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Examining the transport to school patterns of New Zealand adolescents by home-to-school distance and settlement types

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A R T I C L E I N F O

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A B S T R A C T

Background: Scholarship on active transport to school has largely focused on children, (large) urban areas, the umbrella term of "active transport" which considered walking and cycling together and without taking into account walking and/or cycling distance. This research examined adolescents' patterns of transport to school in diverse settlement types and in relation to home-to-school distance in the Otago region of Aotearoa New Zealand.
Methods: Patterns of transport to school by home-to-school distance, and across school locations, are described for a sample of 2,403 adolescents (age: 15.1 ± 1.4 years; 55% females) attending 23 out of 27 schools in large urban areas (n = 1,309; 11 schools), medium urban areas (n = 265; three schools), small urban areas (n = 652; four schools) and rural settings (n = 177; five schools). Empirical data were collected through an online survey, in which adolescents reported

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sociodemographic characteristics, travel to school, and perceptions of walking and cycling. Home-to-school distance was measured on the shortest route determined using Geographic Information Systems (GIS)-based network analysis.

Results: Transport to school patterns differed significantly by home-to-school distance and across settlement types. Profiles of different transport user groups showed significant variability in sociodemographic characteristics, family factors, average distance to school, self-reported physical activity, and perceived health.

Conclusions: Initiatives to promote active transport and reduce reliance on car transport to school, whether to improve health and the environment or to reduce greenhouse gas emissions, need to pay closer attention to the settlement types, distance to school, and characteristics of different transport user modes.

1. Introduction

Active transport to school (ATS) – either alone or in combination with motorised transport – contributes to daily physical activity accumulation among adolescents (Khan et al., 2021; Kek et al., 2019; Larouche et al., 2014), with potential benefits for human health and reductions in greenhouse gas emissions and particulate matter (Gerike et al., 2019; Quam et al., 2017). ATS habits persist over time and relate to higher physical activity levels in emerging adulthood (Yang et al., 2014; Simons et al., 2017). However, the prevalence of ATS in adolescents has been declining worldwide (McDonald, 2007; Ministry of Transport, 2015) while rates of motorised transport to school have been increasing.

Sociodemographic factors (Pabayo et al., 2011), distance to school (Babey et al., 2009; Larsen et al., 2009; McDonald, 2008), and characteristics of the built environment (Larsen et al., 2009; Timperio et al., 2006; Panter et al., 2010; Kerr et al., 2006) are associated with ATS. Distance to school is the strongest correlate of walking and cycling to school among adolescents (Babey et al., 2009; Ikeda et al., 2018). Although distance to school has been controlled for in multivariate analyses in most previous ATS studies, few have presented results for, or limited the sample to, those who lived within walking and/or cycling distance to school (Mandic et al., 2017;

Table 1
Examples of active transport to school literature and definitions of urban and rural.

Citation	Location	Categories	Defining characteristic(s)	Interpretation
Babey et al. (2009)	California, USA	1. Urban	1. Greater than 4,150 persons per square mile [ppsm]	Population densities
		2. Suburban	Moderate density areas adjacent to population centres (above 1,000 ppsm but not an urban area)	
		3. Rural	Fewer than 1,000 ppsm including "isolated small towns or other less-developed areas surrounded by farmland or open spaces" (s208).	
Martin et al. (2007)	USA	1. Urban 2. Metro-suburban 3. Second city 4. Town 5. Rural	Categories quantified using quintiles of population density, along with the density of the areas surrounding the houses.	Population densities
Carver et al. (2014b)	Victoria, Australia	1. Metropolitan	Metropolitan Melbourne	Proximity to metropolitan areas and population size
		2. Rural cities	Rural cities as defined by the Australian government and areas within a 10 km radius of the centre of these cities	
		3. Rural areas	Areas completely within a 10 km radius of the centre of other Victorian cities with a population over 20,000 people.	
		4. Rural	Outside a 25 km radius of rural cities and outside metropolitan Melbourne	
Rahman et al. (2020)	Otago region, New Zealand	1. Major urban centres	Population ≥100,000 residents (study data not available for this category)	Population size
		2. Large urban areas	Population ≥30,000–99,999 residents	
		3. Medium urban areas	Population 10,000–29,999 residents	
		4. Small urban areas	Population ≥1,000–9,999 residents	
		5. Rural settings	<1,000 residents	
Vitale et al. (2019)	Halifax, Nova Scotia, Canada	1. Inner city	Pre-1960 areas of Halifax and Dartmouth, within 5 km radius of downtown.	Proximity to city areas, distances, service provisions and total population
		2. Suburbs	Built-up areas serviced by central water and sewage systems.	
		3. Inner commuter belt	Other areas within 25 km of downtown Halifax.	
		4. Outer commuter belt	25–50 km from downtown Halifax or another town with population over 10,000.	
		5. Remote rural	Beyond 50 km from Halifax or another large town.	

Pocock et al., 2019; Mandic et al., 2020). Recent findings show that attitudes to walking and cycling to school among urban adolescents (Mandic et al., 2022) and their parents (Mandic et al., 2020) differed by how far they lived from school. These findings highlight the importance of addressing mode-specific and distance-specific barriers to active transport in adolescents.

