

Are Safety-Related Features of the Road Environment Associated with Smaller Declines in Physical Activity among Youth?

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ABSTRACT *This study examined how objective measures of the local road environment related to safety were associated with change in physical activity (including active transport) among youth. Few longitudinal studies have examined the impact of the road environment on physical activity among children/adolescents in their neighborhoods. Participants were children aged 8–9 years (n=170) and adolescents aged 13–15 years (n=276) in 2004. Data were collected in 2004 and 2006 during follow-up of participants recruited initially in 2001 from 19 primary schools in Melbourne, Australia. Walking/cycling to local destinations was parent-reported for children and self-reported by adolescents. Moderate-to-vigorous physical activity (MVPA) during nonschool hours was recorded using accelerometers. Road environment features in each participant's neighborhood (area within 800 m radius of their home) were measured objectively using a Geographical Information System. Linear regression analyses examined associations between road features and changes in active transport (AT) and MVPA over 2 years. Children's AT increased but MVPA levels decreased in both age groups; on average, younger girls recorded the greatest declines. The number of traffic/pedestrian lights was associated with Δ AT among younger girls (B=0.45, p=0.004). The total length of walking tracks (in meters) was associated with Δ AT among younger girls (B=0.0016, p=0.015) and adolescent girls (B=0.0016, p=0.002). For adolescent boys, intersection density was associated with Δ AT (B=0.03, p=0.030). Slow points were associated with Δ MVPA among younger boys before school (B=1.55, p=0.021), while speed humps were associated with Δ MVPA among adolescent boys after school (B=0.23, p=0.015). There were many associations for adolescent girls: for example, the total length of local roads (B=0.49, p=0.005), intersection density (B=0.05, p=0.036), and number of speed humps (B=0.33, p=0.020) were associated with Δ MVPA during nonschool hours. Safety-related aspects of the built environment are conducive to physical activity among youth and may help stem age-related declines in physical activity. Passive road safety interventions may promote AT and physical activity among less active girls, in particular.*

KEYWORDS *Child, Adolescent, Physical activity, Neighborhood, Safety*

INTRODUCTION

Road safety is a major concern for both parents and children.^{1–3} This concern contributes to parents' restriction of their children's independent mobility,¹ outdoor

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play, and active transport in their local neighborhood.^{1,4,5} Compared with previous generations, children now spend less time playing outdoors^{6,7} and more time engaged in indoor sedentary leisure pursuits at home.^{7,8} This suggests that physical activity opportunities are being missed since time spent outdoors is positively associated with physical activity.^{9,10} In addition, participation rates in active transport (particularly to/from school) have declined.^{1,11} This is of concern from a public health perspective because the health benefits of regular physical activity during childhood and adolescence may be missed,^{12,13} and there are links between inactivity during childhood and increased morbidity.¹⁴⁻¹⁷

Parental concerns about road safety are justified as road traffic injuries cause most deaths by injury among 1- to 14-year-old children in developed nations¹⁸ and most deaths overall among 10- to 19-year-olds worldwide.¹⁹ Children injured in road accidents tend to be pedestrians or cyclists.^{1,19} Furthermore, there is evidence that child pedestrian injuries are sustained most frequently on local streets,²⁰ mainly within 500 m of the victims' homes.²¹ Hence, road safety in the neighborhood is a valid concern. During the 1990s, road trauma/injury prevention strategies changed their focus from road safety education to re-engineering or modification of road infrastructure to increase the safety of pedestrians, cyclists, and children at play.²¹ It was recognized that driver behavior and/or youth behavior, as well as the physical/social environment, are contributing factors in road accidents involving youth.²¹ Consequently, there is now more emphasis on adapting physical/social aspects of the road environment to improve young people's safety.²¹ In addition, there is growing interest in how the physical environment influences physical activity²² and active transport²³ among youth.

Little is known about the influence of the physical road environment on physical activity among youth. While physical infrastructure designed to improve road safety is recognized as particularly important, few studies have examined how such infrastructure is associated with walking/cycling and overall physical activity levels among youth. To date, much road safety research is centered on prevention of injuries to child pedestrians and cyclists.²⁴⁻²⁷ Cross-sectional findings from the current study,²⁸ when participants were aged 8-9 and 13-15 years, demonstrated that adolescent girls who resided in neighborhoods with two to three sets of traffic/pedestrian lights were more likely to make at least one walking/cycling trip per day, while adolescent boys were more physically active if they resided on a cul-de-sac or if there were speed humps on local streets. It is unclear, however, what effect the local road environment has on children's and adolescents' active transport and physical activity over time.

