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Associations between the neighbourhood built environment and out of school physical activity and active travel: An examination from the Kids in the City study

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ABSTRACT

This study's aim was to examine selected objectively-measured and child specific built environment attributes in relation to proportion of out-of-school time spent in moderate-to-vigorous physical activity (%MVPA) and active travel in a group of ethnically and socio-economically diverse children ($n=236$) living in Auckland, New Zealand. Street connectivity and distance to school were related to the proportion of trips made by active modes. Ratio of high speed to low speed roads and improved streetscape for active travel were related to %MVPA on weekdays only. Inconsistent results were found for destination accessibility. Local destinations (particularly schools) along a safe street network may be important for encouraging children's activity behaviours.

1. Introduction

Many national bodies recommend that children participate in at least 60 min of moderate to vigorous physical activity (MVPA) per day for optimal health (World Health Organization, 2010; NZ Ministry of Health, 2015; UK Department of Health, 2011). Children's MVPA can be accumulated via a range of activities (e.g., organised sports, unstructured free play, and active travel – walking or cycling for transport), which can occur in a variety of settings (e.g., school, home, neighbourhood). Active travel is a physical activity of particular interest, with studies showing a positive relationship between active travel and objectively assessed MVPA (Oliver et al., in press; Schoeppe et al., 2013a, in press). Moreover, reducing trips made by car has significant co-benefits such as enhancing children's knowledge of their local environment (Mitchell et al., 2007), and reducing traffic congestion and carbon emissions (Badland and Oliver, 2011).

Much is known about the associations between children's physical activity and demographic, home, and school factors (Sallis et al., 2000; Ferreira et al., 2007; Sterdt et al., 2013; National Institute for Health and Clinical Excellence, 2008). A range of individual (sex, age), social (parent support, parent perceptions), household (socio-economic status, car accessibility), and environmental (programme/facility access, time spent outdoors) factors have been associated with overall physical activity and MVPA in children (Pont et al., 2009; Copperman and Bhat, 2007; Carver et al., 2008; Butte et al., 2014; Edwardson and Gorely, 2010; Bergh et al., 2011). A recent meta-analysis revealed that children accumulate more MVPA on weekdays than weekend days (Brooke et al., 2014). In addition, findings showed that on school days, more MVPA is accumulated in school than out of school (Brooke et al., 2014). For active travel, negative relationships have been found for higher household income and increased car ownership, and positive relationships have been observed for ethnicity (non-white), and having presence (rather than absence) of recreation

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facilities and active travel infrastructure (Pont et al., 2009, Davison et al., 2008).

Socio-ecological models are especially useful for understanding associates and predictors of children's activity behaviours, as the activity must be undertaken in specific physical settings (Sallis et al., 1998). It has been suggested that the specificity of socio-ecological models could be improved by using theory-driven behaviour and context measures (Giles-Corti et al., 2005). There has since been a call for “more age- and sex-specific research using behaviour- and context-specific measures, with a view to building a more consistent evidence base to inform future environmental interventions” (Giles-Corti et al., 2009). Use of objective measures of the environment and behaviours is also an important consideration (Ding et al., 2011).

Active travel is an important component of children’s physical activity and one that has declined in many countries over recent decades (Fyhri et al., 2011; Ministry of Transport, 2009; Ministry of Transport, 2012). In New Zealand over a 20 year period the mean number of minutes per week children engage in active travel has almost halved from 130 min to 69 min, while the proportion usually travelling to school by car has almost doubled (Ministry of Transport, 2012). Travel to or from school has been the focus of research investigating associations between active travel and the built environment to date (Panter et al., 2008). Distance to school appears to be a consistent predictor of actively travelling to school (Wong et al., 2011; D’Haese et al., 2011; Oliver et al., 2014a; van Loon, 2011). Traffic may also be an important contributing factor; for example, Giles-Corti et al. (2011) observed a significant interaction effect of “traffic volume” (characterised by road hierarchy) in the relationship between street connectivity and children’s walking to school. Findings showed a link between street connectivity and walking, but this relationship did not hold true for children attending schools where traffic volume was high.

