Walking alone or walking together: A spatial evaluation of children's travel behavior to school

Abstract:

The purpose of this research is to extend our understanding of children's walking behavior to school in an understudied region of the world, Istanbul, Turkey. Children (aged 11-17) and their parents were surveyed to comprehend subjective and objective factors on walking behavior to school when alone or with someone. Using participatory mapping and GIS, a route detour index was first created to highlight differences in walking behaviors. A robust spatial analysis, consisting of spatial statistics and a hierarchical spatial error model, then signified important survey responses, urban design factors from space syntax, and neighborhood composition and contextual variables on between-group route choices. Empirical and geovisual analysis confirmed that accompanied children deviated more from GIS shortest routes to school than their unaccompanied peers and "hot-spot" analysis showed it was dependent on where children reside. The spatial error models exhibited notable relations among route choice, children's age, health, and gender. Parent attitudes concerning greenspace positively affected children's longer route choices, while street connectivity had the opposite influence. Surprisingly, neighborhood walkability did not impact children's route choice decisions for either group. The results provide new insights on how to encourage additional walking trips to school.

Keywords: Children's active school travel, walking, GIS, route detour, space syntax, spatial regression, public health

Introduction

Promoting physical activity (PA) in children remains of vital importance for elevating public health and preventing disease (WHO, 2019) However, 80% of 11-17 year-olds worldwide fail to meet minimum recommended levels of PA (Sallis et al., 2016). When children incorporate PA into their life, physiological health, cardiovascular fitness, and cognitive ability increase (Poitras et al., 2016). Since walking is a common form of PA among children, and is a common commuting mode to school, a key opportunity exists for understanding the means to elevate active school travel (AST).

The literature has shown that several real and perceived factors affect children's AST. The travel distance to school, population density, land-use diversity, route aesthetics, safety, sidewalks, and street connectivity – among many others – influence children's AST (Ding et al., 2011; Panter et al., 2010; Schlossberg et al., 2006; Sun et al., 2018). The relationships remain incongruent for many of these factors, unfortunately. Land-use diversity was shown to promote active travel among children in some research (Das and Banerjee, 2021), while others established weak associations (Yarlagadda and Srinivasan, 2008). Street network design impacts children's AST and children's route choices while walking to school (Han et al., 2021), but its impact has been inconsistent. Prior research has suggested that space syntax formed urban design metrics may be more effective than standard measures of connectivity at validating this relationship (Ortegon-Sanchez et al., 2021; Zhao et al., 2022). Ozbil et al., (2021) discovered that important space syntax metrics corresponded to children's AST. Hence, space syntax methodology offers a valuable resource with which to provide planners, transport and highway engineers and other policy makers with transformative, evidence-based spatial models, analyses and maps to identify streets to focus investment for traffic reduction measures (e.g., preventing 'pavement parking', installation of new pavements and walkways, densifying street network by installing footways on streets which lack them, etc.) as well as testing alternative intervention scenarios (e.g., pedestrianisation of specific streets) to encourage a shift to more active modes of travel, including more “excess” walking to school, which in turn would help support initiatives such as “low-traffic neighbourhoods” and “15-minute cities.” An additionally important consideration for understanding a child’s AST are parent effects. Parents are largely responsible for managing a child’s “mobility license” (Page et al., 2010). Their time, travel patterns, attitudes (i.e., crime, traffic, personal, or stranger danger), SES, family composition, and physical activity levels are considerable influences (Mah et al., 2017; Pfledderer et al., 2021; Evers et al., 2014). Route-specific factors for school-based trips are another feature of children’s AST.

Currently, we have a limited understanding of the children’s route choice criteria while walking to school, especially in less-developed countries such as Turkey (Dias, 2022; Ozbil et al., 2021). Understanding how to encourage a child’s independent mobility and decision to take longer walking routes is critical as it positively impacts their physical, social, and personal development (Schoeppe et al., 2013). The utility of a travel route is largely based on the level of directness, personal preference, safety/perceptions, mode-choice, and the built environment (Broach and Bigazzi, 2017; Moran et al., 2018; De Vos et al., 2016). The evidence so far regarding children remains indeterminate. As an example, Ikeda et al., (2018) found that children choose routes to school with heavy traffic in Auckland, New Zealand, while Dessing et al., (2016) witnessed an opposite relationship in the Netherlands. Companionship levels (i.e., walking with parents or friends) may also be an important route choice consideration (Yarlagadda and Srinivasan, 2008). Lee et al., (2021) posited that when children travelled with a companion, their decision to choose the most direct path decreased by 39%. Similarly, past findings indicate that walking with friends might allow children to take longer school journeys, providing possibilities for environmental engagement (Ross, 2007). The decision to walk alone or with someone is impacted by a child’s age, gender, parent attitudes, environment, distance from school, and safety issues (Jones et al., 2000; Marzi et al., 2018). Research has indicated that boys tend to travel alone more than girls (Page et al., 2010); however, Medeiros (2021) found girls travelled alone as age increased. Parental attitudes also affect a child's route choice behavior and independent mobility. Parents are usually worried about "stranger-danger" as well as the traffic volume around their child's school (Mammen et al., 2012). Where children live matters too. For example, a child's walking route will differ depending on if they reside in an urban versus a rural environment (Moran et al., 2018). Unfortunately, accounting for these spatial differences has not been controlled for in the literature.