This longitudinal study examined associations between safety-related features of the neighborhood road environment (present at the start of the study) and changes in active transport and physical activity among children and adolescents over 2 years. By examining these associations for children and adolescents who resided in neighborhoods with diverse road environments, it was possible to conclude whether children/adolescents who resided in neighborhoods with more safety-related features of the road environment (e.g., speed humps) recorded greater change in physical activity, compared with children/adolescents who resided in neighborhoods with less of these features. As discussed earlier, children's active transport and outdoor play may be restricted due to parental concerns about local road safety^{1,4,5} so physical infrastructure designed to improve road safety may help to promote physical activity among youth in the local neighborhood. Furthermore, international longitudinal studies have demonstrated age-related declines in physical activity among

youth.^{29–31} It is, therefore, important to identify features of the local road environment which may help to stem such declines.

METHODS

Sample

Data were gathered during a 5-year longitudinal study called “Children Living in Active Neighbourhoods”.^{32–34} This paper refers only to follow-up data collected at 3 and 5 years. Complete sampling methods have been published previously^{32–34} and are described briefly here. Originally designed as a cross-sectional study, at baseline (2001), 295 children aged 5–6 years (27% response rate) and 919 children aged 10–12 years (44% response rate) were recruited from 19 government primary schools in ten high and nine low socioeconomic areas across Melbourne, Australia. Parents were asked if they could be recontacted in the future for further research. In 2004, among those whose parents had agreed to be recontacted, 76% ($n=191$) of the younger age group, then aged 8–9 years, and 64% ($n=416$) of the older age group, then adolescents aged 13–15 years, participated in the first follow-up. Of those who agreed to future contact regarding the second follow-up in 2006, participation rates were 93% for children ($n=177$) aged 10–11 years and 68% for adolescents ($n=326$) aged 15–17 years, representing 60% and 35% of their respective age groups in the baseline sample. Ethics approval for this study was obtained from the Deakin University Ethics Committee, the Department of Education and Training Victoria, and the Catholic Education Office.

Data Collection

Active consent by parents was required for each wave of data collection. Data were collected between July and December each year and, where possible, within the same month for each participant to avoid seasonal differences in physical activity. Questionnaire data were collected from parents and from adolescents. Children and adolescents were asked to wear an accelerometer. The two time points, “T1” and “T2,” of the current study correspond to the data collection in 2004 and 2006, respectively.

Measures

Active Transport. At T1 and T2, children’s parents reported how often per week their children walked/cycled to 15 neighborhood destinations: bike/walking tracks, friends’ houses, sports venues/leisure centers, skate ramps, parks/playgrounds, waterways, beach, other open spaces, public transport, school, amusement arcades, DVD rental stores, convenience stores, takeaway/fast food outlets, and other shops or destinations. These frequencies were also self-reported by adolescents. Frequency values (in parenthesis) were assigned to each response category: (0) “not within walking/riding distance”; (0) “never/rarely”; (0.5) “less than once per week”; (1.5) “one to two times per week”; (3.5) “three to four times per week”; (5.5) “five to six times per week”; and (7) “daily”. These measures were based on an existing instrument with eight destinations.³² The total number of walking/cycling trips per week was computed and 1-week test–retest reliability was moderate to high (intraclass correlation [ICC]=0.86, children; ICC=0.68, adolescents). The change between T1 and T2 in number of walking/cycling trips was also computed (T2 minus T1).

Physical Activity. This was objectively measured at T1 and T2 using an accelerometer (Manufacturing Technologies, Inc. [MTI] Model 7164 [Actigraph, Inc., Florida, USA]) worn on an elasticized belt on the hip, removed only for sleeping, showering, or swimming.^{33,34} Participants were asked to wear the accelerometer for eight consecutive days. The data were downloaded and entered into a data reduction program. Data were excluded for any day on which less than 10,000 counts (suggesting the accelerometer was not worn as requested) or greater than 20 million counts (suggesting the accelerometer had malfunctioned) were recorded.^{33,34} Mean duration (in minutes per day) spent in physical activity of moderate-to-vigorous intensity (i.e., ≥ 3 METs) was calculated for three nonschool periods on weekdays (where data for at least four weekdays were available) and all day on weekend days (where data for at least one weekend day were available) using an established regression equation³⁵ that identifies age-specific counts per minute thresholds for a particular physical activity intensity. The weekday periods were: before school (6 A.M. to first school bell); after school (last school bell to 6 P.M.); and evening (6–9 P.M.). The mean duration of moderate-to-vigorous physical activity (MVPA) during nonschool hours was calculated using summed durations for these periods. The change between T1 and T2 in duration of MVPA was calculated for each period of interest (T2 minus T1).

