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Active travel, public transport and the built environment in youth: Interactions with perceived safety, distance to school, age and gender

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ABSTRACT

Introduction: This study examined interactive effects of the built environment, perceived safety, age and gender on active travel and public transport use among adolescents for school journeys.
Method: This study used cross-sectional data from 440 adolescents (mean age 15.4 ± 1.5 years, 58% girls) in Melbourne, Australia. Adolescents self-reported their school travel modes, perceptions of traffic and personal safety. Exclusive active travel and public transport use to/from school were determined. Objective built environment features around home and school (1 km buffer) were generated. Multilevel logistic regression was used to estimate main and interactive associations.
Results: Overall, 18% travelled exclusively by active travel and 32% by public transport. Distance to school was negatively associated with exclusive active school travel (OR = 0.44, 95%CI: 0.34, 0.56). Distance to school moderated the association between some built environment attributes (land use mix, residential density around home, distance to public transport stops) and odds of active school travel. There was a positive association between residential density around school and active school travel among those who perceived their traffic environment to be safer. Boys were more likely than girls to use public transport if they lived further from school. A negative association between distance to a public transport stop from home and the odds of public transport use was observed among those who perceived their environment to be less safe.
Conclusion: The findings highlight the complexity of influences on mode choice for the school journey. Distance to school remains one of the most important predictors of active travel/public transport use. Supportive built environment attributes, such as a diverse mix of land use around home had facilitating effects on active travel among adolescents who lived closer to school.

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Multilevel interventions that target both the environment and perceived safety are needed to promote active travel and public transport use among adolescents.

1. Introduction

Sufficient physical activity is important for adolescent health, contributing to healthy growth and development (Vanhelst et al., 2016; Verburgh et al., 2014), healthy bone deposition and formation (Boreham and McKay, 2011), cardiometabolic health (Ekelund et al., 2012), weight management (Lätt et al., 2015) and positive mental health outcomes (Rodriguez-Ayllon et al., 2019). However, in Australia, only 15% of 10–14 year-olds and 11% of 15–17 year-olds achieve the recommended 60 min per day of moderate to vigorous physical activity (Australian Institute of Health and Welfare, 2021). A steep decline in the amount of regular physical activity performed is observed during the transition to young adulthood (Dumith et al., 2011; Larouche et al., 2012). This makes adolescence a key window for intervention to maintain and increase physical activity levels.

Active travel, the use of non-motorised travel including walking or cycling, is an important contributor to daily physical activity and can be easily incorporated into the daily routine. In particular, active travel to school has been shown to play an important role in the accumulation of physical activity among adolescent girls (Kek et al., 2019). Adolescents who walk or cycle to school are more likely to attain recommended levels of physical activity than those who travel by car (Loh et al., 2022b). However, rates of active travel to school have declined over the last few decades in many countries, including Australia (Adepoyibi et al., 2022; Hesketh et al., 2022), New Zealand (Oliver et al., 2022; Smith et al., 2019) and China (Yang et al., 2017). Overall, 60% of trips to school by Victorian (Australia) adolescents involved a car (Loh et al., 2022a), including many trips within a walkable or cyclable distance (Loh et al., 2022a, 2022b).

For trips that are too far to exclusively walk or cycle, the use of public transport (e.g., bus, train) can be a healthier alternative to car travel, as it often involves active travel as part of the trip (Le and Dannenberg, 2020). In 2020, nearly 30% of journeys to secondary schools in Melbourne on a given day involved public transport (Victorian Integrated Survey of Travel and Activity, 2018), yet there remains a gap in the literature understanding the factors that may promote greater adoption of public transport use. Active travel and public transport use also have a wide range of co-benefits, including environmental sustainability, less noise pollution and less traffic congestion (Götschi et al., 2020).

Previous research has examined the environmental influences of active travel among adolescents (Ikeda et al., 2018; Mandic et al., 2015; Panter et al., 2013). Distance is identified as one of the strongest determinants for active travel (Ikeda et al., 2018; Mandic et al., 2015, 2022). Other built environment features associated with active travel to school among children and adolescents include higher intersection density near home (Ikeda et al., 2018), higher objectively measured walkability near home and school (Wang et al., 2017), more diverse mix of land use near home (Wang et al., 2017), and higher number of parks and recreation facilities near home (Panter et al., 2008). In most of these studies, the measures of active travel varied, making it difficult to ascertain whether participants walked or cycled exclusively or in combination with another mode. For example, in the systematic reviews by Nordbø et al. (2020) and Ikeda et al. (2018), many studies classified participants as engaging in active travel when they or their parents reported at least one walking or cycling trip to school over various time periods (e.g., the last week, last two days or on a typical day). This classification of participants could misrepresent findings as individuals who reported any walking could use other modes for most or many other school trips in a given week. To better understand the relationship between the built environment and active travel, improving the characterisation of active travel users, and examining modes of travel separately versus in combination with other modes may be important.