Since ATS behaviour – as with all travel behaviours - is context-specific, differences between geographical settings are expected. For example, in New Zealand, the large and medium urban areas of the Otago region where the research reported in this article has been conducted have limited provision of public bus transport and no rail transport and New Zealand's Ministry of Education funds free school buses for adolescents living more than 4.8 km from their school in areas where there is no suitable public transport (Ministry of Education, 2018). Those context specific factors likely have effects on travel to school patterns. Yet most previous studies examining ATS in adolescents have been conducted in urban areas (Babey et al., 2009; Larsen et al., 2009; Timperio et al., 2006; Panter et al., 2010; Kerr et al., 2006; Ikeda et al., 2018; Bringolf-Isler et al., 2008; Huertas-Delgado et al., 2017). Only a few studies have examined adolescents' transport to school patterns in rural areas (McDonald, 2007; Pabayo et al., 2011; Babey et al., 2009; Mandic et al., 2015; Booth et al., 2007; Dalton et al., 2011), and even fewer have compared adolescents' transport to school patterns between different settlement types (Babey et al., 2009; Martin et al., 2007; Vitale et al., 2019; Grize et al., 2010). Most (McDonald, 2007; Pabayo et al., 2011; Babey et al., 2009) but not all (Mandic et al., 2015; Booth et al., 2007) reported a higher prevalence of ATS among adolescents in urban versus rural areas. A recent study using accelerometer-measured physical activity reported that adolescents from large and medium urban areas accumulated more moderate-to-vigorous physical activity during the school commute time compared with rural adolescents (White et al., 2021).

In those ATS studies that have examined both 'urban' and 'rural' contexts, a range of different approaches have been used to characterise so-called 'urban' and 'rural' places. This includes use of government definitions (e.g., (Garnham-Lee et al. (2017)); the design of new definitions of urban/rural distinctions; the description of an urban-rural continuum (Vitale et al., 2019); or paying limited, or no, attention to defining spatial characteristics (e.g., Carver et al. (2014a)). Across these approaches, 'rural' is often defined in terms of what the area lacks (e.g., active transport infrastructure, a densely built environment, public transport provision). This is interpreted in relation to the 'urban' context, where these infrastructures and services are often more prevalent. Other distinctions include rural schools having larger catchment areas (e.g.,Vitale et al. (2019)), and different employment dynamics (i.e., different types of work, hours of employment and distances travelled) which may contribute to enhanced or reduced trip chaining characteristics (Porskamp et al., 2019; Bosworth et al., 2020; Camarero et al., 2016), and norms of independent mobility. In New Zealand, for instance, rural communities can view young people's access to private motor vehicles as particularly important given the distances to be travelled and a lack of public transport: they were at the centre of opposition to increasing the age at which adolescents could learn to drive in 2011 from 15 to 16 years (Guardian, 2011). These characteristics are at least part of the explanation why children and adolescents might not travel to school using active modes (e.g. (Babey et al., 2009)). Table 1 presents a sample of ATS research, which indicates the different ways that 'urban' and 'rural' are categorised.

Although the body of knowledge related to active and motorised transport to school in adolescents is extensive, limited information is available for adolescents who combine active and motorised transport for their school travel (i.e., mixed transport users). Most previous ATS studies in adolescents collected and analysed transport to school data for main/dominant modes without taking into account mixed transport users (i.e., compared ATS with non-ATS users) (Babey et al., 2009), excluded mixed transport users from the analysis, or did not specify how mixed transport users were considered (Ikeda et al., 2018). Few studies present mixed transport to school data (Mandic et al., 2017) and even fewer studies report data for mixed transport users separately (Kek et al., 2019). For instance, adolescents using both ATS and combined active and motorised transport to school accumulate greater amounts of daily physical activity as well as physical activity during the school travel time compared with those using only motorised transport to school (Kek et al., 2019). Understanding sociodemographic characteristics, motivations and barriers of adolescents using mixed transport to school is important if walking and/or cycling to school are to be promoted as one of the approaches to address currently low levels of physical activity among adolescents and increase use of low-carbon transport modes. In that case, ATS (primarily walking and cycling) should be encouraged among *all* adolescents, including those living beyond walking and cycling distance to school; this could be achieved through initiatives and interventions aimed at promoting and supporting mixed transport (Mandic et al., 2022).

Previous research on ATS has largely focused on children, (large) urban areas, the umbrella term of "active transport" which considered walking and cycling together and without taking into account walking and/or cycling distance. To address some knowledge gaps in the existing literature, this research examined adolescents' patterns of transport to school in diverse settlement types and in relation to home-to-school distance in the Otago region of Aotearoa New Zealand (hereafter New Zealand). Four categorisations for the spatial context (large, medium and small urban areas and rural settlements) allowed for a more detailed analysis across settlement types than two (urban/rural) or three (urban, peri-urban, rural) categories. The novelty of this research includes: a) focus on adolescents (adolescent-specific research is limited and this is a specific population group with different challenges and needs to children; this age group also has high rates of insufficient physical activity); b) examining results specific to a range of settlement types including large, medium and small urban areas and rural settlements; c) reporting analysis for individual school transport modes, including walking and cycling separately as well as considering mixed modes, which is not often done in the ATS literature; and d) presenting data by distance to school categories using home-to-school distance thresholds for adolescents' walking and cycling to school.

2. Material and methods

The Otago region of New Zealand is predominantly rural, with only one large urban area (Dunedin (without Mosgiel), ca. 95,000 inhabitants) and several medium and small urban areas (e.g., Oamaru ca. 13,000 inhabitants; Milton ca. 2,000 inhabitants). Otago is representative of many rural areas in New Zealand with its small and isolated rural communities. Many of these rural communities are from 45 min to an hour and half away from basic services like secondary education, healthcare clinics and supermarkets. Highways do not exist. Arterial roads and major side roads are sealed, but some are still gravelled. Many roads outside the large settlements are narrow and winding.