In addressing these research gaps, our study set out to spatially and empirically investigate children's walking behaviors to school in an understudied region of the world, Turkey. Our research has two research objectives: to i) statistically and spatially gain a better understanding of children's walking (school) route choices in a Turkish context; ii) apply a comprehensive spatial analysis – integrating key children attributes and attitudes, parent characteristics and perceptions, and neighborhood features – to determine their effect on children's walking route choices to school when unaccompanied or accompanied.

Methods and Data

Study area

The study area in this research was Istanbul, Turkey. It has an area of 5461 km² spreading across two continents and an estimated population of 15,462,452 (TUIK, 2019). The city is the largest and most important in terms of its role in the economic and cultural transformation of the country. One out of every three people in Istanbul resides in low socio-economic neighbourhoods (Demirel, 2017). Bicycling among youth is low in the city (Ozbil et al., 2021); however the 2012 Istanbul household survey indicated that 68.8% of school trips among children consisted of walking (ITMPPM, 2012). The focus is on the centralized Anatolian section of the city where population density is high and there is a great diversity of demographics, socioeconomic-status, and land-use. The map (figure S1) in the supplementary document shows the study area, neighbourhoods, and research participants' residences.

Sampling protocol and survey instrument

A cross-sectional survey instrument was created in 2014-2015 to aggregate children and parent demographics and attitudes regarding AST in their neighbourhoods. We randomly recruited 11-17 year-old-children (i.e., 6th, 7th, and 8th graders) from twenty schools in selected neighbourhoods. We chose this age group as middle-school children begin to travel independently and explore their environment (Hillman et al., 1990). The initial number of participating children and parents who fully completed the surveys in-person was n = 492 (27% response rate) and n = 421 (24% response rate), respectively. For additional details on the human ethics approvals, sampling approach, and survey development, please see Ozbil et al., (2021).

Children attitudes and character

The attitudes and children characteristics were categorized into three sections: individual characteristics; commuting habits to school; and perceptions of their neighbourhood (i.e., safety and the travel environment). Children reported their gender, age, and home address, while their height and weight were measured using an electronic scale with a stadiometer. The latter calculation was used to categorise "obese" children using standard thresholds of body mass index (BMI) using ((kilograms/(meters^2)) × 703) (WHO, 2007; CDC, 2022). Information about their walking experience to/from school was aggregated using several multiple-choice questions adapted from prior research (Hume et al., 2006). We also collected their travel mode to and from school, and accompaniment status (i.e., unaccompanied or walked with somebody) to school. We focused on the trip to school and in doing so built off recent research (Bucko et al., 2021) and all answers were dichotomized in this research.

Household conditions, parent attitudes and attributes

Several parental and household attributes, including mean monthly household income, education level, and car ownership were aggregated from the survey instrument. The respondents also reported their level of agreement with twenty-six, five-item, Likert choice sets (strongly disagree to strongly agree) concerning the safety of their neighbourhood that were based on NEWS (Neighborhood Environment Walkability Scale) (Cerin et al., 2006). To fully understand latent factors underlying their attitudes, we employed principal component analysis (PCA) and a Promax rotation using statistical software (IBM SPSS, version 26). We verified that independent sampling, normality, and moderate linear relationships between variables (i.e., Spearman's rho $p < 0.05$) were present. A seven-factor solution was found, and each component exhibited eigenvalues greater than 1.0. Table S1 located in the supplementary materials shows the factor loadings, factor labels, and communalities and table S2 shows measures of central tendency for the sample population.

Neighbourhood variables

Several neighborhood scale contextual and compositional factors were applied in this research. The compositional variables included population density and socio-economic status (SES) obtained from the Turkish Statistical Institute (TURKSTAT) and Mahallem Istanbul (http://mahallemistanbul.com/), respectively. The SES of each neighbourhood ranged from zero to one-hundred: elevated values indicated high SES. The contextual variables consisted of land-use diversity, greenspace, urban density, walkability, topography, and urban design. The floor area ratios for residential, retail, institutional, recreational, greenspace, and other categories from the land-use layer were used to create a common diversity index (Shannon, 1948; Mavoa et al., 2018). The mean and maximum slope was derived from the elevation layer, as topography invariably affects travel modes. As a measure of accessibility, street intersections (3-way or above) were applied to this research. Park space and greenspace were also used in this research due to their impact on walking modes. As an additional measure of walking potential, we created a common walkability index built off of the work from Frank (2010). The reader can find the equation in the methods section of the supplementary materials.