In comparison to the extensive literature on active travel, only a few studies have explored correlates of public transport use among this age group. Among the limited studies conducted, evidence suggests that the built environment features associated with public transport use may differ from those that influence active travel. For example, a study conducted in Belgium found that public transport use to school was positively associated with perceived low diversity in land use, and greater distance between home and school (Verhoeven et al., 2016). In Hong Kong, higher levels of perceived personal safety from crime, more barriers to walking in the neighbourhood, and having public transport stops closer to home were all positively associated with public transport use but not walking to/from school (Barnett et al., 2019a).

A fundamental principle of the ecological model is that behaviours, such as travel behaviours, can be influenced by the interactive effects of multiple levels of influence operating at the policy, environment, interpersonal and intrapersonal factors (Sallis et al., 2006). Yet, only a small number of studies have focused on the interactions between factors at various levels and their association with active travel and/or public transport use among adolescents (Wang et al., 2017). For example, in a study of American adolescents aged 12–16 years, supportive built environments (higher walkability score, higher number of parks and recreation facilities) had stronger facilitating associations with active travel among those who reported more favourable psychosocial characteristics (higher self-efficacy, social support from peers) (Wang et al., 2017). Moderating effects of gender and age on the relationships between social support and active travel have also been observed among adolescents in Hong Kong (Barnett et al., 2019b).

Improving our understanding of the factors that influence adolescents' active travel and public transport for trips to and from school, and under what circumstances, may help guide interventions designed to shift from car-centric planning. Ultimately this will help to reduce demand for exclusive car use, and promote healthy and sustainable travel. This study aimed to identify associations (main and interactive effects) of the built environment, perceived safety, and age and sex with: 1) exclusive active travel; and 2) use of public transport (without a car trip) for travel between home and school in a sample of adolescents living in Melbourne, Australia.

2. Methods

2.1. Study population

This study used data from the Neighbourhood Activity in Youth (NEArbY) study, which included adolescents (aged 12–17 years) living in Melbourne, Australia. Melbourne has a population of approximately 5 million and is characterised as sprawling (covers 9900km2 and 500 people/km^2) (Australian Bureau of Statistics, 2021; City of Melbourne, 2024). The public transport system in Melbourne includes buses, trams, trains and limited ferry routes. Bus stops are widely distributed across Melbourne, with around 75% of households having access to a bus stop within 400 m from their homes (Badland et al., 2017). Melbourne has the world's largest tram network, with more than 1700 tram stops through the city centre and in inner and middle suburbs (Yarra Trams, 2024). The train network consists of 16 train lines connecting suburban regions to the city centre (Metro Trains Melbourne, 2024). However, it is important to note that the frequency of the services and the destinations they service varies across Melbourne (Infrastructure Victoria, 2023). Data were collected between August 2014 to December 2015 as part of the multi-country IPEN Adolescent project (Cain et al., 2021). Ethical approval was obtained from the Human Ethics Advisory Committee - Health, Deakin University (HEAG-H 152_2013) and approvals to conduct research in schools sought from the Department of Education and Training (2013_002182) and the Catholic Education Office (Project #1950).

2.2. School and participant recruitment

Full details regarding school and participant recruitment have been described elsewhere (Loh et al., 2019). To optimise heterogeneity in built environments, each statistical area level 1 (SA1-the smallest administrative unit for the release of census data used by the Australian Bureau of Statistics (2016)) across Melbourne was ranked by walkability and income. The walkability index was created in a geographic information system (GIS) based on earlier conceptual work by Frank et al. (2010) and Cain et al. (2021) that combines street connectivity, land use mix and residential density. Income was based on the median household income within the SA1 from the 2011 census data. Each SA1 was classified into four categories: (i) high walkable/high income, (ii) high walkable/low income, (iii) low walkable/high income, and (iv) low walkable/low income, based on the median values of walkability and income, respectively. Of the 137 secondary schools from these four categories that were invited to participate, 18 agreed and consented to participate (13% response rate). The schools selected specific year levels to participate, and interested students received recruitment packs including study information, consent forms and a parent survey. Written parental consent and student assent were received from 528 students. Of these, 465 had complete survey and residential and school address data and were included in the analysis.

2.3. Outcomes

Participants were asked to report how many days (0 days–5 days) they used each of the eight travel modes to, and separately, from school on a typical school week. The modes included walk, cycle, skateboard/scooter, train, tram, public bus, school bus, and car. Participants could report more than one mode per day. For instance, if participants walked to a tram stop every day on the way to school, they would select '5 days' for walking and '5 days' for tram. For these analyses, walking, cycling, or skateboarding/scootering were classified as active travel, whereas train, tram, public bus or school bus were classified as public transport. From these data the following categories were created:

Exclusive active school travel: Participants who only ticked active travel options were categorised as exclusive active travel users. Participants who ticked car only, public transport only, a combination of active travel and car, or a combination of active travel and public transport were categorised as non-exclusive active travel users.

Public transport travel (with or without active travel): Participants who ticked one or more public transport options, with or without any active travel, were categorised as using public transport to/from school (with or without active travel). Participants who ticked car only, active travel only or a combination of public transport and car were categorised as non-public transport users/public transport with car users.