This study analysed data from adolescents attending 23 out of 27 high schools (85% school recruitment rate) in the Otago region that participated in the Built Environment and Active Transport to School (BEATS) Study (2014–2015; 1,780 adolescents) (Mandic et al., 2016) and BEATS Rural Study (2018; 1,014 adolescents) (White et al., 2021). After excluding adolescents who did not have signed consent (n = 25) or required parental consent (BEATS Study only; n = 59), missing or invalid surveys (implausible responses, e.g., travelling by plane, n = 74), students boarding at school or privately (n = 196), those with invalid home address (n = 22) and invalid transport to school survey data (implausible responses, e.g., using all travel modes all/most of the time, n = 15), data from 2,403 adolescents were included in this analysis. Adolescents attended schools located in a large urban area (n = 1,309; 11 schools), medium urban areas (n = 265; three schools), small urban areas (n = 652; four schools) and rural settings (n = 177; five schools). Details on recruitment of schools and adolescents for both studies have been published elsewhere (White et al., 2021; Mandic et al., 2016). Briefly, adolescents were recruited through their schools. Interested adolescents provided written informed consent prior to participation. Parental opt-in or opt-out consent was used in the BEATS Study, based on each school's preference, while no parental consent was required in the BEATS Rural Study. The study protocols for both studies were approved by the University of Otago Human Ethics Committee (BEATS Study: 13/203; BEATS Rural Study: 17/178).

2.1. Procedures

Participants completed an online survey at their school during one school period while being supervised by research staff. Survey items related to sociodemographic characteristics, travel to school, and self-reported physical activity and self-perceived health were analysed in this study.

Demographic information included home address, date of birth, gender, ethnicity, and number of vehicles and bicycles in the household. Adolescents' age was calculated at the time of survey completion. The New Zealand Index of Deprivation (1 = least deprived to 10 = most deprived) was reported spatially via census meshblock areas (Salmond et al., 2006). Therefore, in order to determine the deprivation index for the adolescents' home neighbourhoods, geocoded home addresses (i.e. addresses converted to coordinates) were matched with the enclosing meshblock (Salmond et al., 2006). New Zealand Index of Deprivation data were subsequently recoded into quintiles for data analysis (quintile 1 = least deprived to quintile 5 = most deprived).

The geocoded home address was also used to calculate home-to-school distance using Geographic Information Systems (GIS)-based network analysis, specifically the shortest route from origin (home) to destination (school) extracted from a connected road network (not including standalone paths and tracks), as described previously (Mandic et al., 2016).

Based on previous research, a threshold distance of ≤2.25 km (Pocock et al., 2019) and ≤4.0 km (Nelson et al., 2008) were used for defining reasonable walking and cycling distances, respectively: these were categorised as 'walking distance' (≤2.25 km), 'beyond walking but within cycling distance' (>2.25–4.0 km) and 'beyond cycling distance' (>4.0 km). Schools were initially categorised into one of the six urban and rural categories (see Table 1, (Rahman et al., 2020)) defined by Statistics New Zealand based on school addresses (Stats NZ, 2021). This categorisation was applied to the urban-rural zoning used to report 2013 census data and was published in the metadata for that dataset available on the StatsNZ data portal (Stats NZ, 2021). In the GIS, the geocoded point addresses were overlaid by the classified zones; local zone information was transferred to the points. In the BEATS research datasets, no adolescent data were collected in an 'urban centre'. Categories 'rural settlement' and 'rural area' were combined into a single category 'rural settlement' due to no schools being located in 'rural areas'. Therefore, based on the settlement type in which they were located, schools were categorised into 'large urban area' (e.g. cities), 'medium urban area' (smaller cities and towns), 'small urban area', and 'rural settlement' (e.g. small towns and villages).

Frequency of use of different mode(s) of transport to school was reported on a 5-point scale for each travel mode ('never', 'rarely', 'sometimes', 'most of the time', 'all of the time'). Based on the mode(s) used 'most of the time' or 'all of the time', adolescents were categorised as users of 'motorised transport', 'active transport', or 'mixed active and motorised transport', as described previously (Mandic et al., 2017). In addition, dominant transport to school modes were used to categorise adolescents into one of the specific transport user categories: 'walkers', 'cyclists', 'other active mode(s)', 'car users (being driven or driving)', 'bus users (public and/or school bus)', 'other motorised mode(s)', 'bus users and walkers', 'car users and walkers', 'other mixed mode(s)' and 'no predominant transport mode users' (those that used multiple transport to school modes but none of them 'all the time' or 'most of the time').

Self-reported physical activity was collected using the question "Over the past 7 days, on how many days were you physically active for a total of at least 60 min per day?" (Currie et al., 2009). Adolescents reporting ≥60 min of moderate-to-vigorous physical activity per day were classified as meeting physical activity recommendations (World Health Organization, 2010; Tremblay et al., 2016; Ministry of Health, 2012). Adolescents rated their overall health using a single survey item ("In general, how would you say your health is?") with five response options ("excellent"/"very good"/"good"/"fair"/"poor"), with no differentiation between physical and mental health (Currie et al., 2009).

2.2. Data analysis

Demographic characteristics were analysed using descriptive statistics. Comparisons across distance to school categories and across settlement types were performed using a Chi-square test for categorical variables. Continuous variables were compared using one-way ANOVA with Scheffé post-hoc multiple comparisons or Tamahane's T2 when the assumption of homogeneity of variance was not met.

Given the aim of this study (i.e., examining adolescents' patterns of transport to school in diverse settlement types and in relation to home-to-school distance in the Otago region of New Zealand), additional analyses (e.g., multivariate analyses) were not deemed necessary to address the research question. Descriptive data were reported as mean ± standard deviation for continuous variables and frequencies (percentage) for categorical variables. P-value <0.05 was considered statistically significant. Data analysis was performed using SPSS Statistical Package version 27.0.

