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Implications of attending the closest school on adolescents' physical activity and car travel in Dunedin, New Zealand

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ABSTRACT

Background: Home-to-school distances and the need for students to be driven to/from school may limit adolescents' physical activity levels. School choice and school zoning policies can influence rates of active transport to/from school, and traffic volumes during school commuting times. This study aimed to quantify the effects of adolescents' enrolment in the closest school or not, on private vehicle use and adolescents' physical activity levels in Dunedin city, New Zealand.
Methods: New Zealand Travel Survey data (2003–2013; 2493 Dunedin respondents) were analysed to examine school-travel related private motorised trips. Dunedin-specific data from adolescents (from six Dunedin non-integrated public schools without school zoning) were analysed including self-reported survey data on school travel modes (797 adolescents), distance to the current and closest schools (797 adolescents) and accelerometer-measured moderate-to-vigorous intensity physical activity (MVPA) (121 adolescents).
Results: During the school commute time (8–9 am and 3–4 pm), an estimated 11.5% of car trips (95% CI 7.8%–16.8%) and 12.5% of car distance driven (95% CI 8.8%–17.7%) were related to secondary-school travel with approximately half of these involving trip-chaining. Compared to adolescents living beyond cycling distance (>4 km) from their current school, adolescents living within walkable distance (≤2.25 km) and cyclable distance (>2.25-≤4 km) accumulated an additional 12.1 min (95% CI 7.0 to 17.2) and 6.1 min (95%CI 1.0 to 11.2) of daily MVPA during the school commute time, respectively. If adolescents currently enrolled at a distant school were to attend the closest school, they could accrue an additional 3.4 min MVPA during the 2-h school commute time period and school travel-related private car trips would be reduced by 7%.
Conclusions: In Dunedin, New Zealand, modest reductions in private vehicle traffic, particularly around schools, and increases in adolescents' MVPA during the school commute period would be expected if all adolescents attended the closest school.

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1. Background

Physical inactivity among adolescents is a common health issue worldwide (Kohl et al., 2012), including in New Zealand (Smith et al., 2018). Travelling to school by car reduces the opportunities for adolescents to engage in physical activity. However, rates of adolescents travelling to and from school using private cars have increased in many high-income countries (McDonald, 2007). In Aotearoa New Zealand (hereafter referred to as NZ), rates of car-based transport to high schools have increased from 21% in 1989/1990 to 32% in 2010–2014 (Ministry of Transport, 2015a). Low levels of active transport to and/or from school (ATS) are concerning, given the established connections between ATS and health (Faulkner et al., 2009).

Adolescents using ATS have higher levels of moderate-to-vigorous physical activity (MVPA) compared to their peers who rely solely on motorised transport to school (Saksvig et al., 2007; Simons et al., 2017), even if active transport is combined with motorised transport within a single journey (Kek et al., 2019). In addition, relative to ATS, travelling to school by car increases traffic congestion around school start/finish times, increases carbon and particulate emissions, contributes to noise pollution, and increases road injury risk (Maizlish et al., 2013). Travelling to and/or from school by car may also have long-term consequences since transport habits established during adolescence may carry over into adulthood (Simons et al., 2017).

Distance from home to school is the strongest predictor of ATS (Ikeda et al., 2018; McDonald, 2007). School choice policies that do not require adolescents to enrol in their closest school are likely to contribute to reduced rates of ATS, as school choice increases distances children and adolescents travel to school (He and Giuliano, 2018; Mandic et al., 2017c). Indeed, higher rates of ATS among students who enrolled at a local school compared to a more distant school have been reported in different countries where school choice policies are in place, including the United States (Marshall et al., 2010; Yang et al., 2012), England (Van Ristell et al., 2013) and NZ (Mandic et al., 2017c). In Dunedin, NZ – our case study city – adolescents who enrolled in the closest school had three times higher rates of walking as a part of their journey to school, five times higher rates of using ATS only and lower rates of reliance solely on motorised transport to school compared to adolescents who did not enrol in the closest school (Mandic et al., 2017c). Another consideration, at least in NZ, is urban adolescents' ongoing preference for car-based transport and reported intentions to learn to drive (Hopkins et al., 2019).

