of motorised travel to school compared to their counterparts (89). Thus choice of neighbourhood, and choice of school, assuming families are able to make these choices, can have substantial impacts on the likelihood of ATS in children and young people.

One of the most commonly reported barriers to ATS for children and young people is parental perceptions of neighbourhood safety (112-114). Research from the US shows parental perceptions of neighbourhood safety and attitudes towards ATS had a greater influence on children's ATS behaviours than physical environment (i.e., presence of sidewalks) (45). Specific barriers to uptake of ATS, combining the social and physical environment, include high traffic volume and speed, poor visibility, unsafe or inadequate road crossings, dangerous driving and parking, stranger-danger, and fear of crime (45, 97, 115). In addition, cycling is perceived to be a less safe mode of travel to school compared to walking by New Zealand adolescents (31). Giles-Corti et al. (115) viewed the integral role of parents as 'gatekeepers' of children's travel mode choice and travel behaviours. While crime and stranger-danger in New Zealand have not increased over time (116), parental concerns about traffic safety are justified, with a substantially increased risk of traffic-related injuries and deaths for child pedestrians and cyclists (117, 118).

4.7 Strengths and implications for future research

A strength of the current study was the use of consistent approaches to neighbourhood buffer development and subsequent generation of objective built environment measures across studies. The choice of buffers depends on the type of environmental exposures being measured, and the level of spatial interactions (i.e., potential or actual) to capture (51, 119). When examining the effects of contextual influences on ATS, fundamental methodological issues arise, namely the modifiable area unit problem (MAUP) and the uncertain geographic context problem (UGCoP). The MAUP and UGCoP refer to the effects of spatial scale and zoning versus spatial and temporal uncertainty of the contextual influences (108, 120-122). Discrepancies in spatial units across studies may hinder comparisons between research findings because the effects of the contextual variables may change depending on the geographic areas defined in the studies.

Another strength of this study was the systematic approach to identifying studies for inclusion in this meta-analysis. Data could not be retrieved for three of the eight eligible studies, resulting in the potential for bias in terms of geographic and demographic representation. However, we believe the potential for bias was small, with the final dataset for this study including 2844 participants residing in four major cities across New Zealand. Ultimately, this research has enabled greater statistical power than with individual studies, and greater confidence in the representativeness of the findings for children and youth residing in New Zealand cities. Reporting bias of individual studies was negligible, with all included studies having published protocols. Opportunities exist for future research to explore the impact of the built environment on different travel modes such as walking vs. cycling and car vs. public transport (e.g., mixed travel modes (93): buses, trains, ferries) to profile and understand these associates and behaviours. For example, information on cycling to school may highlight a need for new cycling infrastructure and safety strategies for children and younger people, and develop policy and programmes for this population (123, 124).

5. Conclusion

In this large study of New Zealand children and youth, significant negative relationships were observed between the likelihood of ATS and distance to school, dwelling density, and school socioeconomic status. Odds of ATS were positively associated with intersection density. The findings of this meta-analysis suggest that factors that influence distance to school such as school location and school zoning/catchment policies have significant influence on school travel mode. Since many of the factors that influence ATS are context specific, these findings may not be generalisable to other geographic settings. Therefore, these factors should be taken into account in planning decisions for school locations. In addition, improving connectivity in school neighbourhoods (e.g., through creating walking and cycle paths, trails and greenways) may have positive effects on ATS in New Zealand children and youth.

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Press release

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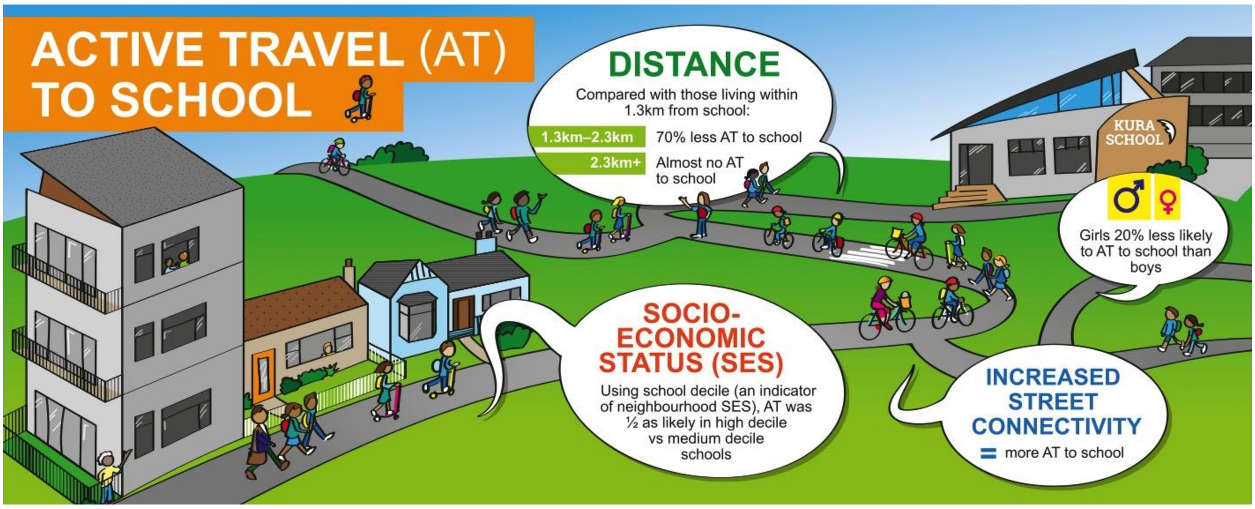

Key ‘ingredients’ of the neighbourhood built environment associated with active school travel in New Zealand children and youth, illustrated by Carol Green. Copyright 2018 The Authors. Published by Elsevier.

Supplementary material

Supplementary Information 1

Search terms and fields used for each database

Academic databases

SPORTDiscus (EBSCO Host Interface)

"active transport" (TX All text)
"active transport" OR "active travel" (TX All text) AND “Zealand” (TX All text)
"active transport" (TX All text) AND “Zealand” (TX All text)
“mode* transport” (TX All text) AND “school”
“mode* transport” (TX All text) AND “school” (TX All text) AND “Zealand”
ABI/Inform (ProQuest Interface)
"active transport" (Abstract) AND “school” (Abstract)
"active transport" (Abstract) AND “Zealand” (Abstract)
“mode* transport” (Abstract) AND “Zealand” (Abstract) AND “school”
"getting to school" Zealand

Web of Science

mode* transport school Zealand
"active travel" OR “active transport" (Topic) AND “Zealand” (Topic)
"active travel" OR “active transport" (Topic) AND “Zealand” (Topic) AND “school” OR “education” (Topic)
“walk*” "to school" (Topic) AND “Zealand” (Topic)
“bik*” "to school" (Topic) AND “Zealand” (Topic)
“trip*” "to school" (Topic) AND “Zealand” (Topic)
“car*” "to school" (Topic) AND “Zealand” (Topic)

Scopus

"active travel" OR "active transport" (Title abstract keyword) AND “school” (Title abstract keyword)
"active travel" OR "active transport" (Title abstract keyword) AND “Zealand” (Title abstract keyword)

"active travel" OR "active transport" (Title abstract keyword) AND “school” (Title abstract keyword) AND “Zealand” (Title abstract keyword)
"active travel" OR "active transport" (Title abstract keyword) AND “school” (Title abstract keyword) AND “Zealand” (Title abstract keyword)
“walk*” "to school" (Title abstract keyword) AND “Zealand” (Title abstract keyword)
“driv*” "to school" (Title abstract keyword) AND “Zealand” (Title abstract keyword)
“bus” "to school" (Title abstract keyword) AND “Zealand” (Title abstract keyword)
“trip*” "to school" (Title abstract keyword) AND “Zealand” (Title abstract keyword)

NZResearch.org.nz
“active travel” OR “active transport”
“school” AND “transport*” OR “commut*” OR “travel*”
“commut* school”
“Walking School Buses”

NewzText
"active transport" AND “school”
"active travel" AND “school”
“walk*” AND "to school"
“bik*” AND "to school"
“bus*” AND "to school" AND “school”
“trip*” AND “to school”

Australian/New Zealand Reference Centre (EBSCO Host Interface)
"active transport" OR "active travel" (TX All text) AND “school” (TX All text)
"active transport" OR "active travel" (TX All text) AND “Zealand” (TX All text)
"active transport" OR "active travel" (TX All text) AND “Zealand” (TX All text) AND “school” (TX All text)
“mode* transport” (TX All text) AND “school” (TX All text) AND “Zealand” (TX All text)
"walking bus" (TX All text)
"walking bus" (TX All text) AND “Zealand” (TX All text)
"walking bus" (TX All text) AND “Zealand“ (TX All text) AND “council” OR "local government" (TX All text)
"mode of transport" OR "active travel" OR "active transport" AND “school” AND “council” OR "local government"

NZ Educational Theses Database (NZ Council for Educational Research)
“school” AND “transport*” OR “commut*” OR “travel*”

Aotearoa NZ International Development Studies Network
“school” AND “transport*”
“school” AND “commut*”
“school” AND “travel*”

Scholarly Commons/Institutional Repository

Auckland University of Technology (http://aut.researchgateway.ac.nz/)
“school” AND “transport*” OR “commut*” OR “travel*” (All of Scholarly Commons)
“school” AND “transport*” OR “commut*” OR “travel*” (AUT Theses, Dissertations and Research Projects)

Massey University (http://mro.massey.ac.nz/)
“school” AND “transport*” OR “commut*” OR “travel*”

University of Auckland (https://www.library.auckland.ac.nz/)
“school” AND “transport*” OR “commut*” OR “travel*”

University of Canterbury (http://ir.canterbury.ac.nz/)
“school” OR “transport*” AND “school” OR “commut*” AND “school” OR “travel*”

University of Otago (https://ourarchive.otago.ac.nz/)
“school” AND “transport*” OR “commut*” OR “travel*” (searched in ‘Division of Health Sciences Departments’)
“school” AND “transport*” OR “commut*” OR “travel*” (search in ‘University Otago, Wellington’)
“school” AND “transport*” OR “commut*” OR “travel*” (searched in ‘Department of Publish Health’)

University of Waikato (http://researchcommons.waikato.ac.nz/)

“school” OR “transport*” AND “school” OR “commut*” AND “school” OR “travel*”

Victoria University of Wellington (http://researcharchive.vuw.ac.nz/)

“school” AND “transport*” OR “commut*” OR “travel” (Search Scope: Faculty of Science)

“school” AND “transport*” OR “commut*” OR “travel” (Search Scope: School of Geography, Environmental and Earth Sciences)

Government and local council reports

The following known and unknown sources were used for hand searching:

Ministry of Health (https://www.health.govt.nz/)

Ministry of Transport (http://www.transport.govt.nz/research/travelsurvey/)

NZ Transport Agency/Land Transport New Zealand (https://www.nzta.govt.nz/resources/)

Google (https://www.google.com/)

Supplementary information 2

Study characteristics

STUDY: Built Environment and Adolescent New Zealanders (BEANZ) (1, 2)

Selection criteria:

Neighbourhood	In the first instance, GIS was used to calculate three built environment measures – street connectivity, residential density, and land use mix – for each meshblock (smallest census tract units available in NZ). The raw scores for these built environment measures were normalised and summed to create a basic walkability index. Next the basic walkability index and pre-existing deprivation data (NZ Dep 2006) were used to classify all Auckland and Wellington urban meshblocks into one of four strata: (i) higher walkable, higher SES; (ii) higher walkable, lower SES; (iii) lower walkable, higher SES; and (iv) lower walkable, lower SES. Meshblocks with the top four walkability/SES deciles are classified as higher walkable/SES, and meshblocks with the bottom four walkability/SES deciles are classified as lower walkable/SES. Meshblocks with walkability or SES in deciles 5 and 6 were excluded. School selection was based on proximity to large numbers of meshblocks in each of the four strata.
Individual	All students of participating schools were invited to participate, irrespective of the walkability strata the individual lived in.