3. Results

Among 2,403 adolescents included in this analysis (age: 15.1 ± 1.4 years), 54.8% were females and 71.4% identified as New Zealand European (Table 2). The majority lived in the two least deprived quintiles of neighbourhoods and in households with two or more vehicles and bicycles. The mean distance to school was 7.3 ± 9.1 km (median: 3.7 km; interquartile range: 1.6 km–9.9 km) with 35.0% of adolescents living within walking distance, 17.2% beyond walking but within cycling distance, and 47.6% beyond cycling distance to school. Among surveyed adolescents, 54.5% attended school in a large urban area, 11.0% in medium urban areas, 27.1% in small urban areas and 7.4% in rural settings.

Overall, 27.0% of adolescents used ATS, 59.6% used motorised transport and 13.4% used mixed transport (Table 3). Further analysis showed that 22.9% of adolescents walked, 38.5% travelled to school by car and 18.0% by bus, while other individual transport modes and combination of modes were less common, including cycling (3.5%) (Table 3).

Transport user groups differed with respect to sociodemographic characteristics, family factors, distance to school, physical activity

Table 2

Sociodemographic characteristics, physical activity levels and perceived health in the total sample and across profiles of adolescents travelling to school using six common active, motorised and mixed transport modes.

	Total sample	Walkers	Cyclists	Car users	Bus users	Bus users and walkers	Car users and walkers	p-value
	n = 2,403	n = 551	n = 83	n = 925	n = 433	n = 90	n = 123	
Age (years) [mean ± SD]	15.1 ± 1.4	15.2 ± 1.3	14.9 ± 1.1	15.3 ± 1.5	14.9 ± 1.4	15.1 ± 1.3	14.8 ± 1.3	<.001
Gender (%)								
Males	45.1%	42.3%	74.7%	43.9%	47.8%	38.9%	36.6%	
Females	54.8%	57.7%	25.3%	56.1%	52.2%	61.1%	63.4%	<.001
Ethnicity (%)	(n = 2,396)	(n = 548)	(n = 82)	(n = 924)	(n = 432)	(n = 90)	(n = 123)	
New Zealand European	73.7%	69.2%	78.0%	77.1%	73.8%	74.4%	74.0%	
Māori	11.5%	13.0%	12.2%	8.5%	13.4%	14.4%	13.8%	
Other	5.8%	17.9%	9.8%	14.4%	12.7%	11.1%	12.2%	.018
Neighbourhood deprivation index (%)	(n = 2,342)	(n = 539)	(n = 80)	(n = 900)	(n = 424)	(n = 88)	(n = 119)	
1 (least deprived)	31.5%	16.9%	30.0%	37.2%	37.3%	28.4%	26.9%	
2	26.7%	23.2%	33.8%	26.4%	32.1%	31.8%	22.7%	
3	20.7%	27.5%	23.8%	18.3%	14.6%	22.7%	26.9%	
4	14.9%	21.9%	12.5%	12.1%	12.3%	14.8%	15.1%	
5 (most deprived)	6.2%	10.6%	0.0%	5.9%	3.8%	2.3%	8.4%	<.001
Number of bicycles (%)								
None	21.2%	26.7%	0.0%	18.7%	24.9%	16.7%	22.0%	
One	20.2%	20.5%	19.3%	20.8%	19.6%	25.6%	13.8%	
Two or more	58.6%	52.8%	80.7%	60.5%	55.4%	57.8%	64.2%	<.001
Number of vehicles (%)								
None	2.5%	4.4%	3.6%	0.9%	3.2%	2.2%	0.8%	
One	22.5%	34.8%	21.7%	18.1%	18.2%	12.2%	22.0%	
Two or more	75.0%	60.8%	74.7%	81.1%	78.5%	85.6%	77.2%	<.001
Distance to school								
Walkable distance (%)	35.1%	87.8%	63.9%	18.85	2.1%	3.3%	56.1%	
Cyclable distance (%)	17.4%	10.2%	27.7%	26.2%	7.4%	10.0%	16.3%	
Beyond cyclable distance (%)	47.5%	2.0%	8.4%	55.0%	90.5%	86.7%	27.6%	<.001
Average distance (km) [mean ± SD]	7.3 ± 9.3	1.3 ± 1.5	2.2 ± 1.3	7.5 ± 7.8	14.3 ± 12.1	12.5 ± 8.0	4.4 ± 7.1	<.001
Physical activity	(n = 2,083)	(n = 484)	(n = 76)	(n = 792)	(n = 382)	(n = 73)	(n = 107)	
Met physical activity recommendations (%)	19.8%	20.9%	35.5%	17.2%	15.4%	28.8%	21.5%	<.001
Perceived personal health								
Excellent	17.2%	12.9%	27.7%	17.9%	17.1%	21.1%	17.9%	
Very good	42.7%	42.8%	51.8%	43.2%	42.3%	40.0%	40.7%	
Good	32.7%	35.8%	16.9%	33.4%	30.5%	24.4%	37.4%	
Fair	6.2%	7.4%	2.4%	4.4%	8.5%	12.2%	4.1%	
Poor	1.1%	1.1%	1.2%	1.0%	1.6%	2.2%	0.0%	<.001

Table 3
Transport to school patterns in the total sample and by distance to school.