Children do not spend time exclusively at school or home – and the recognition of neighbourhoods as child-relevant ‘places’ to spend time in, travel through, experience, and ‘colonise’ is becoming commonplace (Hooper et al., 2015; Rogers, 2012; Carroll et al., 2015). Limited research has considered out-of-school physical activity and trips to non-school destinations in relation to built environment factors (Schoeppe et al., 2013a). Yet such investigations remain an important step towards ensuring greater analytical specificity for the hypothesised environment-activity relationship. Positive associations between out-of-school physical activity and dwelling density, destination accessibility (Giles-Corti et al., 2009), and street connectivity have been found in some studies (de Vries et al., 2007; Frank et al., 2007), and negative associations found in others (Copperman and Bhat, 2007; Mecredy et al., 2011). One recent US investigation revealed that areas profiled as having higher walkability and recreation/park access were associated with children's MVPA accumulated out of school hours in one study region (San Diego), but not another (Seattle/King County) (Kurka et al., 2015). A time-use examination of weekend physical activity in children aged 5–17 years revealed associations between physical activity and destination availability, dwelling density, and active transport infrastructure (Copperman and Bhat, 2007).

Increasingly, innovative approaches are being developed to understand the built environment from a child's perspective. Two particularly relevant examples are the child-specific neighbourhood destination accessibility index (NDAI-C) (Badland et al., 2015) and the school walkability index (Giles-Corti et al., 2011). The NDAI-C is a spatial index of accessibility to destinations that are relevant to children. The index builds on the previous adult-focused NDAI (Witten et al., 2008) by drawing on child-specific locational data and frequency of access to destinations to develop an empirically-derived objective index pertinent to children's activity behaviours. To our knowledge, no research has yet considered the relationship between the NDAI-C and children's physical activity or travel behaviours. The school walkability index also improves on its adult-focused ‘walkability index’ predecessor (Leslie et al., 2007), by including a measure of traffic exposure, drawing from the well-established link between traffic exposure and children's active travel behaviours. Since its development, the school walkability index and derivatives (in terms of traffic exposure) have consistently been linked with children’s active travel (Trapp et al., 2012; Kurka et al., 2015), but this variable has rarely been explored with regard to MVPA. Lastly, while not child-specific, the Systematic Pedestrian and Cycling Environmental Scale (SPACES) provides an objective assessment of a given streetscape from the perspective of a pedestrian or cyclist (Pikora et al., 2002, 2003). This tool considers the most vulnerable street users using a comprehensive range of factors at the street level and thus may contribute to a more detailed understanding of factors related to children's activity behaviours. Indeed, links between the environment as assessed by the SPACES and children's active travel have been established (McMillan, 2007), but again this measure has seldom been explored in terms of children's MVPA.

Advances in GIS technologies offer new approaches for delineating population-specific neighbourhood boundaries, or buffers, in health and place research. Buffers are boundaries placed around a point or area using a predefined scale and a Euclidean or street network distance (Thornton et al., 2011). The scale used for these buffers have traditionally been relatively arbitrary, generally ranging from 200 m to 1600 m (Wong et al., 2011). The alignment of objective physical activity data with global positioning systems (GPS) monitoring data or participant mapping data overlaid with GIS spatial information has led to greater insight on buffer distances that are more meaningful to specific populations of interest. For example, in a study using GPS and accelerometry to investigate the mobility of US adults, findings revealed most MVPA occurred in locations “near home” (125–1666 m from the residential address), as compared with locations further or closer to home (Hurvitz et al., 2014). Such findings can be useful in identifying buffer distances that are likely to yield the greatest sensitivity for a given population.

Accordingly, the present challenge is to gain a deeper understanding of how specific built environment features outside the school and home environments are associated with children’s MVPA, and active travel beyond school to other neighbourhood destinations. This paper builds on earlier research and provides greater specificity by using objective child-specific measures of activity and the built environment to consider out-of school activity on weekdays as well as weekend days, while accounting for relevant individual, social, and household factors. By taking a deliberate child-centred approach to describing built environments, we aim to provide improved specificity in socioecological modelling of the built environment–physical activity relationship.

2. Methods

2.1. Protocol

The Kids in the City study was an investigation of children's use and experiences of diverse urban neighbourhoods (Carroll et al., 2015). Data collected enable associations between built environment features and children's independent mobility, active transport, physical activity, and body size to be examined. Design and methods of the full study are described in detail elsewhere (Oliver et al., 2011c, in press).

