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Associations between streetscape characteristics at Chinese adolescents' activity places and active travel patterns on weekdays and weekends

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ABSTRACT

Background: Adolescents' daily active travel (AT) has positive health effects. However, previous studies had paid little attention on the differences between the streetscape characteristics-AT relationship on the weekdays and weekends, and most of them only focused on the environmental exposure around home and schools.

Methods: This study used data from a survey (N = 476) in Guangzhou, China between April and September 2018 and streetscape images from the Tencent Map. By using the Hurdle models and the Tobit models, we examined the associations between the streetscape characteristics and AT patterns (i.e., frequency and duration) among adolescents on weekdays and weekend days.

Results: Streetscape greenery was negatively associated with odds of AT and positively associated with the number of AT trips on weekdays, while it was negatively related to AT duration on weekends. Pavement ratio and traffic volume were negatively associated with odds of AT and AT duration on weekdays. Safety facilities and street vitality were positively associated with the AT frequency and AT duration on weekends and weekdays. Our stratified analyses indicated that gender is an effect modifier of the built environment-AT patterns associations.

Conclusion: The results showed that the relationships between streetscape characteristics and AT patterns differed between weekdays and weekends. Streetscape characteristics related to the odds of AT were not necessarily the same as those associated with AT intensity. These findings offer practical guidance for creating sustainable cities in China through AT promotion.

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1. Introduction

Frequent physical activity in children and adolescents positively affects many health outcomes (Pozuelo-Carrascosa et al., 2018; Sibbick et al., 2022; Dale et al., 2019). However, among Chinese adolescents, physical activity levels are declining (Lin and He, 2020). Based on the Eighth National Study of Students' Physical Fitness and Health in 2019, only 43% of junior high school students and 31% of senior high students fulfill the WHO recommendation of being physically active at least 1 h active a day (WHO, 2020) (http://www.moe.gov.cn). To stimulate physically active behaviour, health professionals and nationwide Chinese programs (e.g., Healthy China, 2030) advocate daily active travel (AT) (i.e., walking and cycling) as a means for health promotion among adolescents (Schoeppe et al., 2013; Guthold et al., 2020). Additionally, AT facilitates the low-carbon transformation of cities (Dong et al., 2020).

Based on the socio-ecological (Vanwolleghem et al., 2016; Carver et al., 2019) and behavioural models (Mitra, 2013; McMillan, 2007), studies have suggested associations between adolescents travel and traditional built environmental (BE) characteristics, including urban form (Özbil Torun et al., 2020; Helbich, 2016) and design (Christiansen et al., 2014), density (Dias et al., 2019; Kaplan et al., 2016; Soroori et al., 2023; Wang et al., 2021), land use diversity (Pont et al., 2013; Carver et al., 2019), and destination accessibility (Ikeda et al., 2020; Mehdizadeh et al., 2018; Zhang et al., 2022).

Recently, evidence is mounting that streetscape design relates to adolescents' travel behaviour. Most previous studies manually audited the street environment's quality (Sun et al., 2018; Buttazzoni et al., 2019). However, using auditing scales is problematic for larger study sites because they are labor-intensive and time-consuming. Machine learning combined with street view images facilitates the assessment of place appearances objectively and highly accurately in an automated manner (Kang et al., 2020; Yao et al., 2019; Yang et al., 2019). Only a few studies have quantified streetscape greenery, pavement ratio, street enclosure, and safety facilities at the vicinity of home or school (Yang et al., 2020b; Wang et al., 2022, 2023); even fewer assessed streetscapes along adolescents' daily activity spaces (Oliver et al., 2015). However, these studies ignored that the effects of the streetscape characteristics on AT may differ between weekdays and weekends (To et al., 2022; Gao et al., 2020; Gim, 2018). Adolescents' travel patterns and environmental exposures may differ between weekends and weekdays, as their travels on weekdays are more related to utilitarian purposes and more time-restricted, while their travels on weekends are more related to leisure purposes and more time-spacious (To et al., 2022).

Another limitation of most studies on adolescents' travel behaviour is that they either focused on the likelihood of engaging in any AT (Lu et al., 2019; Yu and Zhu, 2013; Ikeda et al., 2019; Siiba, 2020) or the intensity of AT (e.g., frequency and duration) (Buttazzoni et al., 2019; Page et al., 2010; Chillón et al., 2014; Hume et al., 2009; de Vries et al., 2010). However, the factors significantly related to the likelihood of AT do not necessarily have the same significant relationship with the intensity of AT, which has been mentioned in previous studies (Mertens et al., 2017; Bayart et al., 2018). A French study suggested that factors positively related to mobility decisions do not necessarily positively affect mobility intensity (Bayart et al., 2018). A multi-country study in European countries also found that the presence of trees within the neighbourhood was positively associated with the odds of transport-related cycling but was negatively associated with the number of cycling trips for people who reported any cycling in the preceding week (Mertens et al., 2017). We are not aware of whether the built environment is significantly associated with not only adolescents' AT decision but also their AT intensity, which requires further investigation.