While school zoning policy that requires students to attend their closest school has the potential to increase adolescents' physical activity levels by increasing rates of ATS, assumptions underlying the potential benefits of this policy require closer scrutiny. For instance, for many adolescents, travel to school behaviours are related to wider family travel practices. Parents and caregivers may chain trips together, for example, dropping off and/or picking a child at school on their way to and/or from another destination. This practice is known as 'trip chaining', with small segments combined into a larger 'trip', which is usually anchored at home or work (Islam and Habib, 2012). Motorised car-based transport is usually the preferred mode for trip chaining, as it offers greater flexibility than public transport modes, and greater speed than active modes (Daisy et al., 2018; Primerano et al., 2008), even for shorter distances, which would be considered 'walkable' (Carver et al., 2013).

The implication is that adolescents may be transported to school as part of a 'chain', or sequence of connected trips, with home to school representing only one part.

Trip chaining is not homogenous, but takes multiple temporal and spatial forms; and the more complex the series of trips becomes, the more likely that preferred travel mode options are flexible and convenient (Hensher and Reyes, 2000 p.341). In primary school children, adult accompaniment and longer onward distances (such as a parent continuing to a more distant workplace) in a trip chain were associated with lower rates of ATS, suggesting that both the chain itself and the distance involved presented an important barrier to ATS (Carver et al., 2019). Buliung et al. (2011) found that weather, convenience and chained activities (i.e. driving children to school en-route to work) were the most difficult barriers to overcome. While weather is likely to have temporal dimensions (e.g. vary by day, month and/or season), convenience and trip chaining are likely to be more sustained reasons for choosing private motor

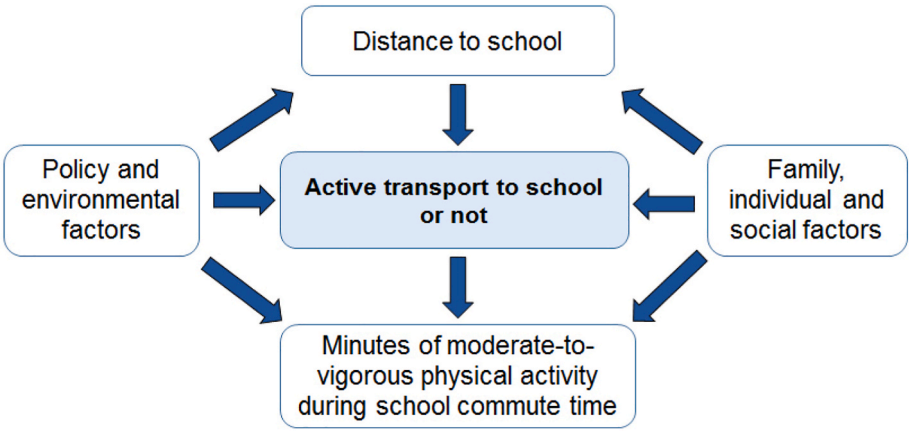

Fig. 1. Simplified influence diagram relating distance to school with moderate-to-vigorous intensity physical activity (MVPA) minutes during school commute time, mediated by whether the trip to school was active (ATS) or not.

vehicle travel over active travel. As distance to school increases, parents more frequently report that the convenience of driving adolescents to school as part of trip-chaining practices is one of the barriers to ATS (Mandic et al., 2020).

The research presented in this paper quantifies the effects of adolescents' school enrolment (i.e. closest school or not) on traffic volumes, and MVPA of adolescents in the city of Dunedin, NZ. Underlying the analysis is the recognition that travel to school mode choice is part of a complex system (Macmillan et al., 2020) characterised by many factors interacting in often changing ways affected by other features of the system (e.g. school zoning policy, urban design, public transport infrastructure, adolescent and familial behavioural norms) (Pont et al., 2009; Spence and Lee, 2003). We examine aspects of this complex relationship through an investigation of trip chaining behaviours in the trip to/from school along with modelling of the associations between home-to-school distance and MVPA. Key to this latter analysis is the theorised relationship between distance to school and mode choice for the trip to school, represented in a simplified form by Fig. 1. This is the basis on which we estimate the associations between distance to school and MVPA minutes during school commute time mediated by mode choice and influenced by other factors, only some of which can be modelled.

2. Methods

2.1. Setting

Dunedin (population: 126,000) is the second-largest city in the South Island of NZ and home to NZ's oldest university. The multiethnic population (9.3% Maori, 3.2% Pacific peoples, 7.8% Asian, and 2.9% other ethnicities) has a large number of tertiary students (Statistics New Zealand, 2018). Topographically, Dunedin is characterised by a harbour surrounded by hills with many suburbs reaching 200 m above sea level. The city has 12 secondary schools, none of which are private. The six non-integrated public schools without school zoning were included in this analysis (three co-educational, two single sex boys and one single sex girls' school). Four integrated/special character schools[1] (in most cases based on religion) and two with school zoning were excluded.

