

# A multi-level analysis of the association between built environmental factors and childhood overweight in the city of Hannover, Germany

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## Research

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# Abstract

**Introduction** In recent years, built environmental characteristics have been linked to childhood overweight, but the results remain inconsistent across studies. The present study examines associations between several built environmental features and body weight status (BMI) among a large sample of preschool children in the city of Hannover, Germany.

**Methods** Walkability (index), green space availability and playground availability related to preschool children's home environments was measured using the Geographic Information Systems (GIS) and data from OpenstreetMap (OSM). These built environment characteristics were linked to the data from the 2010-2014 school entry examinations in the Hannover city (n = 22,678), and analysed using multi-level linear regression models to examine associations between the built environment features and the BMI percentiles of these children (4-8 years old). Several socio-demographic factors were included in the analysis, including migration background, family structure and parental educational level.

**Results** No significant associations of built environmental factors on children's BMI were detected, but the effect between green space availability and BMI was modified by the parental educational level. In children with lower compared to higher educated parents, a higher spatial availability of greenspace was significantly associated with reduced body weight.

**Conclusion** The finding of no overall association between the built environment and body weight could be due to misclassification in the presence of suboptimal variable reliability. However, the environmental effects may also be restricted to the less privileged children, which may indicate that built environmental features might have the potential to reduce health inequalities. Future research should continue to monitor the disparities in diverse built environment features and how these are related to children's health.

## 1 Introduction

Childhood overweight and obesity have become a global epidemic in the last decades (1). In Germany, according to the German Health Interview and Examination Surveys for Children and Adolescents (KiGGS Wave 2, 2014–2017), 15.4% of children aged 3 to 17 years were overweight and 5.9% were obese (2). Though current trend analysis has shown that prevalence rates of overweight and obesity in children has reached stagnation (3, 4), it is important to understand their determinants in order to control the epidemic.

In line with the fact that overweight and obesity are multifactorial in origin, the potential impact of the built environment on children's health has gained increasing attention (5, 6). Among others, the concept of walkability is applied to explore the ways in which built environment characteristics fail to support walking and consequently influences on body weight. Duncan et al. (7) found that neighbourhood walkability could significantly impact on children's physical activity levels. According to Carrol-Scott et al. (8), children living in walkable neighbourhoods with adequate spatial measurements have a lower risk of obesity because these environments promote physical activity behaviours. Kowaleski-Jones et al. (9) have shown that children who live in more walkable neighbourhoods have a lower risk of childhood obesity.

In order to operationalize walkability, two area-based measures have been used. The first type is the Walkability Index, which is designed to reflect various built environment elements by capturing the multiple attributes of a place. Frank et al. published it in 2005, and proposed to measure intersection density, net residential density, retail floor-area ratios, and entropy scores within the index (10). Based on the walkability index, a Moveability Index was published by Buck et al. in 2011, which further explores the built environment by using the kernel density estimation method. This method is for smoothing point patterns into a generalized surface by applying a kernel function with specified radius to each point in the data set (11). The second type is a group of measures which emphasize the distribution of potential destinations. These measures examine that a place is more walkable if more amenities are available within certain area which could better represent from the pedestrian choice. However, this emphasis can be double-edged, as it may be failing to differentiate between amenities and overlooking various walking purpose (12, 13). Here in our study, we decided to choose the former one which is building a walkability index based on data availability.

Other than the walkability itself, features which promote an active lifestyle like greenspaces, parks, and playgrounds, have also been analysed in most current studies (14, 15). Liu et al. found that higher availability of greenspace was associated with a decreased risk of overweight, but only among those in areas with a greater population density (16). Multiple studies indicated that parks within children's living environment were neighbourhood predictors of childhood obesity (17–19). However, these relationships were highly dependent on the socioeconomic status (SES) of the child's parents or neighbourhood (20). There are likely to be many mediators of the relationship between SES and overweight including barriers associated with willingness, time and opportunities (e.g. within a local neighbourhood) to eat a healthy diet or take part in physical activity (21, 22).

A detailed knowledge of the spatial patterns and influencing factors on area-level is required to explore association between the built environment and childhood overweight. Whereas most studies concerning built environmental factors have been mainly located in the United

states (21), there is still a gap in European and German research about the built environment impact (23, 24). However, findings from different cultural and environmental backgrounds can add to the existing knowledge. For that reason, this study aims to explore associations between built environment and overweight among pre-school children in a German setting. With a sample of pre-school children from the Hannover city area, this study applied a multi-level linear modelling to estimate how the weight status of children may vary based on built environment features.