Inclusion/Exclusion criteria: English speaking

Published results for ATS: Not completed for ATS. For PA & SED: There were significant positive associations with the composite subjective (perceived land use mix - diversity, street connectivity and aesthetics) and objective (residential density and number of parks within 2km distance from home) environmental indices of activity-friendliness with MVPA. No significant objective environmental correlates of SED were found. The composite subjective environmental index of non-sedentariness, consisting of perceived land-use mix-diversity, street connectivity, aesthetics, pedestrian/automobile traffic safety, minus values of perceived physical barriers to walking was linearly negatively related to SED.

Analyses:

Confounders	Not yet completed for ATS. For PA & SED: Associations of perceived environmental attributes with objectively-additive mixed models (GAMMs).
Clustering	Children were clustered in classes, in schools, and in cities (Auckland, Wellington).

STUDY: Built Environment and Active Transport to School (BEATS) (3)

Selection criteria:

	Neighbourhood	No neighbourhood selection was made. Adolescents from all 12 Dunedin secondary schools participated in the BEATS Student Survey in 2014/2015.
	Individual	Schools identified classrooms for recruitment. All adolescents within selected classes were eligible to participate.
Inclusion/Exclusion criteria:		Age 13-18 years (school years 9-13); enrolled in one of the 12 Dunedin secondary schools; Students boarding at school were allowed to participate in the survey but were excluded from any GIS analyses.
Published results for ATS:		To date there is no published data on ATS and built environment variables from the BEATS Study.
Analyses:		
	Confounders	No analyses on this dataset have been performed to date. Our other analyses from this dataset took into account clustering of students within schools.
	Clustering	Adolescents were clustered within school.

STUDY: Kids in the City (KITC) (4, 5)

Selection criteria:		
	Neighbourhood	Selection of study localities was undertaken in consultation with local government and Housing New Zealand Corporation (HNZC; government housing provider). Recognizing the potential influence of walkability (an index combining measures of street connectivity, dwelling density, land use mix and retail floor ratio) and access to services and amenities (an index of walking access to child-appropriate destinations on physical activity and independent mobility), Auckland maps of walkability and destination access were also referenced in locality selection. Potential schools for recruitment were then identified using a strategy of pairing schools with a similar school decile rating (an indicator of SES of a school's catchment area), and differing neighbourhood walkability and neighbourhood access scores.
	Individual	Schools identified classrooms for recruitment. All children within selected classes were eligible to participate.
Inclusion/Exclusion criteria:		School years 5-8, English speaking
Published results for ATS:		Street connectivity and distance to school were related to the proportion of trips made by active modes.
Analyses:		
	Confounders	Generalised estimating equation modelling was used to assess relationships between daily repeated measures (clustered by child) for each physical activity outcome (i.e., %MVPA and active travel) and individual built environment features, controlling for individual (child age, ethnicity, sex), parent (neighbourhood perceptions), and socioeconomic (car availability, socio-economic status) factors as

		fixed factors. Statistical significance was set at α = 0.05, an exchangeable correlation structure was employed, and the Huber-White sandwich estimate of variance was specified.
	Clustering	Children were clustered within classes, within schools; however this was not included in analyses: School was not included as a fixed factor in analyses. It is possible some clustering effects may have existed due to school, in which case the standard errors would have been underestimated, and the p-values would be smaller than if clustering was taken into account. However, this situation is unlikely, due to the small number of participants from each school "cluster". In addition, schools were measured at different times across a year, so the inclusion of school as a fixed factor could have inadvertently reflected other factors contributing to the relationships under examination (e.g., seasonality). Accordingly, the approach employed was considered appropriate for the current study.
STUDY:	Pacific Islands Families (PIF) (6, 7)	
	Selection criteria:	
	Neighbourhood	NA: Cohort study of 1398 children born at Middlemore Hospital, South Auckland, in 2000.
	Individual	All potential child participants were selected from live births at Middlemore Hospital where the child had at least one parent who identified as being of a Pacific Island ethnicity and also a NZ permanent resident. While in Middlemore Hospital, permission was sought from the mothers of potential participants to contact them six weeks later. At this initial approach 98% of mothers consented to a visit by an interviewer to further explain the study when their infant was 6-weeks old.
	Inclusion/Exclusion criteria:	All potential child participants were selected from live births at Middlemore Hospital where the child had at least one parent who identified as being of a Pacific Island ethnicity and also a NZ permanent resident. There were no further eligibility requirements for participation in the Study.
	Published results for ATS:	NA
	Analyses:	
	Confounders	Not yet completed for any built environment features.
	Clustering	NA
STUDY:	Understanding the Relationship between Activity and Neighbourhoods (URBAN) (8, 9)	
	Selection criteria:	
	Neighbourhood	Neighbourhood walkability was calculated using GIS-derived street connectivity, dwelling density, land use mix, and retail floor area ratio at the mesh-block level. Summary scores (average of the mesh-block level walkability values) were calculated for each neighbourhood and neighbourhoods were partitioned into walkability tertiles (low/medium/high). In the interests of attaining maximal variability, only meshblocks with low (deciles 1-3) and high (deciles 7-10) walkability and Māori residential density were considered.

Individual	A total of 42 households in each of the 48 neighbourhoods were recruited. A door-to-door recruitment strategy was utilised, where every nth household within a neighbourhood was sampled. The sampling rate was determined by density of dwellings within the neighbourhood, assuming a 60% response rate. One usually resident adult (aged 20-65 years) and child (aged 3-18 years) in each household were invited to participate.
Inclusion/Exclusion criteria:	Aged 3-18 years, English speaking, able to walk without aids (for PA measurement), and having resided in the household at least three months prior to, and for the week during, the measurement period. Children were only eligible to participate if there was a participating adult in the household. Where there was more than one eligible adult or child, the individual(s) with the next birthday were recruited.
Published results for ATS:	Female sex (p = 0.10), child age (p = 018), city (p = 0.07), ethnicity (p = 0.12), living in a household with a higher household income (p = 0.02), residing within zone of school attended (p = 0.09), shorter distance to school (p<0.001), NHSSOTH (p = 0.08), city (p = 0.07), and sunlight hours (p = 0.16) all had p-values of<0.20 in the bivariate analyses and so were simultaneously considered in a multivariate model. Following backwards elimination of non-significant factors (p > 0.05) in the multivariate model, shorter distance to school (p<0.001), child age (p = 0.005), city (p = 0.03), and NHSSOTH (p = 0.04) remained significantly associated with likelihood of undertaking ATS. Accounting for age, city, and NHSS status, those living further than 2 km from school were significantly less likely to undertake ATS than those residing 700m or less from school (OR 0.02, 95%CI 0.003, 0.10). Accounting for distance to school, city, and NHSS status, children of intermediate and secondary school age were significantly more likely to undertake ATS than their younger counterparts (OR 3.44, 95%CI 1.31, 9.01 and OR 2.88, 95%CI 1.15, 7.22, respectively). Taking distance to school, child age, and city into account, those children residing in a low walkable area and whose parents preferred a high walkable neighbourhood were 3.02 times less likely to use ATS than their counterparts (95% CI 1.07, 8.51). Finally, taking distance to school, child age, and NHSS status into account, significant differences were observed in ATS prevalence between cities whereby children residing in North Shore City were approximately twice as likely to use ATS than children residing in other cities. Compared with children living in North Shore City, children residing in Christchurch had the lowest odds of undertaking ATS (OR 0.23, 95%CI 0.08, 0.72).
Analyses:	
Confounders	Preliminary crude (bivariate) analyses were first conducted for daily ATS and potential predictor factors. Factors were simultaneously considered in a binomial generalised estimation equation (GEE) model, clustered by child (assuming exchangeable correlation structures), and with the logit link function and Huber-White sandwich estimate of variance specified. Factors with Wald's p-value<0.20 in the bivariate analyses were entered into a multivariate GEE model and backward elimination of non-significant terms was conducted until the most parsimonious multivariate model was found. City

		was specified as a fixed effect in the model and retained irrespective of statistical significance in the bivariate and multivariate analyses.
	Clustering	Children were clustered within cities - city was included as a fixed factor in analyses. Daily repeated measures of ATS were employed, and clustered by child.

ATS = active travel to school, CI = confidence interval, GIS = geographic information systems, MVPA = moderate-to-vigrous physical activity, NA = not available, NHSS = neighbourhood self-selection, NHSSOTH = neighbourhood self-selection otherwise (i.e., prefer low walkable, live high or low walkable; or prefer high walkable, live high walkable), NZ = New Zealand, OR = odds ratio, PA = physical activity, SED = sedentary behaviour, SES = socioeconomic status.

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Appendix B

Ethics Approval

A U T E C

S E C R E T A R I A T

3 September 2014

Melody Oliver
Faculty of Health and Environmental Sciences

Dear Melody

Ethics Application: **14/263 Neighbourhoods for active kids.**

Thank you for submitting your application for ethical review. I am pleased to confirm that the Auckland University of Technology Ethics Committee (AUTEC) has approved your ethics application for three years until 1 September 2017.

AUTEC would like to commend you on the overall quality of the application.

AUTEC noted that the Teachers Information Sheet needs to be edited for reference to 'your child' and the withdrawal statement needs to be completed by including the words 'prior to the completion of data collection'.

As part of the ethics approval process, you are required to submit the following to AUTEC:

- A brief annual progress report using form EA2, which is available online through http://www.aut.ac.nz/researchethics. When necessary this form may also be used to request an extension of the approval at least one month prior to its expiry on 1 September 2017;
- A brief report on the status of the project using form EA3, which is available online through http://www.aut.ac.nz/researchethics. This report is to be submitted either when the approval expires on 1 September 2017 or on completion of the project;

It is a condition of approval that AUTEC is notified of any adverse events or if the research does not commence. AUTEC approval needs to be sought for any alteration to the research, including any alteration of or addition to any documents that are provided to participants. You are responsible for ensuring that research undertaken under this approval occurs within the parameters outlined in the approved application.

AUTEC grants ethical approval only. If you require management approval from an institution or organisation for your research, then you will need to obtain this.

To enable us to provide you with efficient service, we ask that you use the application number and study title in all correspondence with us. If you have any enquiries about this application, or anything else, please do contact us at ethics@aut.ac.nz.

All the very best with your research,

Kate O’Connor

Executive Secretary

Auckland University of Technology Ethics Committee

Auckland University of Technology Ethics Committee

WA505D Level 5 WA Building City Campus

Private Bag 92006 Auckland 1142 Ph: +64-9-921-9999 ext 8316 email ethics@aut.ac.nz

Appendix C

Parent Information Sheet

Neighbourhoods for Active Kids

PARENT INFORMATION SHEET

Dear Parent/Caregiver

We are a team of researchers from AUT University, Massey University, and the University of Auckland. Together, with the lead researcher Melody Oliver, we are running a study looking at where children go and how active they are in their neighbourhood. We would like to invite you and your child to take part in this study. Deciding to take part is voluntary and neither you nor your child will be disadvantaged if you choose not to be involved.

This study is funded by the Health Research Council of New Zealand.

What is the purpose of this research?

In this study we will be looking at where children go and how active they are in their neighbourhood. Findings from this research (with no-one identified) will be shared with city councils, the Ministry of Health, and Housing New Zealand Corporation so that children's needs can be considered in urban planning. Findings (with no-one identified) may also be presented at conferences and in reports. Findings (with no-one identified) will be used in a PhD project examining factors relating to children's school travel.