2.2. New Zealand household travel survey (NZHTS) data

Dunedin-specific NZHTS data (Ministry of Transport, 2007) collected throughout the year between mid-2003 and mid-2013 from adolescent drivers and adults transporting school students (age 12–18 years) as car passengers were analysed. We examined trips made both before and after the home-school trip to explore whether the car trip purpose was only related to transporting adolescents to school or involved travelling to other destinations (i.e., trip chaining). The number of participants in the annual national survey of travel behaviour from Dunedin each year was relatively small (range: 111–472 respondents/year). Therefore, eleven years of data to reduce the variability in the estimates was required. Data on adolescent travel to/from school studied here consisted of 152 trips reported from 40 households.

The survey data were clustered within meshblocks, the primary sampling units (each approximately the size of a city block), and then within households subsampled from the meshblocks. Detailed travel behaviour data for two specified days of the year were collected via face-to-face interviews, and travel diaries kept by the participants. The annual response rate was 65%–70% (Ministry of Transport, 2007).

2.3. BEATS study data

Adolescents from all 12 secondary schools in Dunedin city participated in the Built Environment and Active Transport to School: BEATS Study in 2014–2015 (Mandic et al., 2015, 2016). Details on the recruitment of schools and adolescents have been described elsewhere (Mandic et al., 2016). Briefly, adolescents were recruited through their schools and they provided written consent before taking part in the study. For those aged under 16 years, parents consented following opt-out or opt-in procedures based on the school's preference. The study was approved by the University of Otago Human Ethics Committee (Reference 13/203).

A total of 1780 adolescents completed the BEATS Student Survey online during class time, supervised by research staff (Mandic et al., 2016). The survey included questions about sociodemographic characteristics, home address, transport to school habits, reasons for school choice and whether adolescents enrolled in their closest secondary school (Mandic et al., 2016, 2018c). Socioeconomic status was measured by the New Zealand index of deprivation (NZDep) (Salmond and Crampton, 2012), derived from Census data collected at the level of meshblocks, which are the smallest geographic units for which statistical data is reported in NZ, with a median size of around 90 people (Salmond and Crampton, 2012). This study included analysis of adolescent survey data from 797 Dunedin adolescents (mean age: 15.2 years; 51.4% boys) who attended one of six non-integrated public secondary schools without school zoning at the time of data collection (Fig. 2). An example of an invalid survey was inconsistent travel to school responses where students nominated several different modes of transport as being used "most of the time" or "all of the time".

2.3.1. Home-to-school distance data

Using student home address data self-reported in the BEATS Student Survey, distance from home to school was determined using

[1] In New Zealand, integrated schools are formerly private schools that have become part of the state system. They have a special character, philosophical or religious, but teach the New Zealand curriculum. See http://parents.education.govt.nz/primary-school/schooling-in-nz/different-types-of-primary-and-intermediate-schools/.

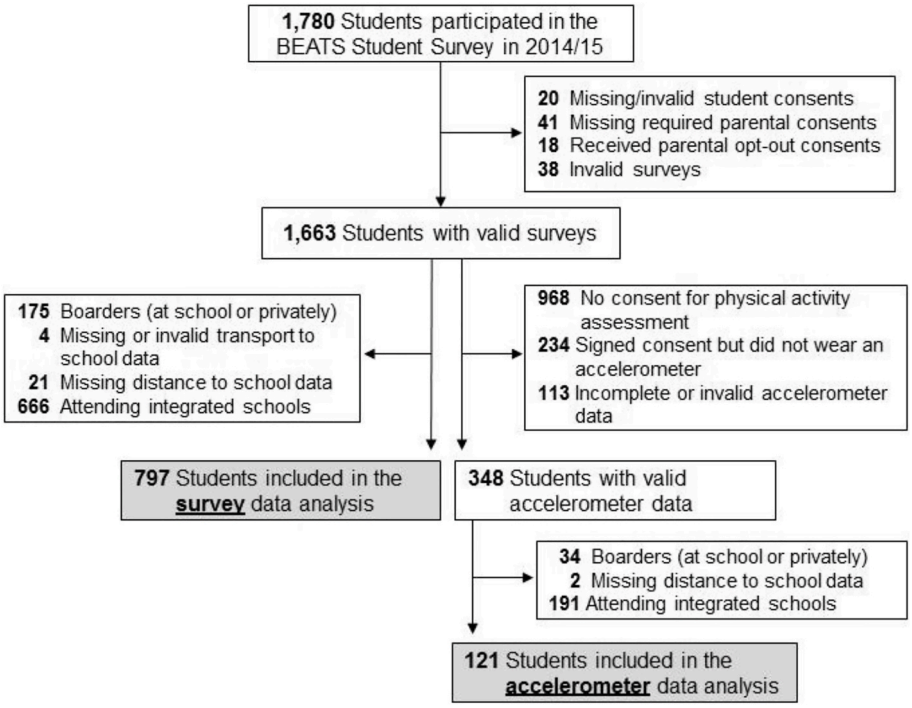

Fig. 2. Flowchart of adolescents' completion of BEATS student survey and accelerometer assessments for inclusion in this analysis.