In brief, data were collected from children in school years 5–8 (9–13 years of age) from nine schools across Auckland, New

Zealand between 2011 and 2012. Children were provided with an accelerometer and GPS unit attached to a neoprene belt, and asked to wear the belt at their waist (with the units above their right hip) for the next seven consecutive days, excluding water-based activities and sleeping. Researchers visited the children at the school daily to assist them in completing travel diaries and to download GPS data and recharge the GPS units. Incentives were a daily sticker chart (on completion of the travel diary and GPS return), and a shopping centre voucher on study completion. A computer-aided telephone interview (CATI) was undertaken with parents of participating children to collect demographic information and parent neighbourhood perceptions. The physical neighbourhood environment was assessed using observational audits and geographic information systems (GIS)-derived variables around children's residential addresses. Measures specific to the current study are detailed below. Ethical approval to conduct the research was granted by the three research host institutions (AUTEC: 10/208, 18 October 2010; MUHECN: 10/053, 16 August 2010; UoA: 15 October 2010).

2.2. Physical activity and active travel measures

2.2.1. Accelerometry

Physical activity was assessed using Actical accelerometers (BMedical Pty Ltd., Milton, Queensland, Australia), set to collect data in 30 second epochs. Data were downloaded using Actical software (Version 2.04). Custom intervals, described previously, were used to extract data for wear times only (Oliver et al., 2011a). A count threshold of >749 counts/30 s was applied to identify MVPA epochs (Puyau et al., 2004).

Out-of-school hours on school days were defined as: (a) the hours between 8.00 am and school start (range 8:45 am–9:00 am); plus (b) the hours between school end (range 2:30 pm–3:00 pm) to 7.00 pm on school days only (Monday–Friday, excluding public holidays) as described previously (Oliver et al., in press). Individual weekdays were included in analyses where 3 or more hours of data remained (60% minimum data inclusion (Cooper et al., 2010)). For weekend days, all days where at least 7 h of data existed were included in analyses (Rich et al., 2013). Data for out-of-school time were extracted using *R* (R Core Team, 2013), and proportion of out-of-school time spent in MVPA (hereafter % MVPA throughout) was then calculated for each school day, and each weekend day.

2.2.2. Travel diary

Participants were provided with a pen and paper diary each day for the 7-day period. Diaries were checked in person by a member of the research team each school day, which involved the children recalling the sequence of activities undertaken and destinations as well as confirming accompaniment and mode of transport (Oliver et al., 2014b). The total numbers of trips made by all travel modes and by active modes were calculated, and proportion of total trips made by active modes calculated.

2.3. Built environment measures

2.3.1. Population-specific neighbourhood buffer calculation

QStarz BT-Q1000 and BT-Q1000XT GPS units were used to collect objective information on children's mobility for calculation of study-specific neighbourhood buffers at the group (rather than individual) level. GPS units were set to collect data in 10 s epochs. Data were downloaded at the school on weekdays. Raw GPS data were cleaned and re-sampled to 30 s epochs using the Physical Activity Location Measurement System (PALMS) (Personal Activity and Location Measurement System (PALMS) website, 2012). The GPS data were linked to the out-of school accelerometer data based on date and time using *R* (R Core Team, 2013). Descriptive information on time spent at different Euclidean buffers from the home environment (at the group level for all matched data) and % MVPA spent at different buffers were calculated to inform buffer use in the current study. Descriptive and visual analysis of these data indicated a road network buffer of 1000 m around participants' home addresses was optimal for use in the current study. This approach was a compromise between sensitivity and specificity for proportion of time spent around the home environment and %MVPA occurring around the home environment (details on request).

2.3.2. GIS variables

Built environment spatial variables were generated in ArcInfo 9.3 (ESRI Inc., Redlands, CA) using a 1000 m road network buffer as detailed below.

