Title

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Journal

Environment and behavior, 47(4)

ISSN

0013-9165

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Publication Date

2015-05-01

DOI

10.1177/0013916513520004

Peer reviewed

Environment and Behavior
2015, Vol. 47(4) 359–394

DOI: 10.1177/0013916513520004
eab.sagepub.com
SAGE

Influence of the Built Environment on Pedestrian Route Choices of Adolescent Girls

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Abstract

We examined the influence of the built environment on pedestrian route selection among adolescent girls. Portable global positioning system units, accelerometers, and travel diaries were used to identify the origin, destination, and walking routes of girls in San Diego, California, and Minneapolis, Minnesota. We completed an inventory of the built environment on every street segment to measure the characteristics of routes taken and not taken. Route-level variables covering four key conceptual built environment domains (Aesthetics, Destinations, Functionality, and Safety) were used in the analysis of route choice. Shorter distance had the strongest positive

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association with route choice, whereas the presence of a greenway or trail, higher safety, presence of sidewalks, and availability of destinations along a route were also consistently positively associated with route choice at both sites. The results suggest that it may be possible to encourage pedestrians to walk farther by providing high-quality and stimulating routes.

Keywords
pedestrian route selection, built environment, walking, discrete choice

Introduction

The role of the built environment in influencing travel behavior has gained increasing research and policy attention in the past two decades. A variety of frameworks and models, such as the socio-ecologic framework (Elder et al., 2007) and the social determinants of health and environmental health promotion model (Northridge, Sclar, & Biswas, 2003), call attention to the importance of upstream, community-wide factors that may influence individual behaviors. Relative to pedestrian travel, the built environment has been examined for its influence on trip-making behavior, travel mode choice, and destination choice, but little attention has been paid to characteristics of the built environment that determine pedestrian route choices.

Examining route choice is important because most of the evidence of individual-level associations between the built environment and walking has focused on home neighborhoods (Kaczynski, 2010; Rodriguez, Aytur, Forsyth, Oakes, & Clifton, 2008; Saelens & Sallis, 2007; Sallis et al., 2009; Witten et al., 2012). Meanwhile, recent research shows that individuals spend significant amounts of time away from their home neighborhoods (Wiehe et al., 2008). Furthermore, the concept of neighborhood does not correspond to the built environment as experienced by pedestrians; rather, pedestrians experience the built environment along the routes traversed (Isaacs, 2001). Therefore, the study of routes as part of the built environment is important to refining the understanding of what motivates and facilitates active travel modes. This study addresses this gap by examining how route-level characteristics of the built environment are associated with pedestrian route choices of adolescent girls.

Route measures of the built environment are distinct from area-based measures, such as neighborhood measures, in a number of ways. First, route measures are much more specific in describing the built environment as it is experienced by an active traveler. Second, in terms of geography, areal measures are usually aggregate measures over a discrete land area, whereas route measures are aggregated over a series of linear segments or other linear features. For example, measuring pedestrian road safety for a neighborhood may involve finding the average road width or the widest or highest speed road within or bordering the neighborhood. For a route, by contrast, one can specifically determine the widest road that is crossed or walked along. Therefore, route measures are distinctive for their specificity and for their linear as opposed to areal character.

Furthermore, examining route choice provides a different perspective on walking behavior than traditional studies of the built environment and active travel. Comparing different pedestrian route characteristics is predicated on the assumption that a walking trip is being made. The question of whether someone will walk or not is moot in this setting. Rather, the question is to understand the choice between Route A and Route B. Analysis of route choice hones in on the question of what types of environments are preferred by a population of active travelers based on their observed behavior. In the next section, we briefly review the broad literature on the built environment and active travel, and then summarize the small body of research on pedestrian route choice.

Built Environment and Active Travel

The association between the built environment and active travel has been a fertile area of research during the last two decades. We identified 16 literature reviews and a review of reviews that were published between 2002 and 2012. The reviews (Table 1) suggested that built environment features can conceptually be organized into four categories: aesthetics, destinations, functionality, and safety (Handy, 2004; Pikora et al., 2006). Aesthetic measures correspond to the sensory elements of the environment such as the appearance, sounds, and smells encountered while traversing a particular area. Destination or accessibility measures convey the number and proximity of any of a variety of destinations in the built environment. Although destinations may serve the main purpose of a trip and induce active travel, they may also make travel in an environment more interesting or stimulating. Functionality measures capture the suitability of the pedestrian or bicycle infrastructure for supporting active travel. Safety measures correspond with objective or perceived impediments to safety while engaging in active travel and typically are related to road safety, but sometimes also may include personal security.

In addition to examining specific environmental attributes, several studies have categorized the built environment using multidimensional indices or typologies and compared behaviors across these different categories. These include walkability indices (Frank, Schmid, Sallis, Chapman, & Saelens,

Table 1. Built Environment Measures Examined in Relation to Physical Activity.

Aesthetics	Destinations	Functionality	Safety	Cross-cutting
Air pollution	Accessibility measures (proximity)	Block size	Crime; perception of crime	Age of homes, average or median
Graffiti	Density; residential density; employment density	Connectivity; street connectivity	Dogs; presence of unattended dogs	Living in city
Litter	Distances to nearest destinations of varying types	Lighting; street lighting	Safety; perception of safety	New urbanist neighborhood; neighborhood types
Neighborhood aesthetics, neighborhood cleanliness; enjoyable scenery	Land use mix	Pedestrian or bicycle facilities; pedestrian/bike trails; pedestrian/bike paths	Crosswalks; pedestrian crossing signals; presence of crossing guards	Urban or rural; living in city
Noise pollution	Parks; proximity of parks; area in green spaces or parks	Sidewalks; sidewalk width; sidewalk quality	Traffic; Major roads; Traffic safety; heavy traffic; high speed streets	Urban sprawl
Tree-lined streets	Recreational facilities; playgrounds; gyms			Walkability indices
Weather; Exposure to weather; poor weather	Schools; school size			
	Shops, stores, retail, or commercial activity			
	Transit; transit access			

Note. Most of these built environment measures can be measured either objectively or through self-reported perceptions of the built environment. Related measures and alternative terminologies are grouped together within each cell. Built environment measures have been aggregated from the following literature reviews: Badland, Duncan, Oliver, Duncan, and Mavoa (2010); Davison and Lawson (2006); Duncan, Spence, and Mummery (2005); Giles-Corti, Timperio, Bull, and Pikora (2005); Handy (2004); Humpel, Owen, and Leslie (2002); Lee and Moudon (2004); McCormack et al. (2004); McMillan (2005); Panter, Jones, and van Sluijs (2008); Pont, Ziviani, Wadley, Bennett, and Abbott (2009); Saelens and Handy (2008); Saelens, Sallis, and Frank (2003); Sugiyama, Neuhaus, Cole, Giles-Corti, and Owen (2012); Wendel-Vos, Droomers, Kremers, Brug, and van Lenthe (2007).

2005; Hirsch, Moore, Diez-Roux, Evenson, & Rodriguez, 2013), measures of urbanicity or sprawl (Pont, Ziviani, Wadley, Bennett, & Abbott, 2009), and high-walkable versus low-walkable neighborhood types (Gallimore, Brown, & Werner, 2011; Rodriguez, Khattak, & Evenson, 2006). These indices can be conceived as combining some or all of the aforementioned aesthetic, destination, functionality, and safety features into integrated built environment measures.

