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RESEARCH ARTICLE

Association Between Perceived and Objective Measures of School Neighbourhood Built Environment and Active Transport to School in New Zealand Adolescents

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School neighbourhood built environment (BE) characteristics are related to active transport to school (ATS) among adolescents. This study examined objectively measured and perceived school neighbourhood BE correlates of ATS in adolescents and compared school neighbourhood BE features in rural versus small-to-medium urban areas. We analysed data from adolescents (n = 95; 68.4% under 16 years of age; 58.9% female) from 11 schools located in small-to-medium urban areas and rural settings in Otago, New Zealand, who were familiar with their school neighbourhood environment and lived within 4.8 km from school. Adolescents reported perceptions of their school neighbourhood using a modified version of Neighbourhood Environment Walkability Scale for Youth (NEWS-Y) questionnaire. Objectively measured BE features were generated using Geographic Information Systems (GIS). In a multivariate analysis, perceived residential density (odds ratio (95% CI): 0.17 (0.04, 0.82)) and traffic safety concerns (0.13(0.02, 0.95)) were negatively associated with adolescents' ATS rates, but those associations were no longer significant once distance to school was taken into account. Compared to small-to-medium urban area schools, perceived land use mix diversity and recreational facilities and objectively measured intersection density in school neighbourhoods were higher, whereas perceived residential density and land use mix accessibility and objectively measured neighbourhood walkability were lower in rural schools (all $p < 0.05$). Future initiatives should address both perceived and objectively measured school neighbourhood BE to promote ATS among adolescents.

Keywords: active transport; school neighbourhood; built environment; adolescents

1. Introduction

Regular physical activity is essential for adolescents' health and mental wellbeing (Reimers et al., 2013). However, adolescents' physical activity rates have decreased globally in recent decades (González et al., 2020; Sallis et al., 2016). Approximately 80% of adolescents worldwide do not meet the daily recommended physical activity guidelines (≥60 minutes of moderate-to-vigorous activity) (Guthold et al., 2020). When feasible, active transport to school (ATS), such as walking and/or cycling to school, is a simple and affordable way to incorporate physical activity into adolescents' everyday lives (Barnett et al., 2019; Stewart et al., 2017). In addition, ATS is an environmentally friendly transport mode with health benefits (Cerin et al., 2007; Marzi and Reimers, 2018). However, ATS rates among adolescents have been decreasing in many countries (McDonald et al., 2011; Uddin et al., 2019). In New Zealand, approximately 31% of adolescents used ATS in 2018 (Smith et al., 2018), much lower than the 45% in 1989–90 (Ministry of Transport, 2021b).

Multiple factors, including individual, social, environmental, and policy factors, contribute to the low rate of ATS in adolescents (Rahman et al., 2020a; Sirard and Slater, 2008; Uddin et al., 2019). Among these factors, there has been an increased interest to assess school neighbourhood built environment (BE) features in studies focused on adolescents' ATS (Campos-Sánchez et al., 2020; Rahman et al., 2020b). Relevant features of the school neighbourhood BE consist of complex interactions between land use mix, transport networks, infrastructure development, and urban planning and design (Handy et al., 2002). School neighbourhood BE features can be classified into micro and macro features (Molina-García et al., 2020; Pocock et al., 2019). Micro-BE features include availability of walking and cycling infrastructure, neighbourhood aesthetics, accessibility to local facilities, and perceived and objectively measured personal and traffic safety, whereas macro-BE features include distance to school, residential density, intersection density, land use mix, and neighbourhood walkability.

School neighbourhood BE features can be assessed using objective and perceived measures (Adams et al., 2009) **(Table 1)**. Objectively measured macro-BE features in school neighbourhood include spatial data generated through analysis functionality in Geographic Information Systems (GIS) to develop precise measures of the BE features (Campos-Sánchez et al., 2020; Pocock et al., 2019; Rahman et al., 2020b; Thornton et al., 2011) (e.g., residential density, intersection density, land use mix, and neighbourhood walkability). Perceived measures of micro-BE in school neighbourhood include participants' perceptions of the availability and quality of walking and cycling infrastructure, neighbourhood aesthetics, accessibility to local facilities, and personal and traffic safety, and can be assessed using surveys (Carlson et al., 2014; Deforche et al., 2010). Both objective and perceived measures of BE need to be considered to provide a comprehensive overview of the home and school neighbourhood environment (Kent et al., 2017).

Both objectively measured and perceived BE features around home and school neighbourhoods have been associated with ATS in adolescents (Carlson et al., 2014). Most previous studies examining the associations between BE features and ATS in adolescents have focused on home neighbourhoods (Carlson et al., 2015; Deforche et al., 2010), with only several studies examining BE features of the school neighbourhoods (Dalton et al., 2011; Rahman et al., 2020b). Although most previous studies focused on home neighbourhoods and route to school, examining the relationship between school neighbourhood BE features and adolescents' transport to school to is also important due to differences in BE features between home and school neighbourhoods (Carlson et al., 2014; De Meester et al., 2013; Ommundsen et al., 2006). In addition, traffic safety interventions aimed at encouraging walking and cycling to school, such as reduction in speed limits, may be focusing on school neighbourhoods (New Zealand Ministry of Transport, 2022). Therefore, BE features in school neighbourhoods hold a promise for targeted interventions to improve safety of walking and cycling to school and in the long run facilitate active transport to school.

Table 1: The relationship between school neighbourhood built environment features and active transport to school.