To address these research gaps, we explored the associations between the streetscape characteristics and adolescents' AT frequency and AT duration on weekdays and weekends in Guangzhou, China. This study contributes to the literature twofold. First, we include the built environment at adolescents' activity locations rather than only at their place of residence as commonly done (Özbil Torun et al., 2020; Moran et al., 2015; Dias et al., 2019). Second, the analyses were done separately for a weekday and a weekend day. This is important because adolescents are likely more sensitive to travel mode choice and travel duration on weekdays due to time restrictions while having more discretionary time for recreational weekend recreational trips.

2. Materials and methods

2.1. Study area

We used cross-sectional data from adolescents in Guangzhou, China. The survey was conducted between April and September 2018. The respondents were selected through the following two stage sampling design: First, we randomly selected 11 neighbourhoods from seven inner-city districts of Guangzhou (i.e., Tianhe, Haizhu, Yuexiu, Liwan, Panyu, Huangpu, Baiyu) employing a multistage stratified probability proportional to size sampling (Fig. S1). Based on the Fifth Guangzhou Official Household Travel Survey conducted by the Guangzhou Transport Commission in 2017, active travel modes accounted for 59.55% of all-purpose travel in the seven inner-city districts of Guangzhou, 61.16% travel to school, and 45.35% travel for recreational purposes among adolescents aged 12–18. Second, we invited 30 to 70 middle school students aged 12–18 in each of the 11 neighbourhoods through convenience sampling. Each respondent was invited to complete 1) a face-to-face questionnaire on their individual and household characteristics, and environmental perceptions, and 2) a two-day activity and travel diary. One diary day was on a working day, while the other was on a weekend day. After removing those with missing data ($N = 26$), our total sample included 476 respondents.

2.2. Dependent variables

Each respondent reported the activities and trips within 24 h in chronological order in the activity and travel dairy data. Each record included trip attributes, such as the travel mode (e.g., walking, cycling, private car, bus, and metro), trip origin and destination addresses, trip purpose, start and end time per trip, travel companionship, etc. Respondents chose the trip mode with the most prolonged duration if there were multimodal trips. Because previous studies on AT have frequently pooled walking and cycling trips (Chillón et al., 2014; Campos-Sanchez et al., 2020; Rothman et al., 2021; Rahman et al., 2020; Tewahade et al., 2019), we considered AT frequency (i.e., the number of walking and cycling trips of each person) and AT duration (i.e., a person's minutes travelled actively) on the weekday or the weekend day as dependent variables. As only the street view data were only available for urban areas, we removed the travel records whose origin or destination was located in suburban areas (Fig. 1).

2.3. Streetscape and traditional built environmental characteristics

We geocoded the activity locations which respondents reported. We used a 500 m circular buffer centered on each activity location to capture fine-scale streetscape characteristics and traditional built environmental characteristics. Streetscape variables and measures of the built environment were generated by calculating their average values across all activity locations that an adolescent visited in a day. Streetscape images for the year 2016 were acquired from Tencent Map (https://map.qq.com/). To obtain images for each cardinal direction through the application programming interface within each buffer, we used sampling points every 50 m along the street network from OpenStreetMap (https://www.openstreetmap.org). In total, we obtained 283,436 streetscape images at 70,859 sample locations.

We used a convolutional neural network (i.e., FCN-8s) based on the ADE20K scene parsing and segmentation database to identify 151 different street objects (including the category of "unknown objects") within every streetscape image (Helbich et al., 2019; Yao et al., 2021; Zhou et al., 2018). Through a pixel-by-pixel comparison, the FCN-8s can predict each pixel's semantic characteristic. The accuracy was 81.44% in the training set and 66.83% in the test set (Shelhamer et al., 2017; Yao et al., 2019). Next, we calculated the pixel-wise proportion of each object per image and averaged the values across the four cardinal directions of each buffered sampling point. Five streetscape characteristics were derived: First, street greenery is the average value of the pixels classified as trees, grass, plant, flower and palm tree in images. Second, pavement ratio refers to the pixel classified as pavement relative to the sum of pavement and roadway pixels. It should be noted that we used the pixels ratio of "sidewalk; pavement" class in ADE20K as pavement in an image. Third, safety facilities are the average value of the sum of pixels of some street furniture related to pedestrians' safety from crime and traffic (i.e., fences, streetlights, traffic lights, cameras, and windows). Fourth, traffic volume serves as a proxy variable for traffic safety and refers to the average value of the sum of pixels classified as motor vehicles. Fifth, street vitality is captured through the average value of the sum of pixels classified as pedestrians, bicycles, booths (the temporary structures used to prepare and sell food to the public, usually located near the densely populated areas. The presence of booths can improve street vitality by attracting pedestrians) and signboards. Supplementary Table S1 provides in-depth descriptions for each streetscape characteristics.

