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Walking to School: What Streets Do Children Prefer?

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Abstract

Active school travel provides children with a daily opportunity to engage actively with their local urban environments. Despite widespread recognition that understanding the underlying factors of children's navigation choices is crucial for developing effective environmental interventions to promote active school travel, there is limited evidence on children's experiences regarding their school journeys. This is due in part to the fact that most studies rely on GIS-calculated routes which may not adequately represent children's actual home-school journeys, and hence actual experiences. This study aims to identify specific environmental attributes influencing children's navigation choices based on children's (9–10 year olds) actual walking routes to school in Newcastle upon Tyne, UK. 45 pairs of selected and avoided streets were compared using a range of urban form (e.g., street connectivity measured through space syntax variables) and street design (e.g., footpath width) characteristics. Statistical analysis highlighted significant design attributes as potential determinants of navigation selections. In-depth street-level observations provided insight into the urban character of these street pairs, identifying the environmental qualities that could offer opportunities for active and safe commuting among children. This study contributes to the literature by broadening our understanding of the environmental attributes that may promote active school travel. Our findings, based on children's actual experiences, may also inform urban planners and designers on designing inclusive child-friendly cities.

Keywords

active school travel; child-friendly cities; children's experiences; neighbourhood design; route selection; street connectivity; street design

1. Introduction

Active school travel (AST) offers numerous benefits for children, including improvements to physical health (Voss, 2018), psychological well-being (Carter et al., 2021), and social welfare (Waygood et al., 2017), along with economic (McDonald et al., 2020) and environmental (De Nazelle et al., 2011) benefits for both the community and individuals. Moreover, walking or wheeling to school provides children with a valuable opportunity to engage with the built/natural environment, confirming their right to participate in the community on an equal basis with adults. Yet there has been a consistent decline in AST rates worldwide (Kontou et al., 2020), with a notable example in England where the percentage of pupils (aged 5 to 16) actively travelling to school decreased from 50% to 44% between 2002 and 2019 (Department of Transport, 2023). Despite a temporary increase in walk-to-school rates from 41% in 2019 to 47% in 2020 during the pandemic, the figures fell back to 43% in subsequent years (Department of Transport, 2023). Previous research has shown that family socio-economic characteristics play an important role in shaping active behaviours for children (Schicketanz et al., 2018). For example, higher household income is associated with lower rates of AST among children (Larsen et al., 2009), possibly because lower-income households may have more limited transportation options. However, according to the socio-ecological models for children's transportation, other factors, such as the design of the built environment, may also affect children's travel choices (Mitra & Manaugh, 2020).

Although an extensive body of literature suggests that the urban environment can encourage physical activity by providing infrastructures and destinations supportive of an active lifestyle (e.g., a large number of destinations accessible within a short walking distance; Zhang et al., 2022), the evidence on the role of the built environment in promoting active trips to school is less conclusive. Previous research investigating the objectively assessed environmental determinants of AST has identified distance to school as a key factor in determining the mode of school travel (Curtis et al., 2015; Oliver et al., 2014; Rothman et al., 2018). However, these studies predominantly analyse the shortest routes to school (usually determined using GIS; Broberg & Sarjala, 2015), failing to capture children's actual home-school journeys, and hence real-life experiences (Ikeda et al., 2018). Emerging methodologies that account for children's actual travel routes to school show a preference for longer routes over shorter ones (Ikeda et al., 2018; Moran et al., 2018), indicating that other factors beyond distance may affect children's navigation choices. For example, traffic calming strategies (Rodríguez et al., 2015), exposure to traffic (Ikeda et al., 2018), ground-level attractions and footpath widths (Argin et al., 2017), as well as street connectivity (Ikeda et al., 2018), significantly influence route choice.

This study addresses the aforementioned research gaps by employing a novel approach that compares streets along actual school routes to those along the metrically shortest ones, using detailed street-level data such as land-uses, street connectivity, and street design characteristics. As a result, this article aims to identify a specific range of urban form and street design attributes that may shape participating children's navigation choices, either positively or negatively.

2. Methods

2.1. Case Study and Sample

The case study was set in Newcastle upon Tyne, a large riverside city of 829,000 people in the north-east of England (UK). The city presents a notable case with low rates of children walking (39%) or cycling/scootering (6%) to school (Schools Health Education Unit, 2019) alongside a high childhood obesity rate (37.5% among 10–11 year olds; Public Health England, 2020). All 74 primary schools of the city were geo-coded in QGIS and grouped into four categories, using a quadripartite matrix of two quantitative dimensions (one spatial and one socio-economic) to ensure a variety of built and social environments. The dimensions were street connectivity, measured by syntactic integration (within 2 km), and socio-economic status, measured by the Index of Multiple Deprivation (see Figure 1). Integration measures how accessible each street is from all others in a network within a defined radius, while the Index of Multiple Deprivation (rank) is a relative measure of deprivation that represents the aggregate social and economic conditions of households in the area based on 37 separate indicators (e.g., income, education, health, etc.), with lower rank values indicating greater deprivation. The average values of both metrics within 2 km buffers around the schools (Giles-Corti et al., 2011) guided the following classification scheme: high connectivity/high deprivation, high connectivity/low deprivation, low connectivity/low deprivation, and low connectivity/high deprivation.

Schools from each category were randomly invited until one from each category accepted, resulting in the selection of four schools across four distinct neighbourhoods as case study sites. Given the limited time and resources, this sampling strategy ensured a manageable sample size for collecting and analysing qualitative data, while also providing enough data for quantitative analysis. Results from an extra school that took part during the pilot study were also included since the data collection methods remained the same.