School neighbourhood built environment features	Relationship with active transport to school	References
Objectively measured built environment features		
Residential density	Positive	(Carlson et al., 2014; Carlson et al., 2015; Dalton et al., 2011)
	Negative	(Rahman et al., 2020b)
Intersection density	Positive	(Carlson et al., 2015; Dalton et al., 2011; Molina-García et al., 2020)
	Negative	(Rahman et al., 2020b)
Land use mix	Positive	(Molina-García et al., 2020; Rahman et al., 2020b)
Neighbourhood walkability	Positive	(Carlson et al., 2015; Molina-García et al., 2020)
	Negative	(Rahman et al., 2020b)
Perceived measures of built environment features		
Land use mix: diversity subscale	Positive	(Carlson et al., 2014)
Neighbourhood recreational facilities	Positive	(Carlson et al., 2014)
Residential density	Positive	(De Meester et al., 2013; Verhoeven et al., 2016)
Land use mix: access	Positive	(Carlson et al., 2014; Deforche et al., 2010)
Street connectivity	Positive	(Carlson et al., 2014)
Neighbourhood aesthetics	Positive	(Carlson et al., 2014; Dalton et al., 2011)
Walking and cycling facilities	Positive	(Carlson et al., 2014; Christiansen et al., 2014; Dalton et al., 2011)
Availability of safe street crossings	Positive	(Carlson et al., 2014; Christiansen et al., 2014)
	Negative	(Molina-García et al., 2020)
Route characteristics (pedestrian route directness)	Negative	(Carlson et al., 2014; Molina-García et al., 2020)
Number of traffic lanes	Negative	(Carlson et al., 2014; Molina-García et al., 2020)
Traffic safety concerns	Negative	(Aranda Balboa, 2021; Christiansen et al., 2014; Hume et al., 2009; Kerr et al., 2006; Rothman et al., 2021; Silva et al., 2020)
Personal safety concerns	Negative	(Carlson et al., 2014)
Parking facilities	Negative	(Carlson et al., 2014; Molina-García et al., 2020)

Objectively measured school neighbourhood BE features, including residential density, intersection density, land use mix, and neighbourhood walkability, were positively associated with ATS among adolescents in several studies in the United States (Carlson et al., 2014) and Spain (Molina-García et al., 2020) and negatively in one study in New Zealand (Rahman et al., 2020b). Among New Zealand adolescents from a large urban area who lived within 2.25 km from their school, adolescents' perception of the safety of walking to school was the strongest correlate of ATS, whereas objectively measured and perceived school neighbourhood BE features were not significantly correlated with ATS (Pocock et al., 2019). In addition, adolescents' perceptions of BE features such as availability of safe street crossings, route characteristics, number of traffic lanes, and parking facilities in school neighbourhoods were negatively correlated with ATS in adolescents in the United States (Carlson et al., 2014) and Spain (Molina-García et al., 2020). Although both objectively measured and perceived school neighbourhood BE features are related to adolescents' ATS, most previous studies examined objectively measured of school neighbourhood BE (Carlson et al., 2014; Dalton et al., 2011) but not both. One study that examined both objectively measured and perceived school neighbourhood BE features assessed adolescents' perceptions of the school route characteristics among adolescents who lived within walkable distance to their school (up to 2.25 km), rather than their perceptions of school neighbourhood characteristics (Pocock et al., 2019).

Previous studies that examined the association between objectively measured BE in school neighbourhoods and adolescents' ATS were conducted either in large urban areas (Carlson et al., 2014; Molina-García et al., 2020) or rural settings (Dalton et al., 2011). In large urban areas, objectively measured residential density and the perceived measure of safe street crossings in school neighbourhoods were positively associated with adolescents' ATS rates in the United States (Carlson et al., 2014). In New Zealand, objectively measured residential density in the school neighbourhood was negatively associated with school-level ATS rates in adolescents across different settlement types, including large urban areas, medium urban areas, small urban areas, and rural settings (Rahman et al., 2020b). A previous study conducted in rural settings in the United States examined the association between objectively measured BE features in school neighbourhoods and ATS rates among adolescents; however, adolescents' perceptions of BE features of school neighbourhoods were not measured (Dalton et al., 2011). In addition, the relationship between school neighbourhood BE features and ATS in a large urban area has been reported in the previous articles published from the Built Environment and Active Transport to School (BEATS) research in New Zealand (Pocock et al., 2019, Rahman et al., 2020b, Rahman et al., 2022), but whether school neighbourhood BE features are associated with ATS in small-to-medium urban areas and rural settings remain largely unexplored. To address the knowledge gap (measuring both objective and perceived school neighbourhood BE features in ATS studies), this study examined objectively measured and perceived school neighbourhood BE correlates of ATS in adolescents and compared school neighbourhood BE features in rural versus small-to-medium urban areas in New Zealand. This study would help to identify specific interventions of ATS for adolescents in small-to-medium urban areas and rural settings.

2. Materials and methods

2.1 Settings

The Otago region is situated in the South Island of New Zealand and has a population of approximately 225,000 (Statistics New Zealand, 2021). Otago is the seventh-largest region of sixteen by area in New Zealand (Statistics New Zealand, 2021). The region has a diverse topography, ranging from coastal plain lands to rural hill country and the Southern Alps mountain range. Consequently, the climate of the Otago region varies greatly, from temperate coastal weather to a combination of hot, dry summers and cool and wet winters inland.

2.2 Participants

This study analysed secondary data collected as part of the Built Environment and Active Transport to School (BEATS) Rural Study conducted in the Otago region, New Zealand, in 2018 (White et al., 2021). Data were collected from adolescents (age: 13–18 years; school years: 9–13) attending one of 11 (out of 15) high schools located in small-to-medium urban areas and rural settings. Four out of 15 approached schools did not participate. Out of 1014 adolescent participants who participated in the BEATS Rural Study, who were missing student consent (n = 5), had an invalid survey (n = 11), did not have survey data (n = 20), those who participated in a focus group only (n = 19), who did not participate in the mapping session (n = 780) and therefore did not complete Neighbourhood Environment Walkability Scale for Youth (NEWS-Y) questionnaire, an incomplete or invalid (n = 2) or blank (n = 2) NEWS-Y questionnaire, who were adolescents boarding at school (n = 5), or who lived >4.8 kilometres from their school (n = 75) were excluded from the analysis. After considering all exclusion criteria, data from 95 adolescents were included in this analysis.