Table 2 summarizes the strength of evidence for the four conceptual categories of built environment variables, how they influence walking for transportation, and whether the studies focused on youth. While there is at least some evidence that each of these categories can have influence in particular situations, recent research suggests that the strongest evidence is with regard to destination measures, followed by the functionality of pedestrian infrastructure (Ewing & Cervero, 2010). The evidence that safety and aesthetic features affect the decision to walk for transportation is less consistent. However, it should be noted that these results may be context-dependent—for example, traffic safety may be more of an issue in certain contexts, whereas personal safety may be more important in others (Davison & Lawson, 2006; McMillan, 2005).

Although largely consistent with the evidence on walkability for adults, the empirical evidence of what constitutes a walkable environment for adolescents has some important differences. Specifically, density and street design of the home neighborhood have been less consistently associated with the physical activity of adolescents (Cradock, Melly, Allen, Morris, & Gortmaker, 2009; Evenson, Murray, Birnbaum, & Cohen, 2010), whereas the presence of parks (Cradock et al., 2009; Ewing, Bartholomew, Winkelman, Walters, & Anderson, 2008; Frank, Kerr, Chapman, & Sallis, 2007; Grow et al., 2008) and physical activity facilities closer home (Dowda et al., 2007; Scott, Evenson, Cohen, & Cox, 2007) have been consistently associated with walking. Several studies have also examined associations between built environments and walking to school. Nationally, distance to school is negatively associated while population density is positively associated with walking to school (McDonald, 2008). High diversity of land uses (Larsen et al., 2009; Voorhees et al., 2009), and pedestrian-oriented street design (Bungum, Lounsbery, Moonie, & Gast, 2009; Hume et al., 2009) around residents' home and schools also have been associated with more walking to school.

Pedestrian Route Choices

Within the body of research on the built environment and active travel, pedestrian route choice remains relatively unexamined. A number of challenges

Table 2. Strength of Associations Between Built Environment Constructs and Walking for Transport.

Authors	No. of studies	Youth included	Aesthetics	Destinations	Functionality	Safety
Sugiyama, Neuhaus, Cole, Giles-Corti, and Owen (2012)	46	N	*	***	**	*
Durand, Andalib, Dunton, Wolch, and Pentz (2011)	62	Y	na	**	*	na
Ding, Sallis, Kerr, Lee, and Rosenberg (2011)	37	Y	na	**	*	*
McCormack and Shiell (2011)	58	N	na	**	*	*
Pont, Ziviani, Wadley, Bennett, and Abbott (2009)	38	Y	*	***	**	*
Panter, Jones, and van Sluijs (2008)	24	Y	na	**	**	**
Saelens and Handy (2008)	29 (plus 13 review papers)	N	*	***	*	*
Wendel-Vos, Droomers, Kremers, Brug, and van Lenthe (2007)	47	N	*	*	***	*
Davison and Lawson (2006)	33	Y	*	***	**	***
Badland and Schofield (2005)	11	N	na	**	**	na
Duncan, Spence, and Mummery (2005)	16	N	na	***	***	***
Handy (2004)	50	N	*	***	**	*
Lee and Moudon (2004)	20	N	**	***	**	**
Cunningham and Michael (2004)	27	N	**	***	***	na
Owen, Humpel, Leslie, Bauman, and Sallis (2004)	18	N	*	*	**	**
McCormack et al. (2004)	31	N	**	**	**	na
Saelens, Sallis, and Frank (2003)	10	N	na	**	na	na
Humpel, Owen, and Leslie (2002)	19	N	**	**	na	na

Note. Strength of empirical evidence: ***strong evidence of a statistically significant association; **moderate evidence of a statistically significant association; *weak evidence of a statistically significant association. na = not enough information for conclusion or not included in the study.

exist to examining pedestrian route choice, especially the difficulty of collecting data on the routes taken by pedestrians. Historically, pedestrian route data had to be gathered firsthand through monitoring individual behavior or through self-reported surveys, which can be unreliable (Cho, Rodriguez, & Evenson, 2011; Stopher, FitzGerald, & Xu, 2007). This is because privacy considerations are paramount in tracking pedestrians. In addition, and in contrast to the literature on the built environment and active travel, most examinations of pedestrian route choices focused on the frequently used downtown areas, which represent only a small fragment of the built environment.

The dominant theme of early work on pedestrian route choice was related to whether the route with the shortest distance was selected. This is not surprising given the focus of the literature on walking to reach destinations as opposed to walking for recreation. Hill (1982) found that the major factor in route selection across ages, gender, trip purposes, and environments was the minimization of distance; only 1 out of 211 observations deviated from the shortest distance. Seneviratne and Morrall (1986) surveyed pedestrians in downtown Calgary, Canada, and reported that selected routes were most often chosen for either shortest time or distance. In addition, they reported that the number of attractions along a route were important for those making shopping trips. However, as Hill (1982) noted, a large proportion of those providing other reasons for their route selection were nevertheless walking routes with the shortest distances. Another study in a downtown setting found that 69% of shoppers attempted to minimize distance, usually by going to the most distant location first and then gradually walking back to the parking area over the course of their visit (Garling & Garling, 1988). Another study found that 75% of recorded walks minimized distance, and that most of the remaining walks were only slightly longer than the shortest distance (Verlander & Heydecker, 1997).

More recent analyses of pedestrian route choice delve into the question of the trade-off between route distance and route quality (Agrawal, Schlossberg, & Irvin, 2008; Duncan & Mummery, 2007; Guo, 2009; Muraleetharan & Hagiwara, 2007; Rodriguez, Brisson, & Estupinan, 2009). Some studies found that road safety was an important determinant of route choices (Duncan & Mummery, 2007); but beyond safety, the evidence of the role of pedestrian infrastructure such as sidewalk widths and sidewalk amenities was less consistent. For example, Muraleetharan and Hagiwara (2007) found that pedestrians were likely to walk slightly longer distances when there are wider sidewalks and better street crossings. Lee, Zhu, Yoon, and Varni (2012) paired students belonging to the same school, living in close proximity of each other, but who traveled to school using different modes of travel, one of which was walking. They found that perceptions of distance, sidewalk, traffic conditions, and walking convenience differed between walkers and automobile users. In contrast, Agrawal et al. (2008) surveyed pedestrians on their chosen routes to transit stations and found that sidewalk condition and route attractiveness were mentioned less frequently than safety and route directness.

Guo (2009) examined the relative attractiveness of route alternatives among transit riders who had two viable transit/pedestrian routing options, either to remain on a single transit line and walk a farther distance, or to transfer lines and walk a shorter distance. He found that crossing a prominent downtown park, wider sidewalks, more intersections, and more destinations along the route all increased the probability of a route being chosen, and that routes requiring walking uphill were less likely to be selected. As a whole, these findings imply that it may be possible to encourage pedestrians to walk farther by providing high-quality and stimulating routes.

Based on the evidence reviewed, we expect routes that are shorter, safer, with more destinations, better aesthetics, and better functionality supports such as sidewalks, to be more likely to be chosen. Relative to earlier work on pedestrian route choice, our study is original in several aspects. First, unlike other studies, we conducted a comprehensive audit to enable examination of which built environment characteristics are influential with regard to route choice. Second, rather than a downtown commercial area, our study setting was primarily residential, increasing the diversity of locations for studying route choice. Third, our population was adolescent girls, who may have different routing behavior than the predominantly adult populations studied previously perhaps based on differences in risk-taking behaviors (Reyna & Farley, 2006) and sense of vulnerability (Steinberg, 2006). Finally, the trips under analysis differed from those in typical studies of commuting because they included diverse trip types, such as walking for shopping, and to get to school.