## 2 Methods

### 2.1. Study population and study area

This study included pre-school children in the city of Hannover, the capital of the federal state Lower Saxony in Germany with about half a million inhabitants. The study population ( $n = 22,678$ ) comprised children at the age from 4 to 8 years old (48.5% girls) registered for school entry within a five-year period from 2010 to 2014. The data collected as part of the school entrance examination provide information about age, sex, height and weight. It also records whether the child has developmental disorders (linguistic, gross or fine motor, psychological, emotional). Socio-demographic data were collected from the children's parents using a German-language questionnaire. This information was voluntary. All data were rendered anonymous. The school entrance examination was run by the standardized examination programme "SOPHIA" ("Sozialpädiatrisches Programm Hannover – Jugendärztliche Aufgaben"- <http://www.sophia-online.org>) that include a documentation and evaluation procedure focused on prerequisites relevant for future school success. The available data were processed and aggregated on the level of 51 district areas comprising the total number of the city district of Hannover. The area information was based on the administrative boundary provided by Statistics office of State Capital Hannover ("Statistikstelle der Landeshauptstadt Hannover").

### 2.2. Dependent variable

Weight and height were objectively measured by the medical staff. The BMI (body mass index) percentile was the dependent variable in the present analyses. Height, weight, sex, and age were used to calculate BMI percentiles using the Kromeyer-Hauschild reference (25). This reference is the national weight status reference for German children based on 17 pooled regional surveys conducted in Germany between 1985 and 1999 that used the sex- and age-specific 90th and 97th percentiles as cut-offs. The weight status was defined as the following categories: normal weight (BMI < 90th percentile), pre-obesity (90th percentile  $\leq$  BMI  $\leq$  97th percentile) and obesity (BMI > 97th percentile). Being overweight in this study refers to the status including both pre-obesity and obesity (25).

### 2.3. Individual-level independent factors.

The children's individual characteristics were recorded during the school entrance examination. All the parents answered a series of questions asked by the medical assistant. By asking parents to answer their self-defined home country, the children's ethnicity was categorized into German children and children with migration background. Parental education status was in line with the International Standard Classification of Education (ISCED) (26). An educational class index consisting of three educational classes for parents (lower, middle and higher) was created and evaluated by a points system and added together using two indicators (primary qualification and professional education). The family structure was coded as nuclear family (children living with both parents together), or other (a single-parent family/a blended family). The child's number of siblings was coded into two categories (one or no siblings, and two or more siblings). The birth weight was provided by the interviewed parents and categorized into three groups (High: > 4000 grams, Normal: 2500–4000 grams, Low: < 2500 grams). To consider the effect of childcare service usage, we obtained the length of child day care (Nurseries, kindergartens and other day care facility forms) participation, which was coded as 3 years or more or less than 3 years.

### 2.4. Area-level socio-demographic factors

We considered two aggregated variables (percentage of people with migration background and unemployment rates) on the level of the administrative districts describing the socio-demographic characteristics. Firstly, the proportion of residents with migration background of the area was considered. Different culture, genetic and physiological factors, ethnic difference might boost up unhealthy weight gain (27). At a macro scale, migrants tend to be geographically concentrated which provide a supportive environment for the retention of traditional diets and lifestyles (28), meaning that an area with a higher proportion of migrants might provide a different obesogenic environment. Second, unemployment rate of the area is expected to be associated with overweight prevalence through a modifying influence of household income (29). These two area-level variables were provided by the Statistics office of State Capital Hannover which annually publishes structural data of the city districts. Here, the years from 2010 to 2014 were selected to match the school entrance examination data.

### 2.5. Area-level Built environmental variables

The built environment variables were assessed using OpenStreetMap (OSM). In this study, the OSM data were collected at OSM Geofabrik (<http://www.geofabrik.de/>). Geofabrik provides pre-processed OSM data for free download by continent and country in shapefile format.

