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Neighborhood walkability and objectively measured active transportation among 10–13 year olds

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ABSTRACT

Current active transportation literature within children is based almost exclusively on questionnaire measures of the trip to school. This literature suggests that the walkability of the built environment can influence active transportation to school. The purpose of this study was to use objective measures to examine the relationship between neighborhood walkability and children's active transportation to school and other destinations. This was a cross-sectional study of 367 children and early adolescents (aged 10–13 years) from Kingston, Ontario, Canada. Participants wore a Garmin Forerunner 220 GPS watch during waking hours for seven consecutive days. Personal Activity Measurement Location System (PALMS) software used the GPS data to identify trips, and for each trip the time spent in that trip and the trip modality (active or passive). GIS measures of connectivity, proximity to destinations, and pedestrian infrastructure and safety were used to create a walkability index. Participants living in the neighborhoods with the highest walkability quartile spent an average of 16.2 min/day (95% CI: 11.8, 22.4) in active transportation while those in the lowest walkability quartile spent an average of 7.1 min/day (95% CI: 5.0, 10.4) in active transportation. Consistent patterns between walkability and active transportation were observed in age, sex, and season of study subgroups. An increase in active transportation minutes was seen across walkability quartiles for all of the most common active travel destinations (i.e., home, school, other people's homes). In conclusion, in this study of 10–13 year olds, those living in the most walkable neighborhoods accumulated more than twice as much active transportation than those living in the least walkable neighborhoods.

1. Introduction

Active transportation is one way that children can incorporate moderate-to-vigorous physical activity into their daily lives (Faulkner et al., 2009). Children who walk and bicycle to school have higher overall physical activity (Larouche et al., 2014; van Sluijs et al., 2009), better cardiorespiratory fitness (Larouche et al., 2014), and healthier waistlines (Pizarro et al., 2013). In Canada, 25% of school-aged children and adolescents report using active transportation as their main mode of transportation to school (Barnes et al., 2016). This number varies worldwide from 79% in the Netherlands (Burghard et al., 2016) to 13% in the United States (Katzmarzyk et al., 2016).

Research on active transportation to school suggests that this behavior can be influenced by the built environment, which consists of the man made surroundings that provide the setting for human activity (Larouche et al., 2014; D'Haese et al., 2015; Wong et al., 2011). Built environment factors associated with increased active transportation to school include measures of walkability such as

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how well the streets connect to each other (Dill, 2004; Giles-Corti et al., 2011), having a variety of destinations within walking distance (Sallis and Glanz, 2006), and the presence of safety features such as traffic calming measures (e.g., speed humps, 4-way-stop intersections) and pedestrian infrastructure (e.g., crosswalks, sidewalks) (Wong et al., 2011). These walkability features can be examined individually or summed to create a walkability index (Giles-Corti et al., 2011; Frank et al., 2010; D'Haese et al., 2014; Carlson et al., 2015).

Although some research on non-school destinations exists (Carlson et al., 2015; Oliver et al., 2016), the pediatric active transportation literature is based almost exclusively on questionnaire measures of the trip to school (Dill, 2004). The lack of insight into determinants of travel behaviors outside of the trip to school is a recognized gap in the active transportation literature (Barnes et al., 2016; D'Haese et al., 2015). Furthermore, the self- or parental-reported nature of the school travel mode data are likely subject to measurement bias, a widely recognized issue in the physical activity field (Adamo et al., 2009), resulting in under or over reporting of the observed associations between the built environment and active transportation. We are only aware of two walkability studies of children that used objective measures of active travel (Carlson et al., 2015; Helbich et al., 2016).

The objective of this study was to examine the relationship between neighborhood walkability and objectively measured total active transportation and active transportation to common travel destinations among 10–13 year olds.