To represent the traditional built environmental characteristics (Table S1) (Kaplan et al., 2016; Lu et al., 2019; Yang et al., 2020b), we calculated the intersection density and recreational facility density from point of interest data obtained from the Urban Data Party (https://udparty.com/). Besides, we calculated the shortest road distance from the activity location to the closest bus and metro stations. Population density is extracted from WorldPop data (https://www.worldpop.org/).

2.4. Covariates

We considered the following covariates as done elsewhere (Medeiros et al., 2021): gender (male vs. female), grade (junior high

Fig. 1. Streetscape images from four different locations in our research area.

school vs. senior high school), hukou status (i.e., a household registration system in China, which identifies a person as a permanent resident of area) (local hukou vs. non-local hukou), number of family members, economic status of the household (poor vs. fair vs. good), household car ownership (no car vs. have car), self-reported health status (fair health or below vs. good health), perceived community safety (5-point Likert scale ranging from totally disagree (=1) to totally agree (=5)), and enrolment in graduating class (i.e., grade 9 for junior high school and grade 12 for senior high school). As travel-related covariates, we included the travel distance and the number of activity locations of each travel day.

Guided through the literature (Helbich et al., 2016; Wei, 2022), we also included three weather-related covariates. We considered whether it was raining on the travel day (yes vs. no). Because some studies have suggested that outdoor thermal comfort (22–28 °C) possibly plays a role in outdoor activities (Labdaoui et al., 2021; Lin, 2009), we calculated the proportion of hours within 22–28 °C during the weekday (6:00 a.m.–19:00 p.m.) and the weekend day (7:00 a.m.–20:00 p.m.). Finally, we also calculated the average humidity (%rh) of each travel day.

2.5. Statistical analyses

We used descriptive analyses to summarize the sample characteristics. First, we employed Hurdle models to examine the associations between the streetscape characteristics and adolescents' AT frequency on a weekday or a weekend day, respectively. A Hurdle model contains a logistic regression to estimate the odds of participation in AT and a zero-truncated count-data model to estimate the trip frequency of those adolescents who did some AT. In our data, 56.72% did not do any AT on a weekday and 63.87% on a weekend

Table 1
Results of the relationship between the streetscape characteristics and AT patterns on the weekdays.

	Model 1 (AT frequency)				Model 2 (AT duration)	
	Hurdle model				Tobit model	
	Logit model		Negative binomial model			
	Estimate	(S.E.)	Estimate	(S.E.)	Estimate	(S.E.)
Streetscape greenery	−3.517*	(1.810)	1.075**	(0.520)	−4.917	(3.791)
Pavement ratio	−4.839***	(1.627)	0.480	(0.480)	−11.160***	(3.471)
Safety facilities	−0.123	(0.064)	−0.016	(0.025)	−4.654	(3.111)
Traffic volume	−0.305*	(0.166)	−0.005	(0.048)	−13.093*	(6.941)
Street vitality	0.462***	(0.173)	0.133***	(0.048)	23.674***	(7.249)
Population density	−0.192	(0.199)	−0.294***	(0.068)	−7.864	(10.229)
Intersection density	−0.861***	(0.277)	0.270**	(0.117)	−37.091***	(14.260)
Recreational facilities density	−0.404	(0.386)	0.204	(0.141)	−23.139	(18.683)
Shortest distance to public transit	−1.376***	(0.335)	−0.347***	(0.062)	15.462	(8.917)
Travel distance	−0.491***	(0.099)	0.004	(0.037)	−20.830***	(4.615)
Number of activity locations	1.258***	(0.249)	0.015	(0.071)	50.474***	(8.851)
Weather (Reference: Non-rainy day)						
Rainy	0.596***	(0.209)	−0.033	(0.067)	31.577***	(10.058)
Proportion of hours with suitable temperature	−0.126	(0.489)	−0.154	(0.170)	−16.080	(23.467)
Average humidity	0.029**	(0.013)	0.008*	(0.005)	1.952***	(0.655)
Gender (Reference: Female)						
Male	0.215	(0.137)	0.064	(0.046)	12.394*	(6.747)
Grade (Reference: Junior high)						
Senior high	−0.020	(0.144)	0.020	(0.053)	1.766	(7.205)
Hukou (Reference: Non-local hukou)						
Local hukou	−0.403**	(0.161)	0.037	(0.050)	−19.528***	(7.357)
Number of family members	−0.023	(0.069)	0.048**	(0.024)	−0.859	(3.457)
Household economic status (Reference: Poor)						
Fair	0.526	(0.392)	−0.196*	(0.111)	28.674	(22.666)
Good	0.366	(0.391)	−0.210*	(0.110)	21.010	(22.981)
Car ownership (Reference: have no car)						
Have car	−0.305**	(0.155)	−0.080	(0.057)	−15.436*	(8.009)
Parents' highest educational level (Reference: Junior high school or below)						
Senior high school	−5.265***	(0.381)	−0.007	(0.117)	−35.501**	(15.110)
College or above	−5.266***	(0.394)	0.059	(0.124)	−35.449**	(15.769)
Self-reported health (Reference: poor health and below)						
Good health	−0.150	(0.198)	−0.016	(0.062)	−5.453	(9.464)
Community safety	−0.187	(0.148)	0.106**	(0.046)	−4.975	(7.796)
Graduating grade (Reference: not in graduating grade)						
In graduating grade	−0.038	(0.153)	−0.020	(0.054)	−3.986	(7.229)
Constant	9.668***	(1.925)	−0.286	(0.587)	101.275	(89.396)
Observations	476					
AIC	665.905				2,605.954	
BIC	890.838				2,722.585	