We incorporated several measures from space syntax in this research. We utilized segment-based and angular segment analysis using Depthmap (version X) (https://github.com/SpaceGroupUCL/depthmapX/) and Java. Segment angular integration measures the number of direction changes needed to move from each street segment to all others within a set radius using the least angle measure of distance, while connectivity calculates the number of segments directly connected to each specific street segment (Hillier and Iida, 2005). Segment Angular Choice represents the number of shortest paths overlapping between all nodes in the graph (Varoudis et al., 2013). Metric reach computes the total length of streets accessible from the mid-point of each segment within a parametrically defined metric distance, while directional reach calculates the total street length accessible from the mid-point of each segment within a specified direction change (Peponis J., 2008). We included connectivity, integration, choice, and metric and directional reach in this research.

Formalizing the home-school environment

We used the reported children’s home addresses and created a 1,600-meter Euclidean distance buffer in ArcGIS (ESRI, Version 10.8). This distance was selected because it is a reasonable walking distance for children (Sun et al., 2018) and has been touted as an area where the majority of a child's physical activity occurs (Smith et al., 2017). All the aforementioned compositional and contextual neighbourhood factors were aggregated to this neighbourhood using an interpolation and a spatial joining technique for raster and vector based GIS layers, and results were then normalized by population or area (km) to minimize issues associated with the modifiable areal unit problem (Kwan and Weber, 2008).

Measuring the dependent variable: a route detour index

In accordance with previous research (Buliung et al., 2013), we utilized a route detour index (RDI) to assess the magnitude of walking route deviation from the GIS shortest-route to school. A participatory GIS mapping exercise was first conducted with children to collect actual walking routes (AR). Each route was then digitized using GIS. The route accuracies were checked manually and corrected by researchers using GIS. The GIS derived shortest path routes (SP) between each child's residence and school were then calculated using ArcGIS's Network Analyst tool. See figure S2 in the supplementary materials for a typical route comparison. The AR and SP route lengths were then used to calculate the RDI, which was considered excess walking (i.e., percent route deviation) in this research. The equation can be found in the methods section in supplementary materials.

Statistical and spatial autocorrelation measures

To meet our first research objective (i), we applied statistical measures of central tendency on all candidate variables. Exploratory spatial data analysis (ESDA) was then utilized to examine the degree of spatial clustering. The global autocorrelation index, Moran's *I* (Moran, 1950) was first implemented. The outputs range from -1 to +1, where increased positive values demonstrate that observations close to one another are similar, and elevated negative values indicate spatial dispersion. A significant ($p \leq 0.05$) z-score was used to assess the index's significance. A local index of spatial association (LISA) was also implemented in this research to geovisualize the spatial dependency of RDI values for each group. The Getis-Ord G_i* index was selected and the results were used to create significant kernel density “hot-spot” and “cold-spot” maps (Getis and Ord, 1992).

Preliminary data processing

A standard protocol to screen significant independent variables and build a set of regression models to predict RDI and reach our second research objective (ii) was instituted. We assessed the histogram, skewness, and kurtosis values for each variable using SPSS software. From this preliminary analysis, our final sample size was *n*= 373. Additional screening protocols are exhibited in the methods section of the supplementary materials. Table 1 exhibits the final set of variables used in this research, descriptive statistics, and Moran’s *I z*-score results.

Table 1

Descriptive statistics and spatial autocorrelation results for all final model variables (n = 373)

