Urban Forestry & Urban Greening 88 (2023) 128081

Contents lists available at ScienceDirect

Urban Forestry & Urban Greening

journal homepage: www.elsevier.com/locate/ufug

Urban environment and green spaces as factors influencing sedentary behaviour in school-aged children☆

Giulia Squillacioti [a,*,1], Samuele De Petris [b,1], Valeria Bellisario [a], Enrico Corrado Borgogno Mondino [b], Roberto Bono [a]

[a] Department of Public Health and Pediatrics, University of Turin, 10126 Turin, Italy
[b] Department of Agriculture, Forest and Food Sciences, University of Turin, Grugliasco, 10095 Turin, Italy

ARTICLE INFO

Handling Editor: Dr Cecil Konijnendijk van den Bosch

Keywords:
Sedentary behaviour
Children
Public health
Green spaces

ABSTRACT

Urban environment has been increasingly recognised as a health determinant able to promote healthy or unhealthy lifestyles. The growing use of technology and urbanization is influencing people behaviours, making them more sedentary. In children, this may be even more relevant as childhood is a critical period for creating bases for lifelong health and well-being. Given the potential for the urban environment to influence health, we investigated the association between some key characteristics of the urban environment and sedentary behaviour in school-aged children. We recruited 331 healthy children (9–11 years, 52% males), whose parents were asked to quantify their time spent in several sedentary activities. We derived two sedentary behaviour outcomes: the total daily sedentary time and the screen time. Exposure to less urbanized and more vegetated area was derived by combining key environmental attributes using Principal Component Analysis. Independently of age, sex and BMI children living in less urbanized and more vegetated areas reported 12 min less of daily sedentary time (β: −12, 95% CI from −22 to −2; p = 0.02) and were less likely to exceed the recommended daily screen time (2 h/day) (OR: 0.86 95% CI 0.74–1, 00; p = 0.056). A stronger association was found in children whose mothers were highly educated, suggesting that maternal education level acts as effect modifier. Our findings highlight that environmental characteristics may shape children's health by influencing their lifestyles, and should be considered in Public Health strategy to prevent sedentary behaviour and promote more sustainable and healthier cities.

1. Introduction

Preventing sedentary behaviour has become a new public health paradigm worldwide. Mounting evidence suggests that sedentary behaviour is rapidly emerging as a health issue. Independently of physical activity (Wilmot et al., 2012), it has been associated with several non-communicable diseases including diabetes, cardiovascular diseases, cancers and all-cause mortality, in adults, and increased adiposity, poorer cardio metabolic health, and reduced sleep duration in youths (WHO, 2020).

Sedentary lifestyles cannot be merely conceived as lack of physical activity, since leisure time spent being sedentary could be relevant also in active people who meet the guidelines of physical activity recommended by the World Health Organization (Rhodes et al., 2012). The ever-growing use of technology, changing patterns of transportation and urbanization degree together with modern-era demands promote sedentary lifestyles (Nieuwenhuijsen, 2016). As result, people are increasingly less active or, in other words, more inactive and sedentary, and this phenomenon has been observed in different age groups (Bernaards et al., 2016). This might be even more relevant in youths as childhood and adolescence are critical periods for developing movement skills, learning healthy habits, and creating a strong basis for lifelong health and well-being.

Physical activity during the developing stages of life has been associated with many features of physical health including increased bone mineral content and density (Tobias et al., 2007), improvements in cardiorespiratory function (Malina and Bouchard, 2004) and enhanced motor skills competence (Gao et al., 2021). In addition, the risk of

☆ This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.
* Correspondence to: Department of Public Health and Pediatrics, University of Turin, Via Santena 5 bis, 10126 Turin, Italy.
E-mail address: giulia.squillacioti@unito.it (G. Squillacioti).
[1] These two authors contributed equally.

https://doi.org/10.1016/j.ufug.2023.128081
Received 13 February 2023; Received in revised form 25 August 2023; Accepted 6 September 2023
Available online 7 September 2023

metabolic syndrome is more likely in sedentary children and adolescents as compared to their active peers (Yin et al., 2022).

On average, European children and adolescents spend up to 9 h/day engaging in various sedentary activities and up to 3 h/day watching television (Verloigne et al., 2016). Depending on the country, up to 68% of European children spend two or more hours of screen time per day (Whiting et al., 2021). American children spend approximately 8 h/day being sedentary (Patterson et al., 2018). Formally, sedentary behaviour has been defined as any waking activity characterized by an energy expenditure $<$ 1.5 metabolic equivalent tasks (Owen et al., 2000). Children may engage in a wide variety of sedentary activities including quiet playing, studying, reading or using electronic media (i.e. television, computer, mobile phone, and video games). Although it seems representative for a small portion of the total sedentary time (Olds et al., 2010), the time spent using electronic devices has been widely referred to "screen time" and consequently used as a proxy of sedentary behaviour in many epidemiological studies. In spite of the inaccuracy of this measure, several sedentary behaviour guidelines for children and adolescents recommend that the recreational screen time should not exceed 2 h per day (American Academy of Pediatrics, 2001).