Figure 1 displays the geographical locations of Schools A, B, and C to the west of the city, while School D and Pilot School are located in the same region east of the city centre. School A is in a multicultural neighbourhood with a population density of 4,179 people/km^2 as of 2020, including many migrants. School B, predominantly characterised by residential land-uses, has a similar density of 4,574 people/km^2. School C has the lowest density (3,284 people/km^2), while School D and Pilot School have the highest

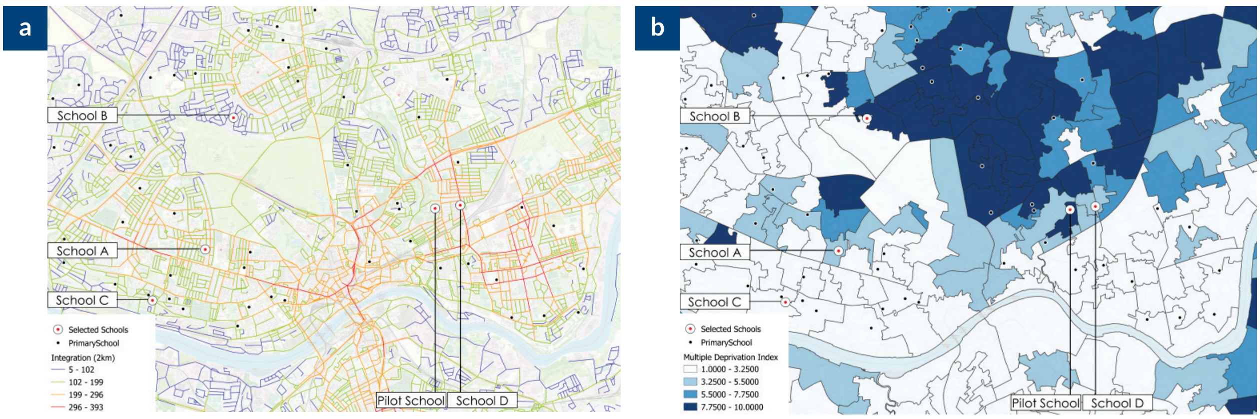

Figure 1. School selection: (a) Street connectivity: syntactic integration (2 km); and (b) the Index of Multiple Deprivation. Sources: (a) Space Syntax (n.d.); (b) Consumer Data Research Centre (2019).

density (7,888 people/km^2). Regarding safety, the average crime rate in the School A neighbourhood exceeds the city average by 34.5%, whereas it falls below 26% around School B. The area around School C has the highest crime rate, a staggering 144% above the city average, making it the most challenging in terms of security. Conversely, the area encompassing School D and Pilot School is considered relatively safe, with a crime rate marginally lower (0.9%) than the city average. The street network configurations also differ significantly across these areas. School A is adjacent to a major road, facilitating easy access to the city centre and is characterised by a regular grid-iron pattern with large blocks, averaging 200x20 m. School B's area features a curvilinear street network with cul-de-sacs, in stark contrast to the mixed patterns of grid-iron and cul-de-sacs found around School C, which is located at a busy intersection. School D and Pilot School benefit from a regular grid-iron network with relatively smaller blocks (150x40 m) and alleys enhancing residential street connectivity. Unique to this area is the active travel infrastructure and placemaking features such as car filters (including bollards and varying curb levels), benches, and urban greenery including trees and planters, which improve both functionality and aesthetic appeal.

All students in year 5 (9–10 year olds) from these schools were randomly invited to the study, with detailed study information sent to their parents. This age group was targeted since the literature suggests a decline in AST among children older than 10 years old (Chillón et al., 2011), but at the same time students of 9–10 years are old enough to provide an accurate description of their journey and neighbourhood experiences (Saunders et al., 1997) and to report their routes to school (Ikeda et al., 2018; Moran et al., 2018). A total of 197 students accepted the invitation, and 145 of these, with the necessary consent, were selected to participate. More details of the sample are presented in Table 1. The study received ethical approval from the Northumbria University's Ethical Committee, UK, on 30 April 2019 (Submission Reference 15592).

Table 1. Characteristics of the sample.

School	Average IMD rank within 2 km buffers around the schools	No. of Year-5 classes	No. of participating students	No. of reported walking routes	No. of diverged walking routes	No. of analysed streets	No. of focus groups
Total	Average 13,797	7	145	56	21	45	21
A	7,228 (low)	2	57	16	v1	0	4
B	16,007 (high)	1	22	9	6	7	3
C	7,849 (low)	2	14	8	3	6	6
D	15,452 (high)	1	25	14	6	24	6
Pilot	16,093 (high)	1	27	9	5	8	2

2.2. Data Collection and Analysis

2.2.1. Measuring the Dependent Variable: Frequently Selected/Avoided Streets Along Self-Reported Routes and Their Metrically Shortest Counterparts

All students participated in a whole-class mapping activity, drawing their typical AST routes from home to school and noting their travel modes. Out of 145 students, 79 participants completed the route mapping task. Among them, 72 walked and 7 cycled to school. Although just 12% of participating children walked or cycled independently, all reported routes involved accompaniment by an adult. Each route was geo-coded into QGIS to identify individual streets (defined as extending between successive street intersections) along the selected routes. The network map was updated through field surveys and manual analysis of the latest aerial photographs to include missing data, such as short-cuts, walkways, and park paths (Giles-Corti et al., 2011). For each route, the metrically shortest route (from home address to school address) was also computed using the network analyst tool in QGIS for a subsequent comparison with the actual routes. In addition to route analysis (see Michail et al., 2022, for detailed findings), most preferred and/or avoided individual streets ($n = 45$) along both sets of routes were statistically modelled and studied further to identify any emerging patterns of preference. Individual streets were selected based on their frequency of actual selection versus potential selection as part of the metrically shortest route. For example, a street that is used by four students for actual travel (actual selection, $AS = 4$) but appears on only 2 metrically shortest routes between students' homes and the school (potential selection, $PS = 2$), would have a frequency of selection (FS) rate of 2 (4–2). Conversely, a street not selected by any students would have an actual selection rate of 0, but a potential selection rate of 3 if it lies on 3 shortest routes, giving it a frequency of selection of –3 (0–3). Figure 2 illustrates these calculations.