Variable	Description	Scale	Mean ± SD	Share (%)	Source	Moran's I [†] (z-score)
Dependent variable						
Route detour index (RDI)[§]	Walking excess (i.e., % deviation from SP)	Cont.	2.01 ± 2.24	SV	SV	2.64***
Independent variables						
Children characteristics						
Male (ref: female)	Dummy; 1-yes, 0-no	Binary		.74	QUE	0.21
Age	Reported age of child	Cont.	13.31 ± .97		QUE	2.93***
Obese	Dummy, 1: yes, 0: no	Binary		.12	QUE	-1.13
Route distance 403m-804m	Dummy, 1-yes, 0-no (ref: 0m-402m)	Binary		.43	QUE	2.14**
Route distance 805m-1,600m	Dummy, 1: yes, 0: no	Binary		.40	QUE	3.20***
Route distance > 1,600m	Dummy, 1: yes, 0: no	Binary		.01	QUE	0.27
Easy road crossings	Dummy, 1: yes, 0: no	Binary		.79	QUE	-0.19
Safe walking	Dummy, 1: yes, 0: no	Binary		.69	QUE	0.22
Walk to/from school	Percentage walking to and from school	Cont.	77.31 ± 14.40		QUE	8.40***
Parent/household characteristics						
Household automobiles	Quantity of autos per household	Cont.	1.51 ± .57		QUE	-0.58
Duel college degrees	Both parents college-educated. Dummy, 1: yes, 0: no	Binary		.27	QUE	0.08
Income ≤ 1,400	Household income. Dummy, 1: yes, 0: no	Binary		.47	QUE	1.26
Factor 4, Street maintenance	Mean factor score	Cont.	2.83 ± 1.01		QUE	-0.72
Factor 5, Greenspace diversity	Mean factor score	Cont.	3.36 ± .89		QUE	-0.40
Factor 6, Pedestrian safety	Mean factor score	Cont.	3.59 ± .86		QUE	-0.33
Urban design						
Connectivity	Mean number of directly connected adjacent spaces	Cont.	2.96 ± .14		SV	0.73
Integration	Mean measure of relative neighbourhood asymmetry	Cont.	5,990.9 ± .51		SV	0.22
Metric reach	Mean total street length accessible within a radius	Cont.	90.99 ± 11.16		SV	-0.28
Neighbourhood context						
Socio-economic status	Mean SES per neighbourhood	Cont.	58.11 ± 14.99		GOV	8.71***
Max slope	Maximum slope per neighbourhood	Cont.	9.05 ± 3.46		GOV	7.87***
Intersection density	Quantity of street intersections (3 or above) per capita	Cont.	559.35 ± 133.21		GOV	-0.65
Land use mix	Land use diversity per neighbourhood	Cont.	.64 ± .10		GOV	2.02**
Walkability[δ]	Ease of walking index per neighbourhood	Cont.	-.02 ± .98		GOV	-1.00
Greenspace density[±]	Quantity of parks per capita	Cont.	.04 ± .01		GOV	6.77***
Population density	Mean population density per neighbourhood	Cont.	26,367.8 ± 6,445.8		GOV	6.26***

Notes: [§] = transformed by square root, [δ] = transformed to z-scores. * < 10% chance random pattern; ** < 5% chance random pattern; *** < 1% chance random pattern. [†] = conceptualization of spatial relationship was inversed distance weighting.

Acronym codes: QUE = Questionnaire; GOV = government data sources; SV = computed study variable, Cont. = continuous variable

A hierarchical modelling protocol was implemented in this research due to the inherent structuring of factors influencing children's AST (Noland et al., 2014). A total of eight global (i.e., ordinary least squares) and spatial models were developed, stratified by children's accompaniment level (i.e., unaccompanied versus accompanied):

Model 1&5: child characteristics only
Model 2&6: child + parent/household
Model 3&7: child + parent/household + urban design
Model 4&8: child + parent/household + urban design + neighbourhood

Four ordinary least-squares regression (OLS) models (i.e., models 1-4) were developed to highlight important global RDI correlates. The significant independent variables were manually entered into SPSS software at each stage. The Akaike Information Criterion (AIC) and coefficient of determination (R^2) were used to assess each model's robustness. The standardized residuals were tested using global Moran's *I* to assess possible model misspecification. Considering the degree of spatial dependency (38%) among the independent variables (see Table 1), and to reduce OLS model violations, spatial regression models were tested.

Two spatial autoregression models were tried in this study to account for spatiality among the research variables. A spatial lag model and spatial error model (SEM) were developed using Geoda software version 1.2 (http://geodacenter.github.io/index.html); the latter proved the most robust and selected for this research. The SEM is an extension of the OLS model and belongs to a family of spatial autoregressive models where the residuals are assumed spatially dependent (Golgher and Voss, 2016). The hierarchical SEM models (models 5-8) for each children's group (i.e., unaccompanied and accompanied) were created using the independent variables utilized in the OLS models. Additional detail regarding the SEM model can be found in the supplementary materials methods section.

Results

Descriptive Statistics

The first objective (i) in this study was to empirically and spatially describe our sample in a Turkish context. The gender split was nearly equal (48.6% and 51.2% for males and females respectively). The average age was 13.1 (SD =.929) and 44.5% of the students were from the 6th grade; 30.1% of the students were from the 7th grade, and 25.4% of the students were from the 8th grade. Most children walked to school (71.8%) and 28.5% of these walked alone. There were marginal differences between the proportions of children who walked to and from school (69.7%), versus those who walked one-way (78.0%). In terms of parent characteristics, we observed that nearly half of the parents in the sample had at least attended a secondary school (i.e., college). The average household income was 2,279.37 Turkish Liras (TRY) and the mean number of automobiles per household was 1.55 (SD = .600). Table S2 displays the full summary statistics of the children and parent participants.