Method

Our approach was built on a micro-economic framework of human behavior based on random utility theory (Ben-Akiva & Lerman, 1985). For a given trip, individuals were assumed to choose among different walking routes such that they select the route that maximizes their utility. Each route has variables that represented its characteristics such as safety, security, aesthetics, and the presence or absence of destinations. The utility that an individual perceives from a route can be expressed as a function of the observable characteristics of each route plus a random component. Thus, the behavioral framework required the identification of the chosen walking route and its characteristics as well as those of suitable alternative walking routes not selected.

Context and Participants

Data were obtained from girls 13.2 to 14.9 years of age who were control participants in the multisite Trial of Activity for Adolescents Girls (TAAG) Study (Stevens et al., 2005). A subset of girls in the San Diego and Minneapolis/St. Paul (Minneapolis from here on) metropolitan areas were invited to participate in a longitudinal follow-up study from 2007 to 2010. After obtaining parental consent and their own assent, 303 girls enrolled, about half from each site. These sites were two of the original TAAG Study sites and they exhibited high participation and retention rates at each measurement time period and represented geographically and ethnically diverse populations. The built environment around the girls' homes and around their schools was distinct for the two sites. Compared with those residing in Minneapolis, girls in San Diego lived in areas that were less suburban, and had higher population density, greater proportion of households under the federal poverty level, and a higher ratio between the number of jobs and the number of households in the neighborhood (Rodriguez, Cho, Evenson, et al., 2012). In contrast, Minneapolis girls lived in a more suburban setting which had less street connectivity, more neighborhood and local streets, and more clustered commercial development at select intersections.

Participants wore two devices simultaneously—an off-the-shelf Foretrex 201 portable (83.8 × 43.2 × 15.2 mm) global positioning system (GPS) device (Garmin Ltd., Olathe, KS), which has been shown to have adequate accuracy and reliability in free-living conditions (Rodriguez, Brown, & Troped, 2005) and ActiGraph model 7164 accelerometer. Previous studies showed the ActiGraph to be reliable and able to detect differing levels of physical activity intensity (Metcalf, Curnow, Evans, Voss, & Wilkin, 2002; Welk, Schaben, & Morrow, 2004). The accelerometers were set to record activity in 30 s epochs to maintain consistency with the methods used in the TAAG Study (Treuth et al., 2004).

On the days they wore the devices, participants also recorded travel information using the Neighborhood Places Log (NPL), a travel diary in which they logged the name, address, and type (e.g., school, home, someone else's house, mall or store, community activity facility) of each destination, as well as the travel mode used, and arrival and departure times. Participants had the option to record the information on a personal digital assistant device or by hand on a paper version. The diary had been previously tested and refined with a convenience sample of girls in California and Minnesota not in the current study.

Participants wore the devices and completed the diary during two different time periods during a school semester (Fall or Spring). About half the sample in each city wore the devices for the first time in 10th grade and then a second time in 11th grade. The other half of the sample wore the units for the first time in 11th grade and the second time in 12th grade. Participants were randomly selected and similarly assigned into either the 10th-/11th-grade or the 11th-/12th-grade groups. Participants were asked to wear both devices during all waking hours for six consecutive days, except when showering, bathing, or swimming. Time stamps on the GPS and accelerometer units and time entered on the diary permitted combining the data.

Identification and Measurement of Routes

To identify walking trips, we used count and bout length information from the accelerometers. Counts register activity acceleration over a period of time and bouts were determined by assessing consecutive minutes of physical activity exceeding a given level. As explained elsewhere, we defined a walking trip as consecutive minutes of physical activity at or exceeding 899 counts per 30 s and lasting at least 5 min (Rodriguez, Cho, Elder, et al., 2012). Each walking trip had a 30% tolerance for counts not meeting the threshold values. For example, in a 15-min episode, 5 min could be under the threshold level and still count as a walking bout.

We also used the speed and time information from the GPS data to improve our identification of a walking trip. When a girl was stationary for at least 10 min, we identified the walking trip as having ended (and potentially a new trip beginning from that location). Finally, all GPS points in a walking trip were required to be within 1.6 km/hr and 6.4 km/hr (1 and 4 mph). These procedures for identifying walking trips have been shown to be accurate and valid (Rodriguez, Cho, Elder, et al., 2012). Once identified, the route of a walking trip was taken from the GPS data and linked by hand to the road and trail network of each city. This was done by taking into account the trajectory of the participant and the orientation and connectivity relative to network links. Combined with the diary information, we also identified the destination of each trip.

To identify the likely alternative routes participants could take but did not, we used a heuristic branch and bound algorithm proposed by Prato and Bekhor (2006). This approach constructs alternative routes by processing one segment at a time starting from the origin. A segment was defined as the length of a right-of-way (roadway, pedestrian path, or shared use trail) between two intersections or between an intersection and a dead end. Segments could be parts of roadways, greenways, trails, or alleyways. Each additional segment could be added to a potential alternative route, provided the partial route (starting at the origin and ending as far as the route had been built thus far) satisfied four behavioral and logical constraints (Prato & Bekhor, 2006): (1) *directional*, as the segment should not advance the person toward the origin by more than 10% of the distance up to that point; (2) *length*, as the partial route cannot be more than 50% longer than the shortest path built thus far; (3) *loop*, as the partial route cannot contain a loop; and (4) *similarity*, as the partial route cannot overlap for more than 75% with the shortest path built thus far. Each alternative route had to meet each of these criteria at each stage of the segment processing.

With a set of alternative routes for each pedestrian trip identified, we then measured the built environment along each of the routes chosen and not chosen for each pedestrian trip. In 2010, we collected data on all the segments of the different possible routes (online Appendix). Each segment was assigned a unique identifier and selected for rating if it was on a route that the girls took according to their GPS, or an alternative route from the one they chose. These segments were examined using an audit instrument designed to capture the four built environment constructs identified in the literature review: Aesthetics, Destinations, Functionality, and Safety (Table 3). The audit used was based on items from three existing audits that have shown adequate interrater reliability (Clifton, Livi, & Rodriguez, 2007; Evenson et al., 2009; Pikora, Giles-Corti, Bull, Jamrozik, & Donovan, 2003). We used pairs of trained raters, traversing the segment twice during daylight hours and good weather, with disagreements resolved by consensus. Working from the exploratory factor analysis in Evenson et al. (2009, Table 3), we selected items that had absolute loadings >0.5 under the urban category for the arterial/thoroughfare, walkable neighborhood, and physical incivilities constructs. The latter were also cross-referenced with Evenson et al.'s (2009) confirmatory factor analysis (CFA) to ensure adequate fit. Items such as the presence of decorations, a neighborhood sign, active adults and children, dogs, and pedestrian-oriented lighting were excluded because they had low inter-rater agreement, deemed not important for data collected during school hours, or had very low loadings in the CFA.

We aggregated segment-level variables into route-level variables with a variety of approaches. For variables that concerned the functional condition of the pedestrian infrastructure (sidewalk condition and greenway), we created a length-weighted average, so that the infrastructure along longer segments contributed more to measures of the route's Functionality. For variables concerning Safety and Destinations, (e.g., the number of traffic lights or the presence of food establishments), we took a simple average over all the segments which comprised the route. These variables reflect what percentage of

Table 3. Segment-Level Data Summary.