Distance from home to school was calculated using Geographic Information Systems (GIS) (ArcGIS 10.6.1 software; Esri, Redlands, CA, USA) shortest-path network analysis based on geocoded home addresses and a connected street network, as described previously (Mandic et al., 2016). In the Otago region, adolescents living further than 4.8 km from school in areas where there was no public transport available, were eligible for free school bus services funded by the New Zealand Ministry of Education (Ministry of Transport, 2021a). Participating schools were located in medium urban areas (n = 2), small urban areas (n = 4), and rural settings (n = 5). Using official categories from Statistics New Zealand, urbanization categories were defined based on population: medium urban area (10,000–29,999 residents), small urban area (≥1000 to 9999 residents), and rural settings (<1000 residents) (Stats NZ, 2018). Since only two schools were in the medium urban area, small and medium urban areas were combined into a small-to-medium urban areas category.

2.3 Procedures

The BEATS research methodology was followed to recruit schools and adolescents, as described elsewhere (Mandic et al., 2016; White et al., 2021). Briefly, school principals were informed about the study. The study information packs, including information sheets and student consent forms, were given to each student one to three weeks before the scheduled data collection. A short video describing the study was also sent to schools by e-mail to be shared with the invited adolescents. Adolescents who signed paper consent participated in the study. Parental consent was not required for this study. The University of Otago Human Ethics Committee has approved the study protocol (Reference: 17/178).

2.4 Data collection

All adolescents were invited to participate in an online student survey, as described previously (White et al., 2021). Adolescents completed a 30- to 40-minute online student survey (Mandic et al., 2016) during class time and under the supervision of the research staff. Adolescents' sociodemographic characteristics and transport to school data were used for this analysis. Adolescents self-reported their date of birth, gender, ethnicity, and home address (Mandic et al., 2016). Adolescents were categorised into two age groups (<16 years and ≥16 years of age) because in New Zealand adolescents at the age of 16 are eligible to start the process of obtaining a driver licence (New Zealand Transport Agency, 2021). Home address was used to define levels of home neighbourhood deprivation using the New Zealand Index of Deprivation (data collected on a scale of 1 to 10; 1 = least deprived to 10 = most deprived, and subsequently categorised into quintiles) (Salmond et al., 2006).

Adolescents reported the frequency of using different modes of transport to school (such as, being a passenger in a car, driving a car, travelling by school bus or public transport, on foot, by bicycle or other modes and mixed modes) using the response categories "never", "rarely", "sometimes", "most of the time", or "all of the time" (Mandic et al., 2017). Based on their dominant mode of transport to school used "most of the time" or "all of the time", adolescents were classified into users of ATS, motorised transport, and mixed (active and motorised) transport (Mandic et al., 2017). Data from mixed transport users were excluded from this analysis.

A total of 175 adolescents (4 to 28 students per school; 11 schools) who participated in a mapping session completed a modified version of the NEWS-Y questionnaire (Rosenberg et al., 2009) to report their perceptions of the school neighbourhood BE. The NEWS-Y questionnaire was initially developed for home neighbourhoods (Rosenberg et al., 2009). In the NEWS-Y questionnaire, the school neighbourhood was defined as a 10- to 15-minute walk in any direction from the school. Several NEWS-Y items had to be modified for this study. For example, "a secondary school" being present in the neighbourhood was modified to "another secondary school" present, and "a school with recreation services available to the public" being modified to "another school with recreation services available to the public". Nine sub-scales of the NEWS-Y questionnaire (land use mix: diversity, neighbourhood aesthetics, street connectivity, residential density, land use mix: access, recreational facilities, walking/cycling facilities, and traffic and personal safety) were calculated using a previously published protocol (Rosenberg et al., 2009) **(Table 2)**. For each school neighbourhood, an overall neighbourhood

Table 2: Objective and perceived measures of school neighbourhood built environment variables and their description.

Variable	Variable description	Variable measurement techniques
Objective measures (1.0 km street-network buffer)		
Intersection density	Number of intersections within each predefined street-network buffer	A count of intersections within each predefined street-network buffer for each school.
Residential density	Residential address points and total land area	The ratio of residential address points to the land area.
Land use mix	Residential; commercial; industrial; and rural land uses	Calculated using mean land use entropy equation (coded between 0 = single class land use mix and 1 = all land use classes present and evenly distributed around each school).
GIS neighbourhood walkability index	Residential density; intersection density; and land use mix.	Standardized z-scores of objectively measured school neighbourhood residential density, intersection density, and land use mix.
Perceived measures (NEWS-Y Subscales)		
Land use mix: diversity subscale	Convenience store (small grocery store); supermarket; hardware store; fruit-vegetable market; laundry or dry cleaners; clothing store; post shop (post office); library; primary school; intermediate or secondary school; book shop; fast food restaurant; coffee place or café; bank; non-fast food restaurant; video shop (video store); pharmacy; hairdresser; any offices or worksites; and bus stop.	7-point scale (1–5 min, 6–10 min, 11–20 min, 21–30 min, 31+ min, do not know, not applicable).

(Contd.)