We observed that unaccompanied children travelled shorter distances to school and deviated less from the SP than their accompanied counterparts. The mean distance between the AR (95% CI: 612.95-722.44) and the SP (95% CI: 563.54-656.27) was 57.99 meters, representing an 8.68% increase over the SP route distance for this group. Among accompanied children, the mean difference between the AR (95% CI: 706.18-808.12) and SP (95% CI: 643.70-733.94) was 68.33 meters; representing a 9.02% difference. The statistical trends of each children group's route behaviors are shown in supplementary table S3.

Spatial analysis and geovisualizations

The geovisualization of statistically significant ($p < 0.05$) Getis-Ord G_i* z-scores (i.e., "hotspot/cold-spot" mapping) of excess travel (i.e., RDI) among our two children groups are shown in figure S3 in the supplementary materials. We discovered that increased values (i.e., "hot-spots") for both groups were largely located in the central section/coastal area of the study area, while reduced values (i.e., "cold-spots") occurred in the northeast areas (Figure S3a). For unaccompanied children, we discovered dispersed significant "hot-spots" in the northern and southeastern sections; and "cold-spots" were found in western/coastal areas (Figure S3b). Contrastingly, for accompanied children, we found significant "hot-spots" in the northwest section of the study area and a solitary "cold-spot" in the northwest coastal area (figure S3c). These outcomes validate that excess walking behaviors are spatially variant.

Modelling results: Unaccompanied children

The diagnostic and coefficient results from the hierarchical OLS and SEM regression models for unaccompanied children walkers are displayed in Table 2, thereby reaching our second research objective (ii). The baseline OLS models (1-4) displayed low to moderate performance, with the full model (4) being the strongest (R^2 = .426, AIC = 797.15). Multicollinearity was not found among our models (max VIF = 8.43). Due to the accounting of spatial effects, each SEM model outperformed the OLS models, with the full model (model 8) showing improvements of 1.38% and 0.11% for R^2 and AIC indices, respectively, over the full OLS model. Provided the strength of the SEM outputs, we focus on these coefficients.

Across each of the SEM models (4-8), several children attributes and perceptual factors were found to be statistically significant ($p < 0.05$). We found that age consistently impacted excess travel among unaccompanied children negatively (max β = -.384) while distance had significant positive associations (805-1600 meters, β = 2.42; > 1600 meters, β = 6.85). Perceived road crossing ease consistently had an inverse effect (max β = -.895) on RDI. In terms of parental effects, we observed that perceived greenspace diversity (max β = .533) and household automobiles (max β = .547) had a positive impact on excess walking for this group. Although urban design measures were not strongly associated with RDI, we noted that land-use diversity had a positive influence (max β = 5.92).

Table 2

Unaccompanied children's mobility; global regression and spatial model results, standardized coefficients, and diagnostics, *n* = 194

	OLS[ƚ]								SEM[ȿ]							
	Model 1[a]		Model 2[b]		Model 3[c]		Model 4[d]		Model 5[e]		Model 6[f]		Model 7[g]		Model 8[h]	
Children character & attitudes	(β)	SE	(β)	SE	(β)	SE	(β)	SE	(β)	SE	(β)	SE	(β)	SE	(β)	SE
Male, yes (ref: no)	-	-	-	-	-		-	-	-	-						
Age	**-.197**	.134	**-.184**	.135	**.185**	.136	**-.168**	.141	**-.384**	.132	**-.341**	.132	**-.336**	.133	**-.365**	.129
Obese, yes (ref: no)	*.107*	.436	*.119*	.432	*.120*	.439	**.136**	.440	*.746*	.423	**.827**	.411	**.825**	.414	**1.06**	.408
Dist. to school 403m-804m	**.238**	.333	**.257**	.333	**.261**	.345	**.255**	.343	**1.06**	.326	**1.17**	.320	**1.19**	.328	**1.19**	.314
Dist. to school 805m-1600m	**.534**	.332	**.581**	.359	**.583**	.363	**.555**	.366	**2.42**	.323	**2.60**	.345	**2.60**	.346	**2.56**	.337
Dist. to school > 1600m	**.310**	1.34	**.320**	1.35	**.321**	1.37	**.337**	1.35	**6.85**	1.30	**7.13**	1.28	**7.16**	1.28	**7.10**	1.26
Walk both ways (%)	**.171**	.009	**.173**	.009	**.175**	.010	-	-	**.025**	.010	**.024**	.010	**.024**	.101	-	-
Safe to walk, yes (ref: no)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	*.560*	.315
Easy road crossing, yes (ref: no)	**-.162**	.344	**-174**	.342	**.175**	.346	**-.176**	.341	**-.753**	.334	**-.812**		**-.811**	.327	**-.895**	.316
Parent/home character & attitudes																
College degrees yes (ref: no)			-	-	-	-	-	-			-	-			-	-
Income ≤ 1400, yes (ref: no)			-	-	-	-	-	-			-	-			-	-
Household automobiles			-	-	-	-	**.147**	.275			*.436*	.254	*.431*	.256	**.547**	.254
Factor 4, Street maintenance			-	-	-	-	-	-			-	-				
Factor 5, Greenspace diversity			**.201**	.177	**.206**	.184	**.217**	.182			**.516**	.167	**.533**	.171	**.526**	.170
Factor 6, Pedestrian safety			-	-	-	-	-	-			-	-	-	-	*-.248*	.150
Urban design																
Integration				-	-	-	*.203*	.000					-	-	*.000*	.000
Connectivity				-	-	-	-	-					-	-	*-3.07*	1.76
Metric Reach				-	-	-	*-.297*	.034					-	-	*-.055*	.031
Home-school environment																
Mean SES							**-.362**	.019							**-.055**	.015
Maximum Slope							-	-							*.082*	.048
Mean Population							-	-							**.000**	.000
Intersection density							**.395**	.003							**.006**	.002
Land-use mix							*.289*	3.01							**5.92**	2.65
Walkability							-	-							-	-
Greenspace access							-	-							-	-