2.2.2. Focus Groups

In addition to the whole-class mapping activity, 19 map-based focus groups were conducted with children who provided relevant consent to be voice-recorded. The activity aimed to elicit children's underlying reasons for their school route preferences. To allow for meaningful and in-depth discussions, groups of three to four were formed. Each group received an A0 high-resolution satellite map, five colourful prompt cards, and stickers representing children's feelings and experiences (favourite, fun, easy, uncomfortable, and

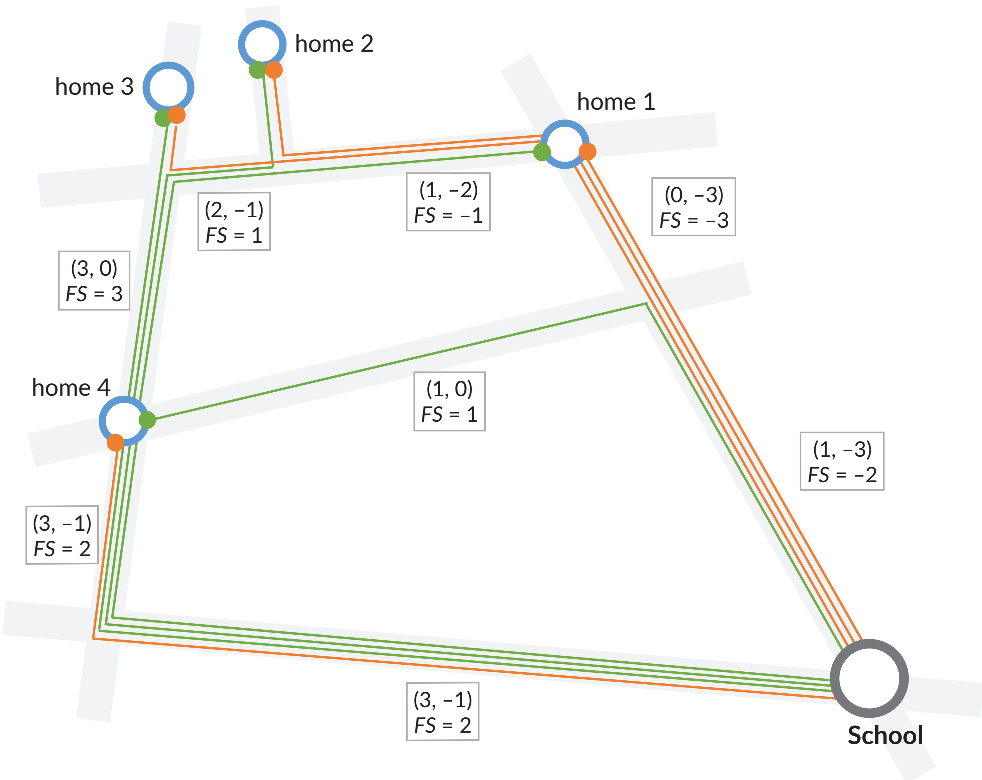

Figure 2. Calculation of street selection frequency. Note: *AS* appears in green and *PS* in orange.

dangerous) to elaborate on their travel experiences. The focus groups took place the same day in a separate classroom and lasted about 20 minutes each. They were audio-recorded, geo-coded in QGIS, and analysed using thematic analysis on NVivo. Risks and mitigations of working with children, including researcher bias, children's equal participation, peer influence, and power imbalance between the researcher and the participants, have been considered. See Michail (2024) for a more extensive overview of the focus groups, as well as the risks and mitigations related to working with children. Results from focus groups conducted during the pilot study were excluded due to methodological differences with the main study. While a detailed analysis of children's comments is presented elsewhere (Michail, 2024), relevant comments are included in this article to provide qualitative context to the statistical analysis.

2.2.3. Built Environment Characteristics of Streets Along the Routes

To investigate the built environment characteristics along both *AS* and *PS* street pairs, street design features were documented using field surveys and Google Street View, and syntactic analysis was conducted to evaluate street connectivity in case-study neighbourhoods. Street-level variables that can be measured objectively (i.e., binary = yes and no = and/or continuous) were analysed to allow for the replication of the study. Five categories of built environment features were defined for each street: land-uses; placemaking features; active travel infrastructure; traffic-environment; and street connectivity, using various syntactic measures of street network design, as described in Table 2.

Table 2. Description of the built environment features.

Variable	Description
Land-uses	
Residential	The total number of doors normalised by 100 m
Commercial	The total number of doors normalised by 100 m
Institutional	The total number of doors normalised by 100 m
Vacant	The length of vacant buildings normalised by 100 m
Greenspace	Existence of a greenspace (yes/no)
Placemaking features	
Setback distance	The average setback distance between buildings and footpath (in m)
Fence Height	The average fence height (in m)
Benches	Presence of benches along the route (1 = yes and 0 = no)
Street Trees	The total number of street trees normalised by 100 m
Graffiti	Presence of graffiti along the route (1 = yes and 0 = no)
Active travel infrastructures	
Street signs	Presence of street signs along the route (1 = yes and 0 = no)
Street lighting	Presence of street lighting along the route (1 = yes and 0 = no)
Footpath width	The average footpath width (in m)
Cycle path width	The average cycle path width (in m)
On-street cycle path length	The total length of the on-street cycle path normalised by 100 m
Bike racks	The total number of bike racks normalised by 100 m
Bus stops	The total number of bus stops normalised by 100 m
Slope	% average total slope/total length of the street

Table 2. (Cont.) Description of the built environment features.