Additionally, epidemiological evidence indicates that excessive screen time is a risk factor of extraordinary importance for some metabolic diseases, including overweight and obesity, considered as emerging pandemics among youths (Carson et al., 2016). Excessive screen time has also been associated with developmental and behavioural problems, developmental delay, speech disorder, learning disability, autism spectrum disorders (ASD), and attention deficit hyperactivity disorder (ADHD) (Qu et al., 2023).

To date, the efforts of Public Health experts to reduce sedentary behaviour have mostly focused on behavioural changes of individuals, targeting the promotion of physical activity, with relatively less attention to the reduction of sedentary behaviour (Keadle et al., 2017).

Even less attention has been paid to the environmental context, which can promote healthy lifestyles, thus should be considered in association to individual-level strategies that, alone, may have a limited impact on sedentary behaviours (Hinckson et al., 2017). Since over 50% of world's population lives in urban areas, the design of cities able to promote healthier lifestyles is imperative (WHO, 1986), especially across susceptible groups like children.

Neighbourhoods and living surroundings include a number of physical attributes such as green spaces, transportation systems and buildings, whose presence and configuration may affect the health of citizens by promoting both healthy and unhealthy lifestyles (McCormack et al., 2019) or by exposing them to environmental factors. For instance, sedentary lifestyles, air pollution, noise, "heat island effects", and lack of green spaces are common issues deriving from living in urbanized areas (Nieuwenhuijsen, 2021).

As early as 2003, land use, facilities, and transportation systems were clearly identified as pivotal neighbourhood-level determinants of health (Northridge et al., 2003) implicated in non-communicable diseases of the urban population. The built environment has been increasingly recognized as a key factor for planning healthier cities that promote healthier lifestyles. However, the available evidence is mostly referred to adults, while the influence of urban environment on sedentary behaviour still remain under investigated in children (Casey et al., 2014; Masoumi, 2017; Timperio et al., 2015). Adding scientific evidence on this topic is necessary to implement more effective prevention strategies that specifically address youths and their parents. Since the existing knowledge referring to the pediatric population is scarce but children are increasingly more sedentary, it is important to understand which urban elements are capable to discourage sedentary behaviours. Therefore, given the potential for the urban environment to influence healthy behaviours, we aimed at investigating the association between its key characteristics and sedentary behaviour in school-aged children from Asti, a town located in the northwest Italy. Our results may support the cultural process behind the raising of awareness of the political class on proper green policies, by supporting policy decision-makers and future interventions aimed at reducing sedentary lifestyles in youths.

2. Material and methods

2.1. Sample population and study design

In this cross-sectional study, 331 healthy children – and their parents or legal tutors – signed out an informed consent to participate (Response rate: 78%), and were recruited as consecutive sample from five Italian primary schools during morning hours in spring 2017. To ensure the enrolment of a representative sample, we first contacted the school heads of primary schools located in Asti. The schools that agreed to participate enabled the representation of all neighbourhoods. Current analyses include only those participants who provided their residential address and details about sedentary behaviour.

Ethics approval was obtained from the A.O.U. Luigi Gonzaga Ethics Committee (No. 0005540, protocol II, cat. 02, Cl. 01) as prescribed by the Declaration of Helsinki on ethical principles for medical research involving human subjects.

2.2. Sedentary behaviour

Parents reported sedentary behaviour of their children by answering the following question "Has your child engaged in and for how long the following activities in the last 7 days?".

They were asked to quantify the time spent by their children in computer/internet browsing, playing video games, reading, listening to music, watching television, and talking while sitting, either in person or by phone.

Internet browsing and video gaming included all potential devices such as computer, tablet, and mobile phones. Parents quantified the daily amount of time during which their children performed each specific activity, expressed in minutes per day. Then, we derived two sedentary behaviour outcomes: the "total sedentary time", obtained by summing up the time spent doing all the aforementioned activities, and the "screen time", resulting from the time used for computer/internet browsing, playing videogames, and watching television.