2. Material and methods

2.1. Study participants

The study sample consisted of a cross-sectional sample of 10–13 year olds from Kingston, Ontario, Canada. Children were excluded if they were not ambulatory or English or French speaking. A sample of 230 boys and 228 girls were recruited from the approximately 5000 children aged 10–13 who live in Kingston. The 21 participants who lived on agricultural properties or on highways or county roads in rural areas were excluded for the analyses for this study because these areas do not reflect the built environment this study intended to capture. Participants' data were collected between January 2015 and December 2016. Because physical activity levels vary by season, enrollment was balanced across the four seasons. Participants were recruited within each of the city's 12 electoral districts in proportion to the population of 10–14 year olds in each electrical district. The economic, social and physical attributes are similar within each electoral district but vary considerably across districts. To recruit participants, we used a comprehensive program with overlapping strategies including word of mouth, social medial advertisements, distribution of study postcards (at schools, day camps, youth organizations), and posting of study materials (at libraries, community centers, stores). Participants and a parent/guardian provided written informed consent prior to participation and children were compensated $40 for completing the study. The study was approved by the General Research Ethics Board at Queen's University.

2.2. Walkability

City of Kingston and DMTI Spatial Inc. (Richmond Hill, Ontario, Canada) geospatial databases were used in ArcGIS software version 10.4 (ESRI, Redlands, California, USA) to obtain all GIS measures in the home neighborhoods of all participants, with the exception of the Walk Score® (Walk Score, Seattle, Washington, USA), which was determined using the publicly accessible Walk Score® application (https://www.walkscore.com/). ArcGIS was used to create a 1 km road network buffer around each participant's home address to define their home neighborhood. This buffer size and type has been identified as the best fit when measuring youth travel environments in Canada (Seliske et al., 2013, 2012). One kilometer corresponds to a ~ 10–15 min walk or ~5 min bicycle ride (Seliske et al., 2012). As described below, within each participant's home neighborhood buffer several measures of connectivity, proximity to destinations, and pedestrian infrastructure and safety were determined. These measures were chosen based on previous findings showing an association with children's active transportation (D'Haese et al., 2015; Wong et al., 2011). First, connectivity, proximity to destinations, and pedestrian infrastructure and safety indexes were calculated. They were determined by creating a percentile rank of the individual measures discussed in the following paragraphs. The percentile ranks were then averaged and ranked to create the individual indexes. Finally, an overall walkability index was created by averaging the connectivity, proximity, and pedestrian safety and infrastructure indexes. Our decision to create the walkability index using an overall average wherein the connectivity, proximity, and pedestrian safety and infrastructure indexes were weighted equally was based on preliminary analyses which demonstrated that these indexes had similar effects on active transportation levels.

The measures of connectivity included: length of roads (Panter et al., 2010), intersection density (i.e., number of intersections per km^2 of land area) (Carlson et al., 2015; Dill, 2004; Mecredy et al., 2011), average block length (i.e., length of roads/number of true intersections) (Dill, 2004; Mecredy et al., 2011) and connected node ratio (i.e., ratio of intersections to all nodes including cul-de-sacs) (Mecredy et al., 2011; Gropp et al., 2012).

The measures of proximity to destinations included the Walk Score® (Carr et al., 2011), distance to school (Wong et al., 2011), and population density per square km of land area (Braza et al., 2004). These measures were chosen as they reflect both proximity to and a variety of destinations within the neighborhood. The Walk Score® has been shown to be a reliable and valid measure of estimating access to walkable amenities and it is strongly correlated with residential density ($r = 0.76$, $p < 0.001$) (Carr et al., 2011). The Walk Score® is, in part, determined by proximity to the closest school; however, in our sample the closest school was often not the school the participants attended. Therefore, we also measured the road network distance to their school. Proximity to destinations is a strong predictor of a children's active transportation to school and other destinations (Wong et al., 2011; Duncan et al., 2016).

The measures of pedestrian safety and infrastructure included the total length of sidewalks and paths (Kerr et al., 2006), estimated traffic volume (Giles-Corti et al., 2011), and the density of traffic calming measures (Rothman et al., 2014). Traffic volume was estimated by multiplying the length of arterial, collector and local roads by the average traffic volume of these roads types in Kingston, adding them together, and dividing by the total length of roads. Traffic calming measures included speed humps (Dessing et al., 2016), low speed zones (i.e., ≤ 40 km/h) including school zones, crosswalks (Rothman et al., 2014), 4-way-stop signs, playground/children playing signs, and pedestrian walking signs.