Objective Measures of Road Environment. A Geographical Information System (GIS) was built using Arcview GIS 3.3 (Environmental Systems Research Institute, Inc., California, 2002), spatial data (address points, cadastral, and road network data) owned and supplied by the State Government of Victoria (VICMAP Address v2, 2003; VICMAP Property v2, 2003; VICMAP Transport v2, 2004), and street directory maps (Ausway, Mount Waverley, Australia, 2003). Using this GIS, road environment variables were objectively measured within each participant's neighborhood, defined as a radius of 800 m around their home (1,600 m was parent-reported as a maximum walking distance for children).³² This definition is consistent with findings that most child pedestrian injuries take place within 500 m of the home.²¹ The residential address of each participant was geocoded (i.e., converted to representative coordinates). Nine indicators of the road environment within each participant's neighborhood were generated and are described below.

Street Network

Several variables relating to the local road environment were sourced or derived from the VICMAP Transport database³⁶ in which roads are described as consisting of linked segments. A segment is a stretch of road existing between two points or nodes, for example, intersections and road-ends.³⁶ The VICMAP Transport database classifies road segments according to type and lists them in descending order within the road network hierarchy: freeway (i.e., motorway); highway; arterial; subarterial; collector; local; two-wheel drive (unsealed, suitable for standard, two-wheel drive vehicles); four-wheel drive (unsealed, suitable for four-wheel drive vehicles); unknown; proposed; and walking tracks.³⁶ Road types that were unknown or proposed were excluded from analyses.

Total Length of Local Roads. Total length (in kilometers) of roads classed as "local" (i.e., residential streets) and unsealed tracks suitable either for "two-wheel drive" or "four-wheel drive" vehicles³⁶ was computed. These roads have maximum speed limits of 50 km/h or less.³⁷

Local Road Index. The ratio of total length of local roads to total length of all roads. This was computed by dividing the total length of all roads classed as “local” and unsealed tracks suitable either for “two-wheel drive” or “four-wheel drive” vehicles³⁶ by the total length of all roads in the neighborhood. As these roads are residential streets, they tend to have less traffic than major highways and arterial roads. The index, therefore, measures the proportion of all roads that have maximum speed limits of up to 50 km/h³⁷ and that tend to have lower traffic volumes than roads classed as freeways (i.e., motorways), highways, arterials, subarterials, or collector roads.

Intersection Density. Usually defined as the number of intersections per unit of area.^{38,39} Since neighborhoods in this study had identical area, number of intersections per neighborhood was used. Greater intersection density is associated with greater street connectivity and traffic calming.³⁸

Residing on a Cul-de-Sac. This indicates participant’s residence on a cul-de-sac. Cul-de-sacs are prevalent in neighborhoods with low street connectivity,⁴⁰ but are considered by parents as safe play venues due to ease of parental surveillance from home and lack of through traffic.⁴¹

Pedestrian Network

Total Length of Walking Tracks. The total length (in meters) of walking tracks.

Re-engineering of Road Environment Indicators generated by examining street directory data were: total numbers of *speed humps*, which have been shown to reduce risk of child pedestrian injury;²⁷ *gates/barriers on roads* (may have a traffic-calming effect); *slow points* or sections of road narrowing (e.g., chicanes) engineered to encourage slower driving; and *traffic/pedestrian lights*.

DATA ANALYSIS

Independent samples *t* tests were performed to examine differences in active transport and MVPA between sex and between age group. In addition, paired samples *t* tests were performed to examine differences within sex in the number of walking/cycling trips made at T1 compared with at T2. Linear regression analyses were performed to examine associations between individual objective measures of the road environment and change between T1 and T2 in the number of walking/cycling trips made per week, as well as associations between individual road environment measures and change in MVPA (Δ MVPA) between T1 and T2 during each time period of interest. Regression analyses were adjusted for T1 values for number of walking/cycling trips and MVPA during each period, where appropriate.