Standard errors in parentheses. $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$.

day. Compared with the traditional Poisson and Negative Binomial model, the Hurdle model allows for the differences in the factors which significantly related to the likelihood of AT and the AT intensity, resulting in lower Akaike information criterion (AIC) values. Second, we fitted Tobit models to examine the associations between the streetscape characteristics and the censored outcome AT duration on a weekday or a weekend day, respectively. Area-level random effects were disregarded in the Hurdle and Tobit model because the streetscape characteristics was assessed through unnested buffers centered on respondents' activity locations.

Model 1 and Model 2 examined the associations between AT frequency and duration and the streetscape characteristics on a weekday, while Model 3 and Model 4 assessed the associations on the weekend. We also fitted gender-stratified models to test possible effect modification of the AT-streetscape characteristics associations (Model 5–8). The analyses were conducted in STATA 17.0.

3. Results

3.1. Descriptive statistics

Table S2 shows summary statistics of the sample. The mean AT frequency varied across the weekday (1.15) and the weekend day (0.76). Adolescents spent more time on AT on the weekday (28.59 min) than on the weekend (18.71 min). The average number of activity locations on weekdays and weekends was 2.20 and 2.34, respectively. Considering the streetscape characteristics, the average values of street greenery, pavement ratio, safety facilities, traffic volume, and street vitality around activity locations that respondents visited on the weekday were 0.27, 0.27, 0.01, 0.03, and 0.03, while those around activity locations that respondents visited on the

Table 2
Results of the relationship between the streetscape characteristics and AT patterns on the weekend days.

	Model 3				Model 4	
	Hurdle model				Tobit model	
	Logit model		Negative binomial model			
	Estimate	(S.E.)	Estimate	(S.E.)	Estimate	(S.E.)
Streetscape greenery	0.268	(1.591)	−1.111	(0.946)	−7.541**	(3.702)
Pavement ratio	1.672	(1.944)	−0.304	(1.224)	−2.691	(4.166)
Safety facilities	0.268***	(0.080)	0.025	(0.045)	11.421***	(3.520)
Traffic volume	0.090	(0.091)	−0.031	(0.047)	0.764	(3.870)
Street vitality	0.002	(0.099)	0.006	(0.046)	0.388	(4.652)
Population density	0.371*	(0.207)	0.269***	(0.104)	27.809***	(8.036)
Intersection density	−0.828**	(0.408)	−0.279	(0.204)	−22.268	(19.453)
Recreational facilities density	0.497	(0.334)	0.200	(0.184)	22.649	(14.577)
Shortest distance to public transit	−0.028	(0.641)	−0.388***	(0.119)	−13.957	(19.707)
Travel distance	−0.243***	(0.054)	−0.116***	(0.034)	−12.534***	(2.298)
Number of activity locations	0.798***	(0.121)	0.106*	(0.057)	33.340***	(4.493)
Weather (Reference: Non-rainy day)						
Rainy	−0.300*	(0.170)	−0.176*	(0.096)	−14.854*	(7.816)
Proportion of hours with suitable temperature	0.748	(0.631)	0.281	(0.331)	45.748	(29.038)
Average humidity	0.014	(0.044)	−0.008	(0.026)	0.123	(2.161)
Gender (Reference: Female)						
Male	0.243*	(0.135)	0.003	(0.065)	12.578**	(6.005)
Grade (Reference: Junior high)						
Senior high	0.010	(0.140)	0.029	(0.068)	−0.140	(6.302)
Hukou (Reference: Non-local hukou)						
Local hukou	−0.086	(0.162)	−0.106	(0.071)	−5.567	(7.246)
Number of family members	−0.075	(0.070)	−0.017	(0.034)	−2.943	(3.078)
Household economic status (Reference: Poor)						
Fair	−1.046**	(0.419)	−0.160	(0.132)	−48.457***	(15.882)
Good	−0.854**	(0.408)	−0.121	(0.133)	−33.113**	(15.403)
Car ownership (Reference: have no car)						
Have car	−0.201	(0.160)	−0.103	(0.083)	−15.748**	(7.221)
Parents' highest educational level (Reference: Junior high school or below)						
Senior high school	−0.144	(0.485)	0.171	(0.291)	−0.031	(21.788)
College or above	−0.263	(0.495)	0.232	(0.296)	−4.534	(22.565)
Self-reported health (Reference: poor health and below)						
Good health	0.031	(0.206)	−0.097	(0.089)	−1.118	(9.989)
Community safety	−0.116	(0.154)	0.043	(0.073)	−2.512	(7.062)
Graduating grade (Reference: not in graduating grade)						
In graduating grade	0.003	(0.155)	−0.086	(0.082)	−0.084	(7.013)
Constant	−2.760	(3.512)	1.080	(2.029)	−100.034	(169.396)
Observations	476					
AIC	656.147				2,166.777	
BIC	881.079				2,283.409	