2.3. Urban environment characteristics

Asti is a town of 73,326 inhabitants, 485 per km^2, (30/06/2022 - Italian national statistical institute) located in Piedmont, 123 m above sea level, 55 km from Turin, the capital of Piedmont, the westernmost Italian Region of the Po Valley. Exposure to environmental characteristics, namely traffic, vegetation height average, vegetation height variability, vegetation biomass and land-use coverages were assessed within fixed buffers centred on children residence. Residential address were geocoded using QGIS software (MMQGis plugin) and fixed buffers (within 300-m, 500-m and 1000-m radii) were built to assess individual exposure around home. The "Base Dati Territoriale di Riferimento degli Enti piemontesi" (BDTRE) vector layer was retrieved from the regional territory geoportal (https://www.geoportale.piemonte.it/cms/), then used to assess both exposure to traffic (annual average number of vehicles) and land-use coverages (agricultural, forest and urbanized percentage) with a nominal scale of 1:10000. In particular, land-use coverages were mapped as polygons layer delineating the main land cover type updated in 2017; while traffic data were provided directly by Piemonte region as lines layer mapping for each feature the annual average number of vehicles derived by regional traffic operation center and updated in 2017.

A proximity analysis was performed to calculate exposure to traffic (i.e. average annual number of vehicles on the main closest road) in a grid of 10 $\times$ 10 m. The digital terrain model (DTM) and digital surface model (DSM) were downloaded and provided as raster layers (5-m geometric resolution) mapping the local altitude of the ground and the surfaces, respectively (Mondino et al., 2016). We used the grid layer resulting from their difference to calculate the Normalized Height Model (NHM), a map of the objects height to the ground. Then, BDTRE was used to mask NHM, resulting in a layer of Canopy Height Model (CHM) to finally assess the vegetation height variable. The normalized difference vegetation index (NDVI) was computed using a multispectral, cloud-free (cloud coverage less than 1%) summer image calibrated at surface reflectance (L2A) acquired by Copernicus Sentinel-2 mission in 2017/07/06 (https://scihub.copernicus.eu/). The resulting NDVI map (10-m geometrical resolution) reflects the vegetation vigour/status of biomass at the pixel level, and it ranges between − 1 and 1. To reduce average NDVI underestimation within the same buffer we masked out water pixels (NDVI < 0). We finally derived the following environmental variables at individual level 1) agricultural coverage (%), 2) forest coverage (%), 3) urbanized coverage (%), 4) Traffic (annual average number of vehicles), 5) average vegetation height (m), 6) vegetation height standard deviation intended as vegetation height variability (m), and 7) average NDVI. Coverages were computed by buffer and land-use maps intersection. Subsequently, for each buffer, related land-use areas were computed and their percentage within the buffer stored into attribute table. All geographic data were processed in QGIS vs. 3.16.11 and SAGA GIS vs. 8.2.1.

2.4. Other covariates

Demographic characteristics were gathered by a modified version of SIDRIA standardized questionnaire (Galassi et al., 2005). Pivotal information included age, sex, residential address, sedentary behaviour and parental education level. Parental education was assessed by asking the highest level of schooling or post-school qualification of each parent, categorized into low (i.e. up to lower secondary level) and high (i.e. from upper secondary level and beyond). In the present study, we used maternal education as proxy of socio-economic status (Cárdenas-Fuentes et al., 2021). Additionally, weight, height, and Body Mass Index (BMI) were measured as described elsewhere (Squillacioti et al., 2019).

2.5. Statistical analyses

The main analysis included 306 participants with a complete exposure assessment. Ten mothers did not provide their educational level, thus the resulting variable had 3.3% data missing. Similarly, 11.4% of children did not provide data on their sedentary behaviour. Continuous variables are presented as mean ± Standard Deviation (SD) or median ± Interquartile range (IQR), for skewed distributions. Categorical variables are presented as relative and absolute frequencies (number of cases and percentages). Comparisons between groups were performed by non-parametric Mann-Whitney test, for continuous variables, and by χ^2, for categorical variables. The relationships between continuous variables were tested by simple correlation analysis (Pearson's r). To explore the association between the environmental characteristics and sedentary behaviour, we built univariate regression models, using average daily minutes of sedentary behaviour/screen time as outcomes, and each of the neighbourhood characteristics as exposure and other available covariates (age, sex, BMI, maternal education level), one at a time. Due to the high multicollinearity among the environmental variables, we could not build a reliable multivariable regression model to assess their overall association with sedentary behaviours. Instead, we combined traffic, vegetation height average, vegetation height variability, NDVI, agricultural/forest/urbanized coverages into uncorrelated components by performing a Principal Component Analysis (PCA). First, we tested the sampling adequacy by inspecting the correlation matrix and the Kaiser-Meyer-Olkin (KMO) value to determine whether the items correlated sufficiently. KMO indicates whether the other variables in the dataset can explain the correlations between variables and ranges between 0 and 1, with small values (< 0.50) indicating that a low-dimensional representation of the data is not possible (Kaiser et al., 1974; Mooi et al., 2018). Since KMO was 0.67, we performed the PCA and then applied different methods to decide the optimal number of components to be selected. We retained the first two components that explained 82% of the whole variance. We did not applied any rotation methods for the interpretation of the components loadings. We tested the goodness of fit by the examination of the residuals in the reproduced correlation matrix. The first principal component (PC1) had a higher positive correlation with vegetation vigour (NDVI), agricultural and forest coverages while the second (PC2) with urbanized coverage (Fig. S1, Table S1). We used multivariable mixed regression models to estimate the unadjusted associations between the combined environmental characteristics (PC1 and PC2) and sedentary behaviour outcomes. Sampling location (i.e. schools) was used as random intercept accounting for hierarchical data structure. In the final multivariable mixed model, we included age, sex and BMI as potential confounders. We also tested the interaction between exposure and maternal education level. We used the same strategy to build multivariable mixed logistic regression models to analyse the association between neighbourhood characteristics and screen time categorized in two categories: less and more than two hours/day according to the American Academy of Pediatrics (American Academy of Pediatrics, 2001). The goodness of fit was assessed by checking the assumptions underlying each model. As sensitivity analysis, we performed PCA using environmental variables assessed in buffers with different sizes (i.e. 300-m and 1000-m radii), while in the main analysis we used 500-m buffer. This specific choice was based on previous literature (Tucker et al., 2009; Larsen et al., 2009) also reporting that children are limited to the surrounding area within which they can walk or cycle, so a 500-m buffer can be equivalent to around 10-minute walking distance for a 12-year-old child, accommodating differences between boys and girls (Mitchell et al., 2016). As additional analysis, we tested the association between the most influent variable alone (NDVI) instead of using the combined exposure assessed by PCA. Statistical significance was set at $p < 0.05$ and 95% Confidence Intervals were calculated (95% CI). All statistical analyses were performed in Stata 17.0 (StataCorp. 2021. Stata Statistical Software: Release 17. College Station, TX: StataCorp LLC) and R (R Core Team. 2022. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/).