Walkability is measured in this study as an indicator of the neighbourhood's capacity to support physical activity. According to the walkability index, it is widely used in the previous literature to assess walkability (10). All assessments of the built environment features and spatial analyses were conducted within an open source GIS software program – QGIS 3.4.5 LTR (<https://www.qgis.org/>). The following components of the walkability index were assessed: intersection density, residential density and land use mix. Each component was measured in 51 district areas according to Frank et al. (10) and Dobesova et al. (30) and modified to fit the data in Hannover city. The intersection density was derived from the street network as an indicator of street connectivity and was calculated as the ratio between the numbers of true intersections (three or more legs) to the land area. Residential density was measured using household data published by the statistics bureau of Hannover. Land use mix was estimated by an entropy index indicating the evenness of the distribution of different land uses (10). We applied entropy measures developed by Lawrence Frank and colleagues with a five-category mix: residential, retail, entertainment, office and institutional (10). The walkability index was obtained by adding the partial scores of the mean of each mentioned indicator after converting them into z-scores in the following expression:

$$\text{Walkability} = [(z\text{-intersection density}) + (z\text{-land use mix}) + (z\text{-residential density})]$$

The original walkability index further includes a floor ratio to estimate the retail area (10, 30) which thought to facilitate pedestrian access. Yet, similar to several European walkability studies (23, 31), the retail floor ratio was left out in this study because in a European context, it may overestimate the actual retail areas, in contrast to land use patterns in the US. European land use is shaped by mixed uses within one building, which are either classified as retail or non-retail, and thereby might lead to biased data (23).

In addition to walkability characteristics, we included greenspace and playgrounds as built environment determinants. Because of their health benefits and strong association to physical activity particularly of children and adolescents, the spatial availability of greenspace and playgrounds has been a focus of planning and research (16, 32). In this study, they were enumerated using GIS shapefiles from OSM data and double-checked using resources provided by the municipalities within the study area. The greenspace here included multiple OSM land use categories, which includes areas of open space for recreation, typically having a semi-natural state (e.g. including grassy areas, trees, and bushes). We then calculated the percentage of area within or intersecting each census block group as additional built environment variables.

## 2.6. Statistical analyses

Initially, descriptive statistics were calculated for the dependent variable and all individual-level and area-level covariates, including the distribution of children across groups. We conducted a multi-level linear regression analysis. First, an unconditional model with no predictors was estimated to assess intra-class correlation in BMI percentiles. Then all individual-level characteristics were added as fixed effects (Model 1). To examine the unique contribution of built environmental factors, three built environment variables (walkability index, availability of playgrounds and availability of greenspace) were added to the previous model separately along with area-level characteristics (Model 2 to 4). In order to assess whether these associations were moderated by SES, we assessed the interaction effect of parental education level. Model 5 represents the main effect models followed by adding the corresponding interaction term between parental educational level with each built environment factor (Model 5a: parental educational level\*walkability index, Model 5b: parental educational level\* playgrounds availability, Model 5c: parental educational level\*greenspace availability). To better display and explain the interaction term discovered, the interaction effect using the predicted values from Model 5 was plotted in a scatter figure. Significance level was defined as  $\alpha = 0.05$ . Moreover, we compared the model fit throughout the model-building process by examining the changes in the Akaike information criterion (AIC) which shows the preferred model having the lowest value (33). All analyses were performed using IBM SPSS Statistics for Windows software, version 24.0 (IBM Corp., Armonk, N.Y., USA).

## 3 Results

The sample used in this analysis included a total of 22,678 children in 51 administrative areas. Of the participants, 51.5% were boys and 48.5% were girls. The overall prevalence of overweight (pre-obesity and obesity) was 9.7%, while the obesity prevalence was 4.1%. Half of the children had a migration background (49.4%). For the family structure, 2.8% of the children came from a single-parent or blended family, and 30.5% of them had two or more siblings (Table 1).

Table 1

Characteristics of the study population and the area (Data from school entrance examination, city of Hannover, 2010–2014, n = 22,678)

		N (%)	Mean	Standard Deviation	Minimum	Maximum
Dependent variables						
Body mass index percentile			50.09	27.97	0.00	99.8
	Overweight*	9.7%				
	Obese	4.1%				
Individual level factors						
Sex	Boys	51.5%				
	Girls	48.5%				
Migration background	Yes	49.4%				
	No	50.6%				
Family structure	Single parent/ Blended family	2.8%				
	Nuclear family	97.2%				
Siblings	≥ 2 siblings	30.5%				
	< 2 siblings	69.5%				
Child day care participation	< 3 years	18.7%				
	≥ 3 years	81.3%				
Parental educational level	Higher	36.9%				
	Middle	26.2%				
	Lower	36.9%				
Birth weight	High (> 4000 grams)	10.6%				
	Normal (2500 grams – 4000 grams)	80.1%				
	Low (< 2500 grams)	6.6%				
Area level factors						
Unemployment rate (%)			8.7	3.2	1.9	16.1
Proportion of residents with migration background in the area (%)			25.6	9.5	6.5	50.3
Built environment variables (Area level)						
Walkability index			0.52	1.79	-3.25	6.41
Playground availability (Area of playgrounds per km <sup>2</sup> )			10.61 × 10 <sup>-3</sup>	9.21	0.15 × 10 <sup>-3</sup>	50.09 × 10 <sup>-3</sup>
Greenspace availability (Percentage of area with greenspace)			8.86	11.50	0.51	73.09
* Overweight refers to the status including both pre-obesity and obesity						