Standard errors in parentheses. $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$.

Table 3
Results of gender-stratified analysis.

	Model 5 (AT frequency on the weekdays)								Model 6 (AT duration on the weekdays)			
	Female				Male				Female		Male	
	Logit model		Negative binomial model		Logit model		Negative binomial model		Tobit model			
	Estimate (S.E.)		Estimate (S.E.)		Estimate (S.E.)		Estimate (S.E.)		Estimate (S.E.)		Estimate (S.E.)	
Streetscape greenery	−1.056	(2.837)	0.828	(1.049)	−5.667**	(2.623)	1.643**	(0.642)	1.539	(5.801)	−12.317**	(5.398)
Pavement ratio	−8.412***	(2.740)	0.055	(0.809)	−2.184	(2.182)	0.670	(0.799)	−18.129***	(5.053)	−0.876	(5.014)
Safety facilities	−0.006	(0.098)	−0.028	(0.035)	−0.205**	(0.096)	−0.009	(0.034)	−0.200	(4.465)	−7.681	(4.610)
Traffic volume	−0.574*	(0.300)	−0.025	(0.068)	−0.293	(0.219)	−0.015	(0.068)	−12.450	(9.866)	−20.084	(10.959)
Street vitality	0.810**	(0.317)	0.131*	(0.075)	0.435*	(0.233)	0.118*	(0.065)	28.847***	(10.518)	27.974**	(11.892)
Observations	240				236				240		236	
AIC	340.339				367.877				1,261.893		1,364.332	
BIC	517.852				547.997				1,352.390		1,457.855	

	Model 7 (AT frequency on the weekend days)								Model 8 (AT duration on the weekend days)			
	Female				Male				Female		Male	
	Logit model		Negative binomial model		Logit model		Negative binomial model		Tobit model			
	Estimate (S.E.)		Estimate (S.E.)		Estimate (S.E.)		Estimate (S.E.)		Estimate (S.E.)		Estimate (S.E.)	
Streetscape greenery	−0.462	(2.503)	−0.051	(1.559)	1.981	(2.290)	−1.335	(1.182)	−12.419**	(5.408)	−2.109	(4.997)
Pavement ratio	7.822***	(2.803)	−0.661	(1.674)	−3.161	(2.712)	−0.070	(1.486)	8.693	(6.379)	−6.337	(5.803)
Safety facilities	0.324***	(0.114)	0.048	(0.085)	0.231**	(0.114)	0.026	(0.054)	17.130***	(5.272)	8.410*	(4.804)
Traffic volume	0.165	(0.125)	−0.076	(0.061)	−0.053	(0.137)	−0.022	(0.069)	1.204	(5.528)	−2.117	(5.592)
Street vitality	−0.074	(0.134)	−0.001	(0.068)	−0.006	(0.150)	0.012	(0.063)	−0.145	(5.864)	−2.857	(7.014)
Observations	240				236				240		236	
AIC	323.337				358.754				1,025.378		1,169.281	
BIC	438.199				531.946				1,119.355		1,262.805	

*$p < 0.10$, **$p < 0.05$, ***$p < 0.01$. All covariates have been adjusted for.

weekend day were 0.26, 0.25, 0.01, 0.06, and 0.01. Intersection density and shortest distance to public transit stations were, on average, lower on the weekday than on the weekend. Differences were also observed in the density of recreational facilities and population density.