3. Results

3.1. Population characteristics and setting

Overall, 306 healthy children aged between eight and eleven years were included in the present study. Demographics and other relevant data, namely total sedentary time, screen time and environmental characteristics, are reported in Table 1. Fig. 1 shows the NDVI and the land-use coverages over the study area.

We observed a significantly higher amount of total sedentary time in boys than girls, with an average of daily minutes equal to 296 ± 166 and 259 ± 149, respectively ($p = 0.03$). Consistently, out of 271 children whose outcomes data were available, 105 (68.8%) spent more than 2 h/day in screen-based activities and 68 of them were boys (64.8%, $p = 0.001$). No differences were observed among children whose mothers reported different education levels, nor in total sedentary time ($p = 0.77$) neither in screen time ($p = 0.34$). Both sedentary outcomes were higher in older children, showing a positive yet weak correlation with age (total sedentary time: $r = 0.14$, $p = 0.02$; screen time: $r = 0.16$, $p = 0.008$). Only the screen time was positively correlated with BMI ($r = 0.15$, $p = 0.01$).

Table 1
Sample population characteristics.

Variable:	
Sex, n (% of male)	158 (51.6)
Mother education level†:	
Upper secondary and beyond, n (%)	174 (58.8)
Age, years	9.1 (1.0)
BMI, kg/m^2	19.0 (3.5)
Total sedentary time, min/day*	278 (159)
Screen time, min/day*	131 (87)
Environmental features:	
Traffic, annual average number of vehicles/day	8664 (4096)
Vegetation height, meters within 500-m buffer	5.1 (1.6)
Vegetation height variability, meters within 500-m buffer	3.9 (0.8)
NDVI within 500-m buffer	0.36 (0.17)
Land coverage (%) within 500-m buffer:	
Agricultural* *	6 (0 – 20)
Forest* *	0 (0 – 1)
Urbanized* *	60 (35 – 84)

†3.2% data missing; * 11.4% data missing; ** median (IQR).
Continuous variables are reported as mean (SD) unless differently indicated.

3.2. Association between environmental characteristics and sedentary behaviours

Children living in less urbanized and highly vegetated areas reported twelve minutes less of total sedentary time per day, independently of age, sex and BMI (β: −12, 95% CI from −22 to −2; p = 0.02), as shown by Table 2. The total sedentary time increased by 21 min/day for each additional year of age (95% CI from 1 to 41; p = 0.04). On average, girls reported 42 min/day less of total sedentary time as compared to boys (β: −42, 95% CI from −79 to −6; p = 0.02). The likelihood of a daily screen time exceeding the recommended guidelines of 2 h per day was lower in children living in less urbanized and greener areas (OR: 0.86 95% CI 0.74–1, 00; p = 0.056), taking into account the potential confounding effect by age, sex and BMI. Girls were clearly less likely engaging in screen-based activities for more than 2 h/day as compared to boys (OR: 0.37 95% CI from 0.22 to 0.6; p < 0.0001).