Variable	Variable description	Variable measurement techniques
Neighbourhood recreational facilities	Indoor recreation or exercise facilities; beach, lake, river or creek; bike or hiking or tramping trails or paths; soccer or rugby field; other playing fields or courts (like basketball, cricket, hockey, softball, tennis, skate park, etc.); swimming pool; walking or running track; school with recreation facilities open to the public; small public park, large public park; public playground with equipment; and public open space (grass or sand or dirt) that is not a park.	7-point scale (1–5 min, 6–10 min, 11–20 min, 21–30 min, 31+ min, do not know, not applicable).
Residential density	Town houses or row of houses; multiple family or duplex homes; and apartment or condo buildings.	5-point scale (none, a few, some, a lot, all).
Land use mix: access	Shops within easy walking distance; difficulty in parking in local shopping area; diverse destinations within easy walking distance; easy to walk to a bus stop; hilly streets making difficult to walk in (alone or with someone); barriers to walking (alone or with someone) to get from place to place (e.g., motorways, railway lines, rivers).	4-point scale (strongly disagree, somewhat disagree, somewhat agree, strongly agree).
Street connectivity	Too many dead-end streets; short distance between intersections; and many different routes to go.	4-point scale (strongly disagree, somewhat disagree, somewhat agree, strongly agree).
Walking and cycling facilities	Availability of footpaths; separation of footpaths from the road or traffic by parked cars; and a grass strip that separates the road from the footpaths.	4-point scale (strongly disagree, somewhat disagree, somewhat agree, strongly agree).
Neighbourhood aesthetics	Trees along the streets; many places to go; many beautiful natural things to look at; and attractive buildings or homes.	4-point scale (strongly disagree, somewhat disagree, somewhat agree, strongly agree).
Traffic safety concerns	Too much traffic along nearby streets; high traffic speed; drives than the posted speed limits; availability of good lighting; easily watch walkers and bikers on the street; availability of crosswalks or pedestrian signals; and lots of exhaust fumes from buses and cars.	4-point scale (strongly disagree, somewhat disagree, somewhat agree, strongly agree).
Personal safety concerns	Presence of crime in neighbourhood or local streets and fear for a local or nearby park.	4-point scale (strongly disagree, somewhat disagree, somewhat agree, strongly agree).
NEWS-Y: neighbourhood walkability index	Considered all perceived school neighbourhood built environment features	Standardized z-scores of all perceived measures school neighbourhood built environment features (NEWS-Y sub-scales) and summing them.

walkability score was calculated using standardized z-scores for nine NEWS-Y sub-scales and summing them (Rosenberg et al., 2009). A higher score indicated higher walkability in this study.

Objectively measured school neighbourhood BE features included residential density (per km^2), intersection density (per km^2), land use mix, and neighbourhood walkability, as described previously (Mandic et al., 2016) **(Table 2)**. The objectively measured BE features were calculated using 1.0 km street-network buffer around each school using ArcGIS 10.6.1 software (Esri, Redlands, CA, USA) (Mandic et al., 2016) as per school neighbourhood buffers used in previous studies (Moudon et al., 2006; Wilson et al., 2006). Previous studies have shown that a 1.0 km buffer represents a comfortable 10- to 15-minute walk (Campbell and Janssen, 2022; Laxer and Janssen, 2013). Standardized z-scores of GIS-measured school neighbourhood residential density, intersection density, and land use mix were calculated to measure the GIS walkability index for each school (Molina-García et al., 2017) using the following equation:

Walkability Index = [(z score of intersection density) + (z score of residential density) + (z score of land use mix)]

2.5 Data analysis

Sociodemographic characteristics were analysed using descriptive statistics. An independent t-test was used to compare the objectively measured and perceived BE features between small-to-medium urban areas and rural settings. Bivariate analysis examined adolescents' sociodemographic characteristics and objectively measured and perceived school neighbourhood BE variables as correlates of ATS. Bivariate correlates significant at p-value <0.10 were entered in the multivariate model. The multicollinearity among variables was checked using a Pearson product-moment correlation. A correlation coefficient of <0.80 and a variable inflation factor (VIF) higher than 5.0 with variable tolerance higher than 0.2 were assumed to indicate that collinearity between variables was not a concern (Campos-Sánchez et al., 2020). After that, among objectively measured and perceived school neighbourhood BE features, perceived residential density, neighbourhood aesthetics, traffic safety and personal safety concerns were considered in the multivariate modelling. A generalised linear mixed logistic model was used to examine an association between objectively measured and perceived school neighbourhood environment and adolescents' ATS rates. The outcome variable (ATS) was a dichotomous categorical variable (ATS vs. motorised transport to school) and was used in the mixed-effects logistic modelling after, including school as a random factor (to account for the clustered sample). Age, gender, and distance to school were included in the multivariate models as fixed effects, being identified from previous studies as important correlates of ATS among adolescents. After adjusting individual-level covariates (age, gender), the first multivariate model included significant bivariate correlates related to perceived measures of school neighbourhood BE but did not include home-to-school distance, whereas the second multivariate model also included home-to-school distance. In the multivariate models, a p-value < 0.05 was considered statistically significant. Data are reported as frequencies (percentage) for categorical variables and mean ± standard deviation (SD) for continuous variables. Data was analysed using IBM SPSS statistics software (version 27.0, IBM, Armonk, NY, USA).

3. Results

In this sample of 95 adolescents who lived ≤4.8 km from school, 68.4% were under 16 years of age, 58.9% were females, 79.8% were New Zealand European, 14.9% lived in low deprivation neighbourhoods, and 2.3% lived in high deprivation neighbourhoods **(Table 3)**. On average, 89.4% of adolescents had at least one bicycle to get to school, and 75.8% lived in households with two or more vehicles at home **(Table 3)**. In this sample of adolescents living ≤4.8 km from school, median distance to school was 1.51 km (interquartile range: 0.7–2.3 km), 64.5% of adolescents used ATS and 35.5% used motorised transport to school **(Table 3)**.