How was your child identified and why are they being invited to participate in this research?

The study is taking place in 12 Auckland neighbourhoods. [SCHOOL NAME] has agreed to support the study and we are now inviting children in Years [5-6, 7-8] to take part.

What will happen in this research?

If your child chooses to take part these are the things that will happen:

- We will ask your child to complete a mapping survey to show us where they go in their neighbourhood and what they think of these places.
- We will give your child an accelerometer to wear on their waistband. The accelerometer measures physical activity.
- The accelerometer will be given to your child at school, and they will be asked to wear it for the next 8 days except when sleeping, bathing, or participating in water sports (like

swimming).

- Your child will be given a log for you to fill in each night. In the log you will need to note if your child removed the accelerometer.
- We will also measure your child's height, weight, and waist (around their belly button against the skin) – note that none of these measures are compulsory, and your child can skip any of these if they choose.

Parent interview

After we have visited your child's school, we would also like to do a brief interview with you. We will be asking you about your household demographics, your neighbourhood, rules around your child's neighbourhood play and travel, and your child's eating habits and activities.

What are the risks?

If you or your child do not want to answer some of the questions during your interviews, that's okay. All questions are voluntary and you and your child can also withdraw from the study at any stage.

What are the benefits?

Your child will be given a summary of the study results. Both you and your child will be given a $20 Westfield voucher to thank you for taking part in the study.

How will my child's privacy be protected?

Your child's friends and teachers may know that your child is taking part in the study, but all your child's information will be kept private. Your and your child's information will be kept in a locked file and sorted by number codes, not by names. This information will be stored for 10 years and will then be destroyed. We will not include information that will make it possible to identify you or your child in our reports.

What are the costs of participating in this research?

It will not cost you any money to take part in this study but you and your child will both be asked to give up some time. Your child will need to attend a 45-minute session during school time and your interview will take about 20 minutes.

Your child will also be asked to wear an accelerometer for 8 days. We will be at your child's school to hand out the accelerometer and will return to collect the accelerometer. We will ask your child to be careful with the accelerometer but if it is damaged or lost there will be no cost to you.

What opportunity do I have to consider this invitation?

If you and your child would like to take part in the study, **please return the signed consent form to school by [DATE]**. Your decision to take part in this study is voluntary.

Will we receive feedback on the results of this research?

Yes, if you want a summary of the results, please indicate this on the consent form.

What do I do if I have concerns about this research?

Any concerns regarding the nature of this project should be notified in the first instance to the Project Supervisor, Melody Oliver, melody.oliver@aut.ac.nz, 921 9999 ext 7078.

Concerns regarding the conduct of the research should be notified to the Executive Secretary, AUTEC, Kate O'Connor, ethics@aut.ac.nz, 921 9999 ext 6038.

Whom do I contact for further information about this research?

If you have any questions about the study please contact either:

Dr Melody Oliver	Julia McPhee	Dr Penelope Carroll
Project Supervisor	Human Potential Centre	The Centre for Social and Health Outcomes Research and Evaluation
Human Potential Centre	AUT University	Massey University
AUT University		
Phone: 921 9999 ext 7078	Phone: 921 9999	Phone: 366 6136
Email: melody.oliver@aut.ac.nz	Email: jmcphee@aut.ac.nz	Email: p.a.carroll@massey.ac.nz

If you and your child would like to take part in the study please sign the **YELLOW** consent form and **return it to school by [DATE].**

Approved by the Auckland University of Technology Ethics Committee on 3 September 2014, AUTEC Reference number 14/263.

Appendix D

Parent Consent Form

Neighbourhoods for Active Kids

PARENT CONSENT FORM

Project Supervisor: Melody Oliver

○ I have read and understood the information provided about this research project in the Information Sheet dated [DATE]

○ I have had an opportunity to ask questions and to have them answered.

○ I understand that notes will be taken during any interviews and that they will also be audio-taped and transcribed.

○ I understand that I may withdraw my child and/or myself or any information that we have provided for this project at any time prior to completion of data collection, without being disadvantaged in any way.

○ If my child and/or I withdraw, I understand that all relevant information including tapes and transcripts, or parts thereof, will be destroyed.

○ I agree to my child taking part in this research.

○ I agree to take part in this research.

○ I wish to receive a copy of the report from the research (please tick one): Yes○ No○

Child's name:……………………………………………………………………………………

Child's year: ………………… **Child's room:** ……………………….

Child's gender (please circle**): Male / Female**

Child's <u>primary</u> address: (This is used to calculate how walkable the neighbourhood is)

Street number and street name: ……………………………………………………………….

Suburb: ……………………………….……………………..Postcode: ……………………

Parent/Caregiver's signature: ....… **Date**: ……………………….

Parent/Caregiver's name: ....……………………………………………………….

Parent Mobile No:………………………………… **Home Phone No:**……………………………

Parent Email:……………………………………………………………………………………

If you and your child would like to take part in the study please sign **THIS YELLOW** consent form and **return it to school by [DATE]**

Approved by the Auckland University of Technology Ethics Committee on 3 September 2014, AUTEC Reference number 14/263.

Appendix E

Child Information Sheet

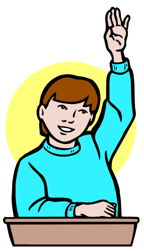
Neighbourhoods for Active Kids

CHILD INFORMATION SHEET

We are a team of researchers from AUT University, Massey University and the University of Auckland. Together, with the lead researcher Melody Oliver, we are running a study at your school. In this study we will be looking at how much activity children do, and the places that they travel to in their neighbourhoods. You are invited to take part in this study. If you choose to take part, these are the things that will happen:

- We will ask you to show us on an online map the places in your neighbourhood that you go to.
- You will be given an accelerometer to wear on your waistband. The accelerometer measures how much physical activity you do.
- The units will be given to you at school, and you will be asked to wear them for the next 8 days except when you are sleeping, bathing, or participating in watersports (like swimming).
- We will also measure your height, weight, and around your tummy.
- We will be asking your parents to answer some questions about where you go, what you eat, and how active you are.

Do you have any questions? Some questions that you may have are answered here:



- Before you start, your parent has to say that it is okay for you to take part in our project.
- You don't have to take part. Taking part in this project is entirely voluntary. In fact both you and your parent need to say it's okay before you take part.
- If you decide after we start that you don't want to do this work anymore, don't worry, that's okay. Just get your parent to let us know.
- You can ask us questions at any time.
- Your friends and teachers may know that you are taking part in the study but we will keep all the information we collect about you private. We will keep all your records in a safe place.
- We are not allowed to use your real name when we write, or talk, about the study. We use codes to know who you are.
- You can ask us for a copy of anything we have written about you.

If you or your parents have any questions or want to know more about our study, our contact details are:

Melody Oliver, Project Supervisor, melody.oliver@aut.ac.nz, 921 9999 ext 7078

Penelope Carroll, p.a.carroll@massey.ac.nz, 366 6136

Dee Holdsworth-Perks, dholdswo@aut.ac.nz, 921 9999, ext 7511

If you want to take part in the study, please fill in your name and **sign the "Child's Assent Form"**
When the consent forms have been signed please give them to your teacher.

Approved by the Auckland University of Technology Ethics Committee on 3 September 2014, AUTEC Reference number 14/263.

Appendix F

Child Assent Form

Neighbourhoods for Active Kids

CHILD ASSENT FORM

RETURN THIS COPY TO RESEARCH TEAM

- ○ I have read through the information sheet with a teacher/parent/caregiver.
- ○ I have had an opportunity to ask questions and to have them answered.
- ○ I understand that I may decide to stop being part of the study at any time.
- ○ I agree to be part of this study.

____

Your name

____

Date

Approved by the Auckland University of Technology Ethics Committee on 3 September 2014, AUTEC Reference number 14/263.

Appendix G

Teacher Information Sheet

Neighbourhoods for Active Kids

TEACHER INFORMATION SHEET

Dear Teacher,

We are researchers from AUT University, Massey University and the University of Auckland. We are running a study looking at how children's neighbourhoods may affect their physical activity levels and independent mobility (e.g., walking to the shops or parks unsupervised). The study is funded by the Health Research Council of New Zealand.

Melody Oliver from AUT is the Project Supervisor.

What is the purpose of this research?

Findings from the research (with no individuals identified) will be shared with agencies such as city councils, the Ministry of Health, and Housing New Zealand Corporation to ensure children's needs are considered in urban planning issues in Auckland and elsewhere in New Zealand. Research findings (with no individuals identified) may also be presented at conferences and in research reports.

How were you identified and why are you being invited to participate in this research?

[SCHOOL NAME] is one of 24 Auckland schools (12 intermediate and 12 primary) which has agreed to take part in the study and we are asking for your support of students (approximately 66) who agree to participate.

What will happen in this research?

We will come to the school and talk to you and your students about the study at a time which is convenient for you and your students. We will need the consent of both students and their parents for them to be able to participate. After the first semester holidays they will participate in a 30-minute on-line survey with a research assistant at the school and will be measured. They will also wear an accelerometer for 8 days.

What are the benefits?

To acknowledge the schools' contribution to the study a koha of $200 will be provided. Students and parents who agree to participate will each receive a $20 voucher as koha. In addition, the research team will provide participants with feedback on their levels of physical activity and if the school is interested we will also present findings (grouped information of all participants, with no individual identified) to the school in a written or oral format suitable to the audience (e.g. students, staff, BOT).

What do I do if I have concerns or queries about this research?

If you have any concerns or queries regarding this project please contact the Project Supervisor, Melody Oliver, melody.oliver@aut.ac.nz, 921 9999 ext 7078; or Penelope Carroll, p.a.carroll@massey.ac.nz, 3666136 or 0274316867.

We really appreciate your assistance with our Neighbourhoods for Active Kids project!

AUT UNIVERSITY TE WĀNANGA ARONUI O TAMAKI MAKAU RAU

MASSEY UNIVERSITY

THE UNIVERSITY OF AUCKLAND NEW ZEALAND Te Whare Wānanga o Tāmaki Makaurau

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Approved by the Auckland University of Technology Ethics Committee on 3 September 2014, AUTEC Reference number 14/263.