3.3. Effect modification by maternal education level

We stratified the main analysis (reported in Table 2) according to the

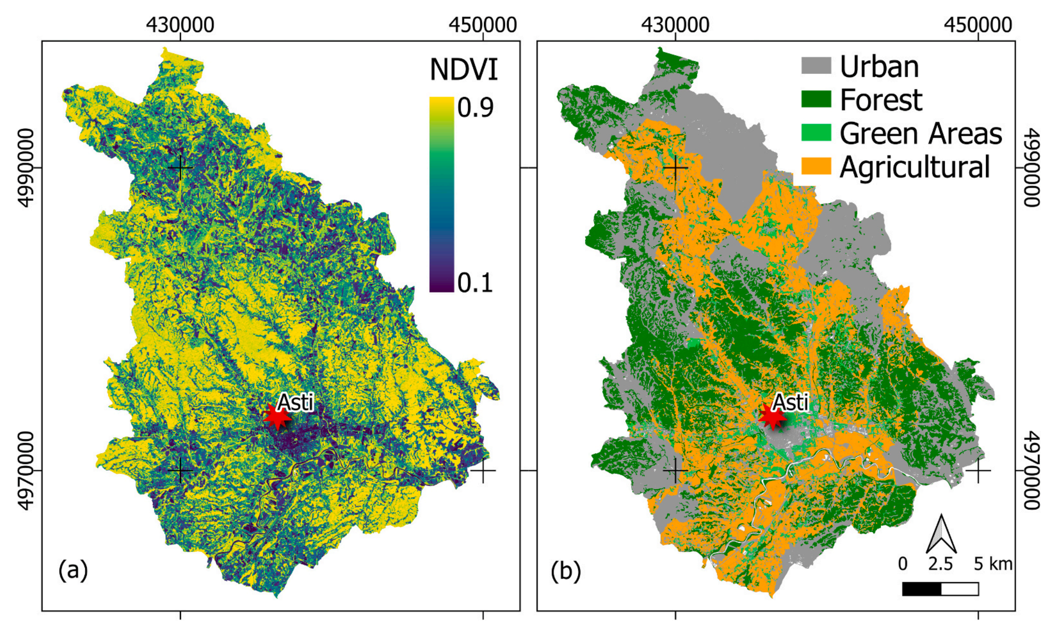

Fig. 1. (a) Normalized Difference Vegetation Index (NDVI) map and (b) land-use coverages (nominal scale 1:10000) over the study area. Footnote: NDVI was derived by Sentinel-2 L2A multispectral image acquired in July 2017 and land-use coverages were derived by institutional data (i.e.,"Base Dati Territoriale di Riferimento degli Enti piemontesi" (BDTRE)), updated in 2017.

Table 2
Relationship between environmental characteristics and sedentary behaviours, assessed by total sedentary time (minutes/die) and the likelihood of exceeding the recommended cut-off of two-hour screen time per day (Whiting et al., 2021).

Covariates	Sedentary time[a] Coeff. (95% C.I.)	p	Sedentary time[b] Coeff. (95%C.I.)	p	Screen time[c] ORs (95% C.I.)	p	Screen time[d] ORs (95% C.I.)	p
Less urbanized	-12 (−23, −2)	0.02	-12 (−22, −2)	0.02	0.86 (0.75, 1.00)	0.06	0.86 (0.74, 1.00)	0.056
More urbanized	1.6 (−10, 13)	0.79	0.9 (−11, 13)	0.89	1.1(0.92, 1.29)	0.30	1.1 (0.90, 1.27)	0.801
Age (years)			21 (1, 41)	0.04			1.2 (0.90, 1.58)	0.221
Sex, female vs male			-42 (−79, −6)	0.02			0.37 (0.22, 0.64)	< 0.0001
BMI as kg/m^2			0.9 (−5, 7)	0.77			1.1 (0.97, 1.14)	0.210

All estimates are derived from multivariable mixed regression models with school as random intercept (n = 271). Less and more urbanized area variables are derived from Principal Component Analysis combining traffic, vegetation height average, vegetation height variability, Normalized Difference Vegetation Index, agricultural/forest/urbanized coverages calculated at individual level within 500-m-radius buffer. Less urbanized area are highly and positively correlated with vegetation vigour (NDVI), agricultural and forest coverages while more urbanized area with urbanized coverage.
[a] Unadjusted beta estimates derived from a linear mixed regression model
[b] Adjusted beta estimates derived from a multivariable linear mixed regression model including age, sex and BMI as covariates
[c] Unadjusted ORs derived from a multivariable logistic mixed regression model
[d] Adjusted ORs derived from a multivariable logistic mixed regression model including age, sex and BMI as covariates

maternal education groups, observing stronger associations for children whose mothers reported higher education levels. As reported by Table 3, maternal education acts as an effect modifier in the association between neighbourhood characteristics and sedentary behaviour. However, this result was only observed for daily screen time (OR: 0.49 95% CI from 0.34 to 0.71; $p < 0.0001$) and not for the total amount of time spent being sedentary (Table 3). Additionally, children whose mothers reported a lower education level were more likely to exceed 2 h/day watching television, browsing internet, using computer and/or playing videogames (+31%, 95% CI from 1.0 to 1.7; $p = 0.04$).