3.2. Determinants of AT frequency and AT duration

There was no evidence of covariate multi-collinearity. Table 1 shows the results of the regressions for AT frequency (Model 1) and AT duration (Model 2) on weekdays. Model 1 indicated that adolescents' higher odds of AT and more AT trips were associated with higher street vitality. Adolescents had a lower AT likelihood and a pronounced number of AT trips with more streetscape greenery. Pavement ratio was negatively associated with the likelihood of AT, while traffic volume also had a marginally significant relationship with the odds of AT, but there were no evidence that the above two characteristics had significant relationships with the number of AT trips.

As for the other covariates, the number of AT trips was negatively associated with population density. Respondents had a lower AT likelihood with higher intersection density. However, when we considered the respondents who had at least one AT trip on the weekdays, AT trips were positively associated with higher intersection density. In addition, respondents with longer distances to public transit showed a negative association with the AT frequency. Travel distance was significantly negatively associated with AT odds, while a higher AT likelihood was positively related to the number of activity locations. Adolescents had a higher likelihood of AT on a rainy day and may have higher AT frequency on a day with higher average humidity. Respondents with local hukou, whose parents had a higher educational level, and whose household owned a private car had a lower AT likelihood. In addition, respondents with more family members, better household economic status, and higher community safety perception were more likely to report a larger number of AT trips.

Only pavement ratio and traffic volume were negatively associated with AT duration in Model 2, while street vitality was positively associated with AT duration. We found null associations between street greenery and safety facilities and AT duration. Intersection density and travel distance were negatively related to AT duration, while the number of activity locations positively correlated with AT duration. Adolescents travel longer actively on a rainy day or a day with higher average humidity. Boys travelled longer actively than girls, and those with local hukou, whose parents had a higher educational level, and whose household-owned private cars had shorter AT duration.

Table 2 shows the results of the regressions for AT frequency (Model 3) and AT duration (Model 4) on weekend days. Model 3 indicated that only safety facilities were positively associated with adolescents' AT likelihood on weekend days. Unexpectedly, the relationships between the streetscape characteristics and the number of AT trips on weekend days were insignificant.

The population density was positively related to the odds of AT and the number of AT trips on weekend days. In contrast, intersection density and shortest distance to the public transit were negatively associated with both response variables. Travel distance and rainy days were inversely associated with adolescents' AT frequency, while the number of activity locations was positively related. Boys had a higher AT likelihood than girls, while respondents with better economic status had lower AT odds.

Streetscape greenery was negatively related to the AT duration in Model 4, while safety facilities showed a positive relationship. Similar to the traditional BE characteristics-AT frequency association on weekend days, adolescents had longer AT duration with higher population density and more activity locations. Travel distance and rainy days showed negative relationships with AT duration. Boys took longer AT duration than girls, and those with better economic status and whose household-owned private cars had a shorter AT duration.

3.3. Heterogeneous effects of respondents' gender

Table 3 summarizes the results of our stratified analyses. On a weekday, streetscape greenery was only significantly associated with boys' AT frequency and AT duration, while pavement ratio and street vitality had stronger relationships with AT frequency and AT duration among girls. Safety facilities had a negative relationship with the likelihood of AT for boys only, while traffic volume was marginally and negatively associated with the odds of AT for girls only. On a weekend day, streetscape greenery was only negatively related to girls' AT duration and a higher pavement ratio was significantly associated with higher AT odds for girls. Safety facilities had a stronger relationship with girls' AT frequency and AT duration. We observed null associations between traffic volume, street vitality, and AT frequency and duration for both boys and girls.

4. Discussion

Promoting active travel behaviour is critical for achieving sustainable communities and improving adolescents' health and well-being. Based on hurdle and Tobit models, we examined the associations between the streetscape characteristics around adolescents' activity places and their AT behaviour separately for weekdays and weekend days.

4.1. Streetscape characteristics

Although the evidence that greenery promotes the behaviours AT is increasing, results remain contradictory. We found a positive relationship between the streetscape greenery and the number of AT trips on weekdays, which was in line with previous studies (Kim and Heinrich, 2016; Lu et al., 2018; Yang et al., 2020a, 2020b; Bai et al., 2022). Greenery along streets may increase people's willingness to travel actively by making street environments more aesthetically pleasant, improving the outdoor thermal environment, and stimulating psychological restoration (He et al., 2022; Łaszkiewicz and Sikorska, 2020; Liu et al., 2019, 2022; Xue et al., 2017). In contrast, the streetscape greenery was negatively associated with adolescents' odds of AT on a weekday and AT duration on weekend days. This finding partially echoed two previous studies (Aarts et al., 2013; Maki-Opas et al., 2016), which focused on four Dutch cities (i.e., Tilburg, Breda, 's Hertogenbosch, and Roosendaal) and five Finish cities (i.e., Helsinki, Turku, Tampere, Kuopio, Oulu), and reported negative relationship between the street greenery and active commuting (Aarts et al., 2013; Maki-Opas et al., 2016). There were two possible reasons for the negative relationship between the street greenery and active travel. On the one hand, higher levels of street greenery may indicate the absence of other street furniture attractive to adolescents, which may inhibit adolescents' willingness to travel actively. On the other hand, for preparing this study, we conducted face-to-face interviews with adolescents to grasp their attitudes toward different streetscape types. Some interviewees stressed that dense and disordered street greenery may provide hiding spaces for criminals, which raised safety concerns. This viewpoint was also consistent with earlier findings (Lee and Maheswaran, 2011).