2.4. Exposures

The selection of exposures is grounded in the ecological framework (Sallis et al., 2006), and previous work by Panter et al. (2008), Ding and Gebel (2012) and Loh et al. (2020). The frameworks presented by Sallis et al. (2006) and Panter et al. (2008) highlight the importance of a broad range of built environment characteristics (upstream factors) on active travel and potential interactions with social and personal influences (mid-stream and downstream factors) in altering the strength of these relationships. Selected built environment characteristics were conceptually matched with active travel (Ding and Gebel, 2012) and considered the environment around school trip origins and endpoints, previously shown to be important for physical activity (Loh et al., 2020). Thus, a range of built environment characteristics relevant to active travel around the home and school environments were examined in this study (e.g., residential density, street intersection, land use mix) and distance, perceived safety, age and gender were selected as potential modifiers.

2.4.1. Objectively measured distance between home and school (km) and distances to the nearest public transport stop from home and school (km)

The shortest distance along walkable roads between home and school, and between home and the nearest public transport stop, were calculated using the Origin-Destination Cost Matrix function in the ArcGIS Network Analyst extension. To represent a walkable network, we excluded non-walkable segments such as freeways from road centreline data. Data were sourced from the Department of Sustainability and Environment (2010) and State Government of Victoria: Vicmap Transport (2013).

2.4.2. Objectively measured built environment around home and school

The built environments around home and school were computed based on the IPEN GIS protocol (Adams et al., 2014). Using ESRI ArcGIS 10.3 (Redlands, CA, US), participants' residential and school addresses were geocoded. A 1-km street network buffer around home and around school were created and used as this represents a walkable distance among this age group (Colabianchi et al., 2014).

2.4.3. Residential density (dwellings/ha) around home and school

Residential density around home and school were calculated based on the number of dwellings divided by the residential area within the buffer (dwellings/m^2). Meshblock level residential dwelling data were sourced from the 2011 census (Australian Bureau of Statistics, 2011). To enhance interpretability, residential density was multiplied by 10,000 so the coefficient is interpreted as one dwelling increase per hectare.

2.4.4. Street intersections (3+ way) around home and school

The total count of street intersections (3-arm) within the 1 km buffer around home and school were calculated using road centreline data (State Government of Victoria: Vicmap Transport, 2013).

2.4.5. Land use mix around home and school

Land use mix was compiled using a range of data from the formula provided by Giles-Corti et al. (2014), which included residential, commercial, entertainment and institutional land use. The land use mix score ranged between 0 and 1. A score of 1 indicates that the area has an even distribution of all land uses and a score of 0 indicates single land use. To enhance interpretability, the land use mix variable was multiplied by 10 so that the coefficient represents an increase in 0.1 units of the land use mix score rather than the difference between the theoretical minimum and maximum value of land use mix.

2.5. Potential moderators

2.5.1. Distance between home and school (km)

This analysis examined whether distance between home and school moderated the associations between built environment factors and travel mode to/from school. Distance between home and school was measured using pedestrian street network data (Department of Sustainability and Environment, 2010) as described above.

2.5.2. Perceived personal safety

Perceived personal safety related to walking or cycling to and from school was adapted from a previous study and has acceptable reliability (test-retest intraclass correlation coefficient = 0.56–0.81) (Forman et al., 2008). Participants rated the statement "*It is difficult for me to walk or cycle to my school because I would have to walk/cycle through places that were unsafe because of crime/things related to crime (*e.g.*, vandalism, graffiti, people drinking alcohol in public places)*" on a 4-point Likert scale ranging from strongly disagree (coded 4) to strongly agree (coded 1). The summed score could range from 1 to 4, with 1 indicating the environment was perceived to be the least safe from crime, and 4 indicating the safest from crime.

2.5.3. Perceived traffic-related safety and pollution

A measure of perceived traffic-related safety and pollution was adapted from the Neighbourhood Environment Walkability Scale-Youth questionnaire, which has acceptable reliability and validity (Cerin et al., 2019). Participants were asked to respond to eight statements about the level of safety from traffic, speed limits, street lighting, visibility of other walkers and cyclists, and exhaust fumes in their neighbourhoods on a 4-point Likert scale ranging from strongly disagree (coded 4) to strongly agree (coded 1). Summary scores were computed by averaging the scores on the corresponding items (reverse coded where necessary). Total scores could range from 1 to 4, where 1 indicates least safe from traffic and more pollution, and 4 indicates most safe from traffic and less pollution.

2.5.4. Age and gender

Adolescents self-reported their age (in years) and gender. Missing information on these variables were supplemented from the parent survey (n = 7). For the analyses, age was categorised as <16 years and 16 years and above, as 16 years is the minimum age for the acquisition of a learner's driving permit in Victoria and this may impact older adolescents' travel mode choice.

2.6. Covariates

Residential area-level disadvantage was obtained from the ABS SEIFA Index of Relative Socioeconomic Disadvantage, reflecting the overall level of disadvantage at the SA1 level. State-specific (VIC) IRSD deciles were used for analysis, with the 1st decile denoting the most disadvantaged areas and the 10th decile denoting the least disadvantaged areas.