3.4. Sensitivity analyses

The association between both sedentary behaviour outcomes and neighbourhood characteristics was tested further by using combined exposure variables assessed within buffers with lower (300 m) and higher (1000 m) radius size, respectively. Following the same methodology of the main analysis, we combined seven environmental variables by PCA and used the first two components in additional regression models (Table S2), yielding similar results. The total sedentary time was lower in children living in less urbanized and greener areas, also when assessing the exposure variables within 300-m and 1000-m radius sizes (β: −11 min/day, 95% CI from −21 to −1 and β: −11 min/day, 95% CI from −20 to −3, respectively). Yet again, girls were less sedentary than boys (−43 min/day, 95% CI from −80 to −7, within 300-m radius and −42 min/day, 95% CI from −78 to −6, within 1000-m radius). Compared to the main analysis, the influence of age was attenuated (18 min/day, 95% CI from −2 to 38, within 300-m buffer and 19 min/day, 95% CI from −1 to 39 within 1000 m). The likelihood of observing the daily screen time exceeding 2 h/day was the same across all buffers.

3.5. Additional analyses

The NDVI variable showed the highest positive correlation coefficient among all environmental variables loaded on the first component herein referred as "less urbanized" variable (300-m: 0.53; 500-m: 0.53; 1000-m: 0.47, Table S1). The less urbanized component showed, in turn, an association with both sedentary behaviours. Therefore, we performed additional analyses to investigate the association between sedentary behaviours and NDVI alone. Fig. 2 and Fig. 3 show that as the buffer dimension increased both sedentary outcomes became more significantly associated with NDVI. In the adjusted models, the total sedentary time was significantly lower for an interquartile range increase in NDVI-1000 (β: −19 min/day, 95% CI from −34 to −4) but not in case of NDVI-300 and NDVI-500. Similarly, the likelihood of an excess of screen time was significantly lower for each NDVI-500 and NDVI-1000 interquartile range increase ($OR_{500\ m}$: 0.67, 95% CI from 0.45 to 0.99 and $OR_{1000\ m}$: 0.78, 95% CI from 0.62 to 0.98, respectively).

Table 3
Association between environmental characteristics and sedentary behaviours across different maternal education levels (i.e. interaction term).

Covariates	Sedentary time[a] Coeff. (95% C.I.)	p	Screen time[b] ORs (95% C.I.)	p
Less urbanized	-3 (−20, 15)	0.79	1.31 (1.0, 1.70)	0.04
More urbanized	-0.7 (−13, 11)	0.91	1.03 (0.86, 1.23)	0.79
Less urbanized * maternal education level	-15 (−36, 8)	0.20	0.49 (0.34, 0.71)	< 0.0001

All estimates are derived from multivariable mixed regression models with school as random intercept and an interaction term accounting for variations across maternal education groups (i.e. upper secondary and beyond versus lower secondary level). Less and more urbanized area variables are derived from Principal Component Analysis combining traffic, vegetation height average, vegetation height variability, Normalized Difference Vegetation Index, agricultural/forest/urbanized coverages calculated at individual level within 500-m-radius buffer. Less urbanized area are highly and positively correlated with vegetation vigour (NDVI), agricultural and forest coverages while more urbanized area with urbanized coverage.
[a] Adjusted beta estimates derived from a multivariable linear mixed regression model including age, sex and BMI as covariates
[b] Adjusted ORs derived from a multivariable logistic mixed regression model including age, sex and BMI as covariates

4. Discussion

Our study highlighted that living in less urbanized and more vegetated areas is associated with lower levels of sedentary behaviour in school-aged children. We observed about fifteen minutes/day less of sedentary time in children living in less urbanized areas as compared to the others. Similarly, the daily screen time was lower by 14%. We additionally found that higher exposure to green spaces (assessed by NDVI) was inversely associated with both total sedentary time and the likelihood of exceeding the recommended screen time. Finally, we detected stronger associations in children whose mothers reported higher education levels, but only in relation to excessive screen time and not for the total sedentary time.

Our findings underline the role of the environment surrounding the residence on sedentary behaviour. This is of considerable importance for the attainment of more effective prevention strategies addressing sedentary behaviour in children. To date, for counteracting childhood obesity, public health actions have often targeted changes at individual level by promoting physical activity or discouraging sedentary behaviours. Regrettably, despite the considerable efforts of the last decades, young people continue to be considerably sedentary (Musić Milanović et al., 2021). Our results suggest that environmental characteristics may influence lifestyles, which in turn, are able to shape children's health. Therefore, more effective public health strategies should target both healthier individual behaviours and health-promoting environments to encourage active lifestyles.