The pavement ratio was significantly and negatively associated with the odds of AT and AT duration on weekdays. This may be because the quality of the urban traffic system, including both the pavement and motorized road, has increased substantially based on the high-quality construction of Chinese urban infrastructure. Therefore, streets with a high pavement ratio may also be suitable for driving, positively affecting adolescents' motorized travel (e.g., traveling by private cars or buses). This explanation was supported by a study in Shenzhen (China), which reported that sidewalk width was positively associated with motorized travel of adolescents (Meng et al., 2018).

We found significant and positive associations between the safety facilities and adolescents' odds of AT and AT duration on weekend days. The safety facilities referred to facilities related to safety from crime and traffic. The presence of fences, cameras, and traffic lights may protect adolescents from possible injury or collisions (Witten et al., 2022; Ikeda et al., 2018), thereby encouraging them to conduct AT (Smith et al., 2017). Streetlights, cameras, and windows may also make adolescents and their parents feel safe from crime, therefore encouraging them to travel actively (Li et al., 2021; Su et al., 2023; Istrate and Chen, 2022). A few studies carried out in Western countries (e.g., in the UK) showed an increase in pedestrians' activities after infrastructure interventions (e.g., enhancement of safety facilities) (Smith et al., 2020; Mackie et al., 2018; Aldred et al., 2019).

Traffic volume was negatively related to adolescents' odds of AT and AT duration on weekdays. Traffic volume is a well-established AT barrier (Lutfur Rahman et al., 2022; Mandic et al., 2022; Leung and Loo, 2020). Adolescents and their parents are likely to have traffic safety concerns due to the exposure to street traffic. For example, a study conducted in the Belgium reported higher traffic volume as one of the major challenge for adolescents' AT (Verhoeven et al., 2017). Parental and adolescents' perceptions of high traffic volume was also recognised as an important barrier for adolescents' AT in the United States and the New Zealand (Esteban-Cornejo et al., 2016; Lutfur Rahman et al., 2022).

Finally, street vitality was positively associated with adolescents' AT patterns on weekdays. Adolescents' travel purposes during the weekdays are more related to utilitarian-purpose travel (e.g., home-school commuting). In the vicinity of adolescents' homes and school addresses, streets with different commercial and human activities may be more attractive for adolescents, which plays a vital role in inducing AT behaviours (Istrate and Chen, 2022; Park et al., 2019; Li et al., 2021). We found null associations between street vitality and AT patterns on weekends. A possible explanation is that many adolescents spend their weekends in the city centers with pronounced quality of street vitality.

4.2. *Other environmental characteristics*

Some traditional, macro-level built environmental characteristics were also associated with adolescents' AT. On weekdays, the population density was negatively related to the number of AT trips, consistent with the previous studies (Özbil Torun et al., 2020; Moran et al., 2015). It could be that higher population density around home and school may relate to adolescent safety concerns and increase schooling injury rates (Amiour et al., 2022). However, on weekend days, there were significant and positive relationships between the population density and adolescents' AT frequency and AT duration. A possible reason was that adolescents would choose to go to the prosperous urban areas with higher population density on a weekend day.

We also found that the intersection density-AT relationships differed depending on the AT characteristics. Specifically, there was a positive relationship between the intersection density and the number of weekday AT trips. However, in contrast to our expectation, intersection density was negatively associated with AT odds and AT duration on weekdays and with AT odds on weekends. Previous studies found that higher intersection densities were supposed to reduce vehicle speed and improve people's accessibility to other activity locations (Kerr et al., 2007; Yang et al., 2020b). One possible explanation was that higher-ordered roads tend to have more traffic (Wu et al., 2020). When adolescents travelled actively along such roads, they may worry about increased traffic accident risk.

Further, we found that adolescents may have a lower AT frequency with increased distance to the nearest transit station, indicating a positive relationship between the increased accessibility of transit stations and the promotion of adolescents' AT. It could be that activity locations with higher transit station accessibility are more prosperous, better connected, and convenient to reach than other activity locations.