Variable	Description
Traffic-environment	
Traffic light crossings	The total number of traffic light crossings normalised by 100 m
Zebra crossings	The total number of zebra crossings normalised by 100 m
Street width	The average street width (in m)
Speed limit	The average speed limit along the route
On-street parking	Presence of on-street parking along the route (1 = yes and 0 = no)
Off-street parking	Presence of off-street parking along the route (1 = yes and 0 = no)
Street connectivity	
Integration (global)	The distance from each street to all the others within the system (continuous variable)
Integration (local)	The distance from each street to all the others within the system within a set radius (continuous variable)
Normalised angular choice (global)	Measures how often a street falls on the shortest path between any two street segments in the system by taking into account the depth of the street segment in the system. This is calculated from each street segment to all others within the system (continuous variable)
Normalised angular choice (local)	Measures how often a street falls on the shortest path between any two street segments in the system by taking into account the depth of the street segment in the system. This is calculated from each street segment to all others within the system within a set radius (continuous variable)
Metric reach (800 m)	The total street length accessible from each street segment within a certain metric radius (continuous variable in m)
Directional reach (20°, 2D)	The total street length accessible from each street segment within a certain number of direction changes (continuous variable in m)

2.2.4. Statistical Analysis

A standard protocol was implemented to identify relevant independent variables and develop regression models to predict children's street preferences. First, to avoid multicollinearity, a correlation analysis among the candidate variables was conducted. To eliminate multicollinearity (Yang et al., 2022), variables with significant correlations ($p > 0.7$) were not considered in the same model, and those with a variance inflation factor (VIF) of 5 or greater were excluded (Akinwande et al., 2015).

Next, the remaining attributes were tested as predictors in univariate analysis: paired t-tests or Wilcoxon signed-rank tests (for characteristics that showed a normal and non-normal distribution respectively) were conducted using SPSS software to identify whether the differences between the values attributed to the built environment features for *AS* and *PS* street pairs were statistically significant. The final set of variables in the univariate analysis, at the 90% confidence interval level significance ($p < 0.1$) in line with earlier children's physical activity studies (Hinckson et al., 2014), were then entered into a multiple regression model to estimate the differences between (a) the *AS* frequencies and (b) the *PS* frequencies of streets to identify the underlying built environment attributes affecting route choice. The independent effects of these features were then analysed in multivariate regression models. A total of three models were developed to understand the contribution of each set of variables to the overall model:

Model 1. Street connectivity measures only.

Model 2. Street connectivity + land-uses measures.

Model 3. Street connectivity + land-uses + placemaking features + active travel infrastructure + traffic-environment measures (full model).

Finally, insignificant variables ($p > 0.1$) in the full model (Model 3) were removed in a stepwise fashion, commencing with the variable with the highest *p*-value, to develop a reduced model. The Akaike information criterion (AIC) and coefficient of determination (R^2, adjR^2) were utilised to evaluate each model's strength and compare models. Lastly, those streets with the highest differences between their frequencies were compared visually and numerically with their shortest counterparts to provide detailed insight into how these selected urban streets look on the ground and how they differ in character from their shortest counterparts. Due to the limited sample size, the statistical analysis was developed for the entire sample, without investigating individual school neighbourhoods.

3. Results

3.1. Selected Streets (AS) Versus the Avoided Streets (PS)

The descriptive statistics (mean and standard deviation) for the design attributes of the selected and avoided streets are summarised in Table 3. Streets in School A area were not included in the analysis due to an inadequate sample size ($n = 1$). The t-test/Wilcoxon signed-rank test results show whether there is a significant difference in the values of these attributes between street pairs.

Table 3. Means and standard deviations of dependent and independent variables by street selection status ($n = 45$).

Explanatory attributes	Selected street		Avoided street		Mean difference (selected-avoided)
	mean	std.	mean	std.	sig.
Street selection					
Difference between frequency of selection and shortest	2.36	0.57	–2.58	0.70	***
Street connectivity					
Global integration[a]	0.02	0.00	0.04	0.00	*
Local integration[a]	0.90	0.03	0.84	0.03	
Global choice[b]	386.92	12.86	169.85	27.97	**
Global Normalised Angular Choice[b]	1.03	0.19	0.95	0.17	
Metric reach (800 m)[b]	1,678.27	427.11	1,725.44	257.89	
Directional reach[b] (0,20°)	1,007.92	321.23	680.76	432.97	***

Table 3. (Cont.) Means and standard deviations of dependent and independent variables by street selection status ($n = 45$).

Explanatory attributes	Selected street		Avoided street		Mean difference (selected-avoided)
	mean	std.	mean	std.	sig.
Land-uses					
#Residential/100 m[b]	6.10	3.25	2.75	4.03	**
#Commercial/100 m[a]	0.42	1.45	1.62	3.06	**
Greenspace (yes/no)[b]	0.32	0.48	0.08	0.27	**
#Institutional/100 m[b]	0.26	0.43	0.01	0.00	**
#Vacant/100 m[a]	0.12	0.18	0.41	0.18	*
Placemaking features					
Average setback distance[b]	6.61	1.86	1.08	1.42	***
Average fence height[b]	1.13	0.67	1.24	0.90	
Benches (yes/no)[b]	0.00	0.00	0.23	0.43	***
#Street trees/100 m[b]	0.90	1.51	0.63	1.25	*
Active travel infrastructures					
Street signs (yes/no)[b]	0.68	0.48	0.46	0.51	
Street lighting (yes/no)[b]	1.72	0.46	1.73	0.53	
Footpath width[b]	2.87	1.01	1.01	2.21	**
Cycle path width [b]	0.56	0.77	0.07	0.37	***
#Bike racks/100 m[b]	0.51	1.77	0.33	1.06	
#Bus stops/100 m[b]	0.11	0.14	0.36	0.14	*
Slope[b]	0.01	0.2	0.02	0.03	*
Graffiti (yes/no)[b]	0.08	0.28	0.35	0.48	**
Traffic-environment					
Zebra crossings (yes/no)[b]	0.08	0.02	0.00	0.00	***
Crossing islands (yes/no)[b]	0.08	0.28	0.00	0.00	
Traffic lights (yes/no)[b]	0.24	0.44	0.12	0.33	**
Street width	7.66	3.68	6.29	3.22	
Speed limit	19.20	8.12	21.54	9.24	
On-street parking (yes/no)	0.80	0.41	0.69	0.47	
Off-street parking (yes/no)	0.36	0.08	0.12	0.08	*