2.7. Statistical analyses

Of the 465 participants, those with missing data for travel mode from school (n = 4), age (n = 9), gender (n = 7), distance to school (n = 2), personal safety (n = 2), and traffic safety (n = 1) were excluded. This reduced the analytical sample to 440 participants. Descriptive analysis of sample characteristics was conducted. Median values and interquartile ranges were calculated due to the skewed distribution of the exposures and moderators. Separate multilevel logistic regressions were conducted to examine associations between distance to school, distance to the nearest public transport stop from home and from school, each built environment variable around home and school (simultaneous adjustment for home and school buffers) and the odds of exclusive active school travel vs. non-exclusive active school travel and public transport travel vs. non-public transport travel/public transport travel coupled with car.

Table 1
Descriptive statistics for the analytical sample from the NEArbY Study, Melbourne, Australia (n = 440).

Age (years)	n (%)	
<16	248 (56.4)	
16+	192 (43.6)	
Gender		
Male	183 (41.6)	
Female	257 (58.4)	
Neighbourhood disadvantage	**n (%)**	
Decile 1	57 (12.9)	
Decile 2	44 (10.0)	
Decile 3	36 (8.2)	
Decile 4	47 (10.7)	
Decile 5	44 (10.0)	
Decile 6	56 (12.7)	
Decile 7	48 (10.9)	
Decile 8	47 (10.7)	
Decile 9	39 (8.9)	
Decile 10	22 (5.0)	
Travel modes to/from school	**n (%)**	
Exclusive active travel	78 (17.7)	
No or non-exclusive active travel[a]	362 (82.3)	
Public transport (with or without active travel)[b]	141 (32.1)	
Non-public transport user/public transport with car user[c]	299 (67.9)	
	Median	**Interquartile range**
Distance to school (km)	3.2	1.9–5.1
Residential density (dwellings/ha)		
Around home	25.8	21.1–30.5
Around school	24.4	22.5–26.4
Intersection density (3+ way)		
Around home	89.0	63.0–114.5
Around school	119.0	96–182
Land use mix (0–10)		
Around home	3.8	2.4–5.3
Around school	3.7	3.2–5.1
Distance to nearest public transport (km)		
Around home	0.3	0.2–0.5
Around school	0.3	0.2–0.4
Personal safety score[d]	3.0	3–4
Traffic safety score[e]	3.0	2.8–3.3

[a] Travel to/from school by car only, public transport only, a combination of active travel and car, or a combination of active travel and public transport.
[b] Travel to/from school by public transport only or a combination of public transport and active travel.
[c] Travel to/from school by car only, active travel only, or a combination of public transport and car.
[d] Higher score indicates higher levels of perceived personal safety from crime.
[e] Higher score indicates higher levels of perceived safety from traffic.

School ID (the unit of recruitment) was entered as a random effect to account for clustering. Interaction effects of built environment, personal and traffic safety and age and gender on the school travel outcomes were estimated by adding a two-way interaction term to the main effects for each built environment exposure separately. Due to the skewed distribution of the exposures and moderators, identified interactions (based on 95% confidence interval) were probed by estimating associations at specific values of the moderators (10th and 90th percentile). Findings were presented graphically with the estimated probability of exclusive active travel and public transport travel to/from school plotted against the 10th and 90th percentile of the built environment variables. No threshold value of statistical significance (probability level) was used in these analyses as this approach has been heavily criticised in the research literature (Greenland et al., 2016; Ioannidis, 2019; Wasserstein and Lazar, 2016). Relying solely on statistical significance may lead to incorrect conclusions and overlook meaningful associations (Wasserstein and Lazar, 2016). As such, 95% CI and the exact p-values are presented to estimate the level of evidence they provide: $p < 0.005$ providing strong evidence; $p < 0.05$ providing some evidence; $0.05 < p < 0.1$ providing weak evidence and $p \geq 0.1$ providing no evidence (Thomas et al., 2021). Data analyses were undertaken using STATA/SE 17.0 (StataCorp LLC, College Station, TX, USA).

3. Results

More than half of the participants were less than 16 years old and 58% were girls. About 18% travelled to and from school exclusively using active travel and 32% travelled to and from school using public transport (with no car use). The median distance to school was 3.2 km. Descriptive statistics for other objectively measured built environment variables are shown in Table 1.

3.1. Main effects

Strong evidence of a negative association was observed between distance to school and the odds of exclusive active school travel. For every 1-km increase in distance to school, the odds of exclusive active school travel were 56% lower. No evidence of associations was observed between street intersections around home and school and exclusive active school travel. There was also no evidence of an association between distance to the nearest public transport stop from school and exclusive active school travel.

Weak evidence of a positive association was found between land use mix around school and the use of public transport to/from school: every 0.1 unit increase in land use mix score was associated with 3.7 higher odds of public transport use. No evidence of an association was observed between the use of public transport to/from school and residential density around home and school, street intersections around home and school, land use mix around home and distance to the nearest public transport stops from home.

3.2. Moderators of association between built environment and school travel mode

Table 2 and Figs. 1 and 2 present identified moderators of associations between built environment and exclusive active school travel and public transport use.

3.2.1. Distance between home and school

Distance between home and school moderated the associations between four built environment attributes and the odds of exclusive active school travel (Fig. 1a–d). A negative association between residential density around home and the odds of exclusive active school travel was observed among those who lived further from school; a one unit increase in residential density around home was

Table 2
Main and interactive effects of the built environment (1 km), perceived safety, age and gender on exclusive active travel and public transport use to/from school among adolescents (n = 440).