Segment environmental attribute	Valid values
Greenway	1 = *hard and soft surface*; 2 = *hard surface only*; 3 = *soft surface only*; 4 = *no*
Sidewalk	1 = *entire segment*; 2 = *part of segment*; 3 = *no*
Sidewalk condition	1 = *good*; 2 = *fair*
Sidewalk buffer	1 = *no buffer*; 2 = <6 *feet*; 3 = ≥ 6 *feet*
Maximum lanes	Positive integer
Pedestrian paddles/signals/crossing signs	1 = *yes*; 0 = *no*
Traffic lights	1 = *yes*; 0 = *no*
Stop signs	1 = *yes*; 0 = *no*
Median or pedestrian refuge	1 = *yes*; 0 = *no*
Pavement markings/crosswalks	1 = *yes*; 0 = *no*
Transit stops	1 = *yes*; 0 = *no*
Building condition	1 = *good or excellent*; 2 = *fair*; 3 = *poor or deteriorated*; 4 = *not applicable*
Abandoned buildings	1 = *yes*; 0 = *no*
Public space condition	1 = *good or excellent*; 2 = *fair*; 3 = *poor or deteriorated*; 4 = *not applicable*
Litter	1 = *none*; 2 = *some*; 3 = *moderate or more*
Graffiti	1 = *none*; 2 = *some*; 3 = *moderate or more*
Residential ground condition	1 = *good or excellent*; 2 = *fair*; 3 = *poor or deteriorated*; 4 = *not applicable*
Commercial establishment	1 = *yes*; 0 = *no*
Parks	1 = *yes*; 0 = *no*
Food outlets	1 = *yes*; 0 = *no*

segments had such a feature present. For some of the Aesthetics variables, we created both average and maximum values; the maximum values represent the worst condition on the route, while average values represent the mean condition along the route. The rationale here was that a route might be avoided entirely because of the condition of its worst segment. Table 4 shows all route-level variables considered, their interpretation, descriptive statistics at the route level (for all route alternatives, chosen and not chosen), and the expected direction of association with the probability of choosing a route.

In addition to these variables that capture a single aspect of the routes along the predetermined domains, we created three indices to capture the concepts of Destinations, Safety, and Aesthetics (Table 4). With minor

Table 4. Descriptive Statistics for All Routes (Chosen and Not Chosen).

Variable	Definition	Expected effect	San Diego (*N* = 232)			Minneapolis (*N* = 107)		
			M	*SD*	IQR	*M*	*SD*	IQR
Segments	Total number of segments in a route	NA	7.76	5.36	7.00	3.66	1.45	2.00
Distance	Total length of a route (ft)	−	3,421	2,545	4,024	2,102	1,176	1,053
Path size	Path size (measure of route independence among alternatives)	+	−0.75	0.53	0.88	−0.45	0.38	0.52
Functionality domain								
% Greenway	Percentage of route length which is greenway	+	0	4	0	8	20	0
Sidewalk condition	Length-weighted sidewalk presence and quality	+	0.70	0.32	0.52	0.15	0.32	0.07
Safety domain								
Average number of lanes	Average street width over all segments	−	2.65	1.03	0.71	2.11	0.52	0.00
% Pedestrian Signals	Percentage of route segments with pedestrian paddles or crossings	+	22	25	33	12	22	25
% Traffic lights	Percentage of route segments with traffic lights	+	18	27	25	12	20	29
% Stop signs	Percentage of route segments with stop signs	+	35	23	30	63	30	33
% Medians	Percentage of route segments with medians	+	8	20	0	4	11	0
% Crosswalks	Percentage of route segments with pedestrian crosswalks	+	19	27	29	50	40	100
Aesthetics domain								
Abandoned buildings	Presence of at least one abandoned building along the route	−	0.13	0.33	0.00	NA	NA	NA
Built environment condition	Worst of average condition of buildings, public spaces, and residential grounds on route	−	1.50	0.41	0.68	1.12	0.23	0.20
Litter	Average amount of litter on route	−	1.59	0.37	0.68	1.37	0.39	0.60
Graffiti	Average amount of graffiti on route	−	1.33	0.34	0.50	1.02	0.12	0.00
Destinations domain								
Transit Stops	Percentage of route segments with transit stops	+	9	16	10	13	26	17
Commercial	Percentage of route segments with a commercial establishment	+	18	25	29	18	29	33
Parks	Percentage of route segments with a public park	+	4	11	0	6	14	0
Food	Percentage of route segments with a food establishment	+	5	13	0	3	9	0
Index variables								
Destinations index	Includes transit stops, commercial, parks, and food	+	0.00	2.71	2.22	0.00	2.38	3.44
Aesthetic index	Includes abandoned buildings, built environment condition, litter, and graffiti	−	0.00	3.02	4.89	0.00	1.94	2.70
Safety index	Includes greenways, pedestrian signals, traffic lights, medians, and crosswalks	+	0.00	3.31	3.55	0.00	3.13	5.01

Note. IQR = interquartile range. *N* represents the total number of alternative routes (chosen and not chosen) considered in each area.

variations, these three indices are comparable with the domains identified in the review of the literature. The functionality domain was not made into an index because it contained only two items. The Destinations index is the sum of the transit stop, commercial establishment, food establishment, and presence of parks variables for each route all standardized to have mean 0 and standard deviation 1. We included number of lanes in the Destinations index after noting that most destinations were located in areas with several lanes, and thus this variable was an appropriate surrogate for destinations. The Safety Index is the standardized sum of the greenway, pedestrian signals, traffic lights, medians, and crosswalks variables. The percent of stop signs variable was omitted from the Safety index because it had a high negative correlation with percent traffic lights. The Aesthetic index is the standardized sum of the abandoned buildings, built environment condition, litter, and graffiti variables (the abandoned buildings variable was omitted in Minneapolis due to the absence of abandoned buildings). These indices were intended to represent holistic measures of the built environment constructs.

Data for the small number of segments that had missing audit data (3 segments in San Diego and 19 in Minneapolis) were obtained using Google Streetview, which has been shown to have high agreement with field audits (Kelly, Wilson, Baker, Miller, & Schootman, 2013; Rundle, Bader, Richards, Neckerman, & Teitler, 2011). For four other segments in Minneapolis without Streetview data, we imputed the values from each of the two neighboring segments by assigning the average values of the observed segments. Finally, a single missing variable (sidewalk condition) for two segments in Minneapolis was filled with statistically imputed values based on other available built environment variables on these segments.

Statistical Methods

McFadden (1974) showed that if and only if the random components of the utilities are assumed to be independent and identically Gumbel distributed, then the association of each characteristic with the odds of choosing an alternative from a set of route choices can be estimated with the conditional logit model. In discrete choice models, the outcome is a binary variable that equals 1 if a given alternative (route) is chosen and 0 otherwise. However, the analysis of route choices is more complex because parts of routes may overlap, and therefore the choices involved have some degree of commonality. We controlled for the degree of commonality among routes through the inclusion of a path size variable, which represents the relative independence of a particular route from other routes in the choice set (Broach, Gliebe, & Dill, 2011). An estimated coefficient of zero for the logarithm of the path size variable means that the route is completely independent relative to alternative routes for the trip. Otherwise, the logarithm of the path size takes on a negative value, with larger negative values assigned to routes with greater overlap with other routes in its choice set. We used the path size formula proposed by Bovy, Bekhor, and Prato (2008) because it is argued to have a stronger theoretical basis than alternative formulations of path size (Frejinger & Bierlaire, 2007). Furthermore, because some girls make more than one trip, not all observations are independent. Therefore, we report robust standard errors clustered at the individual level.

We estimated three sets of models for each site separately. First, we tested each individual route variable while controlling for route distance and path size. Second, we estimated models that include all independent variables that belonged to each of the built environment domains (Aesthetics, Destinations, Functionality, and Safety) at once. This resulted in four additional models (one per domain) for each site. Third, we estimated a model that contained the three indices that we developed for Destinations, Safety, and Aesthetics all together in a model with the distance and path size controls. We report point elasticities for the last two sets of models using a sample enumeration approach (Louviere, Hensher, & Swait, 2000). All analyses were conducted in Stata 12.1 for Windows 64-bit (College Station, TX) and given the relatively small sample size, we report when p values are <.1, <.05, and <.01.