Our findings partly overlap existing literature, although previous authors mostly referred to green spaces exposure and less evidence is available for combined environmental attributes. Previous evidence from a recent multicohort study indicated that living in more vegetated and facility-dense areas was associated with less sedentary behaviours in school-aged children (n = 1581) (Fernández-Barrés et al., 2022). Sedentary and screen time were inversely associated with the presence of natural spaces, including green and blue spaces. In line with our findings, an IQR-increase of NDVI, within 100-m buffers, was associated with 23 min/day less of sedentary time. Conversely, a previous

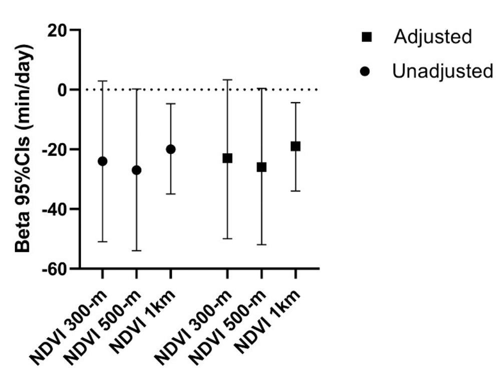

Fig. 2. Association between the total sedentary time (minutes/day) and green spaces assessed by Normalized Difference Vegetation index (NDVI) across different residential buffers. Footnote: Beta estimates are derived from multivariable linear mixed regression models with school as random intercept. Adjusted by age, sex and BMI (n = 271).

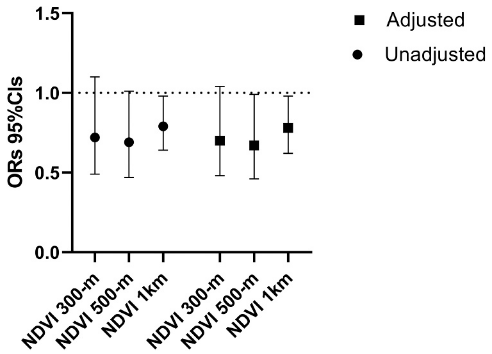

Fig. 3. The likelihood of exceeding 2 h/day of screen time in children exposed to green spaces assessed by Normalized Difference Vegetation index (NDVI) across different residential buffers. Footnote: Odds Ratios are derived from multivariable logistic mixed regression models with school as random intercept. Adjusted by age, sex and BMI (n = 271).

cross-sectional study did not find any significant association between the perceived neighbourhood characteristics and sedentary screen time in 423 Brazilian adolescents (11–17 years old) (Parajára et al., 2021). A possible explanation for diverging findings may lie in the different age groups considered, with younger children in our study.

Dr Bringolf-Isler and colleagues did not find any relationship between neighbourhood characteristics and accelerometer-based sedentary behaviour in 1742 Swiss youths (4–17 years) (Bringolf-Isler et al., 2014). Only the exposure to forest coverage was significantly associated with lower daily sedentary time. We did find similar results but in relation to a combined PCA-derived exposure. This latter was highly correlated with forest coverage (r = 0.48). We observed the same result by analysing forest coverage alone, finding significantly lower sedentary time in 1000-m buffer (−118 min/day 95% CI from −226 to −10) and a tendency for smaller radii (data not shown). In a longitudinal study was observed that living in greener neighbourhoods is associated with a reduction in weekend television viewing in pre-schooler Australian boys, but not in girls (Sanders et al., 2015). We did not analyse television watching independently of other screen-based entertainments and in our analyses, girls were generally less engaged in screen-based activities as compared to boys. In a cross-sectional study on 3178 Spanish children (9–12 years old), the authors found that exposure to green spaces (i.e. NDVI) was associated with 11–15% lower likelihood of observing excessive screen time (Dadvand et al., 2014). We observed same results with a stronger association, varying from 11% to 34% depending on the buffer size (500 and 1000 m, respectively). The partial discrepancy might be due to differences in the set of confounding variables used to adjust the models, smaller in our study thus possibly not accounting for part of the residual confounding. A small but significant inverse association between green space availability and sedentary time was observed in Danish adults (n = 48,192) (Storgaard et al., 2013). The authors also reported that the total sedentary time was more likely to exceed 3 h/day in people from less vegetated neighbourhoods. We found similar results in children from our study. The observed associations between environmental characteristics and sedentary behaviours seemed to be influenced by the exposure assessment scale (e.g. buffer size), and were slightly stronger in larger buffers. Additionally, some individual characteristics showed a slightly weaker association with sedentary behaviour among different buffers. As previously reported (Bernaards et al., 2016), age was positively associated with sedentary behaviour in the main analysis. However, we did not observe the same result for exposure variables assessed within 300-m and 1000-m buffers, although the same trend was confirmed. Although other studies showed mixed results (Bernaards et al., 2016), our findings suggested that girls were less sedentary as compared to boys, especially in terms of screen time. This might be due to the documented greater propensity of boys towards the use of electronic devices (Dahlgren et al., 2021).