	Exclusive active travel (n = 78) vs No or non-exclusive active travel (n = 362)			Public transport (*with or without active travel*) (n = 141) vs other (n = 299)		
Built environment	Main effect		Moderator	Main effect		Moderator
attributes	OR (95% CI)	*p-value*		OR (95% CI)	*p-value*	
Distance to school (km)	0.44 (0.34, 0.56)	*<0.0001*		1.15 (1.05, 1.28)	*0.004*	Gender
Residential density (dwelling/ha)						
Around home	1.03 (0.96, 1.11)	*0.326*	Distance to school	1.02 (0.96, 1.08)	*0.452*	
Around school	1.03 (0.95, 1.12)	*0.425*	Traffic safety	1.04 (0.96, 1.12)	*0.314*	
Street intersection (3-way or more)						
Around home	1.01 (0.99, 1.01)	*0.112*		1.00 (0.99, 1.01)	*0.967*	
Around school	1.01 (0.99, 1.01)	*0.217*		1.00 (0.99, 1.01)	*0.085*	
Land use mix						
Around home	1.23 (0.33, 4.63)	*0.751*	Distance to school	2.17 (0.71, 6.64)	*0.171*	
Around school	0.25 (0.04, 1.33)	*0.105*	Distance to school	3.70 (0.91, 15.12)	*0.068*	
Distance to nearest public transport stop (km)						
Around home	0.83 (0.49, 1.42)	*0.505*	Distance to school	0.98 (0.67, 1.43)	*0.925*	
Around school	0.51 (0.16, 1.63)	*0.259*		0.28 (0.06, 0.70)	*0.011*	Personal safety

All models adjusted for built environment around home and school, age, gender and neighbourhood disadvantage.