In cases where several road environment variables were significantly associated ($p < 0.05$) with individual physical activity measures, multiple linear regression analyses were performed. All explanatory variables were assessed for multicollinearity, which is prevalent among neighborhood environmental characteristics,⁴⁰ using correlation coefficients between each pair of variables and the variance inflation factor (VIF).⁴² If significant variables were highly correlated (i.e., $VIF > 2.0$), only the variable with the highest unadjusted beta was used.

RESULTS

Data were analyzed for 170 children (51% boys), mean age 9.0 years (standard deviation [SD]=0.4), and 276 adolescents (43% boys), mean age 14.5 years (SD=0.6) at T1, who participated at both time points. The parent survey was completed mostly by mothers/female carers (87%) and 78% of parents were married. Over 45% of mothers were tertiary educated.

Road Environment

The mean (and range of) values of road environment measures within participants' neighborhoods are presented in Table 1.

Change in Active Transport

Mean walking/cycling trips/week and the mean change in walking/cycling trips are presented in Table 2. At T1 and T2, adolescents made more walking/cycling trips than children. Among children, paired sample *t* tests revealed significant increases between T1 and T2 in walking/cycling trips among boys (mean change 1.8 trips; $p=0.001$) and girls (1.1 trips; $p=0.027$). By contrast, adolescent boys and girls made fewer walking/cycling trips/week at T2 than at T1, but the differences were not statistically significant (mean change -1.3 trips, $p=0.069$ and -0.1 trips, $p=0.839$, respectively).

Change in Physical Activity

The mean time spent engaged in MVPA at T1 and the mean Δ MVPA between T1 and T2 (i.e. MVPA at T2 - MVPA at T1) during each nonschool period are presented for boys and girls in each age group in Table 3. During all periods, there were reductions in mean time spent in MVPA by boys and girls in each age group. With few exceptions, younger boys and girls recorded greater reductions over 2 years for each period compared with adolescents. While the significant increase in children's active transport may not at first appear to reconcile with decreased MVPA, it should be noted that distances walked/cycled were not recorded and any short trips would have contributed little to the total MVPA. Differences in Δ MVPA between T1 and T2 were statistically significant between age groups for girls during all periods and for boys during all periods except after school and on weekends. Except for before

TABLE 1 Median (and range of) values of road environment measures within participants' neighborhoods (by age group)

Measure of road environment (within 800 m radius of home)	Children median (min, max)	Adolescents median (min, max)
Total length of local roads (km)	16 (2, 32)	16 (0, 37)
Local road index	0.8 (0.3, 1.00)	0.8 (0.3, 1.00)
No. of intersections	89 (4, 255)	87 (1, 279)
Total length of walking tracks (m)	27 (0, 3707)	0 (0, 3977)
No. of speed humps	4 (0, 82)	5 (0, 99)
No. of gates/barriers on road	0 (0, 8)	0 (0, 8)
No. of "slow points" or sections of road narrowing	0 (0, 15)	0 (0, 24)
No. of traffic and/or pedestrian lights	3 (0, 16)	3 (0, 21)

TABLE 2 Change between T1 and T2 in mean number of walking/cycling trips per week according to age group and sex

	Children		Adolescents	
	Boys	Girls	Boys	Girls
Mean (SD) trips at T1	6.0 (3.7)** ****	5.2 (4.5)* ****	12.6 (7.8)	9.8 (7.4)
Mean (SD) trips at T2	7.8 (5.5)****	6.3 (5.1)****	11.3 (7.6)	9.7 (7.0)
Mean (SD) change in trips	1.8 (5.0)***	1.1 (4.4)	-1.3 (7.6)	-0.1 (6.6)

* $p < 0.05$, ** $p < 0.01$: paired samples t test—significant differences between trips at T1 and T2 by sex within age group; *** $p < 0.01$, **** $p < 0.001$: independent samples t test—significant differences between age groups within sex

school, younger girls recorded the greatest reductions in mean time spent in MVPA between T1 and T2. During all periods, adolescent boys recorded greater reductions in mean time spent engaged in MVPA, compared with adolescent girls. However, adolescent boys remained more active than girls at T2, having recorded significantly more ($p < 0.001$) MVPA during all periods except evenings at T1.