- *Street connectivity:* Ratio of number of intersections with three or more intersecting streets per square kilometre to land area.
- *Net residential density:* Ratio of residential dwellings to the residential land area.
- *Distance to school:* Shortest road network route from home to school. Data were highly skewed (Shapiro–Wilk $p<0.0001$) so were log-transformed prior to analyses.
- *Destination accessibility:* The NDAI-C was used to provide a measure of the intensity of child-specific neighbourhood destination opportunities (Badland et al., 2015). This empirically driven index accounts for 35 destinations in nine domains that reflect the destinations that children regularly access. Destination weightings were weighted based on frequency of visitation from children's 7-day travel diaries from the KITC study.
- *Socioeconomic status:* Area level socioeconomic status was determined using the NZDep2013 (Atkinson et al., 2014). The NZDep2013 is a measure of socio-economic deprivation at the meshblock level, with values ranging from 1 (least deprived) to 10 (most deprived). The index is derived from principal component analysis of nine socioeconomic deprivation variables administered in the national census. Meshblocks are the smallest standard administrative area used by Statistics New Zealand, and at the time of the 2013 census contained a median of approximately 81 people (Atkinson et al., 2014). Classifications for lower (8–10), mid (4–7), and higher (1–3) area-level disadvantage were generated using NZDep2013 scores.
- *Ratio of high speed roads around schools:* Drawing from the child-specific walkability index of Giles-Corti et al. (2011), road hierarchy was used as a proxy for traffic speeds around the school, as follows: Improved road centreline data (2011) was downloaded from www.koordinates.com. Roads with a speed limit greater than 60 km/h were classified as high speed roads. The remaining roads were classified as low speed roads. The length of high and low speed roads were calculated within 1000 m of each school. The road speed measure was calculated as the ratio of the length of high to low speed roads. A higher ratio indicated a less walkable area due to a greater proportion of high speed roads.

2.3.3. Streetscape audit

The New Zealand SPACES (NZ-SPACES) was used to assess streetscapes in each study area (Badland et al., 2010). This measure provided a reliable assessment of street features associated with activity (e.g., aesthetics) that could not be captured by GIS (Pikora et al., 2002, 2006). All complete street segments within an 800 m network buffer around each school were audited virtually within Google Street View as described previously (Oliver et al., 2011c; Badland et al., 2010). The 800 m buffer was employed at the inception of the study, prior to determining the population-specific buffer of 1000 m. Response categories for each item were given a value between a 1 and 0 (between two and four levels were employed for each item), where 1 equalled the most supportive environment for the behaviour.

2.4. Demographic, parent, and household information

Parents completed a CATI survey that collected information on child demographics (including sex, ethnicity, age) and car availability for picking up and dropping off children (never, sometimes, always). Parent perceptions about their neighbourhood safety were obtained using items from the Ranui Action Survey (Adams et al., 2005). Parents were read a series of eight statements about their neighbourhood and asked to respond using a 5-point Likert scale (ranging from strongly agree to strongly disagree). Statements covered perceptions of safe places for children to play, personal safety when walking in the dark, roaming dogs, graffiti and vandalism, bullying, concern about crimes, and whether parents thought their neighbourhood was a good place to buy a home or to bring up children. Responses for the eight items were aggregated using principal components analysis, and values were rescaled to range from 0 (low) to 10 (high) with a high score representing perceptions of a safer neighbourhood.

2.5. Analyses

Generalised estimating equation modelling was used to assess relationships between daily repeated measures (clustered by child) for each physical activity outcome (i.e., %MVPA and active travel) and individual built environment features, controlling for individual (child age, ethnicity, sex), parent (neighbourhood perceptions), and socioeconomic (car availability, socio-economic status) factors as fixed factors. Statistical significance was set at $\alpha = 0.05$, an exchangeable correlation structure was employed, and the Huber–White sandwich estimate of variance was specified. Analyses were conducted using STATA SE 12.0 (StataCorp LP, College Station, TX, USA).

Table 1
Participant and neighbourhood characteristics.