Appendix H

Perceived physical environment attributes and social and sociodemographic characteristics of included studies

Author (Year)	Perceived physical environment			Objective physical environment*	Social environment							Other measures
					Social characteristics			Sociodemographic characteristics				
	Child	*Parent / Caregiver*	*School*		*Child*	*Parent / Household*	*School*	*Child*	*Parent / Household*	*School*	*Neighbourhood*	
Aarts et al. (2013) (1)	-	Distance to school; Degree of high-/low-rise buildings^ (2 items); Presence of green; Presence of water; Traffic situation^ (5 items); Quality of sidewalks & bike lanes^ (4 items); Diversity of routes; Traffic safety around school; Social safety^ (5 items); Degree of unoccupied houses; Presence of trash & litter; Presence of dog dirt	Traffic safety around school; Sufficiency of bicycle shed	-	-	Social cohesion^ (6 items)	-	-	Parental education; Net household income; Parental ethnic background; Working situation of parent(s); Number of siblings; Number of cars in household	-	Neighbourhood SES	BMI; Number of days/week child going home after school time; Type of neighbourhood
Bringolf-Isler et al.	-	Safety of the way to school	-	✓	-	-	-	-	Nationality (Swiss, non-Swiss); Maternal education;	-	-	BMI; Allowed to go out alone after dark in general;

Author (Year)	Perceived physical environment: *Child*	Perceived physical environment: *Parent / Caregiver*	Perceived physical environment: *School*	Objective physical environment*	Social characteristics: *Child*	Social characteristics: *Parent / Household*	Social characteristics: *School*	Sociodemographic characteristics: *Child*	Sociodemographic characteristics: *Parent / Household*	Sociodemographic characteristics: *School*	Sociodemographic characteristics: *Neighbourhood*	Other measures
(2008) (2)									Family structure (single-/dual-parent family); Number of household cars			Allowed to go by bus by him/herself; Children accompanied to school; Regular day care attendance after school; GIS: distance to school, motorway crossing, main street crossing, side street crossing, total length of street segments with motorway, main street, side street, altitude difference between home & school, population density around home, number of inhabitants around home
Carver et al. (2005) (3)	Travel time; Easy to get around by bike; Feel safe	Have good sports facilities in neighbourhood; Safe for child to walk/ride a bike	-	-	Have many friends in neighbourhood; Have friends	-	-	-	Maternal education level	-	-	Activity (Monday-Friday): cycle for recreation, cycle for

Author (Year)	Perceived physical environment			Objective physical environment*	Social environment							Other measures
					Social characteristics			Sociodemographic characteristics				
	Child	*Parent / Caregiver*	*School*		*Child*	*Parent / Household*	*School*	*Child*	*Parent / Household*	*School*	*Neighbourhood*	
	walking/riding; Safe roads in neighbourhood; Worried about dogs roaming; Worried about older kids; Worried about strangers; Take-away/fast food shops near home; Convenience stores near home	in neighbourhood; Have good places child being physically active in neighbourhood; Difficult/unpleasant to go for a walk because of so much traffic			close to house; Lots of boys/girls of same age to hang out with; Know some neighbours well; Wave or talk to neighbours most days							transport (not to school), walk for exercise, walk for transport (not to school), walk the dog; Activity (Saturday & Sunday): cycle for recreation, walk for exercise, walk for transport, walk the dog
Carver et al. (2013) (4)	-	Parental concern about child being injured while crossing a road	-	✓	-	Social trust^ (2 items)	-	-	Household car ownership; Mother's employment status (full-time, part-time, not at all); At least one parent not employed full time	School level: secondary (Years 7-10), primary (Years 3-6)	-	Urban rural location; GIS: distance to school; Reason for parent driving child home from school (10 reasons); Enrolment at school closest to home; Reason for child not attending the

Author (Year)	Perceived physical environment: *Child*	Perceived physical environment: *Parent / Caregiver*	Perceived physical environment: *School*	Objective physical environment*	Social environment – Social characteristics: *Child*	Social characteristics: *Parent / Household*	Social characteristics: *School*	Sociodemographic characteristics: *Child*	Sociodemographic characteristics: *Parent / Household*	Sociodemographic characteristics: *School*	Sociodemographic characteristics: *Neighbourhood*	Other measures
												closest school (6 reasons); Child usually driven by parent to non-school destinations within walking distance of home; Reason for not allowing child to travel alone or with other children (8 reasons); Reasons why parents allowed to get about alone at a younger age (7 reasons)
Chillón et al. (2014) (5)	Perceived barriers^ (13 items): traffic, weather, no time in the morning, too tired in the morning, parents don't let them	Travel distance; Safety & weather^ (6 items); Suitability of the route to school^ (6 items)	-	✓	Active school travel norms: other kids walking/biking to/from school	Active school travel norms: others walking/biking to biking to school with children every day and a few times/week; No walking companion^ (3 items)	-	-	-	Race/ethnicity; Children receiving free/reduced price lunch	-	Temperature; Walkability and Bikeability Suitability Assessment (WABSA); Time issue^ (3 items); Children's resistance^ (2 items)
Christiansen et	Cycle route safety;	-	-	✓	Friends cycle daily;	-	-	-	[Child report] Household	-	-	GIS: distance to school,

Author (Year)	Perceived physical environment			Objective physical environment*	Social environment							Other measures
					Social characteristics			Sociodemographic characteristics				
	Child	*Parent / Caregiver*	*School*		*Child*	*Parent / Household*	*School*	*Child*	*Parent / Household*	*School*	*Neighbourhood*	
al. (2014) (6)	Many cycle paths; Safe crossings; Heavily trafficked; Speeding traffic				Parents cycle weekly; Parents' support				income; Parent ethnicity			school walkability index^, pedshed, vehicular traffic exposure, residential density
Curriero et al. (2013) (7)	Neighbourhood safety; Neighbourhood safety on the way to school	Neighbourhood safety; Child feeling safe at home	-	✓	-	-	-	Race/ethnicity	Parent education level; Annual household income	Children receiving free and reduced meals: free lunch, reduced meals	Neighbourhood Statistical Area: number of children per tract, median income, % with high school degree or greater, % below poverty level	Neighbourhood Inventory for Environmental Typologies (NIfETy): incivility for home street block; GIS: walking path quality, walking path length
Cutumisu et al. (2014) (8)	Safe to engage in physical activity in neighbourhood	Feel at ease to let child walk/cycle to school	-	-	-	-	-	-	Parents' education; Family income	School level: secondary (Grades > 7), primary (Grades 3-6)	Area deprivation: area material deprivation index, area social deprivation index	Presence of impairment; Parent's gender; Parent's age
Ducheyne et al.	-	Physical environment	-	-	-	Siblings active commute;	-	-	Parents' highest education level;	-	-	BMI; Independent

Author (Year)	Perceived physical environment			Objective physical environment*	Social environment							Other measures
					Social characteristics			Sociodemographic characteristics				
	Child	*Parent / Caregiver*	*School*		*Child*	*Parent / Household*	*School*	*Child*	*Parent / Household*	*School*	*Neighbourhood*	
(2012) (9)		factors (NEWS-Y): residential density^ (3 items), walking/cycling facilities^ (4 items), maintenance of walking and cycling facilities^ (5 items), connectivity^ (3 items), accessibility^ (5 items), aesthetic^ (4 items), traffic safety^ (6 items), crime safety^ (4 items); Route to school: quiet roads, busy roads, roads with walking & cycling facilities, roads with street lights, (a) road(s) with a steep incline, a busy intersection, centre of town, countryside; Distance to school				Friends active commute; Parents encourage child active commute; Siblings encourage child active commute; Friends encourage child active commute; Many children active commute in neighbourhood; Many parents active commute to work in neighbourhood; Many peers in neighbourhood; Neighbours willing to help; Close knit neighbourhood; Child often play in street with other kids			Number of children; Number of cars in household; Family structure (single-/dual-parent family)			mobility; Parents walk/bike along with child; Many parents walk/bike along with child in neighbourhood; Parental perceived motor competence of the child; Parental perceived biking skills of the child; Sports participation; TV-watching; PC-using; Reading; Attitudinal factors: physical activity, cycling to school, cycling to work, cycling training; Specific risk situation could happen on the way to school; Habit of cycling to school^ (4 items);

Author (Year)	Perceived physical environment			Objective physical environment*	Social environment							Other measures
					Social characteristics			Sociodemographic characteristics				
	Child	*Parent / Caregiver*	*School*		*Child*	*Parent / Household*	*School*	*Child*	*Parent / Household*	*School*	*Neighbourhood*	
												Perceived behaviour control for cycling to school^ (3 items)
Durand et al. (2012) (10)	-	Distance to school; Neighbourhood environment (NEWS): residential density^ (6 items), land use mix diversity^ (23 items), land use mix access^ (4 items), street connectivity^ (3 items), infrastructure & safety for walking^ (10 items), aesthetics^ (6 items), traffic hazards^ (6 items), crime^ (4 items), lack of parking (1 item), lack of cul-de-sacs (1 item), hilliness (1 item), physical barriers (1 item), walkways	-	-	-	Neighbourhood environment (NEWS): social interaction while walking (1 item)	-	Race/ethnicity	-	Children receiving free/reduced price lunch	-	Child objectively measured MVPA (ActiGraph GT3X+; Freedson's age-specific cut points); Community of residence (conventional, smart growth†)

Author (Year)	Perceived physical environment			Objective physical environment*	Social environment							Other measures
					Social characteristics			Sociodemographic characteristics				
	Child	*Parent / Caregiver*	*School*		*Child*	*Parent / Household*	*School*	*Child*	*Parent / Household*	*School*	*Neighbourhood*	
		connecting cul-de-sacs (1 item)										
Hume et al. (2009) (11)	[Adolescent self-report & Child proxy report] Too dark & cold in winter to spend time outside; Too hot in summer to spend time outside	Limited public transport; Difficult car parking at school; Hilly streets; Many cul-de-sacs, courts, or not-through roads; Many alternative routes; Free from litter, rubbish, or graffiti; No traffic lights/crossings; Heavy traffic; Stranger danger; Road safety; Satisfied with number of pedestrian crossings; Footpaths on most streets; Lots of parked cars on street	-	-	-	People willing to help neighbours; A close-knit neighbourhood; People generally getting along; People sharing the same values; Have many friends; Know many people; Good place children growing up; Good place to live	-	-	Parents' highest level of education; Maternal education level	-	-	Weight status (BMI); Not the outdoor type; Haven't got the energy to be physically active; Too lazy/can't be bothered
Kim et al. (2016) (12)	-	Travel time; Distance to school; Environmental features en route to school: sidewalk, parking lot/garage, bus stop, walking	-	-	-	School volunteer; Social cohesion	-	[Proxy report] Race	Highest education level of household; Household car ownership	Special lunch program; School bus availability	-	BMI; Reasons for neighbourhood choice

Author (Year)	Perceived physical environment			Objective physical environment*	Social environment							Other measures
					Social characteristics			Sociodemographic characteristics				
	Child	*Parent / Caregiver*	*School*		*Child*	*Parent / Household*	*School*	*Child*	*Parent / Household*	*School*	*Neighbourhood*	
		path/trail, playground; Crossing barriers en route to school: intersection without painted crosswalk, intersection without street signal/stop signs, road with busy traffic; Environmental changes en route to school in the past year: signage, traffic calming devices, playgrounds, bike lanes, crosswalks, walking paths/trails; Safety concerns: bullied/teased/harassed, stray dogs, traffic safety, air pollution, crime surveillance										
Larouche et al. (2014) (13)	Travel time	-	School Health Environment Survey: identify safe	✓	-	-	School Health Environment Survey: allow	-	Household income; Mother's education; Number of	School language (French, English); School board	-	School audit: walking & cycling provisions in the school

Author (Year)	Perceived physical environment			Objective physical environment*	Social environment								Other measures
					Social characteristics			Sociodemographic characteristics					
	Child	*Parent / Caregiver*	*School*		*Child*	*Parent / Household*	*School*	*Child*	*Parent / Household*	*School*	*Neighbourhood*		
			routes to school, provide crossing guards, designate car free zone, access to bike racks during school hours, bikes stored in a secure area, garbage/litter perceived as problem, drugs/drinking perceived as problem, gangs perceived as problem, traffic perceived as problem, vacant/shabby housing perceived as problem,				students to bring bicycles, allow students to bring small wheel vehicles, encourage use of helmets & safety gear, organise events (i.e., walk to school days), religious tension perceived as problem		motorised vehicle(s)	(Catholic, Public)			environment (12 items); Predominant land use around school

