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# How are the built environment and household travel characteristics associated with children's active transport in Melbourne, Australia?

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ABSTRACT

*Background:* Children's active transport (AT) is a potential source of habitual physical activity with established health benefits. We aimed to examine built environment and household travel characteristics as predictors of AT to school and total daily duration of physical activity accumulated via AT.
*Methods:* Cross-sectional household travel survey data from 713 households with children aged 5–12 years (n = 1024) residing < 2 km from school (i.e. walking distance) across Melbourne, Australia (2012–16) were combined with objectively-measured distance to school and walkability (based on intersection density, housing density, land use mix) around home and school. Multilevel multivariable modified-Poisson regression analyses examined built environment variables (distance to school, walkability, traffic) and household travel behaviours (children's and adults' trip chaining, adult accompaniment to school) as predictors of: (1) AT to school; (2) total daily duration of AT of ≥ 20 min; adjusted for spatial clustering (at SA1 level) and household variables (income, employment, cars, bicycles).
*Results:* Most children (80%) had adult accompaniment to school but only 28% walked/cycled with an adult. Overall, 39% of children used AT to school and 24% accrued ≥ 20 min of AT-related physical activity. AT to school was positively associated with higher (rather than lower) walkability around home and school, direct travel (not trip chaining) and residing close to school (< 0.75 km rather than ≥ 1.25 km), and negatively associated with adult accompaniment and longer distance travelled onward in adult trip chains. AT of ≥ 20 min duration daily was positively associated with higher walkability around school, direct travel to/from school; and negatively associated with adult accompaniment to, and distance trip chained onward from, school.
*Conclusions:* To increase AT to school it is worth investing in infrastructure designed to improve walkability around schools, coupled with campaigns that target whole households to promote age-appropriate independent mobility rather than adult accompaniment, which tends to involve children being driven.

## 1. Background

Regular physical activity during childhood is beneficial for bone mineral density (Christoffersen et al., 2015; Strong et al., 2005), as well as reduced prevalence of overweight/obesity and risk factors for cardiovascular disease (Strong et al., 2005; WHO, 2010).

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Consequently, health authorities worldwide recommend that school-aged children engage in at least 60 min of physical activity of moderate-to-vigorous intensity per day (Australian Government Department of Health, 2014; WHO, 2010). Children's active transport (AT) is a potential source of habitual physical activity (PA) (Schoeppe et al., 2013; Tudor-Locke et al., 2001), and a dose-response relationship has been demonstrated between frequency of AT to school and time spent overall in moderate-to-vigorous PA (Carver et al., 2014b). A systematic review of AT to school and physical fitness reported that walking/cycling to school was associated with healthy weight status and cardiovascular fitness (Lubans et al., 2011). In addition, a recent integrative review (Waygood et al., 2017) highlights that AT may confer psychological benefits, promotion of social interaction and cognition (e.g. acquiring spatial knowledge).

Despite the associated benefits, rates of walking and cycling to/from school in some developed nations, such as Australia and UK, have declined during recent decades and remain low (Hillman et al., 1990; Salmon et al., 2005; Van der Ploeg et al., 2008). For example, between 1985 and 2001 in Australia, rates of walking to school daily declined from 37% to 26%, while rates of cycling to school dropped from 20% to 8% (Salmon et al., 2005). More recently, an Australian study (Carver et al., 2014b) of 8–15 year-olds reported rates of 25% for walking and 6% for cycling to school, while a US study (Behrens et al., 2017) reported rates of 11% and 2% respectively among similar-aged children. Even in other developed countries such as Denmark, Finland and Norway (Fyhri, 2011), that typically have high rates of AT (Shaw et al., 2015), increasing trends towards car travel to school have been reported. Reasons for these ongoing low rates of active transport are multifaceted but the built environment in which homes and schools are located, and the complexity and time pressures of modern family life, may play a role. Built environment characteristics that act as facilitators and barriers to AT to school have been identified, including distance between home and school (Carver et al., 2012; Davison et al., 2008; Oliver et al., 2014) and walkability of routes to school (Carver et al., 2014a; Villanueva et al., 2013). However, much research on the association between built environment and active transport has been based on the home location, giving rise to potential for residential effect fallacy, due to possible confounding from other environments visited throughout the day (Chaix et al., 2017). Research that has investigated activity spaces outside home environments (e.g. work and school neighbourhoods), suggests localities outside of the home neighbourhood are important influences on active travel and physical activity (Chaix et al., 2017; Howell et al., 2017; Hurvitz et al., 2014).