Geographic Information Systems shortest path network analysis, as described previously (Mandic et al., 2016). For each adolescent, home-to-school distance was calculated for their current school and their closest of the six non-integrated schools without school zoning, taking into account participants' gender and the co-education status of schools (Mandic et al., 2017d). The closest school was determined based on comparing the distance to the current school and closest school for each participant (Mandic et al., 2017d). Home-to-school distances were categorised as 'walking distance' ($\leq$2.25 km), 'cycling distance' (>2.25 and $\leq$ 4.0 km) and 'beyond cycling distance' (>4.0 km) based on previously published work for reasonable walking (Pocock et al., 2019) and cycling (Nelson et al., 2008) distances to school for adolescents.

2.3.2. Transport to school

Adolescents self-reported their transport to school habits in the BEATS student survey by responding to a question *"How do you usually travel to school?"* for different transport modes with response categories *"never"*, *"rarely"*, *"sometimes"*, *"most of the time"* and *"all of the time"* (Mandic et al., 2017b). Dominant modes of transport to school (used "most/all of the time") and multi-modal transport were used to classify adolescents into ATS (walking, cycling, or riding a non-motorised scooter "most/all of the time"), motorised transport or mixed modes (Mandic et al., 2017b).

2.3.3. Accelerometer-measured physical activity

A subgroup of adolescents wore an accelerometer (ActiGraph, GT3XPlus, Pensacola, FL, USA) above the right hip for seven consecutive days, as described previously (Kek et al., 2019). Briefly, participants were given their device and verbal and written instructions at school. To promote compliance, participants were given a log to record the wear/removal times and reasons, and sent e-mails/text reminders to complete the log. Accelerometer data were downloaded using ActiGraph software (ActiLife 6) and stored in 10-s epochs to detect short bursts of vigorous PA. The wear time validity was set at $\geq$5 days with $\geq$10 h/day (inclusive of $\geq$3 school days and $\geq$1 weekend day) (Corder et al., 2008; Riddoch et al., 2004). The wear time validity for one hour before school (08:00–09:00 h) and one hour after school (15:00–16:00 h) was set at $\geq$75% of wear time for each period (Kek et al., 2019). Data were analysed by MeterPlus Data Analysis Service (MeterPlus, San Diego, CA, USA) in 2016 using Evenson cut points (Evenson et al., 2008) and included total minutes of accumulated physical activity. Non-activity periods were determined based on 20-min or more bouts of inactivity (Cain et al., 2013). Accelerometer-derived variables included average physical activity (light, moderate, vigorous, MVPA) and sedentary time per day, school day and weekend day and one hour before and after school, accounting for school-specific start/end times. Participants who accumulated $\geq$60 min of MVPA/day on all valid days met the minimum PA guidelines (Tremblay et al., 2016). Data from 121 adolescents with valid accelerometer data who attended one of the six non-integrated public secondary schools without school zoning were analysed (Fig. 2). In comparison with the students who completed the survey, a higher proportion of students who wore an accelerometer were NZ European (73% vs. 83%) and a lower proportion were of Māori descent (15% vs. 5%) whereas no difference was found in age, gender, neighbourhood level deprivation or main mode of transport to school between the two groups

(data not presented).

2.4. Data analysis

2.4.1. Trip chaining (NZHTS data)

Using the NZHTS detailed travel data, home-school car trips were analysed based on whether they were chained to other trips/destinations or not, using the labels shown in Table 1. As this analysis was concerned with the impact of the private motor vehicles themselves, trips by private motor vehicles carrying more than one secondary school student were counted as single trips.

When a special trip was made involving the driver taking their school-aged passenger to school and then returning home (or driving from home to pick up the adolescent before returning home), trips were labelled as "**home**" to signal the principal origin or destination of the trip (apart from the school).