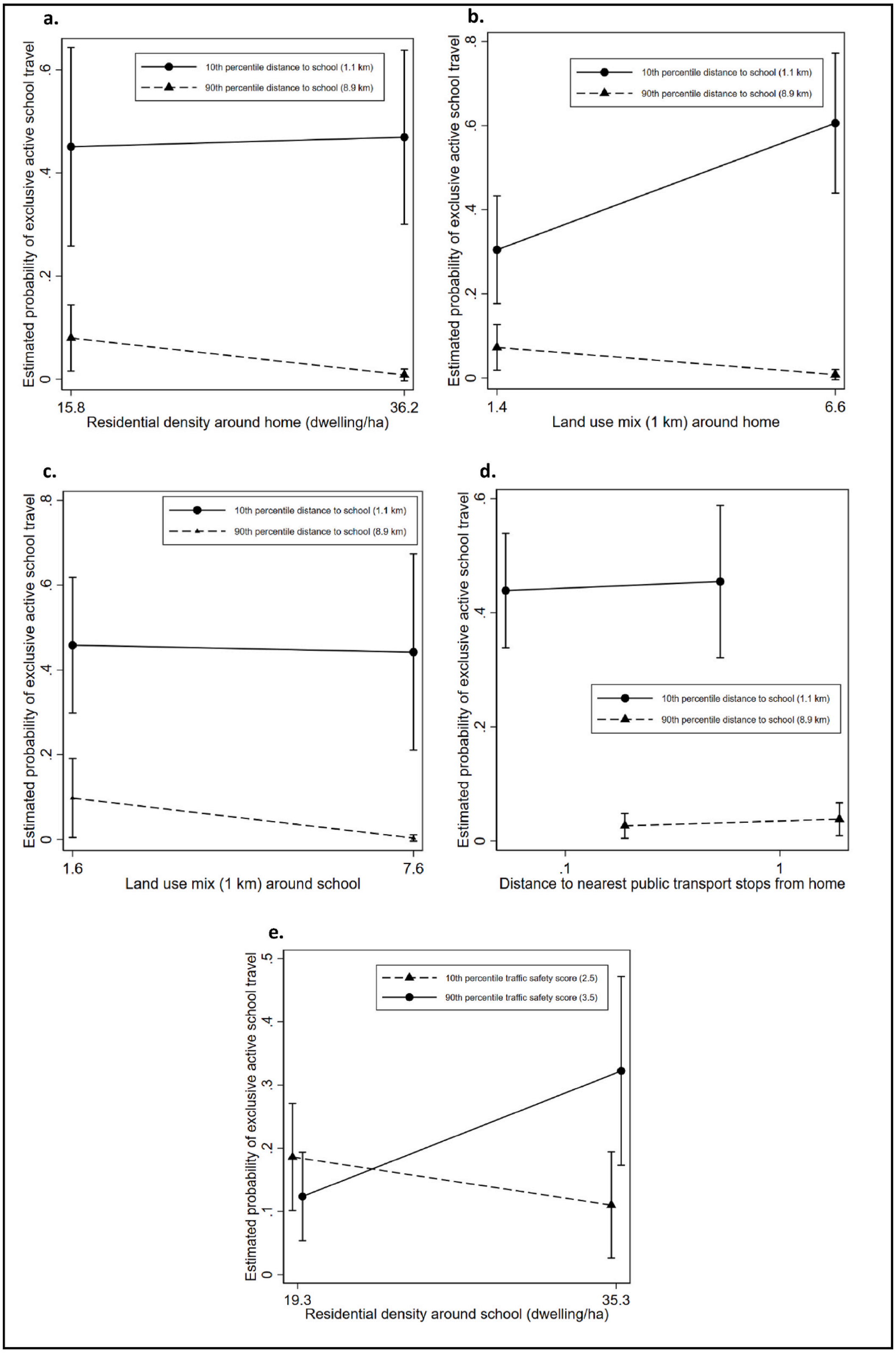

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Fig. 1. Marginal means plots depicting the moderating effects of distance to school (estimated at the 10th and 90th percentile values) on the association between **a.** residential density around home; **b.** Land use mix around home; **c.** Land use mix around school **d.** Distance to the nearest public transport around home and exclusive active school travel; and **e.** Moderating effects of perceived traffic safety (estimated at the 10th and 90th percentile values) on the association between residential density around home and exclusive active travel to school.

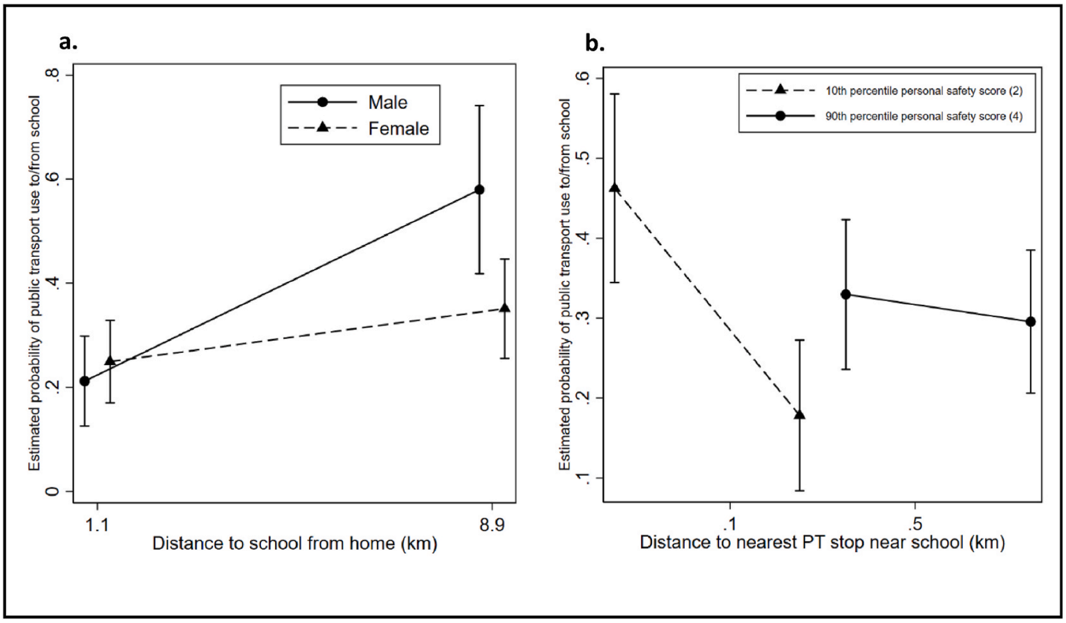

Fig. 2. Marginal means plots depicting the moderating effects of **a.** Gender on the association between distance to school from home and public transport use to/from school and **b.** Personal safety (estimated at the 10th and 90th percentile values) on the association between distance to the nearest public transport stop near school and public transport use to/from school.

associated with 11% lower odds of active school travel among those who lived further from school (distance at the 90th percentile = 8.9 km; OR = 0.89, 95% CI: 0.81, 0.96; $p = 0.007$). Among those who lived closer to school (distance at the 10th percentile = 1.1 km), no evidence of an association between residential density around home and the odds of exclusive active travel was observed (Fig. 1a).

The association between land use mix around home and exclusive active school travel differed according to distance to school (Fig. 1b). A positive association was observed between land use mix around home and active school travel among those who lived closer to school; a one unit increase in land use mix was associated with 29% increased odds of active school travel among those who lived closer to school (OR = 1.29, 95% CI 1.03, 1.60; $p = 0.021$). Conversely, negative associations were observed between land use mix around home and school and exclusive active school travel among those who lived further from school; a one unit increase in land use mix around school was associated with 68% lower odds of active school travel among those who lived further from school (OR = 0.31, 95% CI 0.14, 0.68; $p = 0.003$). Among those who lived closer to school, the probability of active school travel was similar across levels of land use mix around school (Fig. 1c). By contrast, among those who lived further from school, a negative association was observed; as the level of land use mix increased, the odds of exclusive active school travel decreased by 45% (OR = 0.55, 95% CI 0.34, 0.90; $p = 0.020$). The associations between distance to the nearest public transport stop from home and exclusive active school travel also differed by distance to school (Fig. 1d): a positive association was observed among those who lived further from school (OR = 2.12, 95% CI 1.12, 4.02; $p = 0.020$), but there was no evidence of association among those who lived closer to school (OR = 1.07, 95% CI 0.57, 2.01); $p = 0.820$).