2.3. Active transportation

Participants were provided with verbal and written instructions on how to wear a Garmin Forerunner 220 Global Positioning System (GPS) watch (Garmin Ltd., Schaffhausen, Switzerland) and how to charge the watch overnight. They were then asked to wear the watch for 7 consecutive days. They were instructed to put on the watch shortly after waking, to turn on the GPS logger function, and to continue wearing the watch until bedtime, at which time they charged the watch so it could be used the next day. The watch continuously recorded their longitude and latitude coordinates during waking hours.

After the GPS data were collected, they were downloaded from the watch using Garmin Connect software (Garmin Ltd., Schaffhausen, Switzerland). The data were then exported to the Personal Activity and Location Measurement System (PALMS) software (Carlson et al., 2015). PALMS identified trips based on sequential GPS points that spanned ≥ 100 m with a speed ≥ 1 km/h lasting at least 3 min. The software allowed for pauses in travel of up to 3 min to account for traffic lights and other brief stops. After trips were identified, PALMS classified the travel modality of each trip as vehicle, bicycle, or walking based on travel speed. Trips with a 90th percentile of speed ≥ 25 km/h were classified as vehicle trips, trips with a 90th percentile of speed ≥ 10 km/h and < 25 km/h were classified as bicycle trips, and trips with a 90th percentile of speed ≥ 1 km/h and < 10 km/h were classified as walking trips. PALMS has been validated as a method for processing GPS data to objectively measure time spent in different transportation modes (Carlson et al., 2015). In comparison with a SenseCam (i.e., a camera worn around the neck that takes multiple images every minute), PALMS algorithms had a mean accuracy of greater than 85% and Intraclass Correlation Coefficients of greater than .80 for classifying min/day in each trip mode.

After the PALMS software identified the trips and modality of each trip, we used Google Fusion Tables software (Google, Mountain View, California, USA) to visually inspect each trip, to remove false positive trips, and identify the starting point and destination of each trip. The false positive trips represent trips identified by PALMS that reflect other movements such as outdoor play in the school yard. We used Google Fusion Tables to view each trip identified by PALMS individually as GPS fixes on a map. Trips that were identified by PALMS that occurred solely within a specific location (e.g., the school yard at recess) were considered false positive trips and were manually deleted during data cleaning; 6595 trips were deleted in this process.

During the cleaning process, the destination of each trip was determined by examining the end of each trip using Google satellite view and Google street view (Google, Mountain View, California, USA). Trip destinations were placed into one of the following categories: participant's home, other people's homes, bus stop, parks or greenspace, recreation facilities, retail, food service, school, and other. Note that only trips to school in the morning were categorized in the trip to school category. Trips leaving school in the afternoon at the end of the school day were captured in the home destination or wherever the participant travelled immediately after school. In addition, trips to school during the day (i.e., field trips or leaving the school property at lunch) and in the evening (i.e., returning for an event) were categorized separately. This was done to be able to differentiate between the primary journey to school and other school related trips.

During the data cleaning we noted that some of the trips that were identified by PALMS had the exact same starting point and destination without a pause point in the trip, such as hikes on a recreational trail (where the start and end points were a trailhead) or going for a walk around the neighborhood (where the start and end points were the participant's home). Since these trips did not appear to reflect travel to a specific destination, we considered these to be examples of walking or bicycling for leisure and not active transportation. Therefore, trips that were identified by PALMS that had the same starting and end points were recoded as leisure-time activities during the data cleaning and they did not count towards the time spent in active transportation.

The final issue we corrected for during the data cleaning was multimodal trips. In some cases, the multimodal trips were identified as two separate trips by PALMS, particularly if there was a pause of > 3 min between travel modes. For example, if a participant walked from their home to a bus stop, waited for the bus to arrive, and then took the bus to school, PALMS would have identified two separate trips, the first a walking trip and the second a vehicle trip. In other cases, particularly if there was not a pause of > 3 min between trip modalities, PALMS would have identified multimodal trips a single trip. For example, if a participant took a bus from school to their bus stop and then walked from the bus stop to their home, PALMS would have identified that as a single trip. When this occurred, we manually reclassified the single trip into multiple trips during the data cleaning process, and ensured that the modality of each of these multiple trips was correctly classified based on travel speed.