[a] R^2 = .325, ΔR^2= .325, AIC = 796.56, ΔAIC = 796.56, Max VIF = 1.36

[b] R^2 = .366, ΔR^2= .041, AIC = 796.97, ΔAIC = -0.41, Max VIF = 1.91

[c] R^2 = .366, ΔR^2= .000, AIC = 802.83, ΔAIC = -5.86,, Max VIF = 2.01

[d] R^2 = .426, ΔR^2= .060, AIC = 797.15, ΔAIC = 5.68, Max VIF = 8.43

[ƚ] Residuals Global Moran's *I* *z*-score (full model) = .122, *p* = .902

[e] R^2 = .330, ΔR^2= .330, AIC = 796.17, ΔAIC = 796.17

[f] R^2 = .374, ΔR^2= , AIC = 795.40, ΔAIC = 0.77

[g] R^2 = .375, ΔR^2= , AIC = 801.09, ΔAIC = -5.69

[h] R^2 = .432, ΔR^2= .101, AIC = 796.27, ΔAIC = 4.82

[ȿ] Residuals Global Moran's *I* *z*-score (full model) = .171, *p* = .864

Notes – bold associated coefficients are significant at the 0.05 level; italic associated coefficients are significant at the 0.1 level; - indicates insignificant association.

Modelling results: Accompanied children

The significant relationships between RDI and the independent variables influencing excess travel among accompanied children are presented in Table 3. The strength of the OLS models ranged from low to moderate: the full model (4) was the strongest, exhibiting an R^2 = .333 and AIC = 785.22. Multicollinearity amongst the independent variables did not exceed the threshold (max VIF = 9.60). Each SEM model (4-8) was marginally stronger than the OLS models, which is due to controlling for spatial effects. We found that the full SEM model (model 8) exhibited a slight improvement of 1.18% and 0.07% over the full OLS model in terms of R^2 and AIC, respectively. Given that the full SEM (8) was the most robust (R^2 = .337, AIC = 784.65), we will focus on these coefficients.

Longer distances to school had a positive and significant ($p < 0.05$) effect on RDI in each model: distances between 805-1600 meters (β = 2.74) had the strongest impact. A child's gender (i.e., male) (β = -.986) exerted a negative effect on excess travel. Of the parental and household characteristics, reduced income (max β = .977) had the most influence on RDI. Parental attitudes had no impact on RDI. Connectivity, measured from space syntax, exerted a significantly ($p < 0.05$) negative effect (β = -4.60) on the dependent variable. Other significant ($p < 0.05$) neighbourhood factors positively affecting RDI included maximum slope (β = .126) and land-use mix (β = 6.86).

Table 3
Accompanied children's mobility; global regression and spatial model results, standardized coefficients, and diagnostics, n = 179