3.2.2. Perceived traffic-related safety

A strong positive association was found between residential density around school and the odds of exclusive active travel from school among those who perceived their traffic environment to be safer; a one unit increase in residential density around school was associated with 7% higher odds of active school travel among those who perceived their traffic environment to be safer (OR = 1.07, 95% CI: 1.01, 1.15; $p = 0.028$; Fig. 1e). No evidence of association was observed between residential density around school and exclusive active school travel among those who perceived their traffic environment to be less safe.

3.2.3. Gender

Adolescent boys were 24% more likely than girls to take public transport to/from school if they lived further from school (OR = 1.24, 95%CI: 1.12, 1.39; $p < 0.0001$; Fig. 2a). No gender difference was observed in the association between distance to school and public transport travel among those who lived closer to school.

3.2.4. Perceived personal safety

A negative association between distance to the nearest public transport stop from school and the odds of public transport use was observed among those who perceived their environment to be less safe from crime; a one unit increase in distance to the nearest public transport stop from school was associated with 97% lower odds of public transport use among those who perceived their environment to be less safe from crime (OR = 0.03, 95%CI: 0.01, 0.23; $p = 0.001$; Fig. 2b). There was no association between distance to the nearest public transport from school and odds of public transport use among those who perceived their environment to be safer from crime (OR = 0.66, 95% CI 0.15, 2.90; $p = 0.588$).

4. Discussion

This study examined the main and interactive associations of the built environment around home and school, perceived safety, and age and gender with adolescents reported active travel and public transport use to/from school. This study is novel as it included a comprehensive examination of the synergy between upstream, mid-stream and downstream factors to support active and sustainable travel. The focus on public transport use also adds to the existing literature as it is rarely investigated among adolescents. Overall, distance was found to be the most consistent correlate and moderator for exclusive active travel and public transport use, with increased distance associated with lower odds of active travel and higher odds of public transport use. There was some evidence that land use mix around school was positively associated with public transport use. When examining associations between built environment characteristics and school travel modes, five out of nine associations had evidence of interaction effects on exclusive active school travel and two out of nine associations had evidence of interaction effects on public transport use. The findings highlight the complexity of built environment influences on adolescents' school travel behaviour in large, sprawling cities such as Melbourne.

4.1. Distance is critical but not the only correlate of active school travel

Consistent with previous systematic reviews (Ikeda et al., 2018), distance to school was identified as the strongest correlate of active school travel in adolescents, but we also found that distance moderated the associations between some built environment characteristics and active school travel. Greater diversity of land use around home appeared to support exclusive active school travel among adolescents who lived closer to school. This is not surprising as a more diverse mix of land use is indicative of having places to walk to (Kerr et al., 2007), and these places may already have existing walking infrastructure that facilitates active travel if the intended destination is within walkable distance. In addition, a more diverse land use mix may make walking to school inherently more attractive to adolescents, as the trip may include visiting other destinations, such as shops, parks and recreation facilities.

However, among those who lived further from school, negative associations between residential density around home, land use mix around home and school, and exclusive active school travel were observed. Consistent with our findings, a Danish study (Christiansen et al., 2014) found no association between walkability and active school travel among adolescents who lived within 0.5 km from school, but a negative association was observed among those who lived further away. In the present study it is possible that a greater distance to school overrode the impact of these built environment characteristics on exclusive active school travel as it was too far to exclusively walk or cycle. These findings suggest that individuals living further from school generally had a low probability of active travel regardless of the supportiveness of the built environment. However, for those residing closer to school, active travel was associated with a supportive built environment. The current study also found that a greater distance to the nearest public transport stop was associated with higher odds of active travel among those living further from school. While the reason for this finding is unclear, it is possible that when the nearest public transport stop is situated further from home, walking and cycling to school may become more time efficient, and therefore more appealing than using public transport.

4.2. Traffic safety moderated the association between residential density around school and active school travel

Adolescents with high residential density around their school environment had higher odds of exclusive active school travel if they perceived their traffic environment to be safe. Traffic-related safety issues are a key barrier to active travel among adolescents (Buttazzoni et al., 2023) so it is not surprising that safety from traffic may increase the odds of active school travel. In contrast to our expectation, age and adolescents' perception of personal safety, did not moderate the association between the built environment and exclusive active school travel. These moderators have been observed to influence the strength and direction of associations between the built environment and active travel among children (Panter et al., 2008). It is plausible that as adolescents gradually gain independence, these factors exert less influence on their travel behaviour.

4.3. Public transport use

Our study found that those living further from school were more likely to use public transport, and that boys were three times more than likely than girls to use public transport to/from school if they lived further from school. It may be that parents place greater restrictions on their daughters compared with their sons. Carver et al. (2010) found that parents of girls are more protective or restrictive than parents of boys when asked about their adolescents' engagement in various outdoor activities in the local neighbourhood, possibly due to fear of assault.