After the data cleaning was completed, the data were imported into SAS 9.4 statistical software (SAS Institute, Cary, North Carolina, USA) for further processing and to calculate the average number of min/day of active transportation. During this process we deleted data from days with < 10 h of GPS data (e.g., invalid days) and participants with < 4 days with 10 h of GPS data. This step is consistent with data processing done with accelerometer measures of physical activity (Colley et al., 2010). Seventy (15%) participants were lost during this data processing step. The SAS program then determined the total number of trips, the total duration of each trip (based on the times that the GPS points of the trip start and end points were recorded), and total daily time spent in trips separately by trip modality and destination. The average min/day of time spent in active transportation was then calculated for each participant and this was the outcome variable for the statistical analyses.

The reliability of the protocol used to clean and process the GPS data and identify trip destinations was determined by repeating all data cleaning and processing steps for the GPS data collected in week 2 for these same participants. The intra-rater reliability was carried out by having the same individual clean the data twice separated by six months. The inter-rater reliability was determined by having a second individual clean the data. Mean daily active transportation times were consistent across all three cleaning scenarios: 14.8 (95% CI: 12.3, 17.3) min for the initial cleaning by observer 1, 15.9 (95% CI: 13.5, 18.3) for the second cleaning by observer 1, and 14.7 (95% CI: 12.7, 16.8) for the clean by the second observer. Intra-rater percent agreement for destinations was 90% and inter-rater agreement was 88%.

2.4. Sociodemographic and covariate data

Sociodemographic characteristics including age, sex, and race (white or non-white including mixed race) of the participant, family structure (single or dual parent home, number of siblings in the home), annual family income (≤ $50,000; $50,001-$100,000; > $100,000), and parent education (high school or less, 2-year college, or 4-year college/university) were considered. Season of participation was categorized based on equinox and solstice dates. Height and weight were measured, the body mass index (BMI) was calculated, and the World Health Organization BMI growth references were used to categorize participants as having a non-overweight (thin + normal), overweight, or obese BMI (de Onis et al., 2007).

2.5. Statistical analysis

Data were analysed using SAS 9.4 statistical software. Multivariate analyses were conducted to compare average daily minutes of active transportation across walkability index quartiles. Eleven percent of participants did not have any active transportation trips and the active transportation data could not be transformed to follow a normal distribution. Therefore, a two-part modelling strategy was used to estimate average min/day of active transportation. This is a strategy commonly used for health-care cost data which is similarly distributed (Diehr et al., 1999; Janssen et al., 2009). In the first part, logistic regression was used to model the probability of the presence of any active transportation minutes according to walkability index. In the second part, a generalized linear model was used to model the relationship between the walkability index and min/day of active transportation. To fit this model the proc genmod procedure was used with a logarithmic link function and gamma distribution since the data were right skewed. Both the logistic regression and generalized linear models were adjusted for age, sex and season. The other covariates were entered in these two models using backwards selection methods, and these covariates were retained in both of the models if they were significantly ($p < 0.05$) related to the active transportation in either the logistic regression or generalized linear model. The mean min/day of active transportation for each quartile of the walkability index was calculated by multiplying the estimates from the two models together. Ninety-five percent confidence intervals (CI) for the means were calculated. ANOVA and Bonferroni post hoc comparison tests were used to compare active transportation by age, sex, season, and destination across walkability quartiles.

3. Results

Characteristics of the 367 participants included in the final analyses are in Table 1. By design, half were boys (50%) and participants were evenly distributed across ages and seasons. The majority were white (86%) and lived in a dual parent household (86%).

The mean time spent in active transportation was 11.8 min/day (95% CI: 8.6, 16.2). Table 2 presents the mean active transportation for the different walkability quartiles after adjusting for covariates. The effect estimates for the covariates that ended up being included in the model are in the Supplementary file table. There was a significant linear trend in active transportation across the walkability index quartiles ($p_{trend} < 0.001$). Overall, those living in the neighborhoods with the highest walkability scores spent an average of 16.2 min/day (95% CI: 11.8, 22.4) in active transportation while those in the lowest walkability index quartile spent an average of 7.1 min/day (95% CI: 5.0, 10.4) in active transportation. Consistent patterns between walkability and active transportation were observed in age, sex, and season of study subgroups (Table 2). Furthermore, the patterns of relationships were consistent when the connectivity, proximity to destinations, and pedestrian safety and infrastructure indexes were examined on their own (Table 3). This is despite the fact that some of these indexes were only moderately correlated with each other (Table 4).