Notes: [a] Wilcoxon ranked; [b] paired t-test; *** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$.

According to these results, a significant difference exists between the selected and the avoided streets for several attributes from each built environment category, suggesting that children preferred to walk along alternative streets with certain built environment characteristics, such as increased directional accessibility and reduced number of bus stops, rather than just minimizing the distance. These students diverged from the metrically shortest streets probably because they preferred streets with increased directional accessibility from their surrounding context (i.e., straight and longer streets) and streets with available off-street parking and green spaces, more zebra crossings, traffic lights, residential uses, increased setback-distance, average footpath width and cycle path width, as well as fewer commercial activities, vacant buildings, and more benches.

3.2. Built Environment Attributes Associated With Street Selection

The diagnostic and coefficient results for 3 different multivariate regression models estimating the difference between the frequency of selection of the walked street (*AS*) and the frequency of potential selection as its shortest counterpart (*PS*) are presented in Table 2. All VIFs are below 2, indicating that multicollinearity was not an issue. The strength of the "connectivity" model (Model 1) is low ($adjR^2 = 0.13$, AIC = 209.87), with the full model (Model 3) being the strongest ($adjR^2 = 0.48$, AIC = 202.14).

When street connectivity measures were included only, directional reach (0 direction changes, 20°) was positively and significantly correlated with the output variable. Directional reach remained significant across models when other variables were also considered. The predictive power of the model increased considerably ($adjR^2$ change = 20%) when land-use variables were included in the model. In terms of land-use measures, the number of residential buildings per 100 mt (std $\beta = 0.31$, $p < 0.05$) was positively and significantly associated with the difference in selection frequencies of the actual street and its metrically shortest, avoided counterpart. Similarly, the availability of green space along the street was positively (std $\beta = 0.26$, $p < 0.1$) related to the outcome variable, albeit marginally. In other words, the more residences that open onto the street, as well as the presence of green space (e.g., parks and parklets), the more likely a child will choose that street over the metrically shortest counterpart during the school journey.

The final model (Model 3) exhibited a substantial improvement over the previous model (Model 2) in terms of $adjR^2$, explaining about 50% of the variation in the outcome variable. Of the street-level design attributes, average footpath width (std $\beta = 0.52$, $p < 0.01$) exerted the most influence on street choice. In fact, when standardised coefficients within the overall model are compared, it is found that average footpath width, along with directional reach, is the most significant variable related to decision-making in children's navigation. The presence of zebra crossings and off-street parking along the street exhibited marginal influence ($p < 0.10$).

Table 4 presents the results of the three multivariate regression models.

Table 4. Multivariate regression models estimating the difference between the *AS* (walked) and *PS* (avoided) frequencies of streets.

	Model 1 (street network)			Model 2 (street network + land-uses)			Model 3 (full model)		
Explanatory attributes	β	$\lvert t \rvert$	std β	β	$\lvert t \rvert$	std β	β	$\lvert t \rvert$	std β
Constant		1.67			1.99**			1.70*	
Street connectivity									
Global integration	−1.09	1.48	−0.28	−1.22*	1.80*	−0.32*	−1.37	−1.61	−0.36
Global choice	0.00	0.91	0.15	0.00	0.89	0.13	0.00	−0.60	−0.15
Metric reach (800 m)	−0.00	1.30	−0.21	−0.00	1.15	−0.17	0.00	0.26	0.05
Directional reach (0, 20°)	0.02**	2.07**	0.44**	0.03**	2.30**	0.44**	0.06**	2.37**	0.52**

Table 4. (Cont.) Multivariate regression models estimating the difference between the *AS* (walked) and *PS* (avoided) frequencies of streets.

	Model 1 (street network)			Model 2 (street network + land-uses)			Model 3 (full model)		
Explanatory attributes	*β*	|t|	std *β*	*β*	|t|	std *β*	*β*	|t|	std *β*
Land-uses									
#Residential/100 m				0.15**	2.41**	0.31**	0.12*	1.95*	0.25*
#Commercial/100 m				–0.16	1.09	0.28	–0.50**	–1.97**	–0.50**
Greenspace (yes/no)				–0.90*	1.83*	–0.26*	–1.03*	–1.97*	–0.30*
Other attributes									
Average setback distance							0.09	1.60	0.25
Benches (no)							–0.21	–0.32	–0.06
#Street trees/100 m							0.11	0.32	0.06
Average footpath width							0.78***	2.91***	0.52***
Slope							–1.75	–0.82	–0.16
#Bus stops/100 m							–0.85	–1.46	–0.21
Zebra crossings (yes/no)							–3.20*	–1.89*	–0.38*
Traffic lights (yes/no)							–0.07	–0.14	–0.02
Off-street parking (yes/no)							–0.67*	–1.73*	–0.24*
No.	45								
R^2	0.21***			0.43***			0.67***		
Adjusted R^2	0.13***			0.33***			0.48***		
AIC	209.87			204.31			202.14		

Notes: *** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$; two-tailed tests.