Descriptive information of objectively measured and perceived school neighbourhood BE features and results of the bivariate analysis for these variables are presented in **Table 4**. Among perceived measures of school neighbourhood BE features, perceived residential density, neighbourhood aesthetic, and traffic and personal safety concerns were significant negative correlates of ATS. Objectively measured school neighbourhood BE features did not correlate with ATS rates.

Table 3: Sociodemographic characteristics of study participants.

	Survey participants (n = 95)
Age [n (%)]	
<16 years	65 (68.4)
16 years or more	30 (31.6)
Gender [n (%)]	
Male	39 (41.1)
Female	56 (58.9)
Ethnicity [n (%)]	(n = 94)
New Zealand European	75 (79.8)
Māori	12 (12.8)
Others	7 (7.4)
New Zealand Deprivation Score [n (%)]	(n = 87)
1 – Least deprived	13 (14.9)
2	25 (28.7)
3	26 (29.9)
4	21 (24.1)
5 – Most deprived	2 (2.3)
Number of bicycles to get to school [n (%)]	
None	10 (10.5)
One	16 (16.8)
Two or more	69 (72.6)
Number of vehicles in a household [n (%)]	
None	0 (0.0)
One	23 (24.2)
Two or more	72 (75.8)
Distance to school in km [median (interquartile range)]	1.51 (0.7–2.3)

Table 4: Bivariate correlates of active transport to school.

Variable	Categories	ATS n (%)	Odds ratio	95% CI	p-value
Objective measures of school Neighbourhood built environment					
Residential density (km^2)	T1 < 493.71 (low) (reference)	26 (53.1)			0.096
	T2 493.71–673.98	17 (34.7)	0.82	0.27, 2.49	
	T3 ≥ 673.99 (high)	6 (12.2)	0.26	0.07, 0.91	
Intersection density (km^2)	T1 < 33.64 (low) (reference)	19 (38.8)			0.073
	T2 33.64–39.40	16 (32.7)	0.26	0.08, 0.88	
	T3 ≥ 39.41(high)	14 (28.6)	0.61	0.16, 2.42	
Land use mix	T1 < 0.45 (low) (reference)	20 (40.8)			0.952
	T2 0.45–0.53	21 (42.9)	1.15	0.41, 3.18	
	T3 ≥ 0.54 (high)	8 (16.3)	1.20	0.30, 4.85	
GIS neighbourhood walkability	T1 < –0.85 (low) (reference)	21 (42.9)			0.571
	T2 –0.85–(–0.23)	18 (36.7)	0.88	0.31, 2.37	
	T3 ≥ –0.22 (high)	10 (20.4)	1.91	0.44, 8.30	
Perceived measures of school neighbourhood built environment					
Land use mix: diversity subscale	T1 < 3 .10 (low) (reference)	17 (34.7)			0.949
	T2 3.10–3.40	18 (36.7)	1.18	0.39, 3.60	
	T3 ≥ 3.41(high)	14 (28.6)	1.18	0.36, 3.90	
Residential density	T1 < 56.0 (low) (reference)	29 (59.2)			**0.011**
	T2 56.0–67.0	10 (20.4)	1.03	0.23, 4.60	
Land use mix: access	T1 < 3.17 (low) (reference)	22 (44.9)			0.683
	T2 3.17–3.33	7 (14.3)	0.58	0.16, 2.16	
	T3 ≥ 3.34 (high)	20 (40.8)	1.00	0.35, 2.85	
Street connectivity	T1 < 3.0 (low) (reference)	21 (42.9)			0.436
	T2 3.0–3.33	7 (14.3)	0.52	0.15, 1.88	
Walking and cycling facilities	T1 < 3.0 (low) (reference)	20 (40.8)			0.544
	T2 3.0–3.33	13 (26.5)	0.52	0.16, 1.66	
	T3 ≥ 3.34 (high)	16 (32.7)	0.71	0.22, 2.26	
Neighbourhood recreational facilities	T1 < 3.17 (low) (reference)	16 (32.7)			0.961
	T2 3.17–3.83	17 (34.7)	0.85	0.27, 2.69	
	T3 ≥ 3.84 (high)	16 (32.7)	0.90	0.27, 2.89	

(Contd.)

Variable	Categories	ATS n (%)	Odds ratio	95% CI	p-value
Neighbourhood aesthetic	T1 < 2.75 (low) (reference)	22 (44.9)			**0.071**
	T2 2.75–3.00	14 (28.6)	0.50	0.18, 1.41	
	T3 ≥ 3.01 (high)	13 (26.5)	3.25	0.62, 17.01	
Traffic safety concerns	T1 < 2.14 (low) (reference)	20 (42.6)			**0.048**
	T2 2.14–2.43	21 (44.7)	0.82	0.26, 2.61	
	T3 ≥ 2.44 (high)	6 (12.8)	0.21	0.07, 0.79	
Personal safety concerns	T1 < 1.5 (low) (reference)	1 (2.0)			**0.024**
	T2 1.5–2.49	5 (10.2)	2.86	0.24, 33.90	
	T3 ≥ 2.50 (high)	43 (87.6)	10.75	1.12, 103.56	
NEWS-Y Walkability	T1 < –0.76 (low) (reference)	14 (28.6)			**0.878**
	T2 –0.76–1.37	16 (32.7)	0.80	0.24, 2.66	
	T3 ≥ 1.38 (high)	19 (38.8)	1.06	0.32, 3.52	

SD = standard deviation; T = Tertiles; CI = confidence interval; NEWS-Y = Neighbourhood Environment Walkability Scale for Youth.