Variable	Weekdays $n=236$		Weekend days $n=210$	
	N or mean	(% or min, max)	*N* or mean	(% or min, max)
Sex				
Male	104	(44.1)	91	(43.3)
Female	132	(55.9)	119	(56.7)
Age (years)	9.8	(8, 13)	9.8	(8, 12)
Ethnicity				
New Zealand European	57	(24.2)	47	(22.4)
Māori	29	(12.3)	28	(13.3)
Pacific Island	83	(35.2)	78	(37.1)
Indian/Asian/Other ethnicity	67	(28.4)	57	(27.1)
Socioeconomic status				
Lower (NZDep2013 8-10)	152	(64.4)	140	(66.7)
Mid (NZDep2013 4-7)	58	(24.6)	50	(23.8)
Higher (NZDep2013 1-3)	26	(11.0)	20	(9.5)
Parent neighbourhood perception score	5.6	(0.008, 9.9)	5.5	(0.008, 10.0)
Car availability for picking up and dropping off children				
Never	28	(11.9)	24	(11.4)
Sometimes	64	(27.1)	59	(28.1)
Always	144	(61.0)	127	(60.5)
Physical activity outcomes				
%MVPA	17.0	(6.7, 33.2)	15.2	(0.7, 40.6)
Number of trips made by all modes	3.7	(1.6, 7.6)	1.8	(1.0, 9.5)
Proportion of trips made by active mode(s)	49.8	(0, 100)	28.3	(0, 100)
Neighbourhood exposures				
Street connectivity	5.3	(2.4, 8.7)	5.3	(2.4, 8.7)
Residential density	5.1	(2.8, 8.7)	5.1	(2.8, 8.7)
Ratio of high speed roads	0.5	(0.1, 1.0)	0.5	(0.1, 1.0)
Distance to school (m)	2469	(60, 50,743)	2278	(60, 50,743)
NDAI-C	59.4	(9.4, 100.0)	60.1	(9.4, 100.0)
NZ-SPACES	7.4	(6.8, 7.9)	7.4	(6.8, 7.9)

Note: %MVPA = proportion of out-of-school time spent in moderate-to-vigorous intensity physical activity; m = metres; *n* = number; NDAI-C = Neighbourhood Destination Accessibility Index-Child; NZDep13 = New Zealand Deprivation Index 2013; NZ-SPACES = New Zealand Systematic Pedestrian and Cycling Environmental Scale; max = maximum; min = minimum

3. Results

3.1. Participants

In total, 253 children participated in the Kids in the City study. Data were excluded from analyses for 14 children due to missing CATI survey data. Data from a further three children were excluded for weekday analyses and 29 children for weekend day analyses due to insufficient or missing physical activity data. A total of 1244 observations were retained from the remaining 236 children for weekday analyses, and 392 observations from 210 children for weekend day analyses. No significant differences in demographic variables were observed between participants included or excluded in analyses. Individual, family, physical activity, and neighbourhood characteristics for children included in analyses are provided in Table 1.

3.2. Built environment, %MVPA, and active travel

Results from the generalised estimating equation modelling are provided in Table 2 (weekdays) and 3 (weekend days). For weekdays, no built environment factors around the residential address were related to children's %MVPA. Instead, the school walkability index and NZ-SPACES were associated with %MVPA. A 1-unit increase in ratio of high speed roads around schools was associated with a 2.5% reduction in %MVPA (95% CI −4.9%, −0.2%; $p=0.036$), and a 1-unit increase in NZ-SPACES score was associated with a 2% increase in %MVPA (95% CI −0.14, 3.59; $p=0.034$). In contrast, when considering number of active trips, street connectivity and destination accessibility were both associated with a greater proportion of trips made by active modes. Distance to school was negatively associated with proportion of active trips made Table 3.

For weekend days, the inverse was found for destination accessibility, whereby a 1-unit increase in NDAI-C was associated with a 0.05% reduction in %MVPA (95% CI −0.09, −0.002, $p=0.040$). No other built environment features were significantly related to %MVPA on weekend days. For proportion of trips made by active modes, a positive relationship was observed for street connectivity, and a negative relationship was found for distance to school.

3.3. Covariates in models

In all instances, the fully adjusted models were significantly

Table 2
Results of GEE analyses for associations between built environment measures and out-of-school physical activity variables on weekdays (n=236 participants, 1244 observations)

Neighbourhood exposure variable	%MVPA			Proportion of trips made by active mode(s)		
	Coefficient	(95% CI)	*p*-Value	Coefficient	(95% CI)	*p*-Value
Street connectivity	0.06	(−0.31, 0.44)	0.731	3.88	(1.87, 5.88)	< **0.0001**
Residential density	−0.04	(−0.62, 0.54)	0.901	−1.01	(−4.33, 2.32)	0.553
NDAI-C	−0.01	(−0.04, 0.02)	0.443	0.15	(−0.00003, 0.31)	**0.050**
Distance to school (log)	0.13	(−0.50, 0.77)	0.685	−10.45	(−13.73, −7.18)	< **0.0001**
Ratio of high speed roads	−2.54	(−4.91, −0.16)	**0.036**	12.49	(−0.90, 25.88)	0.067
NZ-SPACES	1.87	(0.14, 3.59)	**0.034**	3.71	(−6.72, 14.14)	0.485