The reduced model (Table 5) showed moderate improvements over the full model, with a 10.42% increase in adjR^2 and a 4.64% improvement in AIC (AIC = 192.77, adjR^2 = 0.53), and no multicollinearity concerns (max VIF = 1.90). Similar to the full model, directional reach (0, 20°) was positively correlated ($p < 0.005$) with the difference in selection frequencies of selected and avoided streets. Surprisingly, global integration had a significant ($p < 0.005$) and strong negative effect (std $\beta = -0.44$) on-street choice. All three land-uses variables appeared to be statistically significant. Significant positive associations included the number of residential uses (std $\beta = 0.31$, $p < 0.008$) and the presence of green spaces (std $\beta = 0.28$, $p < 0.034$) along the street. The number of commercial uses, on the other hand, had an inverse effect on the output variable (std $\beta = -0.34$, $p < 0.027$). In other words, children walking to school preferred streets with an increased number of residences and green spaces and a reduced number of commercial activities, such as shops and restaurants, during their school trips. Of the street-level design characteristics, average footpath width (std $\beta = 0.41$, $p < 0.006$) had the strongest impact. Other significant street-level attributes positively affecting street choice included average setback distance (std $\beta = 0.24$, $p < 0.05$), and the presence of zebra crossings and off-street parking (std $\beta = 0.29$, $p < 0.02$, std $\beta = 0.23$, $p < 0.05$, respectively).

Table 5. Reduced model estimating the difference between the *AC* (walked) and *PS* (avoided) frequencies of streets.

Explanatory attributes	β	$\lvert t \rvert$	std β	std error	*p*-value
Constant	25.46	3.04	0	8.37	0.005
Street connectivity					
Global integration	−1.67	3.01	−0.44	5.54	0.005
Directional reach (0, 20°)	0.02	3.04	0.44	0.00	0.005
Land-uses					
#Residential/100 m	0.14	2.80	0.31	0.05	0.008
#Commercial/100 m	−0.34	2.31	−0.34	0.15	0.027
Greenspace (yes/no)	−0.98	2.20	−0.28	0.44	0.034
Other attributes					
Average setback distance	0.09	1.98	0.24	0.04	0.050
Average footpath width	0.62	2.90	0.41	0.21	0.006
Zebra crossings (yes/no)	−2.47	2.44	−0.29	1.01	0.020
Off-street parking (yes/no)	−0.64	2.04	−0.23	0.32	0.050
No.			45		
R^2			0.63		
Adjusted R^2			0.53		
AIC			192.77		

3.3. Street-Level Observations Along Frequently Selected (AS) and Avoided (PS) Streets

To provide detailed insight into how these selected and avoided streets look on the ground and how they differ in urban character, streets with the highest differences (2, or −2) between their *AS* and *PS* frequencies were compared visually and numerically. The width of the line on the maps represents the frequency (1–3) of selection/avoidance. Figures 3, 4, and 5 illustrate these streets per neighbourhood. The selected streets along the actual routes are shown in green, while the avoided streets are shown in orange.

Figure 3 compares the frequently selected (*AS*) streets along the actual routes to their avoided (*PS*) counterparts along the metrically shortest routes during home-school trips in School B area. These snapshots indicate that children preferred to walk along local streets with medium motorised traffic, as opposed to pedestrian-only ones, with increased directional accessibility, wider footpaths, and the presence of a green verge between the footpath and the carriageway. The selected streets also have a higher average setback distance as compared to their avoided metrically shortest counterparts. This finding supports the results of linear models and might indicate that children prefer to walk along these streets due to the existence of residential front gardens and/or urban green features.

Observations from street pairs in School C area (Figure 4) display similar patterns of selection. Children's decision-making in urban navigation appears to be influenced by the directional accessibility of streets along with the existence of green spaces, the lack of vacant buildings, and increased setback distance between the footpath and the buildings. Moreover, the existence of a cycling path as well as bus stops along the actual street (Figure 4a) may promote its selection as part of the journey to/from school.

Figure 3. Frequently selected and avoided streets in School B area.

Figure 4. Frequently selected and avoided streets in School C area.

Finally, a comparison of the selected streets and their counterparts along the metrically shortest walking routes in School D and Pilot School areas (Figure 5) demonstrates similar findings. Students in this neighbourhood preferred to walk along streets with increased directional accessibility, a higher number of residential uses as well as larger setback distance and footpath width. In addition, children avoided major streets with heavy car traffic or alleys without any motorised traffic, possibly due to personal safety (i.e., to avoid high traffic volumes or stranger danger) and comfort/ environmental issues (i.e., to avoid noise and pollution along the major streets). On the other hand, they preferred streets that had green spaces, traffic lights, or a car filter. Similar to the finding in School C area, Figure 5e and Figure 5f indicate that the existence of a cycling path may be an underlying reason for children's street preference.