Results

During the weeks observed, San Diego girls walked 73 trips and Minnesota girls walked 39 trips, yielding an average weekly rate of less than 0.5 and 0.26 trips per person. Compared with U.S. adult average number of walking trips per week of 0.52 (Buehler, Pucher, Merom, & Bauman, 2011), the girls had fewer trips. San Diego trips were considerably longer ($p < .05$), more likely to have a traffic light ($p < .01$), or stop sign ($p < .01$), and took place along wider streets ($p < .01$; Table 5). In terms of all the routes, the total number of routes (chosen and not chosen) in San Diego was 232, with an average of 3.2 alternative routes per trip (minimum = 2, maximum = 10). The total number of alternative routes in Minneapolis was 107 (chosen and not chosen), with an average of 2.7 alternative routes per trip (minimum = 2, maximum = 8). Destinations of walk trips differed between cities. In San Diego, 34% of all trips had home as destination, 21% other destinations, 18% school, 7% someone else's home, and 27% did not record a destination. In Minneapolis, 41% of trips had school as destination, 18% home, 18% someone else's home, 33% other destinations, and 8% did not record a destination.

Table 5. Selected Characteristics of Chosen Routes.

	San Diego (N = 73)	Minneapolis (N = 39)	t test	p value
Average distance (ft)	2,259	1,523	2.49	.01
Average street width	2.84	2.05	−3.44	<.01
Average % of road segments with traffic lights	26.8%	9.0%	−2.76	<.01
Average % of road segments with stop signs	3.7%	62.7%	4.84	<.01
Average % of road segments with commercial	23.1%	20.9%	−0.34	.37
Average % of road segments with food establishments	5.0%	3.4%	−0.59	.28

Note. N represents the total number of chosen routes in each area.

Differences in the built environment between the two cities were evident from inspection of descriptive statistics of characteristics of all routes (Table 4). San Diego routes were longer, along wider streets, with sidewalks of higher quality, with more traffic lights and pedestrian signals, but fewer stop signs than Minneapolis routes. In terms of aesthetics, the San Diego routes had more abandoned or vacant buildings, litter, and graffiti, and lower condition of the built environment.

San Diego Choice Model Results

Table 6 shows associations between built environment characteristics and route choice, with a separate model estimated for each characteristic. Some associations were consistent and others varied across the two locations. In San Diego, a higher likelihood of choosing a route was associated with the following route features: percentage of the trip taking place on a greenway ($p < .05$), presence and quality of a sidewalk ($p < .1$), percentage of traffic lights ($p < .05$), and crosswalks ($p < .05$), presence of abandoned buildings ($p < .01$) and parks ($p < .05$), and the Safety index ($p < .05$).

When variables of a domain were included in a single model for San Diego (Table 7), all domains had variables with statistically significant coefficients. Specifically, the two variables in the functionality domain, greenway ($p < .01$) and sidewalks ($p < .1$), remained statistically significant. For the safety domain, routes with traffic lights were more likely to be selected ($p < .1$). For aesthetics, presence of abandoned buildings ($p < .01$) was associated

Table 6. Associations Between Individual Built Environment Characteristics and Route Choice.

	San Diego (*N* = 232)			Minneapolis (*N* = 107)		
	Coefficient	*SE*	*p* value	Coefficient	*SE*	*p* value
Functionality domain						
% Greenway	**25.03**	**10.87**	**.02**	**7.84**	**4.45**	**.08**
Sidewalk condition	**1.57**	**0.93**	**.09**	2.10	1.30	.11
Safety domain						
Average number of lanes	0.34	0.30	.25	**0.82**	**0.42**	**.05**
% Pedestrian signals	1.67	1.06	.12	−1.15	1.00	.25
% Traffic lights	**2.73**	**1.20**	**.02**	1.89	2.19	.39
% Stop signs	−1.07	1.05	.30	−0.56	1.15	.62
% Medians	0.03	0.87	.97	**−9.65**	**3.75**	**.01**
% Crosswalks	**2.28**	**1.20**	**.06**	**3.67**	**1.20**	**.00**
Aesthetics domain						
Abandoned buildings	**2.69**	**0.85**	**<.01**	Not applicable		
Built environment condition	1.28	1.00	.20	**−5.25**	**2.82**	**.06**
Litter	−2.02	1.25	.11	−1.76	1.66	.29
Graffiti	1.09	0.70	.12	Not applicable		
Destinations domain						
Transit stops	−1.00	1.73	.56	0.88	0.78	.26
Commercial	0.28	0.95	.77	3.29	2.80	.24
Parks	**4.94**	**2.22**	**.03**	**6.96**	**4.08**	**.09**
Food	−0.87	1.90	.65	**8.82**	**3.71**	**.02**
Index variables						
Destinations index	0.04	0.09	.69	**0.78**	**0.33**	**.02**
Aesthetic index	0.18	0.15	.22	−0.38	0.29	.18
Safety index	**0.20**	**0.10**	**.04**	0.01	0.38	.98

Note. N represents the total number of alternative routes (chosen and not chosen) considered in each area. A separate model is run for each individual built environment variable. All models have errors clustered at the individual level and include distance and path size as controls. Statistically significant route variables at 10% level in bold.

with a higher probability of choosing a route and the amount of litter ($p < .1$) was associated with a lower probability of choosing a route. For destinations, the average number of lanes ($p < .05$) and the presence of parks ($p < .05$) were associated with a higher probability of choosing a route and the percent of segments with transit stops ($p < .05$) was associated with a lower probability of choosing a route. Two statistically significant variables were associated in the direction opposite of that expected: the presence of abandoned buildings made it *more* likely for a route to be selected, while the presence of transit stops made it *less* likely for a route to be selected. When the Destinations, Safety, and Aesthetic index variables were included in a single model, the Safety ($p < .01$) and Aesthetics Indices ($p < .1$) were associated with a higher probability of choosing a route.

Table 7. Associations Between Built Environment Characteristics and Route Choice, by Built Environment Domain.

	San Diego (*N* = 232)				Minneapolis (*N* = 107)			
	Coefficient	Elasticity	*SE*	*p* value	Coefficient	Elasticity	*SE*	*p* value
Functionality domain								
% Greenway	**26.31**	**0.01**	**9.73**	**.01**	**7.94**	**0.10**	**4.30**	**.07**
Sidewalk condition	**1.61**	**0.47**	**0.93**	**.09**	**2.92**	**0.06**	**1.53**	**.06**
Goodness of fit χ^2				.10				.08
Safety domain								
% Pedestrian signals	−0.42	−0.04	1.31	.75	**−6.04**	**−0.11**	**1.96**	**.00**
% Traffic lights	**2.89**	**0.21**	**1.54**	**.06**	8.67	0.15	8.36	.30
% Stop signs	−0.29	−0.04	1.02	.77	−0.69	−0.05	1.59	.67
% Medians	−1.50	−0.05	1.59	.35	**−9.89**	**−0.08**	**3.60**	**.01**
% Crosswalks	1.18	0.09	1.80	.51	**6.71**	**0.44**	**2.00**	**.00**
Goodness of fit χ^2				.20				.11
Aesthetics domain								
Abandoned buildings	**2.83**	**0.13**	**0.82**	**<.01**		Not applicable		
Built environment condition	1.40	0.79	1.19	.24	**−5.41**	**−1.02**	**2.57**	**.04**
Litter	**−3.19**	**−1.88**	**1.84**	**.08**	0.22	0.05	0.90	.81
Graffiti	1.58	0.79	1.02	.12		Not applicable		
Goodness of fit χ^2				.01				.12
Destinations domain								
Average number of lanes	**1.57**	**1.52**	**0.75**	**.04**	**2.34**	**0.48**	**0.74**	**.00**
Transit stops	**−7.68**	**−0.26**	**3.03**	**.01**	**4.99**	**0.05**	**2.71**	**.07**
Commercial	0.20	0.01	1.40	.88	1.69	0.04	2.47	.49
Parks	**4.89**	**0.06**	**2.32**	**.04**	**15.07**	**0.13**	**4.83**	**.00**
Food	−1.54	−0.04	2.35	.51	**14.59**	**0.02**	**4.85**	**.00**
Goodness of fit χ^2				.01				<.01
Index variables								
Destinations index	−0.12	−0.11	0.13	.35	**1.22**	**0.23**	**0.42**	**.00**
Safety index	**0.29**	**0.29**	**0.11**	**.01**	**0.91**	**0.25**	**0.36**	**.01**
Aesthetics index	**0.29**	**0.28**	**0.17**	**.08**	−0.28	−0.05	0.37	.45
Goodness of fit χ^2				.02				<.01