Household level factors are also influential, such as parental restrictions on children's AT due to concerns about road safety and perceived risk of harm from strangers (Carver et al., 2008, 2013; Mammen, 2012; O'Connor and Brown, 2013). As a consequence, children are frequently accompanied by parents, siblings and friends on their school commute (Carver et al., 2013; Cole et al., 2007). Factors associated with parental accompaniment to school include child's sex and age; parent's sex, ethnicity and employment status; and there is some evidence of an association with built environment characteristics such as accessibility of employment, population density and residential location (Ho and Mulley, 2015b; Hsu and Saphores, 2014; Mammen, 2012; Vovsha and Petersen, 2005; Yoon et al., 2011). Other motivations may be to achieve maximum efficiencies from family-level travel resources (e.g. cars) and budgets (time; money) through joint travel. The growing complexity of family lifestyles has resulted in some school journeys being combined with parental commutes to work, trips to shops (Mitra, 2013) or other structured activities (Pooley et al., 2005). This behaviour is described as 'trip chaining' where smaller trips are combined into a larger trip chain, commonly 'anchored' at either home or work (Islam and Nurul Habib, 2012; Primerano et al., 2008). For example, an adult's trip chain may comprise a journey from home to work via their younger child's kindergarten and their older child's primary school for drop-off purposes; while a child's trip chain may comprise the journey from school to home via a recreation centre or pool for swimming lessons.

Although directionality of association is uncertain, decisions on the travel behaviours of mode choice, accompaniment and trip chaining are interdependent and are often made at a household level (Islam and Nurul Habib, 2012; Ye et al., 2007). Depending on trip type, week day and the spatial dispersion of origins and destinations, as well as their accessibility by public transport systems, car travel may be more flexible for complex journeys, and trip chaining complexity is associated with car mode choice, compared to walking or cycling, and often public transport (Daisy et al., 2018; Primerano et al., 2008; Xianyu, 2013; Ye et al., 2007). Therefore, transport mode choice for accompanied children may depend on parental commuting patterns (McDonald, 2008), with even short, potentially walkable journeys often made by car (Carver et al., 2013). The tendency to drive children may be exacerbated where the parent's trip chain involves mandatory travel (e.g. home-school-work), rather than a simple home-school-home escort trip (Cole et al., 2007), where there may be greater discretion over and flexibility in travel behaviour (Ho and Mulley, 2015b; Primerano et al., 2008; Vovsha and Petersen, 2005). Household income, presence of children, vehicle ownership, sex, age, employment, population density, land use and transit accessibility are associated with trip chaining decisions (Daisy et al., 2018; Islam and Nurul Habib, 2012; Primerano et al., 2008; Xianyu, 2013). Despite increasing carbon emissions, car travel on short trips to school may be normalised due to increased car availability, travel complexity, time constraints and perceived convenience (Faulkner et al., 2010; Lang et al., 2011; Mackett, 2003; Mitra, 2013; Trapp et al., 2011). As children's mode choice is probably influenced by travel decisions made at a household level, more research on how household level travel decisions and behaviour related to the journey to school (e.g. accompaniment, trip chaining) influence children's travel mode choice is needed to combat this trend (Ewing and Cervero, 2001; Ho and Mulley, 2015b; Primerano et al., 2008).

Household travel surveys that collect self-reported information on travel patterns and modes for all members of randomly-selected households over one or more days within a geographical area have traditionally been used for transport planning (Merom et al., 2010), with data analysed at the aggregate level, e.g. across a city travel zone. However, public health researchers have identified the potential of household travel survey data for exploring AT behaviours (Durand et al., 2016; Ho and Mulley, 2015a; Merom et al., 2010), analyzing disaggregate data at an individual or household level to avoid ecologic fallacy (Handy et al., 2002; Merom et al., 2010). The potential of intersecting household travel surveys with Geographic Information System (GIS) data to investigate simultaneous individual, household and built environment influences on mode choice is yet to be fully explored, especially how individual travel behaviours are 'bundled' through household accompaniment and trip chaining and facilitated by transport systems and built environments (Buliung and Kanaroglou, 2006a; Buliung and Kanaroglou, 2006b). To our knowledge, few if any studies have combined these data types to investigate how household travel behaviours and built environment factors are associated with AT to school and how this contributes to achieving children's PA guidelines.

This study is guided by a socio-ecological framework that assumes there are multiple layers of intrapersonal, social and physical environment characteristics that impact an individual's health behaviours (Sallis et al., 2008). Specifically, this study aims to answer the following questions:

1. Are built environment characteristics, such as distance to school and walkability around school, associated with AT to school and daily duration of AT?
2. Are household travel behaviours related to the journey to school, such as children's trip chaining and accompaniment patterns, associated with children's AT to school and daily duration of AT?
3. For accompanied children, are adults' trip chaining characteristics such as the destination and distance of the adult's onward journey, associated with children's AT to school and daily duration of AT?
4. Do observed associations between distance to school, walkability around school, children's trip chaining and AT of children vary by adult accompaniment?