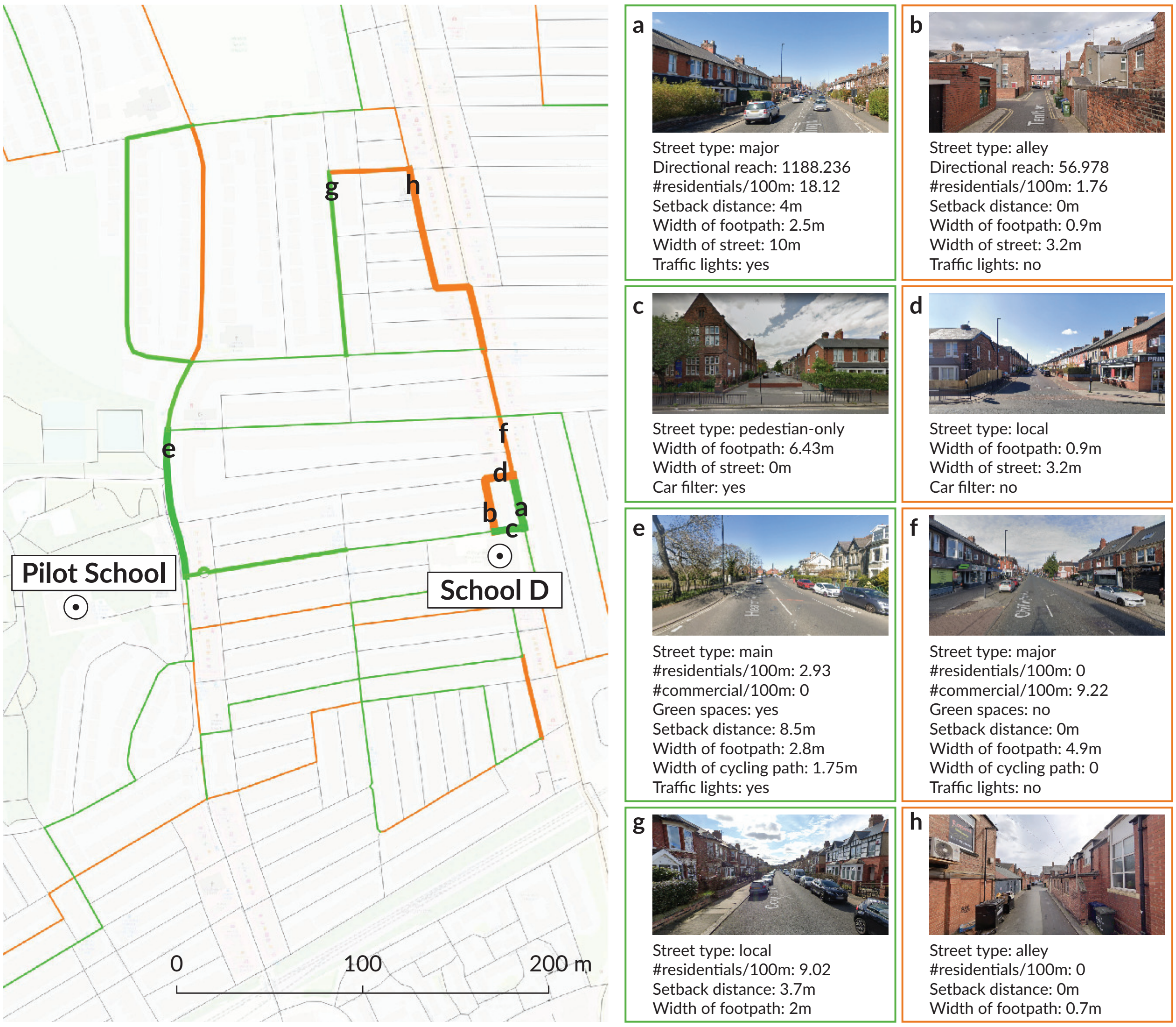

Figure 5. Frequently selected and avoided streets in School D and Pilot School areas.

Overall, these examples indicate some underlying trends in children's street selection regardless of the geographical context. Increased directional accessibility and residential uses appeared to shape street selection in tandem with certain street-level design attributes including wider footpaths, larger setback distances, as well as the presence of house gardens, green verges or green spaces, traffic lights, and cycling paths. In other words, children preferred to walk along more direct, linear, and continuous streets that provide such pedestrian-friendly urban characteristics.

4. Discussion

4.1. Pedestrian-Friendly Urban Forms

4.1.1. Street Network Design

The results of this research demonstrate that street network design is a key factor in children's navigation during AST. The statistical models revealed that street network design had a considerable impact on children's preference for street choice, even when considering street-level design and land-use around schools. This finding contributes to the limited understanding of how street network layout influences children's school travel, a factor that is frequently disregarded in favour of street-level features.

More importantly, the findings highlighted the significance of the spatial structure of street networks, specifically the alignment of streets, in children's route choice behaviour. Directional accessibility appeared to be the most significant correlate of street choice, indicating children's preference for more direct and linear streets with reduced direction changes. Focus group discussions supported this quantitative conclusion. As one School B student put it: "It is easy to go….All I have to do is go straight down…yeah! I walk." This finding supports research suggesting that the perceived convenience of direct travel routes is a major aspect in route selection (Helbing, 2017). On the contrary, street connectivity measure integration was negatively associated with children's preferences. Although contrasting with some past research (Ikeda et al., 2018) indicating that connected routes offer increased opportunities and accessibility for children, this finding is supported by evidence in northern Europe (Dessing et al., 2016), and may suggest that integrated streets within their surroundings are considered unattractive by active travellers due to heavy traffic commonly associated with higher accessibility (Giles-Corti et al., 2011). This finding highlights the necessity of measuring street network design through multiple syntactic measures to identify which specific characteristics of the street networks may promote AST.

4.1.2. Land-Use

The results of this research suggest that the spatial structure of the street network works mutually with land-use to support active travel. The linear models and street-level observations showed that children mostly preferred streets with more residential uses and fewer ground-floor commercial activities, which contradicts previous research that suggests residential uses discourage AST (Rothman et al., 2021). This finding could be explained by children's sense of ownership on residential streets where they, their friends, and relatives live. In focus groups, children expressed a preference for familiar streets, stating, "cause that's our road." Moreover, our findings suggest that the presence of off-road parking on residential streets, often observed as front garden parking spaces, may increase the likelihood of route selection by children and their parents, underscoring the positive impact of residential streets on children's navigation choices.