2.4.2. Models to estimate proportion of all private motor vehicle travel

Using NZHTS school-related car trip data, models were fitted using SAS (SAS Institute Inc, 2014) to estimate rates of private motor vehicle trips per trip purpose using a generalised linear model with a log link function and binomial distribution, called log-binomial regression by Blizzard and Hosmer (2006). Generalised Estimating Equations were used to specify the clustered data structure (within meshblocks, as described above) to estimate confidence intervals appropriately.

2.4.3. Time spent in MVPA regression models

BEATS Study accelerometer data for adolescents' time spent in MVPA during the school commute period (8–9 am and 3–4 pm) was approximately normally distributed (the Kolmogorov-Smirnov test goodness-of-fit test for the normal distribution had a P-value>0.15). Therefore, these data could be modelled appropriately using the SAS procedure GENMOD (SAS Institute Inc, 2014) using the identity link function that fits an additive model. The outcome variable MVPA minutes during the school commute time was fitted, with explanatory variables: enrolled at closest school or not, distance from home to school, gender, ethnicity, NZDep, and age (as shown in Table 4).

For the explanatory variables, the average school day MVPA minutes accumulated during the school commute time were estimated relative to a reference level (set as zero). The intercept value estimates the mean MVPA minutes for adolescents who were classified by all the reference levels of the variables (enrolled at closest school; more than 4 km from home to school; etc).

3. Results

Table 2 shows the results of NZHTS analysis of school-related private motor vehicle trips in Dunedin where adolescents were either driven or drove themselves between home and school. Half of the car trips related to school travel were home-school-home trips. Those trips accounted for 43% of distance of all school travel-related car trips with a mean home-to-school distance of 4.8 km (which is 0.8 km less than the mean distance for all school-related car trips in Dunedin).

These school travel-related private motor vehicle trips were then analysed in the context of all private motor vehicle travel occurring in the periods before and after school, on all weekdays excluding the month of January, which is a school summer holiday month in NZ. The results showed that approximately 11.5% of private motor vehicle trips (95% CI 7.8%–16.8%) and 12.5% of distance driven by private motor vehicles (95% CI 8.8%–17.7%) of all Dunedin private car trips that either occurred (started and finished) during the 8am–9am or during the 3pm–4pm periods were related to adolescents' travel between school and home.

Using the BEATS Study data, among Dunedin adolescents who did not attend their closest school, 42% lived >4 km from any school, whereas 36% lived within 2.25 km (walkable distance) and 22% lived within 2.25–4 km (cycling distance) from the closest school (Table 3).

As the distance to school increased, the rates of ATS decreased from 62% within walkable distance to 24% within cycling distance and 2% beyond cycling distance to school with the corresponding increase in the proportion of private motor vehicle travel to and from school (Fig. 3).

A minority of the estimated parameters were statistically significant (with 95% CIs not including zero) in explaining time spent in MVPA over the two hours of school commute time when the other variables were controlled for. The strongest predictor was home-to-

Table 1
Classification of school-related car trip types (NZHTS data analysis).

Trip type	Description
Home trip	Home → School → Home
Work trip	Home → School → Work *or* Work → School → Home
Other trip	Home → School → Other *or* Other → School → Home
Self-driven trip	Home → School *or* School → Home (Adolescent drove self)
Not household driver trip[a]	Details unknown (no data on driver's travel before or after)

[a] If the driver with an adolescent passenger on their way to/from school was not a participant in the NZHTS survey (i.e., not members of the surveyed household), then no other details were available about prior or subsequent destinations apart from the adolescents' journey to or from school.

Table 2
NZ Travel Survey data for Dunedin (2003–2013) for secondary school-related journeys by private motor vehicles.

Trip type	Proportions of trips [weighted % (n)]	Proportions of trip distance	Mean home-to-school distance
Home[a]	50% (68)	43%	4.8 km
Work[a]	12% (23)	9%	3.9 km
Other[a]	15% (21)	10%	3.6 km
Not household driver[b]	16% (28)	33%	11.4 km
Drive self	6% (12)	6%	5.7 km
Overall	100% (152)	100%	5.6 km

[a] Subsequent destination (for trips to school) or prior trip origin (for trips home) of the driver. These were unknown for non-household drivers.
[b] Drivers not members of surveyed households provided no information on trip chaining.

Table 3
Proportion of Dunedin adolescents by home-to-school distance categories and enrolment at closest school or not (Source: BEATS Student Survey, 2014/2015).