The first multivariate model included all significant bivariate correlates except distance with age and gender as fixed effects **(Table 5)**. In this model, adolescents who perceived higher residential density in their neighbourhood had lower odds of using ATS (odds ratio (95% CI): 0.17 (0.04, 0.82)) compared to adolescents who perceived lower residential density in their school neighbourhoods. Adolescents who perceived higher levels of traffic safety concerns in their school neighbourhoods had lower odds of using ATS (0.13 (0.02, 0.95)) compared to adolescents who perceived lower levels of traffic safety concerns in their school neighbourhoods **(Table 5)**. When home-to-school distance was included in the second (final) multivariate model, no other perceived school neighbourhood BE features were significant multivariate correlates of ATS **(Table 5)**.

Objectively measured school neighbourhood residential density, land use mix, and walkability were higher, whereas intersection density was lower in small-to-medium urban areas compared to rural settings **(Table 6)**. Similarly, perceived measures of school neighbourhood land use mix: diversity, recreational facilities, street connectivity, walking and cycling facilities, neighbourhood aesthetics and walkability index calculated based on perceived measures were lower in small-to-medium urban areas than rural settings. In contrast, perceived measures of school neighbourhood land use mix: access, and traffic and personal safety concerns were higher in small-to-medium urban areas compared to rural settings.

Perceived measures of school neighbourhood personal safety concerns were positively correlated with objectively measured land use mix (r = 0.21; p = 0.044), whereas land use mix: diversity (r = –0.26; p = 0.011) and neighbourhood recreational facilities (r = –0.27; p = 0.008) were negatively correlated with objectively measured residential density **(Table 7)**. No other correlations between objective and perceived measures of the school neighbourhood built environment were statistically significant.

Table 5: Estimated odds of ATS adjusted for individual-level covariates.

	First multivariate model[1]			Second (final) multivariate model[2]		
	Co-efficient	**OR (95% CI)**	**p-value**	**Co-efficient**	**OR (95% CI)**	**p-value**
Age						
<16 years (reference)						
16 years or more	–0.56	0.57 (0.14, 2.31)	0.424	–1.07	0.34 (0.07, 1.73)	0.191
Gender						
Male (reference)						
Female	0.45	1.57 (0.34, 7.28)	0.558	0.12	1.13 (0.20, 6.42)	0.889
Distance to school	–	–	–	–1.32	0.27 (0.13, 0.57)	**<0.001**
Perceived residential density						
T1 < 56.0 (low) (reference)						
T2 56.0–67.0	0.67	1.95 (0.22, 17.36)	0.543	1.01	2.76(0.23, 32.79)	0.417
T3 ≥ 68.0 (high)	–1.78	0.17 (0.04, 0.82)	**0.027**	–0.95	0.39 (0.06, 2.44)	0.308
Perceived neighbour-hood aesthetic						
T1 < 2.75 (low) (reference)						
T2 2.75–3.00	–1.03	0.36 (0.08, 1.68)	0.187	–0.73	0.48 (0.09, 2.58)	0.387
T3 ≥ 3.01 (high)	1.14	3.15 (0.34, 29.34)	0.308	2.20	9.05 (0.73, 112.66)	0.086
Perceived traffic safety concerns						
T1 < 2.14 (low) (reference)						
T2 2.14–2.43	–0.86	0.43 (0.08, 2.33)	0.318	–0.85	0.43 (0.07, 2.50)	0.340
T3 ≥ 2.44 (high)	–2.04	0.13 (0.02, 0.95)	**0.045**	–1.86	0.16 (0.02, 1.56)	0.112
Perceived personal safety concerns						
T1 < 1.5 (low) (reference)						

(Contd.)

	First multivariate model[1]			Second (final) multivariate model[2]		
	Co-efficient	OR (95% CI)	p-value	Co-efficient	OR (95% CI)	p-value
T2 1.5–2.49	1.63	5.09 (0.23, 112.36)	0.117	1.26	3.52 (0.09, 133.39)	0.491
T3 ≥ 2.50 (high)	2.11	8.29 (0.58, 118.62)	0.297	1.78	5.93 (0.24, 149.15)	0.274

T = Tertiles; OR = odds ratio; CI = confidence interval.

[1] Estimated odds of ATS adjusted for individual-level covariates (age and gender) without home-to-school distance.

[2] Estimated odds of ATS adjusted for both individual-level covariates (age and gender) and distance to school.

Table 6: Objective and perceived measures of school neighbourhood built environment.

	Small-to-medium urban area		Rural settings		p-value
	Mean ± SD	Range (min-max)	Mean ± SD	Range (min-max)	
Objective measures (1.0 km street-network buffer)					
Intersection density	374.173 pt	29.04–41.18	36.13 ± 6.99	23.23–45.16	**0.738**
Residential density	630.67 ± 82.42	493.71–721.39	328.83 ± 120.79	115.38–429.78	**<0.001**
Land use mix	0.53 ± 0.11	0.33–0.68	0.44 ± 0.08	0.31–0.63	**<0.001**
GIS neighbourhood walkability index	–0.50 ± 0.46	–1.34–0.33	–1.90 ± 1.03	–3.43–(–0.69)	**<0.001**
Perceived measures (NEWS-Y Subscales)					
Land use mix: diversity subscale	3.00 ± 0.58	1.70–4.10	3.30 ± 0.38	2.45–3.85	**0.013**
Neighbourhood recreational facilities	3.35 ± 0.73	1.83–4.83	3.72 ± 0.53	2.17–4.58	**0.015**
Residential density	63.58 ± 17.70	42.00–119.00	59.30 ± 18.84	43.00–122.00	0.279
Land use mix: access	3.22 ± 0.27	2.67–3.67	3.00 ± 0.40	2.17–3.67	**0.003**
Street connectivity	2.87 ± 0.54	2.00–4.00	2.97 ± 0.50	1.00–4.00	0.459
Walking and cycling facilities	2.99 ± 0.50	2.00–4.00	3.04 ± 0.36	2.33–4.00	0.574
Neighbourhood aesthetics	2.69 ± 0.62	1.00–4.00	2.71 ± 0.56	1.50–4.00	0.889
Traffic safety concerns	2.26 ± 0.36	1.00–3.14	2.14 ± 0.40	1.43–3.29	0139
Personal safety concerns	1.27 ± 0.50	1.00–3.00	1.33 ± 0.50	1.00–3.00	0.608
NEWS-Y: neighbourhood walkability index	0.03 ± 2.29	–5.68–3.78	0.58 ± 3.23	–3.35–4.58	0.275

GIS = Geographic Information Systems; SD = standard deviation; NEWS-Y = Neighbourhood Environment Walkability Scale for Youth.