	Total sample	Distance from school			p-value
		Within walking distance (≤2.25 km)	Beyond walking but within cycling distance (>2.25–4.0 km)	Beyond cycling distance (>4.0 km)	
	n = 2,403	n = 842	n = 416	n = 1,145	
Usual transport modes to school [a] (%)					
On foot	22.9%	57.5%	13.5%	1.0%	
By bicycle	3.5%	6.3%	5.5%	0.6%	
Other active mode(s)[b]	0.7%	1.7%	0.5%	0.0%	
By car [c]	38.5%	20.7%	58.2%	44.5%	
By bus [d]	18.0%	1.1%	7.7%	34.2%	
Other motorised mode(s) [e]	3.1%	0.4%	1.2%	5.8%	
By bus and on foot	3.7%	0.4%	2.2%	6.8%	
By car and on foot	5.1%	8.2%	4.8%	3.0%	
Other mixed modes combinations	1.9%	0.8%	1.9%	2.7%	
No predominant transport modes	2.6%	3.1%	4.6%	1.5%	<.001
Transport to school categorisation (%)					
Active	27.0%	65.4%	19.5%	1.6%	
Motorised	59.6%	22.2%	66.6%	84.5%	
Mixed	13.4%	12.4%	13.9%	14.0%	<.001

[a] Usual transport modes to school were used by adolescents “most of the time” or “all of the time".
[b] Other active mode(s) (including combinations).
[c] By car (driven by others or driving).
[d] By bus (public or school bus).
[e] Other motorised mode(s) (including combinations).

and perceived health (Table 2). Transport mode gender differences were most pronounced among cyclists, with a three times higher proportion of males compared with females. The proportion of New Zealand European adolescents was lowest among walkers, whereas the proportion of Māori adolescents was lowest among car users, compared with other transport user groups. Walkers had the highest proportion of adolescents from the most deprived neighbourhoods and the lowest proportion of adolescents living in households with two or more vehicles. The proportion of adolescents having two or more bicycles available in the household to cycle to school was highest among cyclists. On average, walkers lived closest to school. Cyclists lived further from school than walkers but closer than all other transport user groups. Cyclists had the highest proportion of adolescents self-reporting ‘excellent’ or ‘very good’ health and meeting physical activity guidelines. Bus users had the lowest proportion of adolescents meeting physical activity recommendations.

Transport patterns to school differed significantly based on distance to school (Table 3). With increasing distance, rates of walking to school decreased significantly while rates of travelling to school by motorised transport (primarily by car and by bus) and some mixed modes increased. Rates of cycling to school declined steeply beyond the pre-defined cycling distance to school.

Transport patterns to school also differed significantly across settlement types (Table 4). While prevalence of walking to school ranged from 19.0% to 24.5% across settlement types, greater variations were observed for other transport modes. Rates of cycling to school were highest in small urban areas, where one in ten adolescents cycled to school compared with 0.7% to 2.8% of adolescents in other settlement types. Car travel to school was most prevalent among adolescents in the large urban area, where over half of adolescents used this mode compared with one quarter of adolescents in small and medium urban areas. Only 15.8% of rural adolescents relied solely on car transport to school. In contrast, bus transport was more common in rural settings (35.6%) compared with the large urban area (12.5%), medium urban areas (26.5%), and small urban areas (21.0%).

Transport patterns to school also differed by distance to school across settlement types (Table 4). Among adolescents who lived within walking distance to school, the prevalence of walking to school ranged from 46.3% in small urban areas to 64.9% in rural settlements. In contrast, rates of cycling to school ranged from 0.5% to 1.8% in large and medium urban areas, respectively, to 17.0% in small urban areas. Car travel was most prevalent in the large urban area (26.0%) and least prevalent in small urban areas (12.7%) whereas bus transport was rare within walking distance in all geographical settings (range: 0% to 3.6%).

Among adolescents who lived within cycling distance to school, approximately half walked to school in the large and medium urban areas and rural settings, while few cycled to school in those settlements (Table 4). The small urban areas had the lowest rates of walking to school and the highest rates of cycling to school compared with other settlement types. Overall, approximately half of adolescents living within cycling distance to school either walked or cycled to school across all settlement types. Rates of car travel within cycling distance also varied across settlement types, with four out of ten adolescents travelling by car in the large urban area, three out of ten in medium and small urban areas, and two out of ten in rural settings. Rates of busing to school within cycling distance ranged from 0.8% in small urban areas to 6.8% in medium urban areas.

Table 4
Transport to school patterns by distance to school categories across settlement types.