Author (Year)	Perceived physical environment			Objective physical environment*	Social environment							Other measures
					Social characteristics			Sociodemographic characteristics				
	Child	*Parent / Caregiver*	*School*		*Child*	*Parent / Household*	*School*	*Child*	*Parent / Household*	*School*	*Neighbourhood*	
			crime perceived as problem									
Leslie et al. (2010) (14)	Adequate equipment at home; Recreational facilities nearby; Safe to walk; Barriers to walk	Community disorder^ (121 items, 29 factors)	-	-	Family support for physical activity^ (5 items); Friend support for physical activity^ (4 items); Sports teams available in neighbourhood; Scouting groups available in neighbourhood; Youth groups available in neighbourhood	-	-	Born in Australia	[Child report] Mother living with child; Father living with child; Maternal employment; Paternal employment; Maternal education; Paternal education	-	Area SES	Locality (urban, regional); Self-reported weight status; Self-described health status; Enjoyment of physical activity; Active after school (Physical Activity Questionnaire for Adolescents); Member of sports team; MVPA (Adolescent Physical Activity Measure; active $\geq$ 5 days/week)
McMillan (2007) (15)	-	Not safe neighbourhood; Travel on road with traffic > 30 mph; Distance to school $\leq$ 1 mile	-	✓	-	Importance of child interacting with other kids	-	-	Number of cars per licensed drivers in household; Caregiver born in U.S.; Number of children in household < 16 years old;	% Hispanic ethnicity; Median income	-	Family's feeling about allowing child to walk to school; More convenient to drive/fitting caregiver's schedule; Observation: %

Author (Year)	Perceived physical environment			Objective physical environment*	Social environment							Other measures
					Social characteristics			Sociodemographic characteristics				
	Child	*Parent / Caregiver*	*School*		*Child*	*Parent / Household*	*School*	*Child*	*Parent / Household*	*School*	*Neighbourhood*	
									Average annual household income			street segments around school with sidewalks on both side street, % street segments around school with > 50% houses with windows facing street, % street segments around school with land use mix
Moran et al. (2016) (16)	Neighbourhood perceived as child-friendly environment^ (5 items); Perceived crime-related safety^ (2 items)	-	-	✓	Know many children living in neighbourhood; Many children playing outside in neighbourhood	-	-	-	[Child report] Number of cars in household; Bike ownership	-	-	Physical activity: afternoon walking to neighbourhood destinations, afternoon bicycling to neighbourhood destinations, afternoon bicycling for leisure; Independent mobility: allowed to walk in the neighbourhood at daytime & in the dark,

Author (Year)	Perceived physical environment			Objective physical environment*	Social environment							Other measures
					Social characteristics			Sociodemographic characteristics				
	Child	*Parent / Caregiver*	*School*		*Child*	*Parent / Household*	*School*	*Child*	*Parent / Household*	*School*	*Neighbourhood*	
												allowed to bike alone in the neighbourhood; Travel preference: pro-walking^ (2 items), pro-biking^ (2 items); GIS: residential density, built coverage, street connectivity, distance to school, distance to nearest park, distance to nearest store
Muthuri et al. (2016) (17)	-	Neighbourhood environment (NEWS): proximity & access to facility (3 items), street connectivity (2 items), infrastructure for getting around (3 items), aesthetics (1 item), safety from traffic & crime (8 items)	-	-	-	Neighbourhood cohesion (Neighbourhood Impact on Kids Survey; 2 items)	-	-	Maternal education level; Paternal education level	Type of school (Public: lower SES, Private: higher SES)	-	Child self-reported sufficient physical activity (≥ 60 min/day, 6-7 days/week); Child objectively measured MVPA (ActiGraph GT3X+; ≥ 60 min/day, ≥ 3000 counts/min)

Author (Year)	Perceived physical environment			Objective physical environment*	Social environment							Other measures
					Social characteristics			Sociodemographic characteristics				
	Child	*Parent / Caregiver*	*School*		*Child*	*Parent / Household*	*School*	*Child*	*Parent / Household*	*School*	*Neighbourhood*	
Page et al. (2010) (18)	Aesthetics^ (4 items); Nuisance^ (3 items); Personal safety^ (4 items); Traffic safety^ (4 items); Playspace^ (2 items); Access 1^ (6 destinations); Access 2^ (2 destinations)	-	-	✓	Social norm^ (4 items)	-	-	-	-	-	UK Index of Multiple Deprivation 2007 score (Local Education Authority)	Physical activity: outdoor play, exercise/sports; Independent mobility: local independent mobility^ (4 items), area independent mobility^ (7 items); Distance to school; Daylight (min/daylight 3pm-sunset); Pubertal status; BMI
Panter et al. (2010) (19)	Not allowed to play outside because my parents think not safe; Safe to walk/play in neighbourhood during the day; Difficult to walk/play near house because not feeling	Neighbourhood walkability score^ (ANEWS; 24 items); Too dangerous traffic; No safe pavements en route to school; No safe cycle paths en route to school; Worried something will happen	-	✓	Friend encouragement; Parental encouragement; Other children near home to go out & play with	Mother's mode of travel to work; Neighbourhood sense of community score^ (7 items)	-	-	Access to/ownership of a car; Education level	-	Neighbourhood socioeconomic deprivation (Index of Multiple Deprivation 2007)	Weight status (BMI); More convenient to take child to school; Usually around to take child to school; GIS: distance to school, urban rural status of home location

Author (Year)	Perceived physical environment			Objective physical environment*	Social environment							Other measures
					Social characteristics			Sociodemographic characteristics				
	Child	*Parent / Caregiver*	*School*		*Child*	*Parent / Household*	*School*	*Child*	*Parent / Household*	*School*	*Neighbourhood*	
	safe; My parents think not safe to walk/cycle to school											
Panter et al. (2013) (20)	Safety to walk/play alone in neighbourhood during the day	Physical neighbourhood environment^ (ANEWS; 24 items); Route safety environment^ (4 items)	-	✓	Parental or peer encouragement; Parental and peer encouragement	Neighbourhood social cohesion & trust^ (7 items)	School travel plan; Walk to school campaigns	-	Age left full time education; Housing tenure; Car access	-	Area-level deprivation score (Index of Multiple Deprivation 2007)	Weight status (BMI); Rules/independent mobility^ (2 items); Frequency of children's non-school walking/cycling; Convenient to take car; Parents around to take child to school; GIS (neighbourhood): road density, % of primary roads, streetlights per km of roads, effective walkable area, connected node ratio, junction density, land-use mix, deprivation, urban-rural status; GIS

Author (Year)	Perceived physical environment			Objective physical environment*	Social environment							Other measures
					Social characteristics			Sociodemographic characteristics				
	Child	*Parent / Caregiver*	*School*		*Child*	*Parent / Household*	*School*	*Child*	*Parent / Household*	*School*	*Neighbourhood*	
												(route): distance to school, streetlights per km of route, presence of a main road en route, route length ratio, land-use mix along the route, route with an urban area; School audit assessment: walking provision, cycling provision
Pont et al. (2013) (21)	-	Distance to school (log (km)); Number of busy roads crossed en route to school; % route to school with footpath(s); Number of roads crossed en route to school; Number of roads crossed with pedestrian crossings en routes to school;	-	✓	-	Number of other children walking to/from school	-	-	Parent's marital status; Father's highest qualification; Mother's highest qualification; Mother's current work status; Number of children in household; Number of cars in household; Annual household income	School administration (Public, Independent/Catholic)	-	Child having adequate road sense; Child being capable in travelling to a destination by him/herself; Child enjoying exercising to get to/from a destination; [Proxy report] Days child physically active (> 60 min, > 5

Author (Year)	Perceived physical environment			Objective physical environment*	Social environment							Other measures
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	Child	*Parent / Caregiver*	*School*		*Child*	*Parent / Household*	*School*	*Child*	*Parent / Household*	*School*	*Neighbourhood*	
		Adequate pedestrian crossings; Sufficient footpaths; Too far; Too many busy roads; Too many roads to cross; Concerned child being kidnapped, molested or hurt by someone; Child not walking to/from school because amount of concern about child being hurt by someone; Concerned child being hurt in a traffic accident; Child not walking to/from school because amount of concern about child being hurt in a traffic accident										days/week); Decision maker(s) regarding travel to/from school (parent only, include child); GIS: distance to school (log (km)), % roads in census collection district (CCD) with footpath(s), % CCD area zoned non-residential, CCDs' environmental supportiveness (walkability: street connectivity, presence of bike/footpaths, land use mix; hot spot analyses): Site A (hot spot z-scores: 2.15 - 6.12, high supportiveness), Site B (hot spot z-scores: -

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	Child	*Parent / Caregiver*	*School*		*Child*	*Parent / Household*	*School*	*Child*	*Parent / Household*	*School*	*Neighbourhood*	
												3.76 - -2.24, low supportiveness)
Ross et al. (2017) (22)	-	Physical environment^ (10 items): too far, no sidewalks/bike lanes, one or more dangerous crossings, too much traffic along the route, no other children to walk/bike with, no other adults to walk/bike with, no crossing guards, not enough time, weather makes walking/biking difficult, easier to take the bus to school; Safety environment^ (4 items): unsafe animals along the way, unsafe because of crime, easier to drive child to school, get bullied/teased/harassed	-	✓	-	Sociocultural environment^ (8 items): child asking permission to walk/bike to/from school, enjoy walking/biking to school, enjoy walking/biking to school with friends, enjoy walking/biking to school with parent/other adult, school encouraging walking/biking to/from school, healthy to walk/bike to/from school, other kids walking/biking to school by themselves, other kids walking/biking to school with parent/other adult	-	-	Parent's employment status; Parent's education level	-	-	Distance to school; District provides a bus; Car available to drive child to school; Too high traffic speed along the route; Not have good lighting; Have fun walking/biking to/from school; Nowhere to leave a bike safely

Author (Year)	Perceived physical environment			Objective physical environment*	Social environment							Other measures
					Social characteristics			Sociodemographic characteristics				
	Child	*Parent / Caregiver*	*School*		*Child*	*Parent / Household*	*School*	*Child*	*Parent / Household*	*School*	*Neighbourhood*	
Rossen et al. (2011) (23)	Feel safe in neighbourhood	-	-	✓	-	-	-	Race/ethnicity	Parent/guardian education; Household yearly income; Parent marital status; Number of children; Parent employed; Employment status (full time, part time, occasional/temp)	Children qualifying for free/reduced price lunch	Neighbourhood SES: median household income, % residents of high school/greater education, % residents living below the federal poverty level	GIS: distance to school; Neighbourhood Inventory of Environmental Typology (NIfETy; street block incivilities): physical layout of the block, types of structures, adult activity, youth activity, physical disorder & order, social disorder & order, violence/alcohol & other drugs (VAOD) indicators
Rothman et al. (2015) (24)	-	Distance to school; Perceptions of traffic danger: child's route to school, school site during morning drop-off period	-	✓	-	-	-	-	Access to a car to drive children to school	% of children not English as a primary language; % of new immigrants (< 5 years in Canada)	-	School site survey: subjective driving speed, dangerous parking, dangerous midblock crossings, dangerous intersections, traffic

Author (Year)	Perceived physical environment			Objective physical environment*	Social environment							Other measures
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	Child	*Parent / Caregiver*	*School*		*Child*	*Parent / Household*	*School*	*Child*	*Parent / Household*	*School*	*Neighbourhood*	
												congestion, presence of school crossing guard, traffic volume; School built environment: density, diversity (4 items), design (4 items)
Salahuddin et al. (2016) (25)	-	Neighbourhood safety	-	✓	-	Social cohesion^ (6 items)	-	-	Level of education of parents; Families received any government assistance; Car ownership; Acculturation: language spoken and thought in at home^ (2 items)	School SES: children receiving free/reduced price lunch or other public assistance	-	GIS: distance to school, neighbourhood walkability index^, school walkability index^
Salmon et al. (2007) (26)	-	Travel time; Concerned child might be injured in a road accident; Concerned child might be assaulted/molested by an adult; Worried child take risks; Other children might bully child; Most drivers	-	-	-	No other children walking to school with; Don't trust the people in neighbourhood	School not encourage children to walk to school	-	Education level of responding parent	-	-	Child's preference to be driven to school; No pedestrian skills; Not enough time in the mornings; Too lazy; School bag too heavy to carry; No adults to walk to school with