Note. N represents the total number of alternative routes (chosen and not chosen) considered in each area. One model was estimated for each domain with all variables from that domain. A single model was estimated with the three index variables. All models have errors clustered at the individual level. All models also adjust for distance and path size, except the Destinations domain model in Minneapolis which does not adjust for path size. Statistically significant variables at 10% level in bold. χ^2 *p* value represents statistical significance of the model relative to a base model with path size and distance as controls using likelihood ratio tests with unclustered errors.

Minneapolis Choice Model Results

In Minneapolis, individual route characteristics included one at a time in models (Table 6) showed that the percentage of the route that was a greenway ($p < .1$), the average street width in lanes ($p < .05$), the percentage routes segments that had crosswalks ($p < .01$), medians ($p < .05$), the average built environment condition ($p < .1$), percentage of route segments with parks ($p < .1$), percentage of route segments with food establishments ($p < .05$), and the Destinations index ($p < .05$) were all associated in the expected direction with higher likelihood of choosing a route (Table 6). One statistically significant variable was associated in the direction opposite of that expected: the presence of medians made it *less* likely for a route to be selected. Graffiti was excluded for the Minneapolis models because only three trips encountered any graffiti, and it perfectly predicted route choice.

When Minneapolis built environment variables of a domain were included in a single model (Table 7) all domains had variables with statistically significant coefficients. For functionality, percentage of the route on a greenway ($p < .1$) and presence and quality of sidewalks ($p < .1$) were associated with selecting a route with those features. In the safety domain, a higher percentage of the route with pedestrian signals ($p < .01$) and a higher percentage of the routes with crosswalks ($p < .01$) but a lower percentage of segments with medians ($p < .01$) were associated with choosing a route. In the aesthetics domain, better built environment conditions were statistically associated with route choice. For the destinations domain, the number of lanes ($p < .01$), presence of transit stops ($p < .1$), percentage of parks ($p < .01$), and presence of food outlets ($p < .01$) were statistically significant. Among the indices created, the Destinations index ($p < .01$) and the Safety index ($p < .05$) were statistically significant. The direction of association of the median and pedestrian signal variables was contrary to expectations, with a greater presence of medians or lights reducing the probability of route selection. Overall, the strongest and most theoretically consistent result in Minneapolis was the significance of assorted variables related to the concept of Destinations.

Comparison With Distance and Magnitude of Effects

Across both settings, route distance was clearly the most salient variable in determining pedestrian route choice across all models (results not shown), with shorter distances positively associated with route choice. Estimated elasticities ranged from −1.49 to −1.97 for San Diego and −1.27 to −1.72 in Minneapolis, which suggests that a 10% increase in distance reduced the probability of a route being selected by 14.9% to 19.7%. In addition, the path

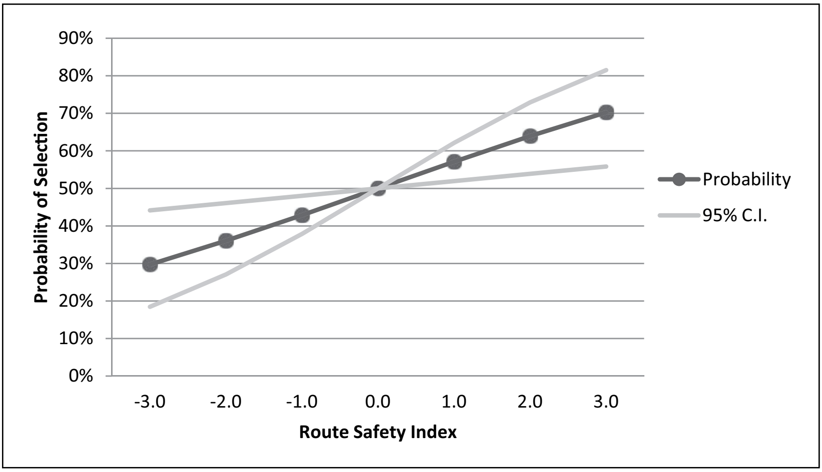

Figure 1. Probability of selecting a route with changes in Safety index, San Diego ($n = 232$).

Note. The graph assumes a set of two alternative routes, with the alternative route's values held at mean values for San Diego.

size variable was associated with choosing a route and had a negative sign. This suggests that routes that have overlaps with viable alternative routes were preferred. Such a negative coefficient for path size is the opposite of what is commonly seen with vehicle route choice but has been observed in transit route choice (Hoogendoorn-Lanser, van Nes, & Bovy, 2005).

Figures 1 and 2 display the estimated effects of the Safety index for San Diego and the Destinations index for Minneapolis, respectively, on the probability of selecting a given route. Although these variables have much less influence than shorter route distances according to their estimated elasticities (Table 7), they play a potentially substantial role in determining route choices. Varying the Safety index from −2 to 2 increases the probability of selection from 36.0% to about 64.0% in San Diego. Varying the Destinations index from −2 to 2 increases the probability of selection from 14.8% to about 85.2% in Minneapolis. In terms of how participants trade walking distance for other amenities, our results indicate that in San Diego participants were willing to go an average of 172 ft beyond the shortest path (or about 0.75 min) for a one standard deviation increase in Safety. Similarly, in Minneapolis participants were willing to go an average of 111 ft beyond the shortest path (or about 0.5 min) for a one standard deviation increase in Destinations. The presentation of tradeoffs between route alternatives was allowed by the use of discrete

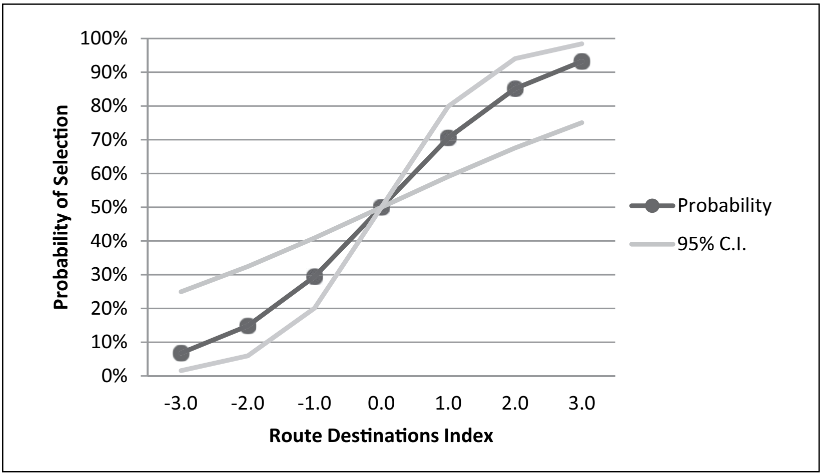

Figure 2. Probability of selecting a route with changes in Destinations index, Minneapolis (*n* = 107).