	Total sample	Large urban area	Medium urban area	Small urban area	Rural settlement	p-value
	n = 2,403	n = 1,309	n = 265	n = 652	n = 177	
Total sample						
Usual transport modes to school [a] (%)						
On foot	22.9%	24.5%	24.5%	19.0%	23.2%	
By bicycle	3.5%	0.7%	1.5%	10.0%	2.8%	
Other active mode(s)[b]	0.7%	0.4%	0.8%	1.1%	1.1%	
By car [c]	38.5%	50.6%	29.4%	23.9%	15.8%	
By bus [d]	18.0%	12.5%	26.4%	21.0%	35.6%	
Other motorised mode(s) [e]	3.1%	4.1%	0.8%	2.0%	2.8%	
By bus and on foot	3.7%	1.5%	3.8%	6.9%	9.0%	
By car and on foot	5.1%	2.4%	7.5%	9.5%	5.1%	
Other mixed modes combinations	1.9%	1.2%	1.9%	2.9%	3.4%	
No predominant transport modes	2.6%	2.1%	3.4%	3.7%	1.1%	<.001
Transport to school categorisation (%)						
Active	27.0%	25.6%	26.8%	30.1%	27.1%	
Motorised	59.6%	66.8%	57.4%	47.5%	53.1%	
Mixed	13.4%	7.6%	15.8%	22.4%	19.8%	<.001
Withing walking distance (≤2.25 km)	(n = 842)	(n = 404)	(n = 110)	(n = 259)	(n = 69)	
Usual transport modes to school [a] (%)						
On foot	57.5%	64.9%	56.4%	46.3%	58.0%	
By bicycle	6.3%	0.5%	1.8%	17.0%	7.2%	
Other active mode(s)[b]	1.7%	0.7%	1.8%	2.7%	2.9%	
By car [c]	20.7%	26.0%	21.8%	12.7%	17.4%	
By bus [d]	1.1%	0.7%	3.6%	0.8%	0.0%	
Other motorised mode(s) [e]	0.4%	0.7%	0.0%	0.0%	0.0%	
By bus and on foot	0.4%	0.2%	0.0%	0.4%	1.4%	
By car and on foot	8.2%	3.0%	10.9%	14.7%	10.1%	
Other mixed modes combinations	0.8%	0.7%	0.0%	1.2%	1.4%	
No predominant transport modes	3.1%	2.5%	3.6%	4.2%	1.4%	<.001
Transport to school categorisation (%)						
Active	65.40%	66.10%	60.00%	66.00%	68.10%	
Motorised	22.20%	27.50%	25.50%	13.90%	17.40%	
Mixed	12.40%	6.40%	14.50%	20.10%	14.50%	<.001
Withing cycling distance (≤4.0 km)	(n = 1,258)	(n = 675)	(n = 146)	(n = 359)	(n = 78)	
Usual transport modes to school [a] (%)						
On foot	42.9%	46.1%	44.5%	34.5%	51.3%	
By bicycle	6.0%	0.9%	2.1%	17.3%	6.4%	
Other active mode(s)[b]	1.3%	0.7%	1.4%	1.9%	2.6%	
By car [c]	33.1%	39.7%	28.1%	25.3%	20.5%	
By bus [d]	3.3%	3.6%	6.8%	0.8%	5.1%	
Other motorised mode(s) [e]	0.6%	1.2%	0.0%	0.0%	0.0%	
By bus and on foot	1.0%	0.6%	0.0%	1.7%	2.6%	
By car and on foot	7.1%	2.8%	11.0%	13.1%	9.0%	
Other mixed modes combinations	1.2%	1.3%	0.7%	1.1%	1.3%	
No predominant transport modes	3.6%	3.1%	5.5%	4.2%	1.3%	<.001
Transport to school categorisation (%)						
Active	50.2%	47.7%	47.9%	53.8%	60.3%	
Motorised	36.9%	44.0%	35.6%	26.5%	25.6%	
Mixed	12.9%	8.3%	16.4%	19.8%	14.1%	<.001
Beyond cycling distance (>4.0 km)	(n = 1,145)	(n = 634)	(n = 119)	(n = 293)	(n = 99)	
Usual transport modes to school [a] (%)						
On foot	1.0%	1.6%	0.0%	0.0%	1.0%	
By bicycle	0.6%	0.5%	0.8%	1.0%	0.0%	
Other active mode(s)[b]						
By car [c]	44.5%	62.3%	31.1%	22.2%	12.1%	
By bus [d]	34.2%	21.9%	50.4%	45.7%	59.6%	
Other motorised mode(s) [e]	5.8%	7.3%	1.7%	4.4%	5.1%	
By bus and on foot	6.8%	2.4%	8.4%	13.3%	14.1%	
By car and on foot	3.0%	2.1%	3.4%	5.1%	2.0%	
Other mixed modes combinations	2.7%	1.1%	3.4%	5.1%	5.1%	
No predominant transport modes	1.5%	0.9%	0.8%	3.1%	1.0%	<.001
Transport to school categorisation (%)						
Active	1.6%	2.1%	0.8%	1.0%	1.0%	
Motorised	84.5%	91.2%	84.0%	73.4%	74.7%	
Mixed	14.0%	6.8%	15.1%	25.6%	24.2%	<.001

Note: In large urban area schools 11.3% of adolescents used school bus and 7.3% used public bus to school regularly ('most of the time' or 'all of the time'), either alone or in combination with other modes. In medium urban area schools, 30.9% of adolescents used school bus and 1.5% used public bus regularly. No public bus was available in small urban areas and rural settings.

[a] Usual transport modes to school were used by adolescents "most of the time" or "all of the time".

[b] Other active mode(s) (including combinations).

[c] By car (driven by others or driving).

[d] By bus (public or school bus).

[e] Other motorised mode(s) (including combinations).

4. Discussion

4.1. Comparison with other studies

The purpose of this study was to examine patterns in transport to school modes by distance to school and across settlement types in the Otago region, New Zealand. There are three main findings from this research. First, transport patterns to school differed significantly across 'walking', 'cycling' and 'beyond cycling' distance to school categories. There were lower ATS rates and higher rates of motorised transport and some mixed transport modes with increasing distance, as expected given that distance to school is the strongest correlate of ATS in adolescents (McDonald, 2007; Ikeda et al., 2018; Mandic et al., 2015). Secondly, transport user groups had distinct sociodemographic and family characteristics, on average lived at different distances from their school and exhibited group-level differences in self-reported physical activity and perceived health. Thirdly, transport patterns to school varied across settlement types and these variations were present within the three distance to school categories.

A novel contribution of this study is demonstrating moderating effects of distance on adolescents' transport to school patterns within 'walking', 'cycling' and 'beyond cycling' distance categories in a large sample of adolescents from diverse settlement types. In addition to emphasising the importance of addressing factors that increase the distance adolescents travel to secondary schools such as school location, sprawling urban areas (Stephenson et al., 2017; Early et al., 2015) and educational policies that support school choice (Ladd and Fiske, 2001), the findings presented in this paper have implications for planning, implementation, monitoring and evaluation of ATS initiatives and programmes (Mandic et al., 2017; Pocock et al., 2019; Mandic et al., 2020). Our findings emphasise the importance of mode-specific interventions being implemented within mode-specific feasible distance from school and for target group(s) who live within that mode-specific distance from their school (see Implication section below for more details).