Road Environment and Change in Active Transport

Among younger boys, there were no significant associations between any of the objective measures of the road environment and change between T1 and T2 in the number of walking/cycling trips they made in their neighborhood per week. For younger girls, however, the total length of local roads (in kilometers) in the neighborhood was positively associated with change in number of trips made ($B = 0.21$, 95% CI = 0.02 to 0.39), as were the total length (in meters) of walking tracks ($B = 0.0016$, 95% CI = 0.0003 to 0.0028) and the number of traffic/pedestrian lights in the neighborhood ($B = 0.45$, 95% CI = 0.15 to 0.75). In the multiple regression model, none of these variables remained significantly associated with change in total walking/cycling trips made by younger girls.

For adolescent boys, intersection density was positively associated with change in the number of walking/cycling trips ($B = 0.03$, 95% CI = 0.003 to 0.06). For adolescent girls, the total length of walking tracks (in meters) was positively associated with change in the number of walking/cycling trips ($B = 0.0016$, 95% CI = 0.001 to 0.003), while the number of slow points was negatively associated with this ($B = -0.38$, 95% CI = -0.73 to -0.04). Both variables remained significantly associated with change in the number of walking/cycling trips in the multiple regression model (total length [in meters] of walking tracks: $B = 0.002$, 95% CI = 0.001 to 0.002; slow points: $B = -0.54$, 95% CI = -1.03 to -0.05).

Road Environment and Change in Physical Activity

For younger boys, the number of slow points (chicanes) in the neighborhood was positively associated with Δ MVPA before school ($B = 1.55$, 95% CI = 0.25 to 2.86), and the total length of local roads ($B = 3.81$, 95% CI = 0.95 to 6.67) and intersection density ($B = 0.49$, 95% CI = 0.14 to 0.84) in their neighborhood were positively associated with Δ MVPA on weekend days. These variables were not entered into multiple linear regression analyses due to collinearity. For younger girls, intersection density ($B = -0.05$, 95% CI = -0.09 to -0.003) and the number of traffic/pedestrian lights ($B = -0.88$, 95% CI = -1.41 to -0.35) were each negatively associated with

TABLE 3 Mean (SD) minutes per day of MVPA at T1 and mean change in MVPA by age group and sex

Time period	Children				Adolescents			
	MVPA at T1 (mean min/day, SD)		Change in MVPA (mean min/day, SD)		MVPA at T1 (mean min/day, SD)		Change in MVPA (mean min/day, SD)	
	Boys	Girls	Boys	Girls	Boys	Girls	Boys	Girls
Before school	23.9 (11.3)*****	20.7 (10.9)*****	-8.6 (11.2)*****	-8.2 (9.5)*****	11.1 (6.6)	8.3 (5.4)**	-4.0 (6.7)	-2.4 (5.7)
After school	43.1 (13.5)*****	42.3 (14.4)*****	-16.4 (15.9)	-22.4 (15.9)*, *****	27.2 (15.7)	20.0 (10.4)***	-11.4 (16.1)	-9.1 (10.6)
Evenings	27.7 (11.9)*****	30.5 (13.6)*****	-12.3 (12.7)***	-16.4 (14.3)*****	12.0 (9.8)	10.3 (7.9)	-7.5 (10.0)	-6.1 (7.9)
Nonschool hours (weekdays)	94.7 (25.3)*****	93.5 (31.5)*****	-37.4 (28.2)*****	-47.0 (29.9)*****	50.9 (23.0)	38.2 (16.1)***	-24.1 (21.5)	-17.1 (15.3)*
Weekends	167.3 (79.5)*****	161.6 (78.2)*****	-46.0 (94.7)	-70.7 (81.5)*****	71.8 (45.5)	47.5 (35.4)***	-36.9 (50.8)	-18.7 (40.1)**

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$; independent samples t test—significant differences between boys and girls within age group; **** $p < 0.05$, ***** $p < 0.01$, ***** $p < 0.001$; independent samples t test—significant differences between age groups within sex

Δ MVPA during evenings. These variables were not entered into multiple linear regression analyses due to collinearity.