## 2. Methods

### 2.1. Sample

The sample was derived from 46,562 people from 18,152 households, who responded in 2012–16 to the Victorian Integrated Survey of Travel and Activity (VISTA), a cross-sectional household travel survey of a stratified, clustered random sample of residents in private households in Mesh Blocks[2] in Greater Melbourne and Geelong, the second largest city (located 75 km from Melbourne) in Victoria, Australia, described elsewhere (Transport for Victoria, 2018). VISTA runs continuously throughout the year surveying different households each day. Characteristics of all trips undertaken on the survey day by all household members are reported including: trip origin and destination; departure and arrival time; main travel mode; destination type; trip distance, duration and purpose; and accompaniment. Origins and destinations are geo-coded using GIS and travel data is linked to an individual's demographic and socioeconomic data (Ipsos Social Research Institute, 2015; Transport for Victoria, 2018).

Among 4490 children of primary school age (5–12 years) in 18,152 households, children were excluded if: surveyed on a weekend (n = 1127); they stayed at home on their survey day (n = 496); they did not take a trip to primary school (e.g. were on school holidays) or did not travel to school before 10:00 hours AND from school after 14:00 (n = 1052) for the purpose of education; and if they did not record a journey to education (n = 7). Distances > 2 km were considered less feasible for AT, particularly walking (Carver et al., 2014a), therefore children who resided > 2 km from school (network distance; n = 781) were excluded, as were children with missing public transport access data (n = 3). Despite distances of more than 2 km being potentially bikeable for children, very few children (3%) in the broader sample (whose survey was on a weekday) cycled to school. The final sample comprised 713 households with 1024 children (5–12 years).

### 2.2. Exposure variables

#### 2.2.1. Built environment characteristics

*2.2.1.1. Distance from home to school.* For confidentiality, geographic coordinates of respondents' home addresses were provided within a 100 m radius of their home. Distance to school using the shortest street network distance between home and school, was measured using ArcGIS 10.4 (ESRI, 2016, Redlands, CA) software.

*2.2.1.2. Walkability around home and school.* Walkability around home and school was measured using a Transport Walkability Index developed for Melbourne, described elsewhere (Giles-Corti et al., 2014). The index comprises three related characteristics measured at a Statistical Area 1 (SA1) level[3]: residential (dwelling) density; intersection density (3 + way intersections); a land use mix entropy measure ranging from 0 (SA1 contains a single land use) to 1 (SA1 contains equal area of five land uses – residential, retail, commercial, community and recreation). Residential (dwelling) density is important for walkability because there tends to be greater service provision (e.g. shops, medical centres, schools) and thus more potentially walkable destinations in areas where more people reside (Giles-Corti et al., 2014). Street connectivity is associated with walking for transport (Talen and Koschinsky, 2013) due to availability and choice of direct routes for walking. Land use mix is important for the co-location of homes, businesses and services and is thus associated with having walkable destinations (Giles-Corti et al., 2014). Values for these input measures were normalised

[2] Mesh Blocks are the smallest geographical area in the Australian Bureau of Statistics (ABS) Australian Statistical Geography Standard (ASGS), on average containing 30–60 dwellings (Australian Bureau of Statistics, 2016).

[3] Statistical Area 1 (SA1) are geographic areas built from whole Mesh Blocks, with a mean population of approximately 400 (range 200–800) people ABS, 2016. Australian Statistical Geography Standard (ASGS): Volume 1 – Main Structure and Greater Capital City Statistical Areas. Australian Bureau of Statistics, Canberra.

(via z-scores), and centred around a mean of 0, with z-scores of ± 1 representing scores at ± 1 standard deviation. Z-scores for dwelling density, street connectivity, and land use mix were summed to give Transport Walkability Index scores, which were categorized using a tertile split as: 1 'lower', 2 'medium' and 3 'higher' walkability.

*2.2.1.3. Proportion of low traffic roads around school.* Roads in Victoria, Australia, are classified within VicMap Transport data (State Government of Victoria and Department of Sustainability and Environment, 2013) using the following hierarchy (which is a proxy for decreasing traffic volume and road width): 'freeway', 'highway', 'arterial', 'sub-arterial', 'collector', 'local', '2 wheel drive track', '4 wheel drive track'. The length of low traffic roads (i.e. 'collector' or 'local') as a proportion (%) of the total length of all roads within a 2 km network buffer around each school was calculated. This was highly negatively skewed (median 87%, range 74–98%) and collapsed into three categories ('lower', 'medium', 'higher') approximating a tertile split.

### *2.2.2. Household travel behaviour exposures (i.e. accompaniment and trip chaining)*

*2.2.2.1. Adult accompaniment to and from school.* Children who were accompanied on trips to and/or from primary school by adult household members were identified (VISTA data). Accompaniment by other children in the household was not significantly associated with outcomes and, therefore, excluded from analyses, as was accompaniment by non-household members, whose demographic information was unavailable.

*2.2.2.2. Child's trip chaining.* Children were classified as travelling directly to and from school (i.e. NOT trip chaining) if their home was the origin and destination respectively for these trips.