Adolescents' transport to school patterns also differed significantly across settlement types and, importantly, those differences were apparent even among adolescents living within the separate distance to school categories. Since ATS behaviour is context-specific, differences in travel behaviour across different settlement types are expected. Few studies have previously examined adolescents' mobility in rural settings (McDonald, 2007; Pabayo et al., 2011; Babey et al., 2009; Mandic et al., 2015; Booth et al., 2007; Dalton et al., 2011). Interestingly - and perhaps counterintuitively - this study shows that adolescents in the large urban area had *higher* rates of private car transport to school compared to their counterparts in medium and small urban areas and rural settlements. This may reflect urban adults' car-driving patterns and their ability to trip chain for school drop-offs and/or pick-ups as part of their travel to other destinations (e.g., work) (Keall et al., 2020). However, these findings need to be interpreted taking into account the specific geographic context in which the empirical material were collected. The large and medium urban areas of the Otago region of New Zealand where this study was conducted have limited provision of public bus transport and no rail transport. In areas where there is no suitable public transport, New Zealand's Ministry of Education funds free school buses for adolescents living more than 4.8 km from their school (Ministry of Education, 2018). In the large urban area (Dunedin), the cost of the existing fare-based public bus service is one of the major barriers for adolescents using public bus for school travel (Mindell et al., 2021). Therefore, although Otago adolescents living in urban areas with available public buses and a conducive built environment may have a greater access to alternative transport modes for school travel, the cost of bus travel to school was not equal across different settlement types. This inequality in bus transport cost may in part contribute to greater reliance on private vehicle transport to school in the large urban area compared with smaller settlement types observed in this study.

Most (McDonald, 2007; Pabayo et al., 2011; Babey et al., 2009) but not all (Mandic et al., 2015; Booth et al., 2007) previous studies reported higher rates of ATS among adolescents in urban versus rural areas, which may be at least partially explained by differing definitions of rural areas used. In this study, however, ATS rates were similar across *all* settlement types, ranging from 25% to 30%.

Our study confirmed characteristics reported elsewhere of adolescents who use different travel modes. Most adolescents who walked to school lived within what is considered to be 'walkable' distance ($\leq$2.25 km); our findings are consistent with previously reported sociodemographic, family and environmental correlates of adolescents' walking to school (Mandic et al., 2015; Martin et al., 2007).

Male gender (Reimers et al., 2013; McDonald, 2012; Leslie et al., 2010) and bicycle ownership (Grize et al., 2010) were positive correlates of adolescents' cycling to school in previous studies and in ours. Consistent with our findings, previous studies reported higher levels of fitness in adolescents who cycle to school compared with walkers and users of motorised transport (Larouche et al., 2014), and a higher odds of reporting very good or excellent health among physically active adolescents compared with their non-cycling peers (Tremblay et al., 2003). Cyclists in the Otago region on average lived further from school than walkers but closer than motorised and mixed transport groups, which is also consistent with greater reasonable distances for adolescents' cycling (Nelson et al., 2008; Bere et al., 2008; Van Dyck et al., 2010; D'Haese et al., 2011) compared with walking to school (Pocock et al., 2019; Nelson et al., 2008; Bere et al., 2008; Chillón et al., 2015).

Previous studies found female gender, high socioeconomic status and more vehicles in a household to be negative correlates of ATS in adolescents (Babey et al., 2009; Mandic et al., 2015), as did we. Using accelerometer-measured physical activity, adolescents relying on motorised transport to school had lower levels of moderate-to-vigorous physical activity compared with their peers who used active or mixed modes (Kek et al., 2019). In our study one-fifth of car users lived within walking distance to school and another quarter lived beyond walking but within cycling distance to school. This finding is not surprising, given the New Zealand context with the country's transport system being dominated by private vehicles (Ministry of Transport, 2015) and adolescents showing an on-going preference for car-based transport (Hopkins et al., 2019).

Given that public transport travel usually involves use of active transport modes on either end of the journey and can contribute to adolescents' physical activity (Durand et al., 2016; Voss et al., 2015), it was disappointing that we found that adolescents who travelled to school by bus had the lowest proportion self-reporting meeting physical activity guidelines. This could be related to the barrier distance to school and other sporting opportunities. It could also reflect the availability of parents with cars to transport their adolescents to school and other destinations. The profile of bus users in this study needs to be interpreted within the local transport context described above. Some schools also fund their own school buses to attract students from different areas. Students travelling by school buses are dropped and picked up directly outside the school, limiting opportunities for physical activity at one end of the bus trip.

Mixed transport users that combined bus travel and walking had nearly twice the proportion of adolescents self-reporting meeting physical activity guidelines compared with bus only users, despite similar sociodemographic and family characteristics. A study using accelerometers and global positioning systems (GPS) in adolescents from Vancouver, Canada, found that school travel-related walking portions of transit trips had similar distance and duration to walking only trips and that walking distance was associated with adolescents' moderate-to-vigorous physical activity in a dose–response manner (Voss et al., 2015). Adolescents accumulated an additional 1 min of moderate-to-vigorous physical activity for every additional ~100 m they walked as part of school-travel (Voss et al., 2015). Another study found higher levels of accelerometer-measured daily physical activity in adolescents who used ATS only or combined active and motorised transport to school compared with their counterparts who relied solely on motorised transport (Kek et al., 2019). Therefore, using active transport modes as part of the school journey, even if combined with motorised transport modes, provides an opportunity for adolescents to accumulate physical activity, especially if active transport portions of public transport trips are of sufficient distance and/or duration.

4.2. Implications

Our findings suggest that initiatives and programmes aimed at increasing walking and cycling to school may be most effective if designed, implemented, monitored and evaluated focusing on adolescents who live within a reasonable walking or cycling distance from their school. If such initiatives also intend to encourage walking and cycling to school among adolescents who live beyond walkable or cyclable distance, it could be beneficial to tailor initiatives to the needs of those adolescents (and their parents) and minimise their barriers to walking or cycling to school (e.g., setting up safe drop-off and pick up points within reasonable but not too short walking distance to school along safe walking routes (Rahman et al., 2020)).