The spatial distribution of childhood overweight in 51 administrative areas in the city of Hannover is shown in Fig. 1. A distinct pattern could be identified, with the highest share of overweight in the surrounding areas of the city, showing a proportion of more than 14% overweight. In contrast, the inner areas of the city (Zoo, Bult, Südstadt) are characterized by low numbers of overweight with less than 5.5%. The distribution of overweight prevalence and the three built environment variables are presented below (Fig. 1).

Table 2 presents the results of the multiple regression analysis. Across all models, children's migration background, number of siblings, birth weight and parental educational level were significantly associated with the children's weight status. The area-level information (unemployment rate and percentage of residence with migration background) revealed no significant relation with the body weight. Overall, no significant associations were found between each environmental factor and children's obesity.

Table 2

Estimates from two-level linear modelling predicting pre-school children's BMI percentiles (Data from school entrance examination, city of Hannover, 2010–2014, n = 22,678)

		Model 1		Model 2		Model 3		Model 4	
		b (SE)	95% CI						
Individual-level independent factors									
Girls (Ref. Boys)		2.38 (0.4)*	(1.6,3.16)	2.38 (0.4)*	(1.6,3.16)	2.39 (0.4)*	(1.61,3.16)	2.32 (0.42)*	(1.49,3.15)
Children with migration background (Ref. German children)		5.07 (0.43)*	(4.23,5.92)	4.92 (0.43)*	(4.07,5.77)	4.91 (0.43)*	(4.06,5.76)	4.94 (0.46)*	(4.03,5.86)
Single parent/Blended family (Ref. Nuclear family)		2.6 (1.2)*	(0.25,4.95)	2.54 (1.2)*	(0.18,4.89)	2.54 (1.2)*	(0.18,4.89)	2 (1.28)	(-0.5,4.51)
Two or more siblings (Ref. one or none siblings)		1.69 (0.45)*	(0.8,2.58)	1.68 (0.45)*	(0.79,2.57)	1.67 (0.45)*	(0.78,2.56)	1.72 (0.48)*	(0.77,2.67)
Childcare less than 3 years (Ref. 3 year or longer)		-0.73 (0.55)	(-1.8,0.35)	-0.71 (0.55)	(-1.79,0.36)	-0.71 (0.55)	(-1.78,0.37)	-0.63 (0.59)	(-1.78,0.53)
Parental educational level (Ref. Higher education)	Lower education level	7.02 (0.51)*	(6.02,8.02)	6.78 (0.52)*	(5.77,7.79)	6.78 (0.52)*	(5.77,7.79)	6.61 (0.55)*	(5.53,7.69)
	Middle education level	4.25 (0.52)*	(3.23,5.26)	4.1 (0.52)*	(3.08,5.11)	4.1 (0.52)*	(3.08,5.11)	3.98 (0.56)*	(2.88,5.07)
Birth weight (Ref. Normal)	High (> 4000 g)	10.84 (0.64)*	(9.6,12.09)	10.85 (0.64)*	(9.6,12.09)	10.85 (0.64)*	(9.61,12.1)	10.54 (0.68)*	(9.21,11.86)
	Low (< 2500 g)	-6.97 (0.81)*	(-8.56,-5.37)	-6.96 (0.81)*	(-8.56,-5.37)	-6.96 (0.81)*	(-8.56,-5.36)	-6.5 (0.87)*	(-8.21,-4.79)
Area-level socio-demographic factors									
Unemployment rate (%)				0.47 (0.27)	(-0.05,1.01)	0.48 (0.26)	(-0.06,1.01)	0.4 (0.28)	(-0.17,0.98)
Rate of population with migration background in the area (%)				-0.03 (0.09)	(-0.21,0.16)	-0.02 (0.09)	(-0.21,0.16)	-0.01 (0.1)	(-0.21,0.19)
Area-level Built environmental variables									
Walkability index				-0.002 (0.20)	(-0.42,0.41)				
Playground availability (Area of playgrounds per km <sup>2</sup> )						-0.01 (0.04)	(-0.1,0.08)		