*2.2.2.3. Adults' trip chaining via primary school.* To delineate adults who accompanied a child to primary school during a discretionary rather than mandatory trip chain (e.g. journey to work), the follow-on destination of adults travelling FROM primary school before 10:00 ($n = 761$) was identified and classified as 'home', 'work' or 'other'. The distance to this destination was categorised as: < 2 km; 2–4.9 km; 5–9.9 km or > 10 km. The first category matches the 2 km cap for distance to school and the other three categories were divided according to the distribution in increasing distance in readily recognisable 5 km contours from school.

*2.2.2.4. Public transport accessibility.* Accompanying adult's capacity to trip chain from home with a combination of AT and public transport was included to see if it explained patterns of active travel to school in accompanied children (i.e. reduced the likelihood of them being driven to school en route to another destination). Public transport accessibility from each home was determined using the Composite Accessibility Index (CAI, with potential values 0–60), developed for Spatial Network Analysis for Multi-Modal Urban Transport Systems (SNAMUTS) (Curtis and Scheurer, 2016). SNAMUTS indices use network analysis to measure city-wide public transport accessibility from an origin, based on spatial characteristics, frequency and speed of services across the public transport network. Mesh Blocks without a stop with a minimum service frequency level (< 20 min in weekday inter-peak and < 30 min on weekends for bus/tram, and < 30 min for rail) within walking distance (400 m for bus/tram, 800 m for train/ferry) from the centroid, were used as a reference category. CAI values ranged from 0–24.8, were highly positively skewed and subsequently collapsed into four categories: 'no minimum public transport service'; and 'low' (CAI < 10); 'medium' (CAI 10–14); and 'high' (CAI ≥ 15) public transport accessibility.

## *2.3. Covariates*

Several covariates associated previously with exposures and outcomes as described above, and that were derivable from VISTA and census data were selected (Hsu and Saphores, 2014). Individual level covariates were child's age-group (5–7, 8–9, 10–12 years) and sex. Household level covariates included household type (nuclear (i.e. two-parent family)/other/sole parent), whether an adult stayed at home on the survey day (and may have been available to accompany children), or was likely to be home after school hours (i.e. employed part-time, casual, homemaker, unemployed or retired); household- size, income, employment status (no adult employed full-time/at least one adult employed full-time), ownership of bicycles and cars. Area-level covariates were seasonality and the Index of Relative Socio-economic Disadvantage (IRSD) score of the home SA1, a measure of area-level disadvantage in Australia (Australian Bureau of Statistics, 2015).

## *2.4. Outcome variables*

### *2.4.1. AT to school*

The child's main transport mode to school was that recorded for the trip ending at primary school. If using multiple modes, the main mode was determined by the following hierarchy: public transport, motorised transport, walking and cycling, other. This was dichotomised as 'motorised transport' (private vehicle, train, tram, school or public bus) or AT (walking/cycling).

### *2.4.2. Accruing 20 min or more of AT on the survey day*

The duration of: a) walking and cycling trip legs; and b) time spent walking to vehicles in motorised trip legs, reported in minutes by survey respondents, were summed to derive total daily duration of AT. The distribution was highly positively skewed: few children ($n = 11$ children; 0.9%) met the PA recommendation (60 min/day) through AT alone, and many ($n = 905$; 88%) accrued less than 30 min of PA through AT. Time spent in AT per day was dichotomized as ' < 20 min' or '≥ 20 min'.

## 3. Statistical analysis

ArcGIS 10.4 (ESRI, 2016, Redlands, CA) software was used for spatial analysis and STATA 14.2 (StataCorp, 2015, College Station, Texas) was used for descriptive and statistical analysis.

Descriptive analysis involved tabulation of sample characteristics. Associations between built environment, household travel behaviours and the two AT outcomes were tested by fitting multilevel multivariable regression models. Initially, two separate sets of models were fitted for each outcome. The first fitted built environment characteristics and the second fitted household travel behaviour characteristics, each adjusted for potential individual-, household-, and area-level confounding factors. Final models included both built environment and household travel characteristics (adjusted for covariates), to identify if patterns of association between both sets of exposures and the two outcomes remained significant when mutually adjusted for each other. All models were replicated for a sub-group of accompanied children (n = 761) where adults travelled onward from primary school before 10:00. Additional variables that described the accompanying adult's follow-on destination and distance travelled were included.

The choice of regression model was dependent on the distribution of the outcome (binary) and the extent of its clustering at the geographic-level of aggregation (SA1s). Odds ratios in logistic regression models do not approximate relative risks when outcomes are not rare, as is the case here (39% reported AT to school) (McNutt et al., 2003). Alternative models including log-binomial or modified-Poisson regression (Poisson regression with sandwich error term) were considered (Zou, 2004). Multilevel multivariable modified-Poisson regression with robust standard errors was used to estimate prevalence ratios, as this class of model allows for explicit adjustment for geographic clustering compared with other model choices; noting that the outcome measure is clustered at SA1 level (Median Rate Ratio): AT to school 1.55 (accompanied children) and ≥ 20 min of AT 1.44 (full sample) 1.80 (accompanied children) (Austin et al., 2018). Multilevel generalized linear models were fitted through the 'meglm' command in STATA with family Poisson and log link.