Distance from home to school	Students enrolled in the closest school [% (n)]		Students NOT enrolled in the closest school [% (n)]	
	Actual school	Closest school	Actual school	Closest school
Within walkable distance (<2.25 km)	64% (260)	64% (260)[a]	6% (24)	36% (139)
Cyclable distance (2.25–4 km)	19% (78)	19% (78)[a]	24% (95)	22% (86)
Beyond cyclable distance (>4 km)	17% (71)	17% (71)[a]	69% (269)	42% (163)
TOTAL	100% (409)	100% (409)	100% (388)	100% (388)

[a] Home-to-school distance data for students enrolled at the closest school are the same for the actual and closest school.

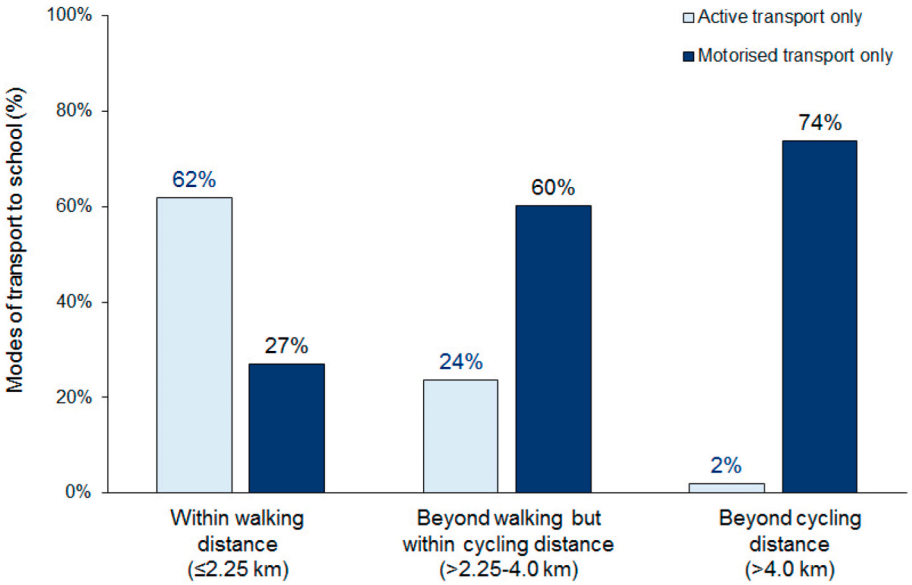

Fig. 3. Percentage of adolescents travelling to and from school on most or all days using active travel to school (ATS) or private motor vehicle in relation to distance from home to school (Source: BEATS Student Survey, 2014/2015). Note that mixed modes (combination of active and motorised transport) are not represented here.

school distance. The parameter estimates shown in Table 4 show students living within a walkable and cyclable distance from school accumulated additional 12.1 min of MVPA/school day (95%CI 7.0 to 17.2) and 6.1 min of MVPA/school day (95%CI 1.0 to 11.2), respectively, during the school commute period compared to those living beyond cyclable distance to school (>4 km).

Only two other variables approached statistical significance: Māori ethnicity and the age group 14–15 years compared to the reference group (16–19 years). Māori students accumulated eight MVPA minutes more during the school commute time than NZ European adolescents, and 14-15-year- olds accumulated approximately five additional minutes of MVPA compared to 16-19-year-olds. The usual mode of transport was not included in the model, even though the data were available, as we were interested in the direct effect of distance to school on physical activity levels that arise (presumably) from ATS as represented diagrammatically in Fig. 1. An additional interaction term was fitted (parameter estimates not shown) to see whether there was a different association between the categories of home-school distance and daily MVPA minutes accumulated during the school commute period for those

Table 4
Estimated coefficients from modelling BEATS data on the average number of minutes of MVPA in the hour before and hour after school combined.

Variable	Category	Parameter estimate (95% CI)
Intercept	[a]	8.7 (1.5, 16)
Enrolled at closest school?	No	4.6 (0.1, 9.1)
	Yes	0 (Reference)
Distance home to school	Walkable (≤2.25 km)	12.1 (7.0, 17.2)
	Cyclable (>2.25–4.0 km)	6.1 (1.0, 11.2)
	>4.0 km	0 (Reference)
Gender	Male	1.4 (−2.3, 5)
	Female	0 (Reference)
Ethnicity	Māori	8.4 (−0.1, 16.9)
	Other	0.1 (−5.3, 5.6)
	New Zealand European	0 (Reference)
Age	12–13 years	1.7 (−3.4, 6.8)
	14–15 years	5.1 (0.1, 10.2)
	16–19 years	0 (Reference)
Neighbourhood deprivation score	1-2 (least deprived)	0.1 (−5.9, 6.1)
	3–4	1.4 (−4.7, 7.5)
	5–6	2.0 (−4.2, 8.2)
	7–8	−1.5 (−8.3, 5.2)
	9-10 (most deprived)	0 (Reference)

[a] The intercept provides an estimate for average minutes of MVPA for students in the combined set of reference categories: enrolled at closest school; more than 4 km from home to school; NZ European; residing in most deprived area quintile.

enrolled at the closest school compared to those not enrolled at the closest school, but there was no evidence that these associations were different (P = 0.32).