Home, school and other people's homes were the three most common active transportation destinations. Mean minutes of daily active transportation were 4.1 min/day (95% CI: 2.9, 5.8) to home, 2.3 min/day (95% CI: 1.7, 3.1) to school, and 1.1 min/day (95% CI: 0.7, 1.7) to other people's homes. An increase in active transportation minutes was seen across walkability indexes for each of these destinations (Table 5) with significant linear trends ($p_{trend} < .0001$) for each. The average for all other travel destinations was < 1 min/day and we did not examine the relationship between walkability and time spent travelling to these uncommon destinations.

4. Discussion

This study examined the relationship between neighborhood walkability and objectively measured total active transportation and active transportation to specific destinations (home, school and other people's homes) among a sample of 10–13 year olds. The key finding of the study is that children living in the most walkable neighborhoods (highest quartile) engaged in almost 3 times more active transportation than children living in the least walkable neighborhoods (lowest quartile). Walkability was associated with active transportation irrespective of age, sex, season, travel destination, and type of walkability construct.

Table 1
Participant characteristics.

Characteristic	N	%
Sex		
Boy	185	50.4
Girl	182	49.6
Age		
10 years	89	24.3
11 years	89	24.3
12 years	98	26.7
13 years	91	24.8
Body Mass Index		
Not overweight	271	73.8
Overweight	57	15.3
Obese	39	10.6
Race		
White	316	86.1
Other	51	13.9
Season of Participation		
Winter	96	26.2
Spring	92	25.1
Fall	87	23.7
Summer	92	25.1
Number of Parents in Household		
Dual Parent	314	85.6
Single Parent	50	13.6
No response	3	0.8
Number of Siblings in Household		
0	46	12.5
1	190	51.8
2	91	24.8
3+	40	10.9
Family Income ($ CDN per year)		
≤ 50,000	55	15.0
50,001–100,000	108	29.4
> 100,000	165	45.0
No response	39	10.6
Parental Education		
High school or less	31	8.5
2-year college	108	29.4
4-year college/university	228	62.1

These results add to the current body of evidence that links both objective (Carlson et al., 2015) and subjective (Giles-Corti et al., 2011; Helbich et al., 2016; Kerr et al., 2006; Christiansen et al., 2016) walkability indexes to measures of active transportation. Most notably, Carlson et al. Carlson et al., (2015) used objective measures of both the built environment and active transportation in a small sample (n = 126) of 12–16 year old Americans and found that adolescents living in highly walkable neighborhoods had almost twice as many minutes of walking and bicycling by comparison to those living in the least walkable neighborhoods. Studies that have used subjective reports of active transportation to examine its association with walkability have seen both positive (Oliver et al., 2016; Kerr et al., 2006; Christiansen et al., 2016) and null (Giles-Corti et al., 2011) results. These null results may be due to the fact that the study considered measures of the school built environment rather than the children's neighborhood built environment and only included two measures of walkability (one measure of connectivity and one measure of traffic exposure) (D'Haese et al., 2014). One notable difference between this literature and the current study is that, to our knowledge, only two studies considered active transportation to destinations other than school (Oliver et al., 2016; Carlson et al., 2015).

The current study found that all three components of the walkability index were associated with active transportation. Although previous studies have found similar associations for measures of connectivity (Carlson et al., 2015; Helbich et al., 2016; Panter et al., 2010), proximity to destinations (Wong et al., 2011; Duncan et al., 2016) and safety features (Giles-Corti et al., 2011; Kerr et al., 2006; Rothman et al., 2014), there is not uniformity in the literature. For example, Timperio et al. (2006) found that street connectivity was negatively associated with active commuting to school and Larsen et al. (2009) found the same for residential density. This may be due to the increased pedestrian safety risk posed by more densely connected street networks such as increased traffic, higher speeds, and more street crossings (Sirard and Slater, 2008).