	OLS Model[ǂ]								SEM[δ]							
	Model 1[a]		Model 2[b]		Model 3[c]		Model 4[d]		Model 5[e]		Model 6[f]		Model 7[g]		Model 8[h]	
Children character & attitudes	*(β)*	SE	*(β)*	SE	*(β)*	SE	*(β)*	SE	*(β)*	SE	*(β)*	SE	*(β)*	SE	*(β)*	SE
Male, yes (ref: no)	**-.174**	.371	**-.281**	.468	**-2.87**	.475	**-.274**	.461	**-.986**	.347	**-1.35**	.431	**-1.38**	.432	**-1.39**	.429
Age	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Obese, yes (ref: no)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dist. to school 403m-804m	*.182*	.477	**.230**	.473	**.238**	.476	**.231**	.463	**.878**	.443	**.996**	.432	**1.02**	.432	**1.02**	.433
Dist. to school 805m-1600m	**.367**	.466	**.386**	.457	**.398**	.464	**.387**	.462	**2.74**	1.51	**1.70**	.430	**1.73**	.433	**1.78**	.428
Dist. to school > 1600m	*.129*	1.61	*.132*	1.59	**.148**	1.63	*.136*	1.58	*2.74*	1.61	**2.92**	1.48	**3.18**	1.50	**3.10**	1.46
Walk both ways (%)	-	-	-	-	-	-	-	-	-	-					-	-
Safe to walk, yes (ref: no)	-	-	-	-	-	-	-	-	-	-					-	-
Easy crossing, yes (ref: no)	-*.140*	.486	**-.156**	.482	**-.150**	.486	-	-	-*.772*	458	**-.883**	.447	-*.848*	.446	-*.761*	.439
Parent/home character & attitudes																
College degrees yes (ref: no)			-	-							-	-	-	-	-	-
Income ≤ 1400, yes (ref: no)			**.211**	.405	**.216**	.414	**.194**	.405			*.728*	.381	**.775**	.385	**.977**	.371
Household automobiles			-	-	-	-	*.131*	.299			-	-	-	-	*.490*	.277
Factor 4, Street maintenance			-	-	-	-	**.167**	.194			-	-	-	-	*.455*	.178
Factor 5, Greenspace diversity			-	-	-	-	-	-			-	-	-	-	-	-
Factor 6, Pedestrian safety			-*.141*	.182	-*.147*	.185	-	-			-	-	-	-	-	-
Urban design																
Integration					-	-	-	-					-	-	-	-
Connectivity					-	-	**-.290**	2.30					-	-	**-4.60**	2.04
Metric Reach					-	-	-	-					-	-	-	-
Home-school environment															-	-
MnSES							-	-							-	-
MaxSlope							*.191*	.066							**.126**	.055
MnPopulation							-	-							-	-
Intersection density							-	-							-	-
Land-use mix							**.307**	3.59							**6.86**	3.12
Walkability							-	-							-	-
Greenspace access							-	-							-	-

[a] R^2 = .154, ΔR^2= .154, AIC = 795.92, ΔAIC = 795.92, Max VIF = 2.04,
[b] R^2 = .225, ΔR^2= .071, AIC = .792.25, ΔAIC = 3.67, Max VIF = 2.06,
[c] R^2 = .233, ΔR^2= .008, AIC = 796.40, ΔAIC = -4.15, Max VIF = 2.11,
[d] R^2 = .333, ΔR^2= .101, AIC = 785.22, ΔAIC = 11.18, Max VIF =9.60,
[ǂ]Residuals Global Moran's *I* *z*-score (full model) = .286, p = .774

[e] R^2 = .189, ΔR^2= XX, AIC = 790.24, ΔAIC = 790.24
[f] R^2 = .253, ΔR^2= XX, AIC = 787.44, ΔAIC = 2.8
[g] R^2 = .259, ΔR^2= XX, AIC = 791.98, ΔAIC = -4.54
[h] R^2 = .337, ΔR^2= XX, AIC = 784.65, ΔAIC = 7.33
[δ] Residuals Global Moran's *I* *z*-score (full model) = .256, p = .797

Notes – bold associated coefficients are significant at the 0.05 level; italic associated coefficients are significant at the 0.1 level; - indicates insignificant association.

Discussion and conclusions

Limited research exists on the factors impacting children's excess walking to school, especially in understudied regions of the world, such as Turkey (Ozbil et al., 2021), leaving us with scant insights on how to elevate children's AST. Unlike previous research, we stratified our analysis between unaccompanied and accompanied children to better understand the important factors on excess walking to school. Using a robust empirical and spatial modelling approach to control for the geographical differences among children/parent characteristics and perceptions, neighborhood context and composition, our results have provided new understandings on important predictors of excess walking to school for two distinct groups of children. The following sub-sections discuss the key findings from this study.

Descriptive and spatial analysis of walking behaviors

Our first research objective (i) was to gain a better understanding of children's walking behavior to school empirically and spatially in Turkey. We found that unaccompanied children travelled shorter distances to school and detoured less from the shortest route (i.e., low RDI). Their actual routes to school, and associated RDI values, were 11.78% and 13.42% less than accompanied children, respectively. The ESDA and geovisulizations indicated that excess walking (i.e., RDI) to school not only differed based on accompanied status but depended on the neighborhood locations. The outcome supports previous research that AST is not a generalized phenomenon (Mitra et al., 2010), and emphasizes the importance of placed-based interventions to encourage additional –exploratory– walking to school.