The parameter estimates regarding home-to-school distance in Table 4 were combined with the estimates presented in Table 3 to model the additional daily minutes of MVPA during the school commute period per student that might accrue if the students attended the closest school (and perhaps used ATS at a higher rate because of the reduced distance to school). It was estimated that, on average, each student not enrolled at their closest school would undertake an additional 3.4 daily minutes of MVPA during the school commute time if they were to attend their closest school. Similarly, if home-to-school distance is assumed to be the main determinant of private motor vehicle usage in the trip to and/or from school, then if these students were to enrol at their closest school, there would be a 7% city-wide reduction in private motor vehicle trips to and/or from school overall.

4. Discussion

This study examined MVPA levels during the school commute period amongst adolescents in relation to distance to school and their attendance or not at the closest school. Adolescents living within walking distance from school (≤2.25 km) accumulated an additional 11.5 min of MVPA daily during school commute period (95%CI 6.6–16.5) and those living beyond walkable distance, but within a cyclable distance (>2.25–4.0 km) accumulated an additional 5.5 min of MVPA daily during the school commute period (95%CI 0.6–10.4) compared to those living beyond cyclable distance to their school (>4 km). This accumulation of additional MVPA during the school commute time appeared to be eight minutes greater for Māori students compared with the other ethnic groups.

Cycling is an uncommon mode of transport to school for NZ adolescents, constituting only about 3% of such trips nationally (Ministry of Transport, 2015b). The current analysis of ATS rates by distance to school categories shows that although Dunedin adolescents living beyond walkable but within cycling distance to their school (>2.25–4.0 km) are theoretically able to cycle to school, the rates of ATS and cycling to school within that distance are very low suggesting more complex factors at play. In the NZ context, cycling to school is perceived as less safe by both adolescents and their parents, and receives less social and infrastructure support compared to walking to school (Mandic et al., 2017b, 2020). A complex range of factors contributes to adolescents' and their parents' perceptions of safety of cycling in NZ, including features and perceptions of the built environment, traffic safety, previous cycling experiences and adolescents' cycling skills and on-road experiences (Hopkins and Mandic, 2017; Mandic et al., 2017a, 2018a) and such perceptions differ based on how far adolescents live from their school (Mandic et al., 2020). Parental perceptions of time constraints associated with cycling to school and cycling-related safety concerns became more pronounced with an increase in home-to-school distance (Mandic et al., 2020). In additional, natural environment factors (e.g., hills and inclement weather), school factors (e.g., school uniforms and school bag weight) and as well as policy factors represent barriers to cycling to school even when adolescents live within reasonable distance for cycling to school (Hopkins and Mandic, 2017; Mandic et al., 2017b, 2018b). Taken together, a complex set of factors influences NZ adolescents' and their parents' decisions related to cycling to school, even when they live within reasonable distance to school, which may contribute to preferences for private vehicle travel often involving trip chaining, as observed in this study.

To quantify the effects of adolescents' enrolment in the closest school (or not), we examined the role of private vehicles in the trip to and from school for adolescents in Dunedin, NZ. Such trips play an important role in the traffic of the city, particularly in the immediate neighbourhood of schools. During the school commute time (assessed in this study as the hour immediately before school and the hour

after school), approximately 11.5% of trips (95% CI 7.8%–16.8%) and 12.5% of distance (95% CI 8.8%–17.7%) were for the purpose of adolescents' travel between school and home. As only 0.3% of the NZ light passenger vehicle fleet is electric (New Zealand Ministry of Transport, 2019), this implies that approximately 12% of emissions from light passenger vehicles is also associated with the secondary school travel in Dunedin. Given that this travel is occurring at times when many other children, adolescents and adults are also travelling either as pedestrians or cyclists, it is likely that motorised travel between home and school is associated with considerably more than 12% of road traffic risk.