Concerns about personal safety are recognised as a common barrier to public transport use (Currie et al., 2013). We found that a low perception of personal safety strengthened the negative association between distance to the nearest public transport stop from school and public transport use. Conversely, regardless of perceived personal safety score, distance from home to a public transport stop was not associated with the odds of public transport use. While it is unclear why perceived safety played a role in the association between distance to public transport stops near school and public transport use, but not distance to public transport stops near home, it is possible that the commute to school is often more structured compared to the commute from school. This may make adolescents less conscious of safety concerns during these trips (Jones et al., 2012). Future qualitative research involving interviews with adolescents should be conducted to better understand this discrepancy.

4.4. Limitations

Due to the cross-sectional nature of the study design, no causal inference can be drawn from the findings. It is important to note that the data were collected in 2014/2015. While our study may not fully reflect current active travel prevalence, associations with the built environment are likely to be similar. Information on response rates were not available for every school in this study. While generalisability may be impacted, the sampling strategy resulted in a diverse sample of adolescents with relatively even distribution of residential neighbourhoods across the quadrants of high/low walkability and income (Loh et al., 2019). A limitation of the data collection method is that travel mode was self-reported by participants, and this may have resulted in recall or social desirability bias. Reporting of multi-modal trips may also have been inaccurate given the way in which the travel questions were asked, which resulted in the need to dichotomise active travel as exclusive active travel or not. Tools that readily capture the detail of multi-modal trips over a week are required. Future studies could also consider using ecological momentary assessment (i.e., real time assessment of participants' behaviour within its environmental context) to further explore the complex relationship between the environment and travel behaviour among adolescents over time. Due to the small percentage of participants who selected 'cycled' or 'skateboard' as their usual mode of travel to/from school, we combined walking, cycling and skateboarding into one category, even though aspects of the built environment may influence walking, cycling and skateboarding differently. The measure of access to public transport was also crude, as it only accounted for distance to the nearest stop from home, without considering whether participants actually used the nearest public transport stop, or other factors that influence public transport use such as frequency, reliability and route (Mindell et al., 2021). The public transport policies in Victoria recommended that most residents should have access to a bus stop within 400 m, a tram stop within 600 m and a train station within 800 m of their homes (Department of Planning and Community Development, 2006). While the policy recommendation for bus stop is delivered for many residents, a Melbourne study found that relatively few (only 20% and 18% of their sample) lived within the recommended catchment of trams and train stops, respectively (Badland et al., 2017).

This study used a generic land use mix measure that combined residential, commercial, entertainment and institutional land uses. A measure such as this does not distinguish type of destinations within the home or school areas. Thus, two neighbourhoods with the same land use mix score could have very different destinations available that may positively or negatively impact travel behaviour. Finally, this study did not account for other factors that may confound relationships between the built environment and travel mode to/from school. The need for a parent to trip chain could necessitate the use of a private motor vehicle (i.e., combining multiple short trips into one long trip), even if distance to the intended destination is within a walkable or cyclable distance (Carver et al., 2019; Keall et al., 2020). For example, a study in New Zealand found that almost 30% of car trips made by adolescents were part of a trip-chain, even among those living within a reasonable distance from school (mean distance to school among trip-chainers <4 km), making it a barrier to active travel (Keall et al., 2020). Other factors that impact active travel or public transport use among adolescents, including weather (Gropp et al., 2012), quality of the built environment (Ghekiere et al., 2015), the desire to travel with others, and the on-board experience and service delivery of public transport (Van Lierop et al., 2018) should be considered in future research.

4.5. Policy implications

Due to the interdependent nature of factors associated with active travel, there is no single policy or one-size-fits-all solution. Despite the limitations, our study suggests that placing new schools in areas characterised by high residential density and diverse land use may support active travel among adolescents. Our findings also suggest potential value in designing interventions that are customised to specific environments, which could enable more targeted approaches to promoting active travel. For example, to promote active travel, traffic calming interventions (e.g., reducing speed limit to 30 km/h (van den Dool et al., 2017) could be implemented in areas with high density near schools to enhance traffic safety, as has been recommended elsewhere (Mandic et al., 2020).

5. Conclusion

This study highlighted the complex relationship between active and public transport school travel and the built environment surrounding home and school among adolescents. Overall, distance to school remained one of the most important predictors of active travel and public transport use to/from school. Supportive built environment attributes, such as a diverse mix of land use around home appeared to have facilitating effects on active travel among adolescents who lived closer to school. Personal safety and perceived safety from traffic also appeared to be important effect modifiers for active travel and public transport use. This study suggests that multilevel interventions that target both the environment and perceived safety may be needed to promote active travel and public transport use among adolescents.

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CRediT authorship contribution statement

Venurs Loh: Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Conceptualization. **Shannon Sahlqvist:** Writing – review & editing, Supervision, Methodology, Conceptualization. **Jenny Veitch:** Writing – review & editing, Supervision, Methodology, Conceptualization. **Anthony Walsh:** Writing – review & editing, Writing – original draft. **Ester Cerin:** Writing – review & editing, Validation, Methodology, Formal analysis. **Jo Salmon:** Writing – review & editing, Funding acquisition. **Suzanne Mavoa:** Writing – review & editing, Methodology. **Anna Timperio:** Writing – review & editing, Methodology, Funding acquisition, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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