Comprehensive walkability indexes created for studies of adults (Frank et al., 2010; Cervero, 2002; Owen et al., 2007) and children (Carlson et al., 2015; Kerr et al., 2006; Christiansen et al., 2016) have not typically considered traffic safety. Within the context of walkability, safety refers to pedestrians and cyclists being protected from automobile traffic. Safety measures are often excluded from built environment analyses because these variables are not widely available in existing GIS datasets (Frank et al., 2010). This is an important limitation because, as shown in our study, these safety measures are associated with active transportation.

Table 2
Average minutes/day of active transportation according to walkability index quartile in the total sample and according to age, sex and season of participation.

Characteristic	Walkability Quartile				P trend
	1	2	3	4	
Total (n = 367)[a]	7.1 (5.0, 10.4)	9.9 (7.4, 13.2)	12.1 (8.9, 16.5)	16.2 (11.8, 22.4)	< 0.001
Sex					
Boys (n = 184)[b]	8.5 (5.9, 12.8)	11.6 (8.7, 15.4)	14.8 (10.9, 20.3)	19.1 (13.9, 26.4)	< 0.001
Girls (n = 182)[b]	5.9 (4.2, 8.3)	7.9 (5.9, 10.8)[e]	9.8 (7.1, 13.4)[e]	12.5 (9.1, 17.2)[e]	< 0.001
Age					
10 (n = 88)[c]	6.2 (4.1, 9.8)	7.6 (5.6, 10.4)	9.3 (6.8, 12.7)	12.5 (9.1, 17.4)[h]	< 0.001
11 (n = 89)[c]	7.3 (5.1, 10.7)	8.9 (6.7, 11.9)	9.7 (7.1, 13.3)	14.1 (10.5, 19.1)	< 0.001
12 (n = 98)[c]	7.4 (5.4, 10.2)	9.9 (7.6, 13.0)	13.2 (9.9, 17.8)	16.9 (12.2, 23.6)[f]	< 0.001
13 (n = 91)[c]	8.0 (5.6, 11.5)	12.5 (9.3, 16.9)[f,g,d]	14.8 (10.7, 20.5)[f,g]	21.0 (15.2, 28.9)[f,g]	< 0.001
Season					
Winter (n = 96)[d]	4.9 (3.5, 7.1)[j]	6.9 (5.3, 8.9)[j,g]	7.8 (5.9, 10.3)[j,k]	9.6 (6.9, 13.3)[j,k]	< 0.001
Spring (n = 92)[d]	8.2 (6.0, 11.5)[i,k]	11.8 (8.9, 15.8)[i]	14.0 (10.2, 19.5)[i]	21.9 (16.4, 29.5)[i]	< 0.001
Summer (n = 87)[d]	7.2 (5.0, 10.4)[j]	10.9 (8.1, 14.7)[i]	13.9 (10.1, 19.1)[i]	17.7 (12.9, 24.3)[i]	< 0.001
Fall (n = 91)[d]	8.1 (5.5, 12.7)[i,k]	10.0 (7.3, 13.8)[i]	13.4 (9.8, 18.6)[i]	16.0 (11.4, 22.4)[i,j]	< 0.001

Data presented as mean minutes/day (95% confidence interval).
[a] Values for the total sample have been adjusted for sex, age, season, number of parents in the household, and number of siblings in the household.
[b] Values for the boy and girl subsamples have been adjusted for age, season, number of parents in the household, and number of siblings in the household
[c] Values for the 10, 11, 12, and 13 year old subsamples have been adjusted for sex, season, number of parents in the household, and number of siblings in the household
[d] Values for the winter, spring, summer, and fall subsamples have been adjusted for sex, age, number of parents in the household, and number of siblings in the household
[e] Significantly different from boys ($p < 0.05$)
[f] Significantly different from 10 year olds ($p < 0.05$)
[g] Significantly different from 11 year olds ($p < 0.05$)
[h] Significantly different from 12 year olds ($p < 0.05$)
[i] Significantly different from winter ($p < 0.05$)
[j] Significantly different from spring ($p < 0.05$)
[k] Significantly different from summer ($p < 0.05$)

Table 3
Average minutes/day of active transportation according to connectivity, proximity, and safety indices within the total sample.