Bold indicates significant relationship between neighbourhood exposure variable and activity outcome.
Note: %MVPA=proportion of out-of-school time spent in moderate-to-vigorous intensity physical activity; CI=confidence interval; GEE=generalised estimating equation; n=number; NDAI-C=Neighbourhood Destination Accessibility Index-Child; NZ-SPACES=New Zealand Systematic Pedestrian and Cycling Environmental Scale

associated with %MVPA and number of active trips made (full model details provided in online supplementary material). For all models investigating %MVPA on weekdays, female sex (child) and 'always' having a car available for picking up and dropping off children (parent) were significantly associated with lower %MVPA. With the exception of ratio of high speed roads around schools, for all models, children identifying as being of Pacific ethnicity had significantly higher %MVPA than their counterparts. Child age was negatively associated with %MVPA in all models except the model for NZ-SPACES. For weekend %MVPA, female sex, and being classified in the Indian, Asian, or 'other' ethnicities group (compared with European, Māori or Pacific ethnic groups) were associated with significantly lower %MVPA across all models.

In the models investigating relationships between active travel and built environment measures, 'always' having a car available for picking up and dropping off children was consistently associated with reduced proportion of the total trips made by active modes. With the exception of the street connectivity model on weekdays, age was positively associated with proportion of trips made by active modes. There was a trend towards higher socio-economic status being associated with reduced active travel across most models. For weekdays only, a higher parent neighbourhood safety perception score was positively associated with proportion of child trips made by active modes in the NDAI-C, residential density, ratio of high speed roads around schools, and NZ-SPACES models. For weekend days (but not weekdays), identifying as being of Pacific Island ethnicity was negatively associated with active travel in the NDAI-C, distance to school, ratio of high speed roads around schools, and NZ-SPACES models.

4. Discussion

The current study employs a child-centred socioecological approach to understanding built environment factors associated with %MVPA and active travel in children, accounting for social and individual demographic factors previously identified as relevant to these relationships. Results showed that street connectivity (positive association) and distance to school (negative association) were consistently related to the proportion of trips made by active travel modes, on weekdays and weekends. It is likely that the school commute contributed substantially to these relationships for weekdays. Indeed, the magnitude of the relationship between distance to school and active travel was approximately three times greater on weekdays compared with weekend days, suggesting this may be the case. In contrast, the degree of the relationship between street connectivity and active travel remained relatively similar between weekdays and weekend days. These findings provide the first evidence for the importance of street connectivity in relation to children's active travel to destinations beyond the school trip, and contribute to ongoing discussions around school siting, closures, and amalgamation (Centers for Disease Control and Prevention, 2006; Kearns et al., 2009).

Inconsistent findings were observed in relation to child-specific destination accessibility and activity behaviours. On weekdays, a positive relationship was found between the NDAI-C and proportion of trips made by active travel modes. Conversely, on weekend days, a negative relationship was found between the NDAI-C and %MVPA. Of note, the scale of these relationships was small (and likely trivial in terms of meaningful differences) in both models (mean −0.05% reduction in %MVPA, 0.15 increase in proportion of active travel). It is possible that a larger sample size, or a greater number of observations would have yielded more insight.

Increased ratio of high speed roads around the school was associated with reduced %MVPA during out-of school hours on weekdays only (mean 2.5% reduction, range of 0.2–5%). When considering the proportion of time children in this study spent in MVPA out-of-school hours (between 0.7–40.6% overall), a decrease of 2% (and up to 5%) reflects a meaningful change, particularly for those at the lowest end of the activity spectrum. It is worth noting

Table 3
Results of GEE analyses for associations between built environment measures and physical activity variables on weekend days (n=210 participants, 392 observations)