Although combining car travel with walking is preferrable to relying solely on private vehicle travel to school, encouraging walking and/or cycling to school and disincentivising car travel among adolescents living within walking or cycling distance to school is particularly important from a public health perspective to contribute to maintaining and/or increasing physical activity in adolescents (Khan et al., 2021; Larouche et al., 2014), and can contribute to minimising the gender gap in adolescents' physical activity levels since females are generally less physically active than males (Guthold et al., 2020).

Monitoring and evaluation of mode-specific initiatives and programmes would also need to focus on intervention-specific target group(s) as well as the overall population. In other words, monitoring and evaluation of initiatives and programmes such as pedestrian and cycling infrastructure improvements along school routes, changes in school neighbourhood built environment, and even interventions focused on improving social support for walking and cycling are likely to underestimate potential benefits if the monitoring and evaluation does not consider stratification or similar approaches to understand impacts for target group(s) who are likely to benefit from such interventions (i.e., adolescents living within reasonable mode-specific distance to school and/or those living within the area(s) affected by such initiatives). This is particularly important in places where a large proportion of adolescents live beyond walking and/or cycling distance to their school.

The transport to school user profiles identified in this study demonstrate the importance of tailoring future interventions to target specific transport user groups (such as adolescent girls) and collecting and analysing mode-specific transport to school data (rather than using generic terms of 'active' and 'motorised' transport) for understanding the local context (Mandic et al., 2017; Mandic et al., 2020). These findings also contribute to the current debate regarding the use of the term 'active transport' for bus users given that public transport journey usually involves use of active transport modes such as walking, cycling and scooting on either end of the journey (Durand et al., 2016; Voss et al., 2015). Such categorisation should consider the local context and may be appropriate in large urban areas where only public transport to school is available to adolescents. However, categorising bus travel to school as an active transport mode may not be appropriate in geographical settings where government- or school-funded school buses are operating and collecting adolescents in the vicinity of their homes and taking them to the school gate (such as in New Zealand), unless school bus users are excluded from the analyses.

The findings from this study provide valuable practical insights into how home-to-school distance and settlement types affect transport to school patterns of adolescents, and which groups appear more likely to benefit from interventions to encourage walking and cycling to school based on where they live. However, additional research is needed to help make more firm policy recommendations. Notably, in addition to well-designed cross-sectional studies using large samples of adolescents and controlling for a variety of relevant confounding factors, studies using longitudinal designs, natural experiments, quasi-experimental methods and simulations are required.

4.3. Study strengths and limitations

Study strengths include a large sample size of adolescents living in different settlement types including non-urban settings; 85% school participation rate across the region; distance to school obtained using GIS-based network analysis; differentiating dominant transport modes including common mixed modes combinations; analysis of transport patterns to school by distance to school category and across different settlement types; and analysis of the transport user group profiles.

Limitations include a smaller sample size of adolescents attending schools in rural settings; lack of detail on time and/or distance for each mode for mixed transport users; lack of differentiation between public and school bus users; a self-reported measure of physical activity; not attending to ethnic and socio-economic differences in mobility patterns; no data on air pollution and noise pollution; and a cross-sectional study design which prevents exploring causality. In addition, though beyond the scope of this article (Smith et al., 2021), this study did not explore alternative methods for calculating the path taken from home to school, including GIS walkable network-based quickest path, GNSS (Global Navigation Satellite Systems – the current generic name for satellite-based positioning technologies such as GPS) -captured paths and participant-reported paths via analogue or digital sketch maps (Smith et al., 2021; Stewart et al., 2017; Ikeda et al., 2018). Therefore, no information is available on whether or not adolescents took the shortest path to school or an alternative route, though a thorough investigation of path measurement means and associated parameters (following on from findings relating to travel mode (Stewart et al., 2017) and street versus walkable network types (Ikeda et al., 2018)) is warranted. Also beyond the scope of this paper is a full spatial analysis based on this dataset, some of which has been performed and reported on elsewhere (Chen et al., 2021).

Although transport to school is context-specific behaviour and therefore findings from this study may not be generalisable to diverse geographical locations within New Zealand or in other countries, the results of this study are consistent with previous research and provide further insight into adolescents' travel patterns by distance and across settlement types. Future studies should focus on examining correlates of walking and cycling to school among adolescents living within mode-specific reasonable distance from their school in different settlement types. In addition, studies should also address the challenge of understanding mixed transport users based on more detailed travel to school data, which in most cases lack detailed information on the proportion of time or distance and/or amount of time that adolescents use for each of the transport modes. Future studies could also use multivariate analysis to examine how travel mode to school varies by home-to-school distance, settlement types and other relevant factors like gender.

5. Conclusion

Adolescents' transport patterns to school vary by distance to school and across settlement types. Different transport user groups were characterised by specific sociodemographic and family characteristics, environmental factors, health behaviours and perceptions of health, which may be related to their transport choice decisions. These findings suggest the importance of mode-specific interventions implemented within mode-specific feasible distance from school and tailored to specific transport user target group(s) to minimise their ATS-related barriers. The differences between walking and cycling characteristics signal the importance of moving away from the umbrella term of 'Active Transport', particularly in terms of interventions to increase uptake. It is also important to note that walking and cycling are not the democratising modes they are often positioned to be, and the ableist discourses of incentivising walking and cycling as a panacea need to be critically assessed in the design of interventions in all settlement types, as well as paying attention to the gendered – as well as racialised and socio-economic mobility patterns of all people, including high school students and their families. Taken together, these findings have implications for planning, monitoring and evaluation of initiatives and programmes aimed at promoting ATS and reducing private vehicle travel for school trips.

Data statement

Data used in data analysis for this project will not be shared due to sensitivity of the collected data as well as participants having been given assurances that the collected data will not be shared.

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Author statement

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Declaration of competing interest

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 conflict of interest.

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