The extent to which such motorised travel is replaceable by active modes is difficult to deduce. The average distance between home and school for students using private motor vehicles was 5.6 km, a sufficient distance to require a reasonably dedicated cyclist, particularly in cities like Dunedin, where the terrain is hilly, the weather often inclement, and the cycling infrastructure is generally poor. A large proportion of the motorised school travel trips may have occurred anyway, as they were chained to other trips with different purposes in our analysis of the NZHTS data. Around 44% of these private motor vehicle journeys and 51% of distance travelled were for school travel-related trips. However, our analysis could not examine the trip chaining practices of drivers from different households driving surveyed students, whose trips made up around one third of the total distance travelled in private motor vehicle travel between home and school.

Health-related behaviours and travel mode choices have been shown to be associated with individual socio-economic factors in NZ (Denny et al., 2016; Utter et al., 2011) and elsewhere (e.g., Beenackers et al., 2012). However, there was no evidence ($P = 0.82$) of any association between socioeconomic deprivation and minutes of MVPA in the hour before and after school in this study.

School zoning is a policy that can potentially reduce car travel, with its associated harms, as well as facilitate ATS, with its associated health benefits (Mandic et al., 2017c). School zoning policy in NZ gives students the right to attend a school that is within their geographical zone (Ministry of Education, 2009). This is complicated by school choice, where students may elect to enrol in another school thereby increasing the distance to travel each day. In response to school zoning policies, wealthy parents may choose to live in neighbourhoods with "good" schools, an option that will be less available to lower socioeconomic groups (Thrupp, 2007). Although some additional MVPA accumulated during the school commute period would be expected for students living closer to school because they are able to walk or cycle to school more readily, the current analysis does have limitations in inferring benefits arising from school zoning for secondary schools. In the population we studied, those students not attending the closest school may be different from those attending the closest school in terms of travel mode preferences and related demands on travel, such as work patterns (Mandic et al., 2017c). Most importantly, compared to those who attend the closest school, students *not* attending the closest school tend to live further from *any* school. Further, while this study did not examine these factors, the decision made by parents and children about which school to attend might be influenced by other transport arrangements, requirements of the family or social factors (Mandic et al., 2018d). Recent findings show that over two thirds of parents expect to participate in adolescents' walking/-cycling to school decision-making, emphasising the critical role that parents and therefore family factors play in ATS-related decision making for teenagers (Mandic et al., 2020).

The school commute period MVPA model fitted included a term comparing those students attending the closest school with those not attending the closest school. Although the associated parameter (the second factor listed in Table 4) was not statistically significantly different from zero, the estimated value was not dissimilar from the parameter estimate for living within a cyclable (but not walkable) distance from school. This highlights uncertainties around the associations of school commute period MVPA with attending the closest school (or not) due to the relatively small sample sizes available for the analysis. Similarly hampered by small sample sizes were our inferences by ethnicity. Although Māori adolescents ($n = 6$) were estimated to undertake more MVPA (8.4 min) than NZ European adolescents ($n = 100$) during the school commute period, the confidence interval was wide (−0.1, 16.9).

Given the urgency of taking action to increase adolescents' physical activity, an additional 3.4 min per day during the school commute period for students not attending the closest school would be a highly worthwhile result of school zoning policy. School-based physical activity interventions involve considerable effort and their results in terms of MVPA have been generally disappointing (Love et al., 2019). When reflecting on their null result in a meta-analysis of the effectiveness of school-based interventions, Love et al. (2019) considered that collective efforts to increase PA levels in one setting (schools) were unlikely to be successful when the wider environment did not support behaviour change. The current study has looked at potential benefits of school zoning, one element of a complex system providing the context for population PA levels (Spence and Lee, 2003). To address some limitations associated with a number of assumptions underlying our analysis, future research could usefully use quasi-experimental approaches to study actual changes arising from a newly-implemented school zoning policy.

4.1. Limitations

A limitation of the current analysis is that the relatively small sample sizes studied of travel and accelerometer data provided relatively poor power to detect associations. This study also could not assess potential causal mechanisms shown in Fig. 1. For example, the additional minutes of MVPA during the school commute period estimated for ATS are likely to arise mainly from walking or cycling. But it is also possible that this relationship between distance to school and MVPA minutes during school commute period is confounded by other factors. For example, students who live close to the school may also engage in convenient school-based physical activities. Their closer proximity to the school also facilitates ATS. Although home-to-school distance (categorised as walkable, cyclable but not walkable and beyond cyclable distance) was controlled for in the models fitted, the models will only partially adjust for a mechanism as suggested above, by comparing minutes of MVPA accumulated during the school commute time between students using different modes of travel to school but living within the same specified distance ranges (e.g., 2.25–4 km).

The data for analysing trip chaining behaviours in Dunedin were relatively sparse, necessitating eleven years of data from the