\*p &lt; 0.05

Model 1: Model on children's BMI percentiles adjusted for individual level factors reported in the table

Model 2: Model 1 plus walkability index &amp; other area level factors

Model 3: Model 1 plus playground availability &amp; other area level factors

Model 4: Model 1 plus greenspace availability &amp; other area level factors

	Model 1	Model 2	Model 3	Model 4
Greenspace availability (Percentage of area with greenspace)				-0.02 (0.03) (-0.08,0.05)
Akaike information criterion (AIC)	175063.8	172552.3	175023.1	154248.6
*p < 0.05				
Model 1: Model on children's BMI percentiles adjusted for individual level factors reported in the table				
Model 2: Model 1 plus walkability index & other area level factors				
Model 3: Model 1 plus playground availability & other area level factors				
Model 4: Model 1 plus greenspace availability & other area level factors				

Table 3 indicates the interaction term between parental educational levels with each built environment factor. One significant interaction was detected between greenspace availability and parental educational level (Table 3). As seen in model 5c, the level of parents' education moderated the association between the greenspace availability and the body weight (b=-0.1, 95% CI (-0.19, -0.01)).

Table 3

Associations between children's weight status and interaction terms of parental educational level (ref. Higher education level) and built environment features (Data from school entrance examination, city of Hannover, 2010–2014, n = 22,678)

	Model 5a		Model 5b		Model 5c	
	b (SE)	95% CI	b (SE)	95% CI	b (SE)	95% CI
Lower education level * Walkability index	0.58 (0.26)	(-0.07, 1.09)				
Middle education level * Walkability index	-0.02 (0.27)	(-0.57, 0.52)				
Lower education level * Playground availability			0.06 (0.05)	(-0.04, 0.16)		
Middle education level * Playground availability			-0.07 (0.05)	(-0.19, 0.03)		
Lower education level * Greenspace availability					-0.10 (0.04)	(-0.19, -0.01)
Middle education level * Greenspace availability					-0.07 (0.05)	(-0.16, 0.02)
Included independent variables:						
Model 5a: parental educational level, walkability index, parental educational level* walkability index						
Model 5b: parental educational level, playground availability, parental educational level* playground availability						
Model 5c: parental educational level, greenspace availability, parental educational level* greenspace availability						

After adjusting for individual and area level characteristics, the Fig. 2 shows that the association of greenspace availability is almost 0 for the high parental educational level group, while the association of the greenspace and BMI is negative among children from the low and middle parental educational level groups. In this case, a higher availability of greenspace was associated with a lower weight status for children whose parents had lower and middle education levels but not for those whose parents had higher education level. Subgroup analyses revealed that the greenspace availability was generally not significant in all three different parental educational level groups (Table 4). However, the trend of effect was reversed in the higher education group compared to the other two groups.

Table 4

Associations between children's weight status and greenspace availability stratified by parental educational level (Higher, Middle, Lower) from multi-level regression analysis (Data from school entrance examination, city of Hannover, 2010–2014, n = 22,678) \*

	Higher education level		Middle education level		Lower education level		
	b (SE)	95% CI	b (SE)	95% CI	b (SE)	95% CI	
Girls (ref. Boys)	1.59 (0.65)	(0.32,2.86)	3.19 (0.85)	(1.53,4.85)	2.54 (0.74)	(1.08,3.99)	
Children with migration background (ref. German children)	6.28 (0.75)	(4.81,7.74)	5.45 (0.89)	(3.7,7.21)	3.10 (0.80)	(1.53,4.67)	
Single parent/Blended family (ref. Nuclear family)	0.26 (2.48)	(-4.61,5.12)	2.66 (2.52)	(-2.29,7.6)	1.74 (1.91)	(-2.01,5.49)	
Two or more siblings (ref. one or none siblings)	1.79 (0.77)	(0.28,3.29)	1.09 (1.05)	(-0.97,3.15)	2.02 (0.77)	(0.50,3.53)	
Children day care less than 3 years (ref. 3 year or longer)	-0.6 (1.02)	(-2.59,1.40)	0.51 (1.3)	(-2.04,3.05)	-1.30 (0.88)	(-3.03,0.44)	
Birth weight (ref. Normal)	High >4000)	11.34 (0.99)	(9.41,13.28)	9.50 (1.33)	(6.89,12.11)	10.39 (1.25)	(7.94,12.85)
	Low <2500)	-8.15 (1.36)	(-10.82, -5.48)	-6.74 (1.76)	(-10.2, -3.29)	-4.93 (1.48)	(-7.83, -2.02)
Unemployment rate (%)	-0.03 (0.32)	(-0.68,0.63)	0.94 (0.42)	(0.09,1.79)	0.32 (0.41)	(-0.51,1.15)	
Rate of population with migration background in the area (%)	0.14 (0.12)	(-0.10,0.37)	-0.12 (0.14)	(-0.41,0.16)	0.01 (0.13)	(-0.25,0.28)	
Greenspace availability	0.02 (0.03)	(-0.05,0.09)	-0.04 (0.05)	(-0.14,0.06)	-0.09 (0.05)	(-0.20,0.02)	