Table 7: Correlation between objective measured and perceived school neighbourhood built environment.

	Objective measure (GIS 1.0 km street-network buffer)			
	Residential density	**Intersection density**	**Land use mix**	**GIS neighbourhood walkability index**
Perceived measures (NEWS-Y)				
Land-use mix: diversity subscale	**–0.26 (0.011)**	0.08 (0.473)	0.04 (0.677)	0.10 (0.376)
Neighbourhood recreational facilities	**–0.27 (0.008)**	–0.01 (0.991)	0.07 (0.530)	0.10 (0.345)
Residential density	0.18 (0.076)	0.15 (0.140)	0.02 (0.881)	0.09 (0.387)
Land-use mix: access	0.17 (0.101)	0.21 (0.043)	0.11 (0.288)	0.16 (0.134)
Street connectivity	0.06 (0.053)	–0.02 (0.817)	–0.17 (0.110)	–0.18 (0.079)
Walking and cycling facilities	–0.01 (0.930)	0.06 (0.543)	–0.07 (0.474)	–0.06 (0.580)
Neighbourhood aesthetics	0.09 (0.371)	0.18 (0.077)	–0.07 (0.489)	0.12 (0.257)
Traffic safety concerns	0.13 (0.218)	–0.15 (0.164)	0.01 (0.934)	–0.05 (0.633)
Personal safety concerns	–0.09 (0.366)	–0.03 (0.797)	**0.21 (0.044)**	0.19 (0.065)
NEWS-Y: neighbourhood walkability index	0.07 (0.511)	0.14 (0.194)	–0.11 (0.313)	–0.02 (0.868)

Pearson's Product Moment correlations are reported with p-values presented in brackets. GIS = Geographic Information Systems; NEWS-Y = Neighbourhood Environment Walkability Scale for Youth.

4. Discussion

Key findings include: 1) In a multivariate model, perceived measures of traffic safety concerns and residential density were negative correlates of ATS. 2) When home-to-school distance was included in the multivariate model, perceived school neighbourhood BE features were no longer significant. 3) For rural settings compared to small-to-medium urban areas, objectively measured intersection density and perceived land use mix diversity, and recreational facilities were higher, whereas objectively measured residential density and neighbourhood walkability, and perceived land use mix accessibility were lower. Even among adolescents who live within 4.8 km from their school (which is considered to be a reasonable cycling distance to school for adolescents (Nelson et al., 2008), in the multivariate analysis, distance to school had a larger effect on how adolescents travel to school than school neighbourhood BE features. Taken together, objectively measured and perceived school neighbourhood BE features differ between small-to-medium urban areas and rural settings.

In the present study, adolescents who reported higher traffic safety concerns in their school neighbourhoods were less likely to use ATS than adolescents who perceived lower traffic safety concerns in their school neighbourhoods. However, traffic safety concerns were no longer significantly associated with ATS when distance to school was controlled for in a multivariate model. Due to small sample size, the present findings may not represent the actual scenario of school neighbourhood environments. Although distance to school was a stronger predictor of ATS than traffic safety concerns, the effects of distance may still have some effects of safety concerns. Previous studies found that adolescents and their parents perceived safety concerns for walking and cycling to school increased with an increase of walking and cycling distance to school in New Zealand (Mandic et al., 2022; Mandic S et al., 2020). Adolescents' and their parents' perceptions of high traffic safety concerns in the school neighbourhood and along school routes was negatively associated with ATS in the United States, Australia, and Spain (Aranda Balboa, 2021; Hume et al., 2009; Kerr et al., 2006). Similarly, Canadian and Brazilian studies found that high traffic safety concerns in school neighbourhood were positively associated with ATS rates among adolescents (Rothman et al., 2021; Silva et al., 2020). The present study suggests that future interventions aiming at encouraging ATS among adolescents should address traffic safety concerns in school neighbourhoods.

Adolescents who perceived higher residential density in their school neighbourhoods were less likely to use ATS compared to their peers who perceived lower residential density in their school neighbourhoods. In contrast, previous studies found that high residential density in school neighbourhood was associated with higher rates of ATS among adolescents in the United States, Belgium, and Finland (Dalton et al., 2011; De Meester et al., 2013; Verhoeven et al., 2016). However, a New Zealand study conducted among adolescents living in a range of urban and rural settlement types reported a negative association between school neighbourhood residential density and school-level ATS rates (Rahman et al., 2020b). Possible explanations for the different findings in this study compared to other studies could be our inclusion of school located in small and medium urban areas and rural settings (rather than large urban areas) and limiting the study sample to adolescents living within 4.8 km from school. Another explanation could be that residential density was higher in small-to-medium urban areas compared to rural settings and was significantly different. Residential density may decrease with an increase of distance from school resulting in an increase the probability of using public transport to school. School located in low residential areas, particularly in rural settings may have limited access to the local facilities, including shops and services resulting in a decrease of walking and cycling rates to school. However, school location in high residential density areas may also create a safe social environment (e.g., more people on the street) for adolescents' ATS (Carlson et al., 2014). Thus, residential density in school neighbourhoods should be taken into account in school neighbourhood redevelopment plans.