To address the fourth aim, statistical interactions were tested between accompaniment and distance to school, trip chaining and walkability around the child's school, for both AT outcomes. These models adjusted for individual-, household-, and area-level confounding factors and for accompaniment, distance to school, trip chaining and walkability. Joint-effects were also modelled for all combinations of interacting variables with unaccompanied status, built environment and household travel behaviour variables conducive to AT as reference category, as they have the highest likelihood of attaining AT outcomes (Knol and VanderWeele, 2012).

Ethics approval was granted by the Melbourne School of Population and Global Health Human Ethics Advisory Group, the University of Melbourne (Ethics ID 1442864.1).

## 4. Results

Descriptive data for all children (N = 1024; 50% male) and their households (n = 713) are presented in Table 1. Most children (86%) had at least one adult carrer in full-time employment, 12% lived in households with very low income, 9% in sole parent households and 26% in households with one car or less. Overall, 39% of children used AT to school (35% walked, 4% cycled) and 24% accrued 20 min of PA via AT daily. Few (0.2%) used public transport. Among those who used motorized transport to school, only 4% accrued 20 min of AT per day (i.e. mainly to other destinations). Although most children (82%) living more than 1.25 km from their school were driven to school, 35% of those residing within a short walking distance (0.75 km) of school were also driven. Higher proportions of older children, in households with less than two cars and with higher walkability at home and school walked/cycled to school and accrued ≥ 20 min of AT, compared with those in reference categories. Most children (80%) had adult accompaniment to school, but only 28% of children accompanied by an adult walked/cycled to school, compared with 82% of unaccompanied children. Low proportions of children who were accompanied to school by an adult who then travelled to their workplace or to 'other' destinations used AT to school (9%, 11%, respectively), compared to children with an adult travelling home (41%).

### 4.1. Separate and fully adjusted regression models

Results from separate multilevel multivariable modified-Poisson regression models for: a) built environment; and b) household travel characteristics as predictors of AT to school and accruing ≥ 20 min of AT are summarised in Tables 2A, 2B. Table 3 presents the results of mutually adjusted models containing built environment and household travel predictors, adjusted for all covariates other than non-predictors of either outcome in separate adjusted models (Tables 2A, 2B). Almost all associations that were statistically significant in the separate models (Tables 2A, 2B) remained so in the fully adjusted model (Table 3) with slightly lower Incident Rate Ratios (IRRs). Exceptions were that distance to school of less than 750 m and higher walkability around school were no longer associated with children who were accompanied to school spending at least 20 min in AT during the day. However, higher walkability in the home area was significantly associated with AT to school for the full sample and sub-sample of accompanied children in the fully adjusted model only (Table 3). Compared to null models, lower Deviance Information Criterion (DIC) values showed better model fit when both built environment characteristics and household travel behavior exposures were included separately, and even better fit when they were combined together and mutually adjusted in the final models (results not presented). For brevity only the results of fully adjusted models are described below.

#### 4.1.1. Built environment characteristics

The first two columns of Table 3 present findings relevant to research aim 1. The built environment factors of living in close proximity (< 750 m) to school (IRR = 2.69, 95%CI 2.02, 3.59) and high walkability around home (IRR = 1.33, 95%CI 1.04, 1.69)

**Table 1** (*continued*)

| | | Whole sample N = 1024 | | Main mode to school was active transport | | | | Active transport for ≥ 20 min on survey day | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | N | Col. % | n | Row % | $Chi^2$ | p. | n | Row % | $Chi^2$ | p. |
| **TRAVEL SEASON** | Summer | 206 | 20.1 | 68 | 33.0 | 6.5 | 0.091 | 50 | 24.3 | 2.0 | 0.580 |
| | Autumn | 282 | 27.5 | 123 | 43.6 | | | 77 | 27.3 | | |
| | Winter | 230 | 22.5 | 85 | 37.0 | | | 54 | 23.5 | | |
| | Spring | 306 | 29.9 | 125 | 40.9 | | | 69 | 22.6 | | |
| **SEIFA (IRSED) SCORE OF HOME SA1** [b] | T1 (Most disadvantaged) | 342 | 33.4 | 127 | 37.1 | 3.3 | 0.197 | 76 | 22.2 | 2.0 | 0.372 |
| | T2 | 343 | 33.5 | 128 | 37.3 | | | 92 | 26.8 | | |
| | T3 (Least disadvantaged) | 339 | 33.1 | 146 | 43.1 | | | 82 | 24.2 | | |
| **LOCATION OF HOUSEHOLD** | Inner Melbourne | 222 | 21.7 | 114 | 51.4 | 23.4 | **0.000** | 73 | 32.9 | 12.0 | **0.007** |
| | Middle Melbourne | 350 | 34.2 | 126 | 36.0 | | | 78 | 22.3 | | |
| | Outer Melbourne | 401 | 39.2 | 135 | 33.7 | | | 85 | 21.2 | | |
| | Geelong [c] | 51 | 5.0 | 26 | 51.0 | | | 14 | 27.5 | | |

[*] Accompanied children only (n = 761); p-value in bold denotes $p < 0.05$ for Pearson $Chi^2$ test.