We also found that on a weekday, adolescents may have longer AT duration on a rainy day or a day with higher humidity. One possible reason was that most travel records were school trips with relatively fixed travel modes. For example, adolescents who used to travel actively to school were unlikely to change their travel modes despite some rain. Under such circumstances, they may walk or bike to school slower than usual due to the weather.

4.3. The heterogeneous effects of socio-demographic attributes

We found that, overall, the streetscape characteristics showed a stronger relationship with girls' AT patterns than boys, especially for the safety-related streetscape characters such as pavement ratio, safety facilities, and traffic volume. One possible reason is that girls might have less freedom to travel independently without their parents' companionship (Marzi et al., 2018). Girls and their parents may have higher safety concerns about the street environment limiting girls' AT (Ghekiere et al., 2017; Foster et al., 2014).

4.4. Limitations

This study had some limitations. First, we cannot infer causalities between the built environment and adolescents' AT, as our data were cross-sectional. Second, the streetscape data did not provide information on the recording date. We pooled images across seasons but could not assess how these variations affected our models. Third, our dependent variables were self-reported, and some recall bias may affect the reliability of our results (Yang et al., 2022). Fourth, we did not consider the streetscape characteristics along the travel routes of respondents, which may also shape adolescents' AT behaviour (Guthold et al., 2020). However, we incorporated the streetscape characteristics at adolescents' activity locations. Fifth, by means of street view data, we can only measure traffic volume at a specific point in time rather than the actual traffic volume throughout a day. Therefore, measurement errors cannot be circumvented using street view images. Finally, we only focused on the difference in the streetscape characteristics-AT relationships between weekdays and weekend days, and the small sample size hindered us from further stratifying sample members by trip purpose. We cannot exclude that the trip purpose may affect adolescents' travel mode choices. Future studies should consider trip purposes when investigating how environmental factors relate to adolescents' active travel.

5. Conclusion

We investigated the relationships between adolescents' AT patterns (i.e., frequency and duration) and streetscape characteristics around activity locations on either a weekday or a weekend day. We found that adolescents had a higher AT frequency and a longer AT duration on the weekday than on the weekend. There was a stark difference between the weekday and the weekend day regarding relationships between streetscape characteristics and AT. Street greenery was positively associated with AT frequency on a weekday, but it was negatively related to AT duration on a weekend day. Pavement ratio and traffic volume were negatively related to adolescents' AT on a weekday, and street vitality was positively related to AT on a weekday, while safety facilities were positively associated with both AT outcomes on a weekend day. Streetscape characteristics associated with the odds of AT may not necessarily be associated with the number of AT trips and AT duration. We found that, on the weekday, streetscape greenery was negatively related to the odds of AT and that streetscape greenery was positively associated with the number of AT trips among individuals who had at least one AT trip. Based on the results of stratified analyses for gender, streetscape aesthetic characteristics (i.e., streetscape greenery) had a stronger relationship with boys' AT patterns. In contrast, girls' AT patterns were more influenced by safety-related characteristics.

We can draw some implications of urban planning from our findings. First, we found that there were significant differences in the relationships between the street greenery and adolescents' AT on a weekday and a weekend day. In the planning process, it may be better to identify the usual travel routes and activity locations of adolescents on a weekday (such as the routes from home to school) or a weekend day (such as the routes from home to physical activity facilities and so on) more accurately. Based on this, the value and quality of street greenery around different routes and activity locations need to be designed more precisely and carefully. Second, when designing the appropriate width and proportion of pavement, it is also important to focused on the distribution of various types of street furniture, not only to enhance the safety of streets, but also to improve the streets' attractiveness to adolescents for promoting their AT behaviours. Finally, planners should make efforts to address the environmental inequality by targeting the important areas and making more improvements. For example, our stratified analyses showed that safety-related streetscape attributes had stronger relationships with girls' AT, which means that in the planning process of child-friendly cities, we should acknowledge that perceived streetscape attributes differ across socio-demographic population groups. We should aim to increase the AT willingness of all adolescents by identifying the optimal value of each of the streetscape characteristics.

Data availability

The data that has been used is confidential.

Authors' contributions

Xiaoge Wang: Methodology, Software, Formal analysis, Writing-original draft. Ye Liu: Conceptualization, Writing - review & editing, Funding acquisition. Yao Yao: Data curation, Writing - review & editing. Suhong Zhou: Data curation, Writing - review & editing. Qia Zhu: Data curation. Mingyang Liu: Data curation. Weijing Luo: Data curation. Marco Helbich: Writing - review & editing. All authors read and approved the final manuscript.

Consent for publication

Consent forms are available upon reasonable request.

Availability of data and materials

The datasets used and/or analysis during the current study are available from the corresponding author on reasonable request.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jth.2023.101653.

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