Author (Year)	Perceived physical environment			Objective physical environment*	Social environment							Other measures
					Social characteristics			Sociodemographic characteristics				
	Child	*Parent / Caregiver*	*School*		*Child*	*Parent / Household*	*School*	*Child*	*Parent / Household*	*School*	*Neighbourhood*	
		exceeding the speed limits; Difficult car parking at school; Too much traffic in neighbourhood; Not enough pedestrian crossings/lights; Too far; No direct route; Not safe neighbourhood; No footpaths in neighbourhood										
Sidharthan et al. (2011) (27)	-	Walk travel time to school (walkers ONLY); Distance to school (all modes users); Attitude towards walk/cycle^: objective (distance to school, amount of traffic along the route; speed of traffic along the route), subjective (violence or crime along the route, poor weather or	-	✓	-	Number of parental bicycle/walk trips in past week: active bicyclists/walkers (> 5 trips/week with > 1 trip of other than escorting children to/from home)	-	-	Household income; Number of household members; Number of vehicles in household; Number of adults in household; Number of workers in household	-	-	Neighbourhood accessibility; Spatial interaction effects: geographic proximity, demographic closeness

Author (Year)	Perceived physical environment			Objective physical environment*	Social environment							Other measures
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	Child	*Parent / Caregiver*	*School*		*Child*	*Parent / Household*	*School*	*Child*	*Parent / Household*	*School*	*Neighbourhood*	
		climate in the area)										
Timperio et al. (2006) (28)	[10-12 years old ONLY] Heavy local traffic; Perceives parents believe there is heavy local traffic; Worried about strangers; Perceives parents worried about strangers; Roads not safe; Perceives parents believe roads not safe	Heavy local traffic; Strong concern about strangers; Strong concern about road safety; No lights/crossings; Need to cross several roads; Limited public transport	-	✓	-	No adults at home after school; Not many other children in neighbourhood	-	-	Maternal education; Usually speak English at home; Parental marital status; Maternal employment; Number of children aged < 18 years old; Number of household cars; Family status (single-/dual-parent family)	School SES	Area-level SES	Weight status (BMI); Physical activity: child has no energy, not enjoying physical activity; GIS: distance to school, busy road barrier (freeway, highway, arterial road) along school route, school route along busy road (freeway, highway, arterial road), pedestrian school route directness, presence of steep incline (≥ 5.7 degrees, ≥ 10% slope along any segment) en route to school
Trang et al. (2012) (29)	-	Concerns about traffic safety in neighbourhood; Presence &	-	✓	-	-	-	-	Household economic status: household wealth index;	School location (wealthy district, less-wealthy district)	Residence (wealthy urban, less-wealthy	Pubertal stage; BMI; GIS: distance to school

Author (Year)	Perceived physical environment			Objective physical environment*	Social environment							Other measures
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	Child	*Parent / Caregiver*	*School*		*Child*	*Parent / Household*	*School*	*Child*	*Parent / Household*	*School*	*Neighbourhood*	
		quality of sidewalks							High parental education		urban, suburban)	
Trapp et al. (2011) (30)	Safe places to leave bikes at school; Have to cross a busy road; Feel safe crossing the road near school; Neighbourhood friendliness; Heavy traffic around school; Heavy traffic around neighbourhood; Fear of stranger danger; Feeling safer being driven to school than cycling; Feel safe whilst	Neighbourhood safe enough to cycle to school with friends; Steep hills; Child cross a busy road; No safe crossings; A lot of traffic near school; Drivers near school often exceeding speed limit; Lack of footpaths; Neighbourhood friendliness; Fear of stranger danger^ (3 items); Fear of child being injured	-	✓	Peer support^ (2 items); School would like students to cycle to school; Have many friends in neighbourhood	Disapproval from others^ (4 items); School encouraging students to cycle to school; Often seeing/hearing news promoting cycling/walking	-	-	Maternal education; Maternal employment	School SES	-	Weight status (BMI); Responding parent gender; Child's preference cycling to school; Cool to cycle to school; More convenient cycling to school; Child confident in ability to cycle to school without adult; Scheduling commitments before/after school; Child having a lot to carry; More convenient driving child to school; Perceiving child's preference cycling to school; Confident in child's ability; Adult home

Author (Year)	Perceived physical environment			Objective physical environment*	Social environment: Social characteristics			Social environment: Sociodemographic characteristics				Other measures
	Child	*Parent / Caregiver*	*School*		*Child*	*Parent / Household*	*School*	*Child*	*Parent / Household*	*School*	*Neighbourhood*	
	cycling to school											after school on most days; Irresponsible to let child cycle to school without adult; Other parents allow child cycle to school without adult; GIS: school neighbourhood walkability, road traffic volume, pedshed, distance to school
Trapp et al. (2012) (31)	Have to cross a busy road; Feel safe crossing the road near school; A lot of traffic in neighbourhood; Heavy traffic around school; Heavy traffic around	Positive neighbourhood perception^ (4 items); Neighbourhood safe enough to walk to school with friends; Steep hills; Enough footpaths; Child cross a busy road; No safe crossings; A lot of traffic in neighbourhood; Speeding traffic near school;	-	✓	School would like students to walk to school; Have many friends in neighbourhood; Many children live in neighbourhood; Friends think cool to walk to school	At least one parent walk/cycle to work; Disapproval from others^ (4 items); School encouraging students to walk to school; Often seeing/hearing news promoting walking/cycling	Walking school bus; Cross-guard ($\geq$ 1)	-	Maternal education; Maternal employment; Number of siblings; Single-parent family; Car ownership	School SES	-	Weight status (BMI); Responding parent gender; House located on highway/busy road; Child's preference walking to school; Cool to walking to school; More convenient walking to school; Child confident in ability to walk

Author (Year)	Perceived physical environment			Objective physical environment*	Social environment							Other measures
					Social characteristics			Sociodemographic characteristics				
	Child	*Parent / Caregiver*	*School*		*Child*	*Parent / Household*	*School*	*Child*	*Parent / Household*	*School*	*Neighbourhood*	
	neighbourhood; Friendliness of neighbourhood; Fear of stranger danger; Feeling safer being driven to school than walking; Feel safe whilst walking to school	Fear of injury^ (2 items); Fear of child being bullied^ (2 items); Fear of child crossing road unsafely; Fear of child getting lost en route; Fear of stranger danger; Often seeing/hearing news traffic dangers; Often seeing/hearing news stranger danger										to school without adult; Scheduling commitments before/after school; Child having a lot to carry; More convenient driving child to school; Perceiving child's preference walking to school; Confident in child's ability; Adult home after school on most days; Irresponsible to let child walk to school without adult; Other parents allow child walk to school without adult; GIS: school neighbourhood walkability, road traffic volume, pedshed, distance to

Author (Year)	Perceived physical environment			Objective physical environment*	Social environment							Other measures
					Social characteristics			Sociodemographic characteristics				
	Child	*Parent / Caregiver*	*School*		*Child*	*Parent / Household*	*School*	*Child*	*Parent / Household*	*School*	*Neighbourhood*	
												school (km, km^2)
Vanwolleghem et al. (2016) (32)	-	Physical neighbourhood environment (NEWS-Y): walkability^ (residential density (3 items), land use mix density (8 items), street network connectivity (2 items)), land use mix access^ (4 items), walking/cycling facilities^ (9 items), aesthetics^ (3 items), safety^ (10 items), recreational facilities^ (5 items)	-	✓	-	Parental support for child physical activity; Social norm in child physical activity	-	-	Parents' educational level	-	-	Transport to leisure time destinations (maintained active, maintained/switched to passive); Self-efficacy of child physical activity^ (4 items); Attitude towards child physical activity^ (benefits (6 items), barriers (5 items)); GIS: difference in distances home-primary & home-secondary school
Veitch et al. (2017) (33)	-	Personal safety^ (3 items); Road safety barriers^ (4 items); Neighbourhood satisfaction^ (4 items)	-	✓	-	Descriptive norms: Lots of kids walk/cycle to school	-	-	Maternal education level; Maternal employment status	-	-	Independent active travel to/from school; Active transport to local destinations (friends' houses, sports/physical

Author (Year)	Perceived physical environment			Objective physical environment*	Social environment							Other measures
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	Child	*Parent / Caregiver*	*School*		*Child*	*Parent / Household*	*School*	*Child*	*Parent / Household*	*School*	*Neighbourhood*	
												activity, parks/playgrounds, shops); Frequency of independent active transport to local destinations; Child enjoying walking/cycling ^ (5 items); Confidence in child's abilities^ (4 items); GIS: distance to school, total area of accessible parks, availability of walking tracks, availability of bike tracks; Area of residence: urban, rural
Yu et al. (2015) (34)	-	Distance close enough; Presence of physical barrier en route to school: highway/freeway, roads with busy traffic, intersection with	-	-	-	Positive peer influence^ (4 items); Positive attitudes toward walking^ (5 items)	-	[Proxy report] Hispanic ethnicity	Parents' highest education; Car ownership; Number of children; Number of adults	School bus availability	-	Walking barriers^ (5 items); Residential self-selection: close to child's school, easy to walk around

Author (Year)	Perceived physical environment			Objective physical environment*	Social environment							Other measures
					Social characteristics			Sociodemographic characteristics				
	Child	*Parent / Caregiver*	*School*		*Child*	*Parent / Household*	*School*	*Child*	*Parent / Household*	*School*	*Neighbourhood*	
		no traffic signals/stop signs, intersection with no crosswalk; Sidewalk availability; Sidewalk quality^ (4 items); Overall walking environment^ (7 items); Presence of land uses en route to school: playground, park, walking path/trail, convenience store, bakery/cafe/restaurant, big box retail, bus stop, community/youth centre, library, office building, industrial site, vacant lot, large parking lot; Safety concern about child^ (6 items)										
Yu et al. (2016) (35)	-	Distance close enough; Traffic safety concern^ (2 items); Walkability^ (9	-	-	-	Positive peer influence^ (3 items)	-	[Proxy report] Hispanic ethnicity	Parents' highest education; Car ownership; Number of children	School bus availability	-	Parental attitudes: attitudinal barriers^ (3 items),

Author (Year)	Perceived physical environment			Objective physical environment*	Social environment							Other measures
					Social characteristics			Sociodemographic characteristics				
	Child	*Parent / Caregiver*	*School*		*Child*	*Parent / Household*	*School*	*Child*	*Parent / Household*	*School*	*Neighbourhood*	
		items); Safety concern about child^ (5 items)										enjoyment of walking^ (4 items); No time to walk with child to/from school
Zhu et al. (2008) (36)	-	Travel time; Distance close enough; Safety concerns^ (6 items); Presence of physical barriers: highway/freeway, busy road; Sidewalk quality^ (3 items); Walking environments^ (5 items); Presence of land use & public transit en route: convenience store, office building, vacant lot, bus stop	-	-	-	Positive peer influence^ (3 items); Child's & parents' positive walking behaviour & attitude^ (6 items)	-	[Proxy report] Ethnicity	Parents' highest education level; Parents' marital status; Household car ownership	School bus service	-	Child's personal barriers^ (2 items); Parents' personal barriers^ (2 items)
Zhu et al. (2009) (37)	-	Travel time; Distance close enough; Safety concerns^ (6 items); Presence of physical barriers: highway/freeway, busy road;	-	-	-	Positive peer influences^ (3 items); Parents' & children's positive attitudes & regular walking behaviours^ (7 items)	-	[Proxy report] Ethnicity	Parents' highest education level; Single-parent status; Household's car ownership	School bus availability	-	Parents' personal barriers^ (3 items); Child personal barriers^ (2 items)

Author (Year)	Perceived physical environment			Objective physical environment*	Social environment							Other measures
					Social characteristics			Sociodemographic characteristics				
	Child	*Parent / Caregiver*	*School*		*Child*	*Parent / Household*	*School*	*Child*	*Parent / Household*	*School*	*Neighbourhood*	
		Sidewalk quality^ (6 items); Quality of overall walking environment^ (5 items); Presence of land uses en route to school: convenience store, office building, vacant lot, Presence of bus stops en route to school										

ANEWS = adapted neighbourhood environment walkability scale; BMI = body mass index; GIS = geographic information systems; mph = miles per hour; MVPA = moderate-to-vigorous physical activity; NEWS = neighbourhood environment walkability scale; NEWS-Y = neighbourhood environment walkability scale-youth; SES = socioeconomic status.
*Objective physical environment attributes are listed in other measures.
^Composite score.
†Smart growth community involving reduced lot size and denser housing, increased walking infrastructure, access to parks and green space, alternative modes of transit, and a mixture of housing, retail, and office space.
Notes. Safety items/factors (e.g., crime, stranger danger, kidnapped/molested/harassed, bullied/teased, hurt/injured) that are categorised as both perceived physical and social environments are listed in perceived physical environment. Items relevant to independent mobility/parental license (i.e. travelling unaccompanied, accompanied but without adult supervisions) and urban rural status/location are listed in other measures. Items relevant to parental mode of transport are listed in social characteristics.