[b] Statistical Area 1 (SA1) are geographic areas built from whole Mesh Blocks, with a mean population of approximately 400 (range 200–800) people (ABS, 2016).

[c] The second largest city (located 75 km from Melbourne) in Victoria, Australia.

and school (IRR = 1.38, 95%CI 1.09, 1.75) were positively associated with children's AT to school, when compared with reference categories. Among these variables, only walkability of the school environment (IRR = 1.49, 95%CI 1.05, 2.13) was associated with accruing ≥ 20 min of AT (Table 3). Residing in an area with a higher (rather than lower) proportion of low traffic roads was not associated with either children's AT to school (IRR = 0.82, 0.60, 1.11) or accruing ≥ 20 min of AT (IRR = 0.90, 95%CI = 0.59, 1.37).

#### 4.1.2. *Household travel behaviour characteristics*

In relation to research aim 2 (first two columns, Table 3), two household travel behaviours related to travel to school were consistently associated with both outcomes. Compared with children who trip chained to/from school, children who travelled there directly were more likely to take AT to school (IRR = 1.46, 95%CI 1.09, 1.95) and to accrue ≥ 20 min of AT (IRR = 1.95, 95%CI 1.29, 2.95) (Table 3). Adult accompaniment was negatively associated with children's AT to school (IRR = 0.42, 95%CI 0.35, 0.50) and accruing ≥ 20 min of AT (IRR = 0.53, 95%CI 0.38, 0.74) when compared with non-accompaniment by an adult (Table 3).

#### 4.1.3. *Built environment and household travel behaviours for accompanied children*

The last two columns of Table 3 present findings from fully adjusted models for the subset of accompanied children (aim 3). Most of the positive associations observed between the built environment factors of distance to school, and walkability of the home and school environment with children's AT to school were similar for all children and the subset of accompanied children. The association between higher walkability around schools and accruing ≥ 20 min of AT approached significance (IRR 1.60, 95%CI 1.00, 2.57).

Regarding household travel characteristics, accompanied children's direct travel to and from school did not predict AT to school (IRR = 1.31, 95%CI 0.85,2.01) when compared with children who trip chained, although it was positively associated with accruing ≥ 20 min of AT (IRR = 1.86, 95%CI 1.05, 3.29). Additionally for accompanied children, the distance that adults were travelling onward predicted children's AT. Those children whose accompanying parent's onward journey was less than two kilometres were more likely to take AT to school (IRR = 4.27, 95%CI 1.56, 11.68) and to accrue ≥ 20 min of AT on the survey day (IRR = 3.65, 95%CI 1.33, 10.05) compared with those whose parents travelled ≥ 10 km after school drop-off. Similarly, the parent's destination predicted AT in the morning: children whose accompanying parent travelled on to an ‘other’ destination were 52% less likely to walk/cycle to school (IRR = 0.48, 95%CI 0.25, 0.93) compared to those whose parent travelled straight home. Access to public transport was not significantly associated with either outcome.

Regarding aim 4, significant interaction terms showed that associations between exposures of distance from home to school ($p < 0.001$) and both outcomes; children's trip chaining and ≥ 20 min of AT - ($p = 0.03$); and walkability around school and AT to school ($p = 0.003$) (not reported in tables); varied according to child accompaniment status. As reported in Table 4, compared to the unaccompanied children with lowest distance to school, only unaccompanied children with the highest distance to school showed a lower likelihood of AT to school (IRR = 0.72, 95%CI 0.51, 1.00). However, with the same reference category, accompanied children in all distance categories had a lower likelihood of AT mode to school, and the higher the distance the lower the likelihood of AT. Unaccompanied children showed an increased likelihood of attaining ≥ 20 min of AT with increased distance from school (0.75–1.24 km: IRR = 1.89, 95%CI 1.14, 3.15; 1.25–1.99 km: IRR = 2.76, 95%CI 1.61, 4.72), while no associations were observed among accompanied children (Table 4).