Neighbourhood exposure variable	%MVPA			Proportion of trips made by active mode(s)		
	Coefficient	(95% CI)	*p*-Value	Coefficient	(95% CI)	*p*-Value
Street connectivity	−0.32	(−0.87, 0.23)	0.253	3.97	(1.40, 6.55)	**0.002**
Residential density	−0.66	(−1.68, 0.37)	0.208	3.54	(−0.04, 7.13)	0.052
NDAI-C	−0.05	(−0.09, −0.002)	**0.040**	0.05	(−0.13, 0.23)	0.576
Distance to school (log)	−0.67	(−1.68, 0.34)	0.193	−3.27	(−6.42, −0.12)	**0.042**
Ratio of high speed roads	−2.85	(−6.77, 1.05)	0.152	6.78	(−10.65, 24.22)	0.446
NZ-SPACES	−1.07	(3.89, 1.77)	0.459	7.91	(−3.51, 19.33)	0.174

Bold indicates significant relationship between neighbourhood exposure variable and activity outcome.
Note: %MVPA=proportion of time spent in moderate-to-vigorous intensity physical activity; CI=confidence interval; GEE=generalised estimating equation; n=number; NDAI-C=Neighbourhood Destination Accessibility Index-Child; NZ-SPACES=New Zealand Systematic Pedestrian and Cycling Environmental Scale

that the road speed measure was a relatively broad assessment of potential traffic exposure based on road hierarchy, drawing from the child-specific school walkability index. Changing road hierarchy would be extremely difficult and expensive. Yet, numerous opportunities exist to change street environments around schools so that they better reflect a 'residential' street typography, ultimately reducing traffic speed and volume. Examples include soft measures such as setting speed limits in school zones before and after school and reducing parking availability for school-drop-offs and pick ups, and minor infrastructural retro-fitting of streets to slow traffic speed and discourage through-traffic around the immediate school environment. Moving forwards, further research is needed to assess actual traffic volume and speeds across networks rather than using the road hierarchy proxy.

In keeping with previous research, a positive relationship was observed between improved streetscapes for walking and cycling (as measured by the NZ-SPACES) and %MVPA, although this association was only found for weekdays. In contrast with expectations, none of the measures assessed around the individual residential address were associated with %MVPA on weekdays. The lack of relationships observed between %MVPA and built environment factors around the residential address (with the exception of the NDAI-C) is especially perplexing. It could be hypothesized from this finding that school active travel modes are making a substantial contribution to the MVPA-built environment relationship on weekdays, and/or that other activities (e.g., sports participation) are contributing more to out-of-school MVPA accumulation than activities occurring in the neighbourhood environment across all day types.

Study findings also showed that socio-demographic factors play an important role in these relationships. Taking all other factors into account, a range of social and demographic variables were associated with children's %MVPA and active travel. In all instances, these relationships were in the expected directions, and in keeping with previous research (Pont et al., 2009; Copperman and Bhat, 2007; Carver et al., 2008; Butte et al., 2014; Edwardson and Gorely, 2010; Bergh et al., 2011). In particular, females accumulated less %MVPA than males, age was negatively associated with %MVPA and positively related to active travel, and car access was related to reduced %MVPA and proportion of trips made by active modes (albeit not on weekend days for the NDAI-C-%MVPA model). Differences between ethnic groups were observed, with those of a Pacific ethnicity generally accumulating more %MVPA (weekdays only) but less active travel (weekend days only), and those of Indian/Asian/other ethnicities accumulating significantly less %MVPA (weekend days only) than their counterparts. Lower socio-economic status was associated with increased active travel in some, but not all, models. Finally, a positive association was observed between parent perceptions of neighbourhood safety and proportion of active trips made, suggesting that parent perceptions may be contributing to decision-making around their child's active travel behaviours on weekdays.

While the study involved a relatively small sample, the repeated measures approach to analysing the data yielded a substantial number of data points, providing a more sensitive insight to these relationships than aggregated or estimated measures of activity behaviours. A further strength is the considerable ethnic and socioeconomic diversity within the study sample (76% non-European, 64% lower socioeconomic status). Although not generalisable, the findings do provide a greater understanding of built environment and physical activity relationships for these groups than has previously occurred. The need to engage children and families from lower socioeconomic backgrounds and minority ethnic population groups in child health research is widely recognised and acknowledged as being challenging and rarely achieved (Brannon et al., 2013; Karlson and Rapoff, 2009; Schoeppe et al., 2013b).