\* Each model was adjusted for all variables in the table

## 4 Discussion

In this study, we examined the relationship between overweight in pre-school children and several built environmental factors. Our main findings indicated no significant associations between built environmental factors (walkability index, availability of playgrounds and availability of greenspace) and children's weight status. However, our results suggested an interaction of individual SES (parental educational level) and the greenspace availability while not for area-level SES: For children with lower compared to higher educated parents, a higher spatial availability to greenspace was significantly associated with reduced body weight.

Our results resonate with previous findings of the literature suggesting that individual SES factors are strongly associated for childhood BMI. To be noted, parental educational level is the only available SES factor in our study. Previous literatures suggest that children from families with low SES are at higher risk of becoming overweight or obese by assessing other SES factors. According to Saelens et al. (34), children from families with low incomes had higher risk of being obese. However, social gradient in the overweight prevalence cannot be fully explained by individual factors only. With the emergence of social ecological theory, the area-level SES as a predictor has been investigated. Prior studies indicate that adolescents who lived in deprived areas were more likely to be overweight and had higher levels of body fat (8, 35). However, the findings of area-level SES are inconsistent. A cross-sectional study authors found that a disparity in income among families affected the occurrence of childhood obesity, irrespective of neighbourhood SES (36). In our findings, area-level factors (unemployment rates and percentage of migrants) did not provide significant associations which could partially due to the reason of that there is no universal area effect on health outcome at present.

Factors of the built environment, such as greenspace availability, playground availability, or walkability, did not show any association with overweight and obesity on the aggregated level of analysis in pre-school children in Hannover. Similar studies targeting German population were not able to identify a significant association neither (31, 37), except a study based on data from the city of Munich (23). This study identified that lack of greenspace, low/middle playground space and low park space are associated with higher BMI although only in the bivariate analyses (23). However, the evidence of an association between built environment and physical activity was solid. Buck et al. (38, 39) found a strong variation in this association between physical activity and built environment using several variables including features of the walkability concept and the availability of recreational facilities like playgrounds and greenspace.

For greenspace availability specifically, while most studies showed a mixed or weak evidence of a relationship between greenspace and BMI, several reports have indicated a positive relationship (i.e., reduced BMI) between greenspace and BMI. Liu et al. (16) found that increased greenspace availability was associated with reduced weight among children living in areas with a high population density, while Petravičienė et al. (40) reported that less greenness exposure was associated with higher odds of being overweight and obese. All these studies highlighted the potential effect of SES on weight status change. Since more affluent parents tend to live in more salubrious areas, the effect of the environment may be partly driven by the parental SES (15).

Moreover, the environmental context may matter more for those otherwise not being able to take advantage of it. An interaction relationship between the SES and the environmental context on the children weight status change was explored in this study. We were able to demonstrate that the associations between the environment and childhood overweight/obesity were moderated by the educational level of the parents. At the same time, two area-level SES variables failed to provide a significant association. According to our findings, higher neighbourhood greenspace availability was associated with a lower BMI percentile, while the effect was stronger for children growing up in less-educated families compared to children from higher-educated families. As a frequently used indicator of SES in health behaviour surveys, parental educational level is believed to reflect the lifestyle among parents, which consequently has an influence on lifestyle among children (41). Our results are consistent with the findings of Lovasi et al. (42, 43) who found that children in lower income families had a reduced risk of obesity if they lived in an area with a higher density of trees. Less affluent families might be more restricted to their immediate surrounding and thus benefit more from greenspace availability (14, 44).

Physical activity is a potential mechanism through which built environments may influence obesity. Among youth, various elements of the built environment have been linked to increased physical activity. Children with access to recreational facilities, usually around their neighbourhoods, are more active than those without such access (42). A large body of literature has found associations between neighbourhood walkability and physical activity (45, 46). Some studies identified physical activity to be a mediator of the neighbourhood environment - body mass index (BMI) association (47, 48).