The present study found that once distance to school was taken into account in a multivariate model, none of the perceived school neighbourhood BE features were associated with adolescents' ATS rates. Adolescents' and their parents' perceptions of personal, environmental, safety-related barriers for both walking and cycling to school increased with an increase of distance from home to school in New Zealand (Mandic et al., 2022; Mandic S et al., 2020). In addition, high residential density is generally a precondition for short distances to school. For example, a Chinese study conducted in large urban areas found that high residential densities in school neighbourhoods were positively associated with short distance to school indicating that more students lived close to school travelled short distances compared to students who lived far away from schools (Mei et al., 2019). These findings suggest that to facilitate ATS among adolescents, schools should ideally be located within reasonable walking and cycling distances from adolescents' homes.

In this study, neighbourhoods of schools located in rural settings had higher objectively measured intersection density and greater perceived measures of land use diversity, more recreational facilities, lower residential density, lower neighbourhood walkability, and lower land use mix accessibility compared to school neighbourhoods in small-to-medium urban areas. These findings are not directly comparable to previous studies because to the authors' best knowledge no previous study examined both perceived and objectively measured school neighbourhood BE features in small-to-medium urban areas and rural settings. The present study findings highlight the need to understand whether the presence of school neighbourhood BE features, including objectively measured intersection density and perceived measures of residential density, land use mix, and recreational facilities in small-to-medium urban areas and rural settings are associated with the ATS rates among adolescents to inform context-specific tailoring ATS initiatives in school neighbourhoods.

4.1 Study implications

These findings suggest that adolescents' perceptions of residential density and traffic safety concerns but not objectively measured BE features in school neighbourhoods are related to ATS, but those relationships became non-significant once the distance to school was taken into account. Since adolescents' ATS rates decreased with an increase in home-to-school distance, future initiatives could consider designing using safe drop-off and pick-up points along the routes within reasonable walking and cycling distance to encourage more adolescents (including those who live beyond reasonable walking and cycling distance to school) to use ATS at least as a part of their journey (Rahman et al., 2020a). When designing safe drop-off and pick-up point, the effects of distance and physical effort or time should be considered because the effect of distance may have an effect of physical effort or time for walking and cycling to school. In addition, perceived traffic safety may also relate directly to time or distance on walk and cycle. The barriers related to traffic safety concerns within reasonable walking and cycling distance to school should be also addressed in future initiatives (such as reduction of speed limits within school walking catchment areas) for encouraging ATS among adolescents. Keeping in mind that adolescents' and their parents' traffic safety concerns for walking and cycling to school increase as the home-to-school distance increases (Mandic et al., 2022; Mandic S et al., 2020). The findings are a useful guide for researchers, transport engineers and/or local councils to inform decision-making related to addressing traffic safety concerns in school neighbourhoods that support ATS.

4.2 Study strengths and limitations

The major strengths of this study are the inclusion of both objectively measured and perceived school neighbourhood BE features, a high rate of school participation in the region, and mix of school neighbourhoods across diverse settlement types. However, this study has several limitations. First, due to cross-sectional data, no causal inferences can be made. Second, the school neighbourhood BE features, including recreational facilities, street connectivity, walking and cycling facilities, and neighbourhood aesthetics, were only measured as adolescents' perceptions. Third, the small sample size of adolescents included in this study may not be representative of all adolescents at participating schools. Fourth, this study had limited statistical power due to the small sample size and inclusion of a large number of categorical variables in the multivariate models. Fifth, due to small sample size, there might be a small chance of detecting a true effect (real difference between groups) of objectively measured and perceived school neighbourhood BE features and ATS rates, and more research may be needed to confirm the findings. Sixth, this study examined the relationship of the school neighbourhood BE with ATS in general and did not consider walking and cycling to school separately as some recent studies recommended (Mandic et al., 2017). Finally, the findings of this study have limited generalisability to other regions of New Zealand or internationally due to context-specific factors (e.g., location-specific typical built environments, cultural diversity, socio-economic position, and urban/rural settings), which is an inherent limitation of most transport research studies. To inform future approaches to enable school neighbourhoods to facilitate ATS, future research should examine objectively measured and perceived school neighbourhood BE features and their associations with walking and cycling to school separately, in diverse settlement types (including a range of urban, suburban, and rural environments) and among adolescents who live within walking and cycling distance to school.

5. Conclusions

Perceived measures of school neighbourhood BE features were associated with adolescents' ATS rates, whereas no associations were found between objectively measured school neighbourhood BE features and ATS rates in adolescents. Adolescents' ATS rates were negatively associated with traffic safety concerns and perceived residential density in their school neighbourhoods, but those associations were no longer significant once distance to school was taken into account. Adolescents living within 4.8 km from school and attending rural schools perceived higher intersection density, land use mix diversity and recreational facilities, and lower residential density, neighbourhood walkability, and land use mix accessibility in their school neighbourhoods compared to their peers attending schools in small-to-medium urban areas. Future initiatives should consider both perceived and objectively measured school neighbourhood BE to promote ATS among adolescents while taking into account distance to school. Perceived measures of school neighbourhood BE, particularly traffic safety concerns should be considered in future interventions because adolescents and their parents have traffic safety concerns along the routes to school within reasonable walking and cycling distance to school. Future initiatives would consider minimising adolescents' perceptions of traffic safety concerns by reducing distance to school.

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Competing Interests

Sandra Mandic is the founder and the director of the research consultancy AGILE Research Ltd. (www.agileresearch.nz) and Principal Advisor Transport Strategy at Wellington City Council (Wellington, New Zealand). Other authors have no conflicts of interest.

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