This study developed a population-specific buffer to create spatial measures around individual addresses. To the authors' knowledge, this approach has only been employed previously in a study of US adults. The findings of this earlier study were surprisingly similar to the current study, whereby most MVPA occurred in locations 125–1666 m from the residential address (Hurvitz et al., 2014). This aligns with a study comparing road network buffers of 200 m, 400 m, 800 m, and 1600 m street network buffers to examine relationships between a range of built environment measures and MVPA in children, whereby the greatest distance best explained these relationships (van Loon et al., 2014). The use of population specific buffers likely provides a more sensitive assessment of activity-specific neighbourhoods than applying an arbitrary scale. Yet, individual variation in locations of activity accumulation likely exists. That is, some active travel and MVPA may have occurred outside the 1000 m buffer employed in the current study. Likewise, for some participants, active travel and MVPA may have been accumulated in close proximity to their residential address. Assessment and characterisation of children's individual activity spaces would help to mitigate these issues and further improve specificity. However, this would make interpretation and development of recommendations challenging.

It is worth noting that GIS-derived land use mix and retail floor area ratio were not considered in the current study. In the context of this examination, both were considered a proxy for having a range of destinations to walk to, which we believed was more appropriately captured by the NDAI-C. Moreover, the available land use mix and retail floor area ratio data only enabled the calculation of coarse measures, for which issues have been identified (e.g., no allowance for vertical data) (Hajna et al., 2014). The complete child-specific school walkability index (Giles-Corti et al., 2011) was not employed in these analyses since the main study focus was on understanding factors of importance around the individual household, rather than school environment. Additionally, the outcomes of interest were physical activity accumulated outside of school hours and *all* trips made by active modes (i.e., both the school trip and trips made for all other purposes). Notwithstanding this, two key measures (ratio of high speed to low speed roads, NZ-SPACES) were applied around the school environment. This approach acknowledged the likely contribution that active school travel would make to both %MVPA and all trips made by active modes, and secondly recognising the contribution that schools can make as activity destinations out of school hours (Ogilvie and Zimmerman, 2010; Play Wales, 2013).

With the exception of the NDAI-C (an aggregate measure of multiple local child-specific destinations), individual built environment factors were considered separately in relation to activity outcomes for this examination. There are merits and limitations to this approach. In particular, estimates can be examined without the threat that they are non-significant due to collinearity, and identifying and articulating specific factors of relevance is useful when communicating with planners. However, it is likely the 'whole is greater than the sum of the parts', and instead it is a combination of features that are important, with the optimal composition differing across regions and population groups (Adams et al., 2011). The current study contributes to the evidence base by identifying factors of importance to consider in intervention design and prioritisation, and for informing the characterisation of areas that may be more or less conducive to promoting children's activity.

School was not included as a fixed factor in analyses. It is possible some clustering effects may have existed due to school, in which case the standard errors would have been underestimated, and the *p*-values would be smaller than if clustering was taken into account. However, this situation is unlikely, due to the small number of participants from each school 'cluster'. In addition, schools were measured at different times across a year, so the inclusion of school as a fixed factor could have inadvertently reflected other factors contributing to the relationships under examination (e.g., seasonality (Ergler et al., 2013; Oliver et al., 2011b)). Accordingly, the approach employed was considered appropriate for the current study.

5. Conclusion

Understanding child-specific built environment features related to children's activity behaviours is challenging and largely hindered by methodological issues and lack of specificity. This study builds on earlier research and provides greater specificity by using objective child-specific built environment measures and an empirically-derived neighbourhood buffer applied around children's homes and repeated daily measures of objectively assessed out-of school total physical activity and moderate-to-vigorous physical activity and child-reported active trips. Differential relationships were observed by activity outcome (%MVPA, active travel), day type (weekend, week day), and built environment measure. Distance to school remains a key associate of children's travel modes; suggesting that discussions around school closures, amalgamation, and siting must remain at the fore for children's wellbeing. This is the first study to show that neighbourhoods with improved street connectivity may be more conducive for children's active travel modes to destinations beyond school, for both weekend and weekdays. Reducing traffic speeds around schools and improving streetscapes for walking and cycling may also be important for encouraging health-promoting levels of physical activity in children.

Conflicts of interest

The authors declare they have no conflicts of interest to report.

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Appendix A. Supplementary material

Supplementary data associated with this article can be found in the online version at http://dx.doi.org/10.1016/j.healthplace.2015.09.005.

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