Note. The graph assumes a set of two alternative routes, with the alternative route's values held at mean values for Minneapolis.

choice analysis. For example, Guo (2009) found that an additional 6 ft of sidewalk width increased the probability of choosing a route almost the same as a reduction of half a min in walking time.

Discussion

The influence of the built environment on pedestrian behavior has been previously examined for trip generation, choice of travel mode, and choice of destinations. Much less work has been done regarding route choices, even though the determinants of route choice may reveal important information about the role of the environment in influencing active travel behavior. Such insights are relevant for city planners, transportation engineers, environmental psychologists, and public health practitioners. In this study, we were assisted by the advent of portable GPS units, which recorded location information over time to identify walking routes that adolescent girls took. Furthermore, we developed and evaluated a comprehensive set of measures of the built environment for a set of available route choices. In particular, our route-level measures covered the concepts of Aesthetics, Destinations, Functionality, and Safety.

The functionality and destinations domains had variables that were consistently associated with route choices in both sites. Functionality stood out in both sites as confirming the attractiveness of greenways and trails and the importance of sidewalk quality for pedestrian travel. Consistent with prior research (Frank et al., 2005; Rodriguez et al., 2008) destination variables such as food establishments and the presence of parks were important. Although it is tempting to conclude that destinations were particularly important in the more suburban setting of Minneapolis because of the greater coefficients, a direct comparison between the two model results is not appropriate (Train, 2009). The results also verified that route distance is a dominant variable in determining pedestrian route choice and is robust across settings and populations. This is consistent with the previous research reviewed (Guo, 2009; Hill, 1982; Verlander & Heydecker, 1997).

Both sites had safety variables that were statistically significant, including the percentage of crosswalks and the Safety index. Although some of the safety variables were statistically significant in the opposite direction anticipated, it is important to keep in mind that safety features are more likely in higher traffic areas, and therefore some safety features may inadvertently be serving as surrogate measures for traffic volumes or speeds. Safety considerations are paramount for pedestrian activity, particularly in areas with considerable vehicle traffic (Duncan, Spence, & Mummery, 2005; Panter, Jones, & van Sluijs, 2008). Other indices were not consistently associated with route choices in both sites. This may be the result of how each index was created a priori, based on conceptual categories. The bivariate and multivariate models show that some of the index items have opposing associations with route choice, and hence the aggregation of such items is likely to be responsible for the non-significance of the indices.

Other route characteristics that were statistically significant in one study site were not statistically significant in the other. This suggests that the most important variables for influencing route choice are likely to depend on the broader built environment context. In particular, variables related to negative features of aesthetics that may induce fear in walkers, such as the presence of litter and abandoned buildings, were more important in the less suburban setting of San Diego than in Minneapolis. Other studies have found inconsistent evidence with respect to aesthetics (Boarnet, Forsyth, Day, & Oakes, 2011; Giles-Corti, Kelty, Zubrick, & Villanueva, 2009).

The focus on adolescent girls is a unique aspect of the study. Adolescent girls are less physically active than adolescent boys (Sallis et al., 2000; Troiano et al., 2008) and are less likely to walk to school (Cooper, Andersen, Wedderkopp, Page, & Froberg, 2005), so understanding the factors that differentially explain physical activity and walking is important to inform local and regional policy. In addition, differences between adolescent females and males in perceptions and behaviors suggest that understanding environmental supports and barriers for each group is warranted. Adolescent girls prefer different activities, participate in physical activity for different reasons, and tend to face different barriers than adolescent boys (Bradley, McMurray, Harrell, & Deng, 2000; Kuo et al., 2009; Tappe, Duda, & Ehrnwald, 1989). For example, a study of adolescent girls revealed that focusing on the area around home to examine environmental exposures may be inadequate because they spent a significant amount of their awake time more than 1 km from their homes (Wiehe et al., 2008). These differences in perceptions and behaviors suggest that similar studies should be conducted in adolescent males and adult populations to determine whether similar built environment attributes are associated with pedestrian route choices.

Although individual perceptions of the built environment tend to be strong predictors of walking and could be examined under the current modeling approach, they were excluded from our analysis for a number of reasons. First, preferences revealed by behavior tend to be more reliable than preferences simply stated. Second, data on perception of the built environment along routes were not collected from participants partly because they would need to report on their perceptions for both the route chosen and for routes not chosen. In many cases, perceptual information of routes not chosen is likely to be unreliable as individuals may not be very familiar with most attributes of that route. Most studies that have involved pedestrian's perceptions of routes are set up as experiments, with pedestrians exposed to both high walkability and low walkability routes or segments of routes (Brown, Werner, Amburgey, & Szalay, 2007; Isaacs, 2001). Third, in such experimental studies, pedestrian perceptions of what is a walkable environment tend to agree with audits conducted by trained experts (Brown & Werner, 2007), although their explanatory power tends to be better (Addy et al., 2004; Giles-Corti & Donovan, 2002; Humpel, Marshall, Leslie, Bauman, & Owen, 2004). Fourth, in the current study participants were going about their normal routines over the course of the study periods. This further undermined the reliability of querying participants about their perceptions of the routes for walking trips that may have occurred several days ago. Finally, focusing on objective information of the physical environmental along routes is helpful for identifying the changes that needed to happen to the built environment.

Some results were contrary to expectations. For instance, in San Diego abandoned buildings appear to make route selection more likely and the presence of transit stops makes route selection less likely. Similarly, in Minneapolis, the percentage of pedestrian signals and road medians along a route made the selection of that route less likely. Perhaps these correlations stem from variables missing from our analysis, such as abandoned buildings being more common in busy districts (or may only be a temporary phenomenon due to a faltering economy), and routes with transit stops, medians, and pedestrian signals being less desirable because they correlate with heavy levels of traffic. Similarly, there are a few important built environment variables that were not captured by our audit, such as level and speed of traffic, which have been shown to have an impact on walkability (Carver et al., 2005; van Lenthe, Brug, & Mackenbach, 2005).

One reason for the unexpected results is that some attributes of the built environment that enhance walkability are co-located with others that detract from it. For example, traffic and the presence of social incivilities cues for unsafe environments tend to occur in busy streets, where destinations, ample sidewalks, and public transportation abound. The net impacts of these environments on actual walkability are an empirical matter, with net positive effects possible in some contexts and net negative effects in others. These counterintuitive results illustrate the difficulty of collecting and interpreting built environment data at the micro-scale, where the number of potential variables to consider is high and the number of potential correlations among these variables may be high as well.

Another potential contributor to the inconsistent results is that we measured walking trips and destinations regardless of their purpose. This concern is ameliorated by the fact that none of the trips began and ended at the same location, a feature more characteristic of recreational trips. Still, some of the walking trips that ended at a different destination from where the trip began may be for the purpose of exercising or for recreation. Or a single walking trip may have several different purposes. This points to the difficulty of associating trip purpose in walking studies (Handy, Boarnet, Ewing, & Killingsworth, 2002). It is to be expected that the importance of some built environment features for walking will depend on the purpose of the trip. For a trip to school activities, for example, one may be less affected by traffic than a trip for a recreational walk. In other cases, however, the effects may be opposite of each other. Bus stops or commercial buildings may be desirable as one walks to a destination but may be overtly avoided when walking for recreation.