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Appendix I

Adaptations made to the quality assessment checklist of Pont et al. (1) and Effective Public Health Practice Project (EPHPP) (2) rating scales

Quality assessment domain	DuRant (Part V: Survey designs and cross sectional studies) (3)	Pont adaptation (1)	Current systematic review (adapted from Pont)
Sample Description	a. Are the criteria for inclusion of subjects described?	1. Are the criteria for inclusion of subjects clearly described?	1. N/C
		YES (If the article reports criteria for recruitment or inclusion of subjects.)	*YES (If the article reports method of participants' recruitment (e.g., phone, school) AND criteria for inclusion of subjects (i.e., child age).)*
		NO (If the study does not report criteria for recruitment or inclusion of subject.)	*NO (If the study does not report method of participants' recruitment (e.g., phone, school) AND criteria for inclusion of subjects (i.e., child age).)*
	b. Has the study sample been clearly described in terms of sample size and demographic characteristics such as age, race, gender, location, socioeconomic status, etc.?	2. Has the study sample been clearly described?	2. Has the study sample (at school or individual level) been clearly described?
		YES (If the article has percentage/ratio/number of males/females AND breakdown of ages (by group or year)/mean and SD.)	*YES (If the article has percentage/ratio/number of males/females AND mean (plus SD or CI)/breakdown of ages (by group or year).)*
		NO (If the study does not report percentage/ratio/number of males/females or breakdown of ages of subjects.)	*NO (If the study does not report percentage/ratio/number of males/females or mean (plus SD or CI)/breakdown of ages of participants.)*
	c. Is the study sample appropriate to the problem being studied or the hypotheses being tested?	3. Is the study sample appropriate to the study objectives?	3. Is the study sample (at school or individual level) appropriate to the study objectives?
		YES (If the subjects match the study objective.)	*YES (If the subjects match the study objective (i.e., representative of the target population).)*
		NO (If the study sample does not match the study objective.)	*NO (If the study sample does not match the study objective (e.g., examines typically*

Quality assessment domain	DuRant (Part V: Survey designs and cross sectional studies) (3)	Pont adaptation (1)	Current systematic review (adapted from Pont)
			developing children, but reporting for children with disabilities).)
	d. Is the study sample large enough to test the hypotheses?	4. Does the study have a sample size calculation?	4. N/C
		YES (If the article reports a sample size calculation being carried out.)	*N/C*
		NO (If the article does not report a sample size calculation.)	*N/C*
Sampling Methods	e. How was the study sample selected (random, haphazard, consecutive patients presenting with a particular disease, all subjects in a particular groups, etc.)?	5a. How was the group sample selected? Choose best option.	5a. N/C
		RANDOM SAMPLING (If group was chosen using randomisation.)	*SIMPLE RANDOM SAMPLING (If group was chosen using simple randomisation.)*
		-	*SYSTEMATIC SAMPLING (If group was chosen using ordering scheme.)*
		-	*STRATIFIED SAMPLING (If group was chosen using stratum.)*
		-	*CLUSTER SAMPLING (If group was chosen using clusters.)*
		PURPOSEFUL SAMPLING (If group was chosen non-randomly for a particular purpose.)	*PURPOSEFUL SAMPLING (If group was chosen non-randomly for a particular purpose (e.g., rural vs. urban school).)*
		CONVENIENCE SAMPLING (If group was chosen non-randomly for convenience.)	*N/C*
	-	5b. How were the individuals selected to participate? Choose best option.	5b. N/C
		RANDOM (If children were selected using methods of randomisation.)	*N/C*
		CONVENIENCE (If children were selected for convenience.)	*CONVENIENCE (If children were selected for convenience (e.g., in school choir).)*
		ALL IN PARTICULAR GROUP (If all children in a particular group were asked to participate.)	*ALL IN PARTICULAR GROUP (If all children in a particular group were asked to participate (e.g., all in particular school/neighbourhood/grade/take certain mode of travel to school).)*

Quality assessment domain	DuRant (Part V: Survey designs and cross sectional studies) (3)	Pont adaptation (1)	Current systematic review (adapted from Pont)
Study Methodology	f. Is the design of the study clearly described?	6. Is the study design (methodology) clearly described?	6a. Is the study design (methodology) (e.g., cross-sectional, RCT, etc.) clearly described?
		YES (If the article clearly describes the study methodology.)	*YES (If the article clearly describes the study methodology (e.g., cross-sectional, RCT, etc.).)*
		NO (If the study methodology is unclear.)	*NO (If the study methodology (e.g., cross-sectional, RCT, etc.) is unclear/not described.)*
	-	-	6b. If described, what is the study design (methodology)? Choose best option.
			COHORT/PROSPECTIVE STUDY
			CASE-CONTROL STUDY
			CASE SERIES
			CROSS-SECTIONAL STUDY
			N/A (If the study design is unclear/not described.)
	g. Does the design of the study adequately test the hypotheses?	7. Does the design of the study adequately answer the research objectives?	7. N/C
		YES (If the study design can answer the research questions/objectives.)	*N/C*
		NO (If the study cannot answer the research questions/objectives.)	*N/C*
	h. How was random selection of subjects achieved? Was any other method besides the use of a random numbers table used?	-	-
Measurement	i. Have the measurement of the outcome, independent, and control variables been clearly described?	8. Have the measurement of outcome, independent and control variables been clearly described?	8. N/C
		YES (If the article clearly describes the study variables/outcome measures.)	*YES (If the article clearly describes the study variables/outcome measures (e.g., including form of data collection – if pedometer: how many hours per day, days per week; if survey/questionnaire: types of questions included).)*
		NO (If article is unclear in description of part or all of variable measurement.)	*N/C*

Quality assessment domain	DuRant (Part V: Survey designs and cross sectional studies) (3)	Pont adaptation (1)	Current systematic review (adapted from Pont)
	j. Are the variables measured with appropriate and accurate methods? Do the operational definitions match the theoretical variables?	9a. Are the variables measured with appropriate and accurate methods?	9a. N/C
		YES (If data collected is appropriate to answer research questions/objectives, and methods are considered accurate/acceptable.)	*YES (If data collected is appropriate to answer research questions/objectives, and methods are considered accurate/acceptable (e.g., self-reported survey, parent-report survey, pedometer or travel diary).)*
		NO (If data collection methods are not appropriate to answer research questions/objectives, or inaccurate methods of data collection are used.)	*N/C*
	-	9b. Do the operational definitions match the theoretical variables?	9b. N/C
		YES (If the study's variables/background information/definitions are congruent with the accepted definitions/indicators of that variable.)	*N/C*
		NO (If the study's variables/background information/definitions are incongruent/contradict accepted definitions/indicators of that variable.)	*N/C*
External Validity	k. Have the laboratory tests instruments and/or questionnaires used to measure the variables undergone validity and reliability testing?	10a. Have scales relevant to the review undergone reliability or validity testing?	10a. Have scales relevant to the review undergone reliability or validity testing OR has the reliability or validity of the scales from previous studies been reported?
		RELIABILITY ONLY (If article states that the scales relevant to the review have undergone reliability testing.)	*RELIABILITY ONLY (If article states that the scales relevant to the review have undergone reliability testing OR the reliability of the scales from previous studies has been reported.)*
		VALIDITY ONLY (If article states that the scales relevant to the study have undergone validity testing.)	*VALIDITY ONLY (If article states that the scales relevant to the study have undergone validity testing OR the validity of the scales from previous studies has been reported.)*
		RELIABILITY AND VALIDITY (If article states that the scales relevant to the review undergone reliability AND validity testing.)	*RELIABILITY AND VALIDITY (If article states that the scales relevant to the review undergone reliability AND validity testing, OR*

Quality assessment domain	DuRant (Part V: Survey designs and cross sectional studies) (3)	Pont adaptation (1)	Current systematic review (adapted from Pont)
			the reliability AND validity of the scales from previous studies have been reported.)
		NO (If the article does not state that scales relevant to the review have undergone reliability/validity testing.)	*NO (If the article does not state that scales relevant to the review have undergone reliability/validity testing OR the reliability/validity of the scales from previous studies has not been reported.)*
		N/A (If no scales have been used.)	*N/C*
	l. Have the procedures or methods used to measure each of the variables undergone standardization for the particular population that is being studied?	10b. If the scale has been validated, have the scales relevant to the undergone standardisation for the particular population?	10b. If the scale has been validated, have the scales relevant to the undergone standardisation for the particular population (i.e., children, parents)?
		YES (If the article states standardisation procedures have been carried out on children for the scale.)	*YES (If the article states standardisation procedures have been carried out on children (e.g., self-reported survey) or parents (e.g., parent-report survey) for the scale.)*
		NO (If the article does not state that scales relevant to the review undergone standardisation on children, or any standardisation procedures.)	*NO (If the article does not state that scales relevant to the review undergone standardisation on children (e.g., self-reported survey) or parents (e.g., parent-report survey), or any standardisation procedures.)*
		N/A (If the scales have not been validated.)	*N/C*
Bias	m. Were the outcome variables measured using appropriate "blinded" methods?	11. Were outcome variables measured using appropriate "blinding" methods?	11. N/C
		YES (If the study states it used methods to blind results for appropriate variables. E.g., taping pedometers so data could not be viewed by participants.)	*YES (If the study states it used methods to blind results for appropriate variables. E.g., child self-administered and parent self-administered.)*
		NO (If the article does not state blinding was used (where variables could be blinded).)	*NO (If the article does not state blinding was used (where variables could be blinded). E.g., face-to-face interview and telephone interview.)*
		N/A (If blinding is not appropriate for variables. E.g., surveys/questionnaires.)	*N/A (If blinding is not appropriate for variables. E.g., parent proxy-report.)*

Quality assessment domain	DuRant (Part V: Survey designs and cross sectional studies) (3)	Pont adaptation (1)	Current systematic review (adapted from Pont)
	n. Have the number of non-respondents, refusals, and subjects lost the follow-up been kept reasonably small (less than 10%)?	12a. Is the response rate 85% or more?	12a. What percentage of selected study subjects agreed to participate?
		YES (If the article states that more than 85% of people approached participated in the study.)	*HIGH (If the article states that 70-100 % of people approached participated in the study.)*
		NO (If the study's refusal/non-respondents rate was more than 15%.)	*MODERATE (If the study states that there was 40-69 % agreement.)*
		-	*LOW (If the study's refusal/non-respondents rate was more than 60%.)*
		-	*NO (If the level of participation is unclear or not described.)*
	-	12b. Is the follow-up response rate 85% or more?	12b. What is the follow-up response rate?
		YES (If the number of drop-outs is 85% or more at follow up.)	*HIGH (If the percentage of participants completing the study was 70-100 %.)*
		NO (If drop-out rate is more than 15%.)	*MODERATE (If 40-69 % of the participants were at follow up.)*
		N/A (If there was no follow up in the study.)	*LOW (If the percentage of drop-outs/withdrawals was more than 60%.)*
		-	*NO (If the follow-up response rate is unclear or not described.)*
		-	*N/A (If there was no follow-up in the study.)*
	o. Was there strict adherence to the protocol?	-	-
Analyses	-	-	Which statistical method(s) were performed in the analysis?
			Does the study indicate relevant confounders that were controlled in the analysis?
			YES (If the study reports confounders were controlled or stratified in the analysis.)
	-	-	*NO (If confounders were not controlled or stratified or unclear, or no justification was provided.)*
	-	-	What clustering was the study adjusted for in the analysis?
			Does the study test a model fit in the analysis?
			Yes (If the study reports a model fit was tested.)