For adolescents, significant associations between objective measures of the road environment and Δ MVPA between T1 and T2 during the specific periods of interest are shown in Table 4. There were few significant associations for adolescent boys; the number of speed humps in the neighborhood was positively associated with Δ MVPA after school, and the local road index was negatively associated with Δ MVPA on weekend days. For adolescent girls, however, there were many associations between road environment measures and Δ MVPA: total length of local roads, intersection density, and the number of traffic/pedestrian lights were each positively associated with Δ MVPA before school. The total length of local roads remained significantly associated in the multiple regression analyses (intersection density was excluded from the model due to collinearity with total length of local roads). These results should be interpreted with caution as adolescent girls, on average, engaged in very low levels of MVPA before school (e.g., mean 5.9 min (SD=4.4) at T2). The local road index was negatively associated with Δ MVPA among adolescent girls after school, as was their residence being located on a cul-de-sac. In the multiple regression model, only the local road index remained significantly associated

TABLE 4 Results of linear regression analyses: associations between road environment measures and change in MVPA between T1 and T2 among adolescents

Δ MVPA (min) T1 to T2 road characteristics	Boys		Girls	
	B^a	Adjusted ^b beta	B^a	Adjusted ^b beta
Δ MVPA before school				
Total length of local roads (km)	–	–	0.21**	0.20*
No. of intersections	–	–	0.03**	Not entered ^c
No. of traffic/pedestrian lights	–	–	0.28*	0.08
Δ MVPA after school				
Local road index (ratio)	–	–	–17.66**	–0.17**
Reside on cul-de-sac (yes/no)	–	–	–2.99*	–0.10
No. of speed humps	0.23*	–	–	–
Δ MVPA in evening				
No. of speed humps	–	–	0.15*	0.09
No. of gates/barriers	–	–	1.05**	0.11
Δ MVPA nonschool hours				
Total length of local roads (km)	–	–	0.49**	0.14
Local road index (ratio)	–	–	–27.62**	–0.23**
No. of intersections	–	–	0.05*	Not entered ^c
No. of speed humps	–	–	0.33*	0.05
Δ MVPA on weekend days				
Local road index (ratio)	–75.31*	–	–	–
No. of speed humps	–	–	0.51*	–

This table shows significant associations ($p < 0.05$) only

* $p < 0.05$, ** $p < 0.01$

^aLinear regression including single road environment variable and Δ MVPA during period of interest, controlling for MVPA at T1

^bMultiple linear regression including all variables with significant bivariate associations, controlling for MVPA at T1

^cNot entered due to collinearity

with Δ MVPA after school. The numbers of speed humps and gates/barriers were positively associated with change in girls' MVPA during evenings, but neither remained significantly associated with change in adolescent girls' MVPA during evenings when entered in the multiple linear regression analyses.

The total length of local roads, intersection density, and the number of speed humps were positively associated with change in adolescent girls' MVPA during nonschool hours, while the local road index was negatively associated. Only the local road index remained significantly associated with change in adolescent girls' MVPA during nonschool hours in the multiple regression model. The only variable positively associated with change in adolescent girls' MVPA on weekend days was the number of speed humps. The multiple regression models explained 53% of variance in Δ MVPA before school, 68% of variance in Δ MVPA after school, and 60% of variance in Δ MVPA during nonschool hours. The inclusion of values of MVPA at T1 accounted for much of the variance; excluding these values resulted in 9%, 5%, and 9% of the variance being explained, respectively.

DISCUSSION

This study sought to examine associations between the local road environment and change in physical activity among youth. In particular, it examined whether safety-related features of the local road environment may reduce age-related declines in physical activity among children and adolescents. For all participants, positive associations were demonstrated between road environment variables and change in active transport or physical activity. However, these associations differed by age group and sex. In particular, the road environment was associated most with change in active transport among girls in both age groups and with Δ MVPA among adolescent girls. This is important considering that younger girls recorded the greatest declines in MVPA and girls were less active overall than boys in each age group. Furthermore, low and declining levels of physical activity among adolescent girls have been reported worldwide.^{29,31,43–45}