On the other hand, statistical analysis showed that children avoided streets with a higher number of commercial activities along their journey to school. While this contradicts past research linking increased commercial land-uses to an increased likelihood of AST (Argin et al., 2017; Torun et al., 2020), one insight into this relationship is that commercial activities are typically located on main streets with higher traffic volume, reducing interest in alternative routes. As one student pointed out, the number of cars a street attracts can affect the travel experience: "Sometimes that just walking up that pathway it is quite peaceful…but at the same time, it can be dangerous, depends on the number of cars." Based on these findings, ensuring that commercial land-uses are more evenly distributed throughout the neighbourhood and along school routes, rather than being grouped along traffic-busy roads, is necessary to support AST.

Finally, our analysis showed that children preferred to walk along streets with urban green features (e.g., parks, street trees, and green verges). Adding urban green features along school streets could facilitate social interactions (Salih et al., 2020) during the school journey and afford opportunities for children to stop, rest, and play, supporting increased free play and physical activity. This aligns with prior studies that found a positive correlation between recreational open spaces and AST (Tewahade et al., 2019; Wilson et al., 2019). Children's positive attitudes to street trees may be linked to the travel comfort provided by their shades (Donnellan et al., 2020) or the aesthetic effect of street greenery. The existence of urban green features may also be attributed to children's inclination towards streets with lower levels of pollution. For instance, one participant during focus groups remarked: "We don't want to go on Ashley Road because there's lots of noise."

4.2. Active Travel Infrastructure

Several modifiable active travel infrastructure features emerged as significant environmental features underlying children's AST behaviour. These were primarily linked to perceptions of comfort, convenience, and safety in streets and footpaths, as described by participating children: "There are loads of cars like actually on the pavement, and it's just like this narrow, you can't get through" and "when you cross this big hill there…when you crossing the road, the cars don't really say like this way or this way." These findings are consistent with previous studies on AST, which highlighted children's discomfort due to unsafe active travel infrastructures (Wilson et al., 2019) or the absence of them (Kirby & Inchley, 2009). Based on the results of linear models, the availability of zebra crossings and wider footpaths emerged as significant predictors of street preference. More specifically, in-depth street-level observations concluded that traffic lights were a common characteristic of most selected streets, regardless of their geographical locations, which is in line with previous research (Dessing et al., 2016). This feature significantly facilitated AST, as described by a participant during focus groups: "Yeah it's easy, cause there is a traffic light." Findings affirming pedestrian-friendly active travel infrastructure as an enabler of AST are corroborated by earlier research (Rothman et al., 2019). The importance of this finding has two implications. First, it indicates that modifications to active travel infrastructure around schools can support AST (as evidenced by both our statistical models and children's school journey experiences). Second, this finding highlights the methodological contribution of this study associated with the application of a refined street analysis as opposed to a GIS-based shortest route analysis.

4.3. Contributions and Limitations

This study adopted an innovative approach to exploring how neighbourhood design influences children's navigation choices, distinguishing itself from previous research by investigating the environmental characteristics of travelled streets rather than relying on GIS-calculated ones. This novel approach offers a more precise insight into the environmental factors children encounter on their school commutes, a method less explored in prior studies (Dessing et al., 2016). This refined scale of analysis enhances our understanding of children's environmental exposures during active transportation. Moreover, this research enhances route-choice behaviour models by integrating linear models with detailed field observations of environmental characteristics along actual versus shortest routes, offering deeper insights into the factors influencing children's navigation preferences. A novel aspect of this study is the incorporation of syntactic measures of street network design, a relatively under-explored aspect in AST research, to better account for the spatial configuration of street networks. By demonstrating the relationship between street network design and AST, this study contributes to a more nuanced understanding of how spatial structure influences children's active travel decisions.

Despite our research contributions, the study's limitations should be acknowledged. These include a small sample size due to limited resources. Despite this, systematic and random sampling across diverse neighbourhoods offers a detailed view of AST barriers/facilitators according to children's experiences. The focus on frequented streets may introduce bias, as children taking the shortest path were excluded. Future research could benefit from more efficient data collection methods like GPS tracking for larger, more accurate samples (Shatu et al., 2019). Additionally, the study focused solely on data from accompanied children, which opens up a critical avenue for future research. Previous studies suggest that the level of companionship, such as walking with parents or friends, can influence children's travel route choices (Yarlagadda & Srinivasan, 2008). Future research should explore these differences among various groups, such as those accompanied and unaccompanied. However, because our study used a participatory strategy to analyse children's opinions on their travel experiences, we ensured to account for their viewpoints. Furthermore, linear models may not fully capture the intricate relationship between the built environment and travel behaviours (Tao et al., 2020). Future studies should explore the non-linear effects of built environment features on navigation behaviour, possibly through intervention studies with multilevel designs, to better understand how specific built environment characteristics influence children's route selection. Finally, data collection was conducted on different days and seasons in each school, which may have influenced both quantitative and qualitative results. However, given the relatively stable weather conditions in the north of England during these months, we expect the themes that emerged to be representative of the winter months when children predominantly travel to school.

5. Conclusion

Overall, the findings from this research demonstrate the significance of pedestrian-friendly urban forms (i.e., more direct and continuous streets and mixed land-uses) and AST infrastructures (i.e., wider footpaths and safe crossings) in supporting children's AST behaviour. By using children's actual navigation choices, the results of this study provide evidence of how neighbourhood and street design may affect children's route selection, which could be used by local stakeholders in similar regions to help create child-friendly environments and promote AST.

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Conflict of Interests

The authors declare no conflict of interests.

Data Availability

The data presented in this study are available on request from the corresponding author. The data are not publicly available due to confidentiality.

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