In addition to the complex mechanism related to physical activity, many other factors could confound the association between built environment and BMI. 'Residential self-selection' has been put forward as a possibly important confounder of the positive associations between walkability and physical activity. Residential self-selection implies that families are likely to select their neighbourhood according to their culture, lifestyle and personal preferences, and consequently those who are already active or who wish to be active may choose to live in a high-walkable neighbourhood and vice versa (49). Many studies on physical activity have controlled for residential self-selection in their analyses, resulting in mixed findings ranging from attenuation of the associations between walkability and PA to minimal effects on the associations (45, 50, 51). Some residents may choose to live in neighbourhoods that support their activity preferences in some cases. In another situation, residents may prefer to live in neighbourhoods with fewer recreational facilities because of low cost housing (48, 50). Although those analyses assume that children have little choice in their residential location (mostly depends on family selection), residential self-selection remains a significant factor (52). Overall, without including the residential selection factor, the association of built environment features and children's BMI might be overestimated. Definitive evidence of the presence or absence of residential selection confounding still awaits further exploration.

The strength of our study is the large sample size ( $n = 22,678$ ), which allowed us to conduct multi-level analyses to explore how the association between neighbourhood environment and childhood overweight and obesity varies by sex and to create maps illustrating the spatial patterns of overweight across the city of Hannover. Moreover, we were able to obtain objective measures assessing built environment in this study. Built environment features can be collected using either subjective or objective ways (46, 53). Many studies had applied subjective methods (54, 55) placing considerable value in subject's judgment of its own neighbourhood and the factors that contribute to it. Subjective tools can relate to self-reported perceptions of the environment, including self-evaluations of the subject's familiarity to the surroundings. However, studies showed a mismatch between objectively and subjectively measured built environment features suggesting that environmental perceptions are stronger correlates of activity among children than objective measures in specific situations (56). Future research could consider combining these two measurements in order to produce a more complete perspective.

This study has several limitations. First, due to the cross-sectional design, causality cannot be attributed to the observed findings. Second, although we captured an important outcome (BMI percentile) objectively for children in the study, several other unmeasured variables, such as physical activity, may be key mediators or confounding factors in the built environment-obesity relationship (57, 58). Objective measuring of physical activity for over 22 thousands children are challenging to collect, but additional research should include multiple health behaviours and outcome measures to better explicate the relationship between key environmental features and obesity. At the same time, there is a potential for residual confounding secondary to unmeasured aspects of the area or individual-level SES measures. Many important SES variables from previous literature, including household income, were not included due to data availability. Moreover, we used administrative boundaries as a proxy for the neighbourhood environment that may have induced a misclassification. Our environmental measures were conducted at the area-level because individual home addresses were not available. Area-level built environment measurement can be coarse,

and variation at a finer or coarser scale (zip-code, home address) may be crucial to influencing physical activity (59). Hence, it was unable to assess the sensitivity of our results to different spatial scales (59). The influence of scale on matched exposure-response relations in the built environment related literature needs for further investigation.

## 5 Conclusions

This research examines the associations between built environments and individual BMI percentile for children. Three built environment factors measured at area-level are walkability index, availability of playgrounds and availability of greenspace. These associations were tested after controlling for risk factors from the individual level to the area levels. Although built environmental factors did not show a significant association with weight status, greenspaces may have a small protective effect on children's overweight that was found to be particularly beneficial to children from less educated parents. These findings demand a more detailed analysis of the built environment-obesity relationship that considers the actual physical activity of children.

## Declarations

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### Availability of data and material

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

### Authors' contributions

YZ, MD and UW conceived the study design. YZ performed the data analyses, interpreted results, and drafted the manuscript. TvL, UW and MD contributed to the research question, analytical approach, and interpretation of results. CB, WM contributed to the spatial data analysis and interpretation of results. All authors critically commented on the drafts of the manuscript and approved the final version.

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### Ethics approval and consent to participate

Not applicable.

### Consent for publication

Not applicable.

### Competing interests

The authors declare that they have no competing interests.