Finally, we observed an effect modification by maternal education levels, with strong associations in children whose mothers were highly educated. This result is in contrast with (Bringolf-Isler et al., 2014), but overlaps the findings reported by (Musić Milanović et al., 2021; Dadvand et al., 2014; Platat et al., 2006; Leech et al., 2014), who hypothesize that watching television may be a more affordable entertainment for children from families with limited economic resources. Other potential explanations underlying the observed associations refer to the indirect impact that the environment can have on lifestyles. Less urbanized environments may have higher availability of green spaces, potentially favouring an active lifestyle in the younger population. Furthermore, they can be perceived as safer in case of less street connectivity and barriers. Noteworthy, the combined action of environmental and individual-level characteristics cannot be ignored. In fact, the education level can influence even the positive effect of a health-supportive environment.

Our study faced some limitations. First, the cross-sectional design did not allow us to exclude the possibility of a reverse causality, although is unlikely that sedentary children moved to less vegetated or to more urbanized areas. At this concern, we also accounted for the effect modification played by maternal education. Second, parent-reported measurements of sedentary behaviours are prone to information bias, which may have produced an underestimation of time spent being sedentary. Third, data on other influencing factors such as crime rate, noise and air pollution were not available; therefore, we cannot consider their contribution to the explored associations. We also acknowledge that the set of variables included in the PCA showed moderate adequacy for data dimension reduction (KMO = 0.67). However, KMO values above 0.50 indicate that items are sufficiently correlated formally enabling a PCA. In addition, we optimized our analysis by maximizing the overall KMO value thanks to the exclusion of other environmental variables with specific KMO below 0.50 (data not shown). Noteworthy, the PCA allowed us to analyse several aspects of the built environment simultaneously, overcoming the collinearity among variables that we could not face using multivariable regression approaches.

Finally, the generalizability of our findings could be affected by a relatively small sample size, although the sampling campaign has involved primary schools located in each neighbourhood of the town. Additionally, our study was implemented in a restricted study area, not including such a big urban centre, therefore its external validity could be limited to similar settings (e.g. towns) and not to bigger cities with larger populations as previously reported evidence (Andrusaityte et al., 2020; Oakley et al., 2021).

As main strengths, we objectively assessed individual exposure to environmental characteristics by using a geographical information system software, official maps and remote sensing-derived indexes. We analysed the overall effect of the built environment by combining several environmental attributes. Lastly, we provided data on an emerging public health issue, which still deserve further investigation in children. This might support future prevention strategies against sedentary lifestyles, especially in youths. Indeed, make people, especially parents and city planners, aware of the importance of the environment is crucial to improve the effectiveness of health-supporting interventions. As practical implications, this might support the redevelopment of urbanised areas from the perspective of the transition to health-promoting cities.

While small, a daily reduction of time spent being sedentary or using screens is recommended to reduce overweight, obesity and support general health. All these steps are part of a complex cultural process that requires many resources and people, however it might be partly achieved by disseminating scientific results able to build awareness.

5. Conclusion

This cross-sectional study suggests that more vegetated and less urbanized neighbourhoods may be associated with a reduction in sedentary behaviours in children. Our findings reinforce the importance of the quality and quantity of the environmental characteristics in shaping children behaviours and health. This might support public health awareness from several point of views. Decision makers should consider the impact that a proper city design could have on dwellers and act accordingly. Public Health professionals and future preventive strategies should target not only individual but also environmental-level attributes. Parents should consider time and cost-effective alternatives to screen-based activities to ensure healthier behaviours to their children, like engaging in outdoors physical activity. Highly sustainable urban environments that can improve lifestyles of entire communities should promote greening actions according to a "One Health" approach, also in consideration of the climate change crisis and the general raising of global temperatures (Hondula et al., 2015; Orusa et al., 2023).

Future research should address important gaps mainly referred to the use of combined exposure and outcome assessments including the combination of both perceived and objectively measured attributes.

CRediT authorship contribution statement

RB conceived and planned the research project. GS and VB carried out the biological analysis. SDP and ECBM performed the spatial analysis. GS and SDP performed the statistical analysis. RB, VB, and ECBM contributed to the interpretation of the results. GS and SDP took the lead in writing the manuscript. All authors provided critical feedback and helped shape the research, analysis and manuscript.

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. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.ufug.2023.128081.

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