Associations between trip chaining and low school walkability and less AT in both outcomes were observed only among accompanied children, compared to unaccompanied children who travelled directly to school, and with high SA1-level school

**Table 4**
Interactions between selected built environment and household travel exposures and adult accompaniment.

| Built environment and family travel exposure | | Accompanied by adult | Took active mode to school in morning | | | | ≥ 20 min of active transport on survey day | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | IRR | p. | Lower 95% CI | Upper 95% CI | IRR | p. | Lower 95% CI | Upper 95% CI |
| DISTANCE FROM HOME TO SCHOOL | < 0.75 km | No | 1.00 | | | | 1.00 | | | |
| | 0.75–1.24 km | No | 0.95 | 0.597 | 0.79 | 1.14 | **1.89** | **0.014** | 1.14 | 3.15 |
| | 1.25–1.99 km | No | **0.72** | **0.048** | 0.51 | 1.00 | **2.76** | **0.000** | 1.61 | 4.72 |
| | < 0.75 km | Yes | **0.59** | **0.000** | 0.48 | 0.72 | 1.05 | 0.872 | 0.61 | 1.80 |
| | 0.75–1.24 km | Yes | **0.32** | **0.000** | 0.24 | 0.42 | 0.91 | 0.726 | 0.53 | 1.55 |
| | 1.25–1.99 km | Yes | **0.15** | **0.000** | 0.10 | 0.22 | 0.66 | 0.142 | 0.38 | 1.15 |
| CHILD'S TRIP CHAINING | Travelled direct to school | No | 1.00 | | | | 1.00 | | | |
| | Trip chained | No | 0.80 | 0.225 | 0.55 | 1.15 | 0.94 | 0.827 | 0.54 | 1.64 |
| | Travelled direct to school | Yes | **0.43** | **0.000** | 0.35 | 0.52 | **0.58** | **0.002** | 0.41 | 0.82 |
| | Trip chained | Yes | **0.27** | **0.000** | 0.18 | 0.40 | **0.22** | **0.000** | 0.12 | 0.42 |
| WALKABILITY OF SCHOOL SA1 | Higher walkability (Q3) | No | 1.00 | | | | 1.00 | | | |
| | Q2 | No | 1.08 | 0.521 | 0.85 | 1.37 | 0.86 | 0.577 | 0.51 | 1.46 |
| | Lower walkability (Q1) | No | 1.05 | 0.706 | 0.80 | 1.39 | 0.88 | 0.620 | 0.53 | 1.46 |
| | Higher walkability (Q3) | Yes | **0.58** | **0.000** | 0.46 | 0.74 | **0.64** | **0.022** | 0.43 | 0.94 |
| | Q2 | Yes | **0.38** | **0.000** | 0.28 | 0.50 | **0.43** | **0.001** | 0.27 | 0.70 |
| | Lower walkability (Q1) | Yes | **0.35** | **0.000** | 0.25 | 0.47 | **0.37** | **0.000** | 0.22 | 0.62 |

p-value in bold denotes $p < 0.05$; p-values for interaction terms between exposures are provided in text.
Adjusted for interacting variables and additional covariates (distance to school, Walkability Index of home SA1, Walkability Index of school SA1, proportion of low traffic roads, accompaniment to school by a child under 10, trip chaining by child to or from school, sex, age group, household type, household income, household vehicles, household adult bikes, household with an adult more likely to be home (home duties etc.), travel season, SEIFA (IRSD) score of home SA1 and location of household.

walkability, respectively. The observed associations confirm that poor walkability and trip chaining, when in combination with accompaniment, reduced the likelihood of AT.

## 5. Discussion

This study is, to our knowledge, among the first to investigate, using separate and fully adjusted models, associations of objective measures of the built environment around home and school, and self-reported travel behaviour of household members travelling to and from school (accompaniment, trip chaining and accessibility of work), with children's AT to school and their accrual of PA via AT throughout the day. We found that built environment factors, including distance to and walkability around the school, along with household travel behaviours (children's trip chaining and adult accompaniment) were associated with children's AT (to school and/or accruing ≥ 20 min ) when mutually adjusted for each other, and for individual, household and area level covariates. Adult accompaniment to school was pervasive (in line with previous Australian research (Carver et al., 2013; Cole et al., 2007)) and consistently negatively associated with children's AT, with accompanied children half as likely to undertake AT. The distance of accompanying adults' onward trip chain was also negatively associated with children's AT, but findings on destination type were less clear. Adult's trip chaining to 'other' (rather than work) destinations were inversely associated with AT, suggesting less habitual (rather than non-discretionary) adult trip chaining may be a barrier to children's AT to school, perhaps as more flexible car travel is useful for less predictable trips. Finally, we found that observed associations between distance to school, walkability around school, children's trip chaining and AT of children varied by adult accompaniment, with associations, less pronounced among unaccompanied children suggesting children who travel independently are more resilient to variations in distance and walkability, compared with children who are accompanied by adults. Given that built environments do not exist in isolation of household travel behaviours (and vice versa), evidence from these analyses on their continued associations with AT when mutually adjusted for each other, as well as interactions between them, considerably add to and strengthen the evidence on built environment and household level characteristics as predictors of children's AT to school.

This study makes several contributions to the evidence base with clear implications for intervention. Firstly, with just over a third (39%) of primary school-aged children in this study engaged in AT to school, there is considerable scope to intervene to increase children's PA through AT to school. The proportion of children taking AT to school was similar to that identified by other studies conducted in Australia (Carver et al., 2012, 2014b; Veitch et al., 2017), lower than that reported in UK (Panter et al., 2010) and in Canada (Buliung et al., 2009), but higher than reported in the USA (Behrens et al., 2017; McDonald, 2008). Our findings suggest that the school journey is a key opportunity for promoting AT, because if children did not walk or cycle to school, they did not tend to walk or cycle much to any other destinations. Promoting AT to school is a crucial intervention to help children meet PA guidelines, particularly those who are less inclined to participate in organised sport.