The higher prevalence of associations between road environment variables and change in physical activity for girls compared with boys may be partly explained by research suggesting that, from an early age, girls are socialized differently from boys with regards to risk-taking behaviors.⁴⁶ For example, in the current study, the total length of walking tracks in the neighborhood was positively associated with change in active transport among girls in both age groups. If girls are encouraged to take fewer risks than are boys, they may prefer to use walking tracks rather than traditional pavements/sidewalks. Therefore, the availability of designated walking tracks in their neighborhoods may be important to encourage active transport among girls. An additional explanation among adolescents may be that these girls gained greater independent mobility during the study period, while boys had been granted this earlier. Cross-sectional analyses at T1²⁸ revealed more associations between road environment variables and MVPA for adolescent boys than for girls (then aged 13–15 years). While the current study is limited by not examining independent mobility specifically, an Italian study suggests that boys gain independent mobility at an earlier age than do girls.⁴⁷

Although this study has focused on how the local road environment may be associated with change in physical activity among youth, it is important to recognize that there may be other associated factors, and non-inclusion of additional intrapersonal and social variables is a limitation of this study. For example, the

children were aged 10–11 years by the end of the study and were, therefore, approaching puberty. Early pubertal maturation among girls, in particular, is related to depression and low self-esteem which predict low levels of MVPA.⁴⁸ For the adolescents aged 15–17 years by the end of the study, there may have been competing demands on their leisure time as sedentary activities such as homework may occupy increasing amounts of nonschool hours.⁴⁹ A longitudinal study demonstrated that, from early to mid adolescence, girls spent increasing leisure time engaged in sedentary behaviors, in particular sitting while chatting with friends.⁵⁰ Two reviews^{51,52} of determinants of physical activity indicated that physical activity is associated with a variety of variables of different types: intrapersonal (e.g., child's preference for PA over other activities), family (e.g., father's physical activity levels), social (e.g., school policies related to physical activity), and physical environment. While most of the studies reviewed^{51,52} were cross-sectional, these variables may have been associated with change in physical activity.

It is also worth noting that since the objective environment was not measured at T2 it was not possible to assess whether there had been changes in the road environment between T1 and T2 that may also have contributed to change in physical activity between these times. However, changes in the road environment tend not to occur regularly and are unlikely to explain the majority of change in physical activity observed in this study.

The findings of this study demonstrate clearly that there is no “one size fits all” solution for promoting active transport/physical activity among youth via road safety measures. However, the aspects of physical infrastructure which appeared to have the most impact on physical activity behaviors were traffic-calming measures: speed humps and traffic/pedestrian lights. In addition, the importance of quiet residential streets (i.e., roads classed as “local”) with speed limit of 50 km/h or less was highlighted, while walking tracks were associated with active transport (among girls in both age groups). The importance of speed humps in reducing child pedestrian injury has already been established. For example, a Californian study reported a reduction of around 60% in the odds of a child being injured or killed when struck by a motor vehicle if a speed hump was located within a block of the child's home.²⁷ Furthermore, in The Netherlands where active transport accounts for over 40% of urban trips,⁵³ traffic-calming interventions are associated with low child pedestrian injury rates.^{25,54} The current study builds on this previous research and indicates that traffic calming may be an important road safety measure that promotes physical activity. In particular, traffic-calming measures can provide passive physical activity interventions which may be beneficial to the broader community.

This study adds to a body of literature which identifies the pros and cons of street networks that contain cul-de-sacs in relation to physical activity.^{28,40,41} There were several different associations between cul-de-sacs and physical activity among adolescents (but not among children) in this study. For example, residing on a cul-de-sac was negatively associated with adolescent girls' active transport at T1²⁸ and also with change in their MVPA after school. These negative associations align with literature on adults' walking where cul-de-sacs are indicative of low street connectivity,⁴⁰ a barrier to active transport. While adolescent boys who resided on a cul-de-sac, rather than on a through road, engaged in significantly more MVPA at T1,²⁸ cul-de-sacs were not associated with change in boys' MVPA. This could, however, indicate that levels of MVPA among adolescent boys who resided on a cul-de-sac remained stable over 2 years.

This study is among the first to provide empirical evidence that safety-related aspects of the road environment contribute to physical activity among children and adolescents and are, therefore, a worthwhile investment. While programs and initiatives such as Active Living by Design⁵⁵ guide community design that supports and encourages physical activity, there was little evidence, until now, of the influence of such infrastructure on youth physical activity. The findings of this study demonstrate that local road environments which are conducive to active transport and outdoor play may help reduce age-related declines in physical activity among children and adolescents. This research may inform urban planners and policy-makers regarding the design of the built environment. In particular, they may guide environmental interventions aimed at increasing physical activity by improving the safety of local streets to accommodate active transport and physical activity among youth.

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