Walkability component	Quartile				P trend
	1	2	3	4	
Connectivity[a]	6.6 (4.6, 9.7)	9.7 (7.3, 13.1)	13.7 (10.2, 18.5)	17.5 (12.6, 24.4)	< 0.001
Proximity[a]	8.8 (6.3, 12.4)	10.4 (7.8, 14.0)	11.9 (8.6, 16.5)	16.2 (11.7, 22.7)	< 0.001
Safety[a]	8.0 (5.7, 11.3)	10.8 (7.7, 15.4)	12.5 (9.1, 17.1)	15.7 (11.6, 21.4)	< 0.001

Data presented as mean minutes/day (95% confidence interval).
[a] All values for the connectivity, proximity, and safety walkability components have been adjusted for sex, age, season, number of parents in the household, and number of siblings in the household.

Table 4
Spearman correlation coefficients of the walkability, connectivity, proximity and safety indices.

	Walkability Index	Connectivity Index	Proximity Index
Connectivity Index	0.87	–	–
Proximity Index	0.77	0.52	–
Safety Index	0.78	0.61	0.34

Note: p values for correlations all < .001

It has also been suggested that changing these safety features represents a simpler and more cost effective way of making changes to the current infrastructure than would making changes to the some of the other walkability constructs, such as connectivity, since that would require the physical restructuring of streets (Carver et al., 2008).

The findings of our study have implications for public health practice and urban planning. The built environment can influence large proportions of the population and has the potential to create sustained changes in walking and cycling habits (Sallis et al., 2000). While it is not feasible to change the connectivity of existing neighborhoods, the potential to impact active transportation should be considered in the construction of future neighborhoods. The current study also indicates that having an increased number

Table 5
Average minutes/day (95% confidence interval) of transportation to the three most common travel destinations according to walkability index.

Destination	Walkability quartile				P trend
	1	2	3	4	
Home[a]	2.6 (1.8, 3.7)	3.3 (2.4, 4.6)	4.3 (3.0, 6.1)	5.4 (3.8, 7.7)	< 0.001
School[b]	1.6 (1.1, 2.3)	2.0 (1.5, 2.8)	2.3 (1.7, 3.1)	3.1 (2.3, 4.2)	< 0.001
Other homes[c]	0.7 (0.5, 1.2)	0.9 (0.6, 1.5)	1.1 (0.7, 1.8)	1.4 (0.9, 2.3)	< 0.001

[a] Values for home destination have been adjusted for sex, age, season, number of parents in household, and number of siblings in the household.
[b] Values for school destination have been adjusted for sex, age, season, and number of siblings in the household.
[c] Values for other homes destination have been adjusted for sex, age, season.

of destinations within walking distance and increasing safety features of a neighborhood could positively impact children's active transportation behaviors. This could be accomplished by changing zoning policies to allow for retail space to be dispersed among residential areas and adding more traffic calming features to streets such as speed humps, low speed zones, and crosswalks. However, the influence of built environment features on active transportation may be different for children and adults: children and adolescents' transportation choices may be more strongly influenced by traffic safety concerns, especially for younger children (Panter et al., 2008).

There are several limitations of this study. First, this is a cross-sectional study. Reverse causality is a possibility as parents who want their children to engage in active transportation could self-select neighborhoods that encourage this behavior (Oliver et al., 2014). Second, we were not able to control for automobile availability in the household, which could have impacted the observed associations. Third, the results may not be generalizable outside of municipalities that are similar to Kingston, a city with a population of 123,363 and Walk Score® of 49. Finally, because active transportation habits change with age (Robertson-Wilson et al., 2008), these results may not be applicable to younger children and older adolescents.

5. Conclusions

In this study of 10–13 year olds, those living in the most walkable neighborhoods accumulated more than twice as much active transportation than those living in the least walkable neighborhoods. In addition, street connectivity, proximity to destinations, and traffic safety were each associated with increased active transportation. Future studies should consider using prospective cohort and natural experiment designs to provide a stronger evidence base for the association between walkability and active transportation.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at https://doi.org/10.1016/j.jth.2017.12.006.

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