Although this is one of the first studies to evaluate detailed route characteristics with actual choice behavior for pedestrians, it has a number of limitations related to external validity. First, the study population is specific to adolescent girls in two distinct U.S. cities. Measures were taken during a school week, when travel during school hours was relatively constrained. It is also possible that some walking trips were missed because of how we defined a walking trip with the concurrent use of accelerometers and GPS data. Second, the number of possible walking routes was relatively small because of the relatively short distance of walking trips. In some automobile applications of route choice there are dozens of routes because the number of possible routes that analysts consider is positively correlated with distance (Prato, 2009). Longer trips will have more possible routes than shorter trips. In reality, individuals only consider a small number of alternatives when making routing decisions (Bovy & Stern, 1990), but there is no guarantee that the routes identified by us coincide with the routes considered by the participant. Perhaps, more importantly, the built environments were somewhat homogeneous within each of the two sites, so the importance of some variables may have been suppressed due to lack of variation.

A third limitation is our use of a common specification of the path size variable in the analysis, even though other specifications have been proposed (Bovy et al., 2008; Frejinger & Bierlaire, 2007). We conducted a sensitivity analysis by including the alternative specification suggested by Ben-Akiva and Lerman (1985) and by examining models without any path size variable, but results (not shown) were nearly identical to those reported here. Fourth, our relatively small sample size did not allow us to examine important interactions. Examining interactions is particularly relevant when studying the built environment because many of the built environment features have synergies with one another. For example, the effect of sidewalks on route choice is likely to be moderated by the presence of destinations and the availability of design features like awnings, plantings, and inviting facades. With destinations and pedestrian-supportive design, sidewalks play a much more important role in enhancing active travel than when destinations are not available or design is not supportive (see, for example, Hirsch et al., 2013). This type of interaction explains why some built environment features such as sidewalks and crosswalks have been positively associated with active travel but are less consistently associated with recreational walking.

Finally, a broader area of concern is our reliance on a behavioral framework based on rational choice. Evidence that individuals do not make "rational" decisions has accumulated rapidly (Kahneman & Tversky, 1979), and concerns may be even stronger for non-adults. For example, travel has been shown to be habitual, in the sense that a deliberate evaluation of tradeoffs is rarely made every time a trip is taken. Rather, a habit relies on automaticity in decision making. It is possible that this extends to route decision making. Similarly, it is possible that other factors (such as traveling with friends), or unobserved route characteristics correlated with observed characteristics, may have affected the results.

Conclusion

We examined pedestrian route choices in a variety of suburban settings using discrete choice analysis. In addition to the strong effect of shorter distances, the results imply that it may be possible to encourage pedestrians to walk farther by providing high-quality and stimulating routes. Functionality aspects of the built environment, such as the presence of a greenway or trail, safety of a route, the presence of sidewalks on a route, and the presence of destinations in attracting pedestrian travel were important predictors of route choice. Specifically, we estimated that increases in our Safety index (which ranges from −3 to 3) from −2 to 2 increases the probability of selection from 36.0% to about 64.0% in San Diego. Similarly, changing the Destinations index from −2 to 2 increases the probability of selection from 14.8% to about 85.2% in Minneapolis. Thus, meeting these characteristics of the built environment appears to be a basic requirement for pedestrian travel. Attention to these aspects of the built environment by designers, planners, and health advocates is likely to improve the walkability of places and ultimately to increase walking in the population.

The heterogeneity of some results suggests the importance of the broader context in attempting to understand the built environment's influence on route choices. For example, the importance of pedestrian safety for route choice emerged among San Diego participants but not among Minneapolis participants, partly because of the less suburban location of the homes and schools in San Diego. By contrast, destinations were important route features that attracted walkers in Minneapolis, where streets were less connected and most commercial space was clustered at key intersections. This finding extends prior research in which destinations are often considered as the endpoint of a trip. Here, we found that destinations along the route made the route more likely to be chosen by pedestrians. Thus, the broader environmental context within which the behavior occurs is often critical in determining which associations are relevant. Future research should examine the approach with different populations and in different locations.

As technology enables the monitoring of pedestrian route choice to be more accurate, less expensive, and less intrusive, the number of studies of how pedestrians choose and experience routes and to what extent quality route environments impact pedestrian travel will increase. These studies are important because they allow researchers to understand the context within which walking occurs by matching activity to specific places. Combined with primary and secondary data, this micro-level data on behavior also enables in-depth examinations of the environments with high and low walkability. The promise of these studies can be contrasted with typical results from macro-scale correlational studies, which measure walkability on the basis of land use mix, intersection connectivity, and density. As shown in the current study and as hypothesized by others (Cervero & Kockelman, 1997; Ewing & Clemente, 2013), the design of the built environment along dimensions such as aesthetics, safety, and its functional aspects are likely to play a significant role in explaining choices.

One challenge that remains is to reliably measure some of characteristics of the micro-level environment. Our experience highlights the importance of having a rigorous methodology for collecting segment-level data, as even a small amount of missing data can make the calculation of route-level measures challenging or impossible. And even then, some of measurement choices were driven by practical considerations. For example, our measures of aesthetics were largely focused on negative aspects of the built environment associated with physical incivilities. Rather than characterizing what a pleasurable walking environment might be, the focus was on attributes that may generate fear or may be disliked by pedestrians. This emphasis was practical: Documenting the presence of graffiti, litter, or abandoned building structures is easier than measuring some of the positive aesthetics attributes like the quality of landscaping, building enclosure, legibility, and interesting facades. The latter positive features are likely to play an important role in determining individual behavior.

Another challenge that remains is how best to combine the wealth of built environment data into measures that are both theoretically and practically useful. This challenge is applicable to the primary data collected here and to secondary data more commonly used in the built environment and active travel literature. Here, we developed sets of ad hoc additive indices. Other studies (Evenson et al., 2009; Jago, Baranowski, Zakeri, & Harris, 2005) for example, have used the covariation in the data to estimate indices using factor analysis. It is not clear that an index that best summarizes variation in the data has good construct validity—that is, that the index is a good representation of the built environment that is purporting to measure. Additional research in comparing the different strategies to summarize and understand the built environment quantitatively, and of the validity of resulting measures, is necessary.

Studying more trips in diverse locations with greater levels of micro-scale built environment variation would contribute to understanding the aspects of the route-level environment that influence pedestrian travel. This would help in two respects. First, because pedestrian safety features are often highly correlated with the amount of vehicular traffic, collecting both safety features and operational traffic data in a variety of contexts may be necessary for disentangling the effects of pedestrian safety features on route choice. Second, it is likely that micro-scale built environment elements interact in multiple ways. Good physical functionality for pedestrians, such as sidewalks, is likely to have higher relevance for walking in areas with high traffic, many destinations, and with positive aesthetic attributes. By contrast, a wide sidewalk in a sleepy neighborhood street may contribute little to transportation walking. These moderating effects can only be disentangled with a larger sample of trips and with greater variation in conditions.

Finally, the role that individuals' perceptions of route conditions play in influencing choices is a promising complement to the current measurement of route attributes. As several recent studies of route choice have underscored, perceptions of route conditions appear to be very important for predicting route choice. Whether the self-reported perceptions are the result of the choice (a justification bias) or they play a causal role in explaining route choice, remains to be determined. If their role is causal, then opportunities to address those misperceptions with education, awareness campaigns, and social marketing become promising.

Authors' Note

The content is solely the responsibility of the authors and does not necessarily represent the official views of the National Institutes of Health (NIH).

Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

This study was supported by the National Institutes of Health (NIH), National Heart Lung and Blood Institute Grant R01HL71244.

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