Objective Measures of the Built Environment and Physical Activity in Children: From Walkability to Moveability

Christoph Buck, Tobias Tkaczick, Yannis Pitsiladis,
Ilse De Bourdehaudhuij, Lucia Reisch, Wolfgang Ahrens,
and Iris Pigeot

ABSTRACT Features of the built environment that may influence physical activity (PA) levels are commonly captured using a so-called walkability index. Since such indices typically describe opportunities for walking in everyday life of adults, they might not be applicable to assess urban opportunities for PA in children. Particularly, the spatial availability of recreational facilities may have an impact on PA in children and should be additionally considered. We linked individual data of 400 2- to 9-year-old children recruited in the European IDEFICS study to geographic data of one German study region, based on individual network-dependent neighborhoods. Environmental features of the walkability concept and the availability of recreational facilities, i.e. playgrounds, green spaces, and parks, were measured. Relevant features were combined to a moveability index that should capture urban opportunities for PA in children. A gamma log-regression model was used to model linear and non-linear effects of individual variables on accelerometer-based moderate-to-vigorous physical activity (MVPA) stratified by pre-school children (<6 years) and school children (≥ 6 years). Single environmental features and the resulting indices were separately included into the model to investigate the effect of each variable on MVPA. In school children, commonly used features such as residential density ($\hat{\beta} = 0.5 \cdot 10^{-4}$, $p = 0.02$), intersection density ($\hat{\beta} = 0.003$, $p = 0.04$), and public transit density ($\hat{\beta} = 0.037$, $p = 0.01$) showed a positive effect on MVPA, while land use mix revealed a negative effect on MVPA ($\hat{\beta} = -0.173$, $p = 0.13$). In particular, playground density ($\hat{\beta} = 0.048$, $p = 0.01$) and density of public open spaces, i.e., playgrounds and parks combined ($\hat{\beta} = 0.040$, $p = 0.01$), showed positive effects on MVPA. However, availability of green spaces showed no effect on MVPA. Different moveability indices were constructed based on the walkability index accounting for the negative impact of land use mix. Moveability indices showed also strong effects on MVPA in school children for both components, expanded by

Buck and Pigeot are with the Leibniz Institute for Prevention Research and