Quality assessment domain	DuRant (Part V: Survey designs and cross sectional studies) (3)	Pont adaptation (1)	Current systematic review (adapted from Pont)
			No (If a model fit was not tested or unclear, or no justification was provided.)

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Appendix J

The scoring criteria of component and overall ratings in quality assessment

Sample Description:	
Strong	"Yes" on Q1, Q2, Q3 and Q4.
Moderate	"Yes" on Q1, Q2 and Q3 **AND** "No" on Q4.
Weak	Any "No" on Q1, Q2 and Q3.
Sampling Methods:	
Strong	Either "Simple Random Sampling", "Systematic Sampling", "Stratified Sampling" or "Cluster Sampling" on Q5a **AND** either "Random" or "All in particular group" on Q5b.
Moderate	Either "Simple Random Sampling", "Systematic Sampling", "Stratified Sampling" or "Cluster Sampling" on Q5a **AND** "Convenience" on Q5b.
Weak	Either "Purposive Sampling" or "Convenience Sampling" on Q5a **AND** either "All in particular group", "Convenience" or "Random" on Q5b.
Study Methodology:	
Strong	"Yes" on Q6a and Q7 **AND** either "Cohort/prospective study" or "Case-control study" on Q6b.
Moderate	"Yes" on Q6a and Q7 **AND** either "Case series" or "Cross-sectional study" on Q6b.
Weak	"No" on Q6a and/or Q7 **OR** "N/A" on Q6b.
Measurement:	
Strong	"Yes" on Q8, Q9a and Q9b.
Moderate	"Yes" on Q8 and Q9a **AND** "No" on Q9b.
Weak	Either "No" on Q8 or Q9a.
External Validity:	
Strong	"Reliability & validity" on Q10a **AND** "Yes" on Q10b.
Moderate	"Validity only" on Q10a and "Yes" on Q10b **OR** "N/A" on Q10a and Q10b.
Weak	Either "Reliability & validity", "Validity only" or "No" on Q10a **AND** either "No" or "N/A" on 10b.
Bias:	
Strong	Either "Yes" or "N/A" on Q11 **AND** "High" on Q12a **AND** "High" on Q12b.
Moderate	Either "Yes" or "N/A" on Q11 **AND** "Moderate" on Q12a and either "High", "Moderate" or "N/A" on Q12b **OR** "High" on Q12a and either "Moderate" or "N/A" on Q12b.
Weak	"No" on Q11 **OR** either "Low" or "No" on Q12a **OR** either "Low" or "No" on Q12b.
Overall Rating	
Strong	No WEAK ratings
Moderate	One WEAK rating
Weak	Two or more WEAK ratings

Appendix K

Destinations, data sources, and weights of the child-specific neighbourhood destination accessibility (NDAI-C) (1)

Domain	Subdomain	Data source	Scoring	Weight*
Education				
	Primary school	Ministry of Education	Binary	50.65
	Intermediate school	Ministry of Education	Binary	0.88
	Pre school	Ministry of Education	Binary	0.29
	Secondary school	Ministry of Education	Binary	0.25
Financial				
	Bank, ATM	GeoSmart, Internet	Binary	0.33
	Post office	Territorial Local Authority	Binary	0.04
Food retail				
	Supermarket	Internet	Binary	3.79
	Fast food	Territorial Local Authority	Binary	3.42
	Dairy	Territorial Local Authority	Binary	3.38
	Bakery	Territorial Local Authority	Binary	1.04
	Petrol station	Internet	Binary	0.54
	Butcher, fishmonger	Territorial Local Authority	Binary	0.13
	Greengrocer	Territorial Local Authority	Binary	0.13
Health				
	General practitioner	Ministry of Health	Binary	0.46
	Pharmacy	Ministry of Health	Binary	0.13
Other retail				
	Mall	GeoSmart, Internet	Binary	2.58
	DVD store	Internet	Binary	0.92
Public transport				
	Stops, stations	Territorial Local Authority	Binary	1.25
Recreation				
	Sports facility	GeoSmart, Internet	Tertile	13.59
	Park	Territorial Local Authority	Tertile	6.13
	Blue space	Ministry of Environment; Koordinates; TerraLink Environmental	Binary	0.71
	Cycle lanes	Open Street Maps	Binary	0.63
Social and cultural				
	Church, religion	GeoSmart, Internet	Binary	5.54
	Café	Territorial Local Authority	Binary	1.25
	Library	Internet	Binary	0.75
	Community centre	Internet	Binary	0.50
	Cinema	Internet	Binary	0.46
	Art gallery, museum	Internet	Binary	0.25

*Weights were calculated based on the proportion of trips made to each destination (1).

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Appendix L

Hypothesised direct relationships between children's school travel behaviour and the physical environment, the social environment, household and child characteristics, and household and child beliefs

Domain	Observed variable	*Latent variable*	Association	References
Built Environment	Residential density	*Active mobility environment*	Positive	(1-4)
	Street connectivity	*Active mobility environment*	Positive	(1-4)
	High traffic exposure	*Active mobility environment*	Negative	(1, 5-7)
	Low traffic exposure	*Active mobility environment*	Positive	(1, 5)
	Distance to school	-	Negative	(1-4, 8-10)
Social Environment	Safety	*Neighbourhood social environment*	Positive	(11-13)
	Cohesion	*Neighbourhood social environment*	Positive	(11, 12)
	Connection	*Neighbourhood social environment*	Positive	(12)
Household Characteristics	Car ownership	-	Negative	(1, 3, 6, 13-16)
	Number of children	-	Positive	(1, 2, 11, 15, 17)
	Number of adults*	-	Negative	(1, 15)
	Parent education*	-	Negative	(1, 13, 15, 18)
	Parent employment (reference category: unemployed)*	-	Negative	(1, 3, 4, 9, 19, 20)
Household Beliefs	Importance of social interaction	-	Positive	(9, 13, 14, 21-24)
	Importance of stranger danger	-	Negative	(3, 7, 9, 13, 14, 17, 23, 25)
	Importance of traffic safety	-	Negative	(1, 3, 11, 13, 14, 17, 23, 25, 26)
	Importance of convenience	-	Negative	(6, 9, 15, 17, 18, 24, 26, 27)
	Importance of distance to school	-	Negative	(1, 6, 7, 9, 13-15, 17, 25-28)
Child Characteristics	Year	-	Positive	(1, 6, 14, 29)
	Sex (reference category: male)	-	Negative	(1, 2, 30)
	Ethnicity (reference category: New Zealand European)	-	Negative	(2)
	Physical activity	-	Positive	(31-35)

Domain	Observed variable	*Latent variable*	Association	References
Child Beliefs	Traffic safety	-	Positive	(1, 11, 13, 17, 23, 25)
	Neighbourhood safety	-	Positive	(13, 14, 17, 23, 25, 36, 37)
	Independent mobility	-	Positive	(9, 18, 19)

*Observed variables deleted after model modification

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Appendix M

Hypothesised indirect relationships between children's school travel behaviour and the physical environment, the social environment, household and child characteristics, and household and child beliefs

Independent variable		Dependent variable (Mediator)		References
Variable†	Domain	Variable†	Domain	
Active mobility environment	PE	Distance to school	PE	(1, 2)
Active mobility environment	PE	*Neighbourhood social environment*	SE	(3-6)
Active mobility environment	PE	Importance of distance to school	HB	(7, 8)
Active mobility environment	PE	Importance of traffic safety	HB	(8, 9)
Active mobility environment	PE	Importance of stranger danger	HB	(5, 8)
Active mobility environment	PE	Traffic safety	CB	(7, 8)
Active mobility environment	PE	Independent mobility	CB	(10, 11)
Distance to school	PE	Independent mobility	CB	(11-13)
Neighbourhood social environment	SE	Importance of stranger danger	HB	(5, 14)
Neighbourhood social environment	SE	Importance of social interaction	HB	(14-16)
Neighbourhood social environment	SE	Independent mobility	CB	(11, 12, 14, 17-19)
Neighbourhood social environment	SE	Neighbourhood safety	CB	(12, 14)
Number of children	HC	Car ownership	HC	(20, 21)
Number of children*	HC	Parent employment*	HC	(22)
Number of adults*	HC	Car ownership*	HC	(20, 21)
Parent education*	HC	Car ownership*	HC	(21)
Parent education*	HC	Parent employment*	HC	(23)
Parent employment*	HC	Car ownership*	HC	(21)
Number of children	HC	Importance of convenience	HB	(24-26)
Importance of stranger danger	HB	Importance of traffic safety	HB	(2, 5, 27, 28)
Importance of stranger danger	HB	Independent mobility	CB	(2, 5, 11, 13, 18, 19, 29)
Importance of traffic safety	HB	Independent mobility	CB	(2, 5, 11, 13, 14, 18, 29)
Independent mobility	CB	Neighbourhood safety	CB	(11, 18, 29)

Independent variable		**Dependent variable (Mediator)**		**References**
Variable†	Domain	Variable†	Domain	
Year	CC	Distance to school	PE	(13, 30)
Year	CC	Importance of social interaction	HB	(31)
Year	CC	Importance of stranger danger	HB	(2, 5, 13, 14)
Year	CC	Importance of traffic safety	HB	(2, 13, 14)
Year	CC	Importance of convenience	HB	(32-35)
Year	CC	Importance of distance to school	HB	(13, 30)
Year	CC	Traffic safety	CB	(36)
Year	CC	Neighbourhood safety	CB	(36)
Year	CC	Independent mobility	CB	(11, 12, 14, 24, 37)
Year	CC	Physical activity	CC	(38, 39)
Sex	CC	Importance of social interaction	HB	(31)
Sex	CC	Importance of stranger danger	HB	(2, 13, 14)
Sex	CC	Importance of traffic safety	HB	(2, 13, 14)
Sex	CC	Importance of distance to school	HB	(30)
Sex	CC	Importance of convenience	HB	(32-35)
Sex	CC	Traffic safety	CB	(36)
Sex	CC	Neighbourhood safety	CB	(36)
Sex	CC	Independent mobility	CB	(11, 12, 37)
Sex	CC	Physical activity	CC	(38, 39)
Ethnicity	CC	Physical activity	CC	(40, 41)
Physical activity	CC	Importance of social interaction	HB	(6, 42)

CB = child beliefs. CC = child characteristics. HB = household beliefs. HC = household characteristics. PE = physical environment. SE = social environment. †Observed variables; *Latent variables*. *Dependent relationships deleted after model modification

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