A second implication of the findings is that although home neighbourhood walkability is important, to increase AT on the school journey it may be most strategic (and cost-effective) to invest in the environments surrounding schools, rather than homes. Higher levels of walkability around schools was consistently associated with a greater likelihood of AT to school and throughout the day, suggesting it facilitates both children's AT to school and to nearby venues (e.g. sport venues, shops) after school. This emphasises that street connectivity and land use mix enable children to reach destinations on foot or by bicycle, and supports investment in infrastructure designed to improve walkability around schools. Investment in pedestrian infrastructure on local streets (e.g. footpaths, pedestrian crossings and bicycle paths) has been associated with increases in parent-reported rates of children's AT to school (Boarnet et al., 2005; McDonald et al., 2013) and identified as a promising approach to promoting children's AT in a recent systematic review (Smith et al., 2017).

Our findings that adult accompaniment to school was both pervasive and negatively associated with children's AT, suggest that infrastructure interventions to improve the safety and walkability of the built environment, will be more effective if matched by concerted campaigns to reduce adult accompaniment and promote age-appropriate independent mobility among children. Interventions that target the travel behaviour of entire households (Sener et al., 2010) are required to assist households to relinquish accompaniment and trip chaining, and transition children toward independent mobility. Programs aiming to have children aged 10 years and older and living within walking distance travelling independently to school may be more effective, as by that age, children tend to have requisite road safety and navigational skills (Congiu et al., 2008; Whitebread and Neilson, 2000) and be granted more autonomy by parents (Carver et al., 2012).

Finally to inform intervention, future research should investigate further the relative influence of, direct and indirect effects of, and interactions between, built environment characteristics, accompaniment and trip chaining, on children's travel mode. For example, is there is an association between walkability and being accompanied, and if so, will improved walkability affect children's AT more directly (i.e. by making it easier for children to travel the distance between home and school) or indirectly (i.e. through facilitating parents' relinquishment of accompaniment)? There is a need for greater understanding of: (1) how children experience, understand and negotiate characteristics of the built environment such as distance and walkability through AT; (2) how accompanying adults also experience these same characteristics and how this in turn influences their understanding of their children's readiness for independent travel and their readiness to relinquish accompaniment; (3) how the legibility and navigability of the built environment for children is in turn mediated through adult or peer accompaniment; and (4) to what extent degree of choice and agency determine children's mode of travel and (5) how all this impacts on children's progress toward independent mobility, at different ages and in different built environments.

### *5.1. Strengths and limitations*

A key design strength of this study is the simultaneous investigation of objective built environment characteristics and self-reported travel characteristics of children and accompanying household members (accompaniment, trip chaining and accessibility of work) in regression models, to provide a fuller picture of their associations with children's AT and physical activity. Other strengths of this study include: the measurement of walkability around both home and school to examine built environment influences on children's active travel in multiple activity spaces and reduce potential for residential effect fallacy (Chaix et al., 2017); and the measurement of both AT to school and daily duration of AT across the day. In addition, the use of household travel survey data provided a large, randomly selected sample of children, and relatively detailed and high quality self-reported secondary data for AT outcomes, when compared to self-reported physical activity data from other sources used for health research (Lee et al., 2011). Whilst all self-reported data may be subject to recall error or social desirability bias, VISTA data are linked to the origin, destination and purpose of trips across a single day (which may prompt recall of AT and provides information for objective measurement of trip distance), and are validated at point of entry for quality control.

Regarding study limitations, this study's cross-sectional design precludes causal inference and the findings may not be generalisable to urban settings beyond Australia. Household travel survey data reported on a single day may not reflect habitual travel behaviour and are prone to underreporting of short trips, often undertaken by AT. Secondary use of this data meant not all characteristics of families that we may have ideally explored or adjusted for, such as parental education, were available in the dataset. In addition, whilst it is not known how much other PA children did, several studies have identified that children who use AT to school tend to be more physically active overall (Carver et al., 2014b; Cooper, 2006; Cooper et al., 2003). A further consideration is that our measures of trip chaining and accompaniment were fairly simple; more detailed measures might include home-based tours to various destinations.

## 6. Conclusions

This study provides important evidence for urban planners, policy-makers and health promotion practitioners of how both the built environment and travel behaviours of household members are related to children's AT. Our findings demonstrate that in order to increase AT to school (and transport-related PA) it is worth investing in infrastructure designed to improve walkability around schools. This should be coupled with campaigns that target whole households to promote age-appropriate independent mobility rather than adult accompaniment to school, which is more likely to involve children being driven rather than walking or cycling.