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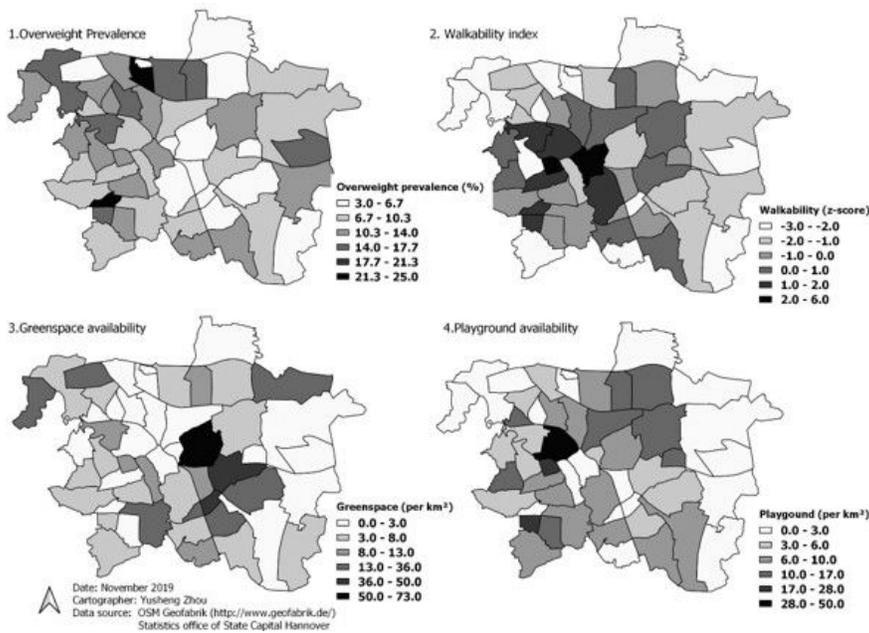
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## Figures



**Figure 1**

Spatial distribution patterns of overweight in pre-school children and built environmental features in the Hannover city (1. Overweight prevalence, 2. Walkability index, 3. Greenspace availability, 4. Playground availability. )

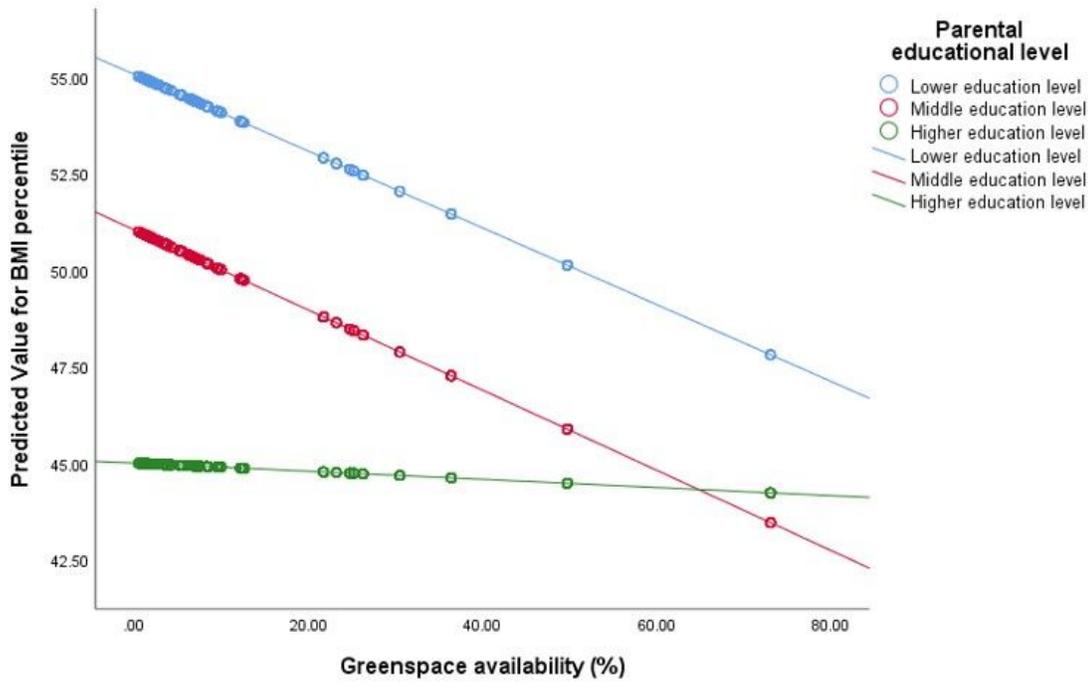


Figure 2

Scatter plot of predicted BMI percentiles for children with different parental education level (higher, middle, lower) by greenspace availability. (Notes: Adjusted for sex, migration background, siblings, family structure, child day care participation, birth weight, unemployment rate and rate of population with migration background in the area.)