Childhood character and attitude

The second (ii) objective in this research was to understand how children's character and perceptions impacted their route choices whether unaccompanied or accompanied. Consistent with previous works, the home-school distance was an important correlate among both groups (Easton and Ferrari, 2015). We found that older unaccompanied children engaged in less excess walking to school than their accompanied classmates. Our finding is correlated with Davison et al., (2008). Interestingly, weight status (i.e., obese) had a positive association with excess walking among unaccompanied children. One feasible explanation is that independent children may be inclined to visit unhealthy food outlets during the school journey which corresponds to work from Madsen et al., (2009). This evidence should prompt the coordination of nutrition programming with safe routes to school (SRTS) plans when designing walkable environments for children (Fraser et al., 2012). Our results showed that accompanied girls engaged in more excess walking to school (i.e., higher RDI) than boys in this study. While contrasting with some past research (Buliung et al., 2017), we contend that safety is elevated when this group is accompanied and induces route choices which deviate from the shortest path to school. Children's perceived road crossing ease hindered excess walking among both children groups – the strongest association was among unaccompanied children. We can infer that easy road crossings present opportunities for children to choose the shortest path because it is the most efficient and likely perceived as safe. Additional research is needed to better understand the local neighborhood conditions where this relationship holds.

Parent and household factors

Among the parental and household factors impacting children's excess travel, we consistently found household SES influenced children's excess walking to school. We noted that household automobile access was positively linked to excess walking among unaccompanied children. While this contradicts some past research (Carver et al., 2013), our finding is promising in that despite the option to be driven to school, this group prefers to take longer routes to school, potentially reducing negative impacts on the environment (Yang et al., 2016). We also discovered that accompanied children in low-income households (i.e., income $\leq$ 1400TRY) engaged in excess walking to school. Our finding lends credence to past literature (Ross and Kurka, 2021) and highlights that such households may reside in neighborhoods with incomplete sidewalks, unsafe streets, and/or don't have access to an automobile, which could require children to detour more often (i.e., excess walking) to find "easier" walking paths to school. As suggested by Müller et al., (2020), walking school busses, where parental groups escort children to their respective schools, could be one intervention to encourage walking safely. Surprisingly, we did not find any relationship between perceived traffic safety and excess walking. A notable link was observed regarding greenspace diversity and unaccompanied children's excess travel. The outcome should be considered by planners and policy-makers examining urban environments lacking greenspace. Past works indicate that this can allay parental fears regarding children's AST (Evers et al., 2014), and promote vital prosocial behaviours among adolescents (Putra et al., 2020).

Urban design, neighbourhood, and excess walking to school

Our lone finding on the effect of urban design on children's excess travel to school occurred largely among accompanied children. We demonstrated that space syntax derived connectivity negated excess walking to school, especially for accompanied children. Supported in part by Kaplan (2016), our results show that syntactically connected streets may be unattractive due to higher traffic densities and unsafe conditions; promoting children to find alternative walking routes to school. Surprisingly, no relationship was found between neighbourhood walkability and excess travel among either group. A comparable surrogate, land-use diversity, universally promoted excess travel for both groups. Aligned with prior research, our finding also suggests that this metric has a positive impact on walking regardless of a child's accompaniment status (Moran et al., 2016). The weak associations between excess walking, urban design and home-neighborhood walkability relative to the importance of social characteristics (i.e., household factors) are not surprising in light of prior works (Mitra and Buliung, 2014; Wong et al., 2011). Our findings suggest that planners and policy-makers should concentrate on assessing social neighborhood conditions such as cohesion and connection when designing impactful interventions (Hino et al., 2021).

Limitations and conclusion

Despite our research contributions, the limitations of this study should be noted. The data collected in this study was cross-sectional and causal relationships could not be verified. We also did not request that children indicate who they travelled with when walking to school: the survey simply questioned if children were accompanied or not. This provides a critical venue for future research, as past works have shown that children's AST differs when walking with an adult versus a peer (Ahern et al., 2017). As recent research indicates (Buliung et al., 2021), how "excess travel" is conceived of can differ among researchers, parents, and children. These are shaped by a person's intra/inter-personal concerns, including work-school constraints, and required family chores/activities, as well as specific street network qualities which impact excess walking conceptually and practically. Future research should acknowledge these differing perspectives when examining children's AST. Our incorporation of a Euclidean 1,600-meter buffer encircling each child's residence may be a limitation. A more refined scale focused on the detailed walking route conditions using GPS, similar to work from Clark et al., (2016) will fuel future work. We also acknowledge that our choice of using a VIF threshold value of ten is relatively high and this index has noted limitations (Alauddin and Nghiem, 2010). Therefore, multicollinearity may still be present in our models and coefficient interpretation (i.e., magnitude and directionality) should be viewed with caution. Overall, the discoveries provided in this study should be acknowledged and used by local stakeholders in similar regions of the world to assist with creating child-friendly environments which encourage children's safe walking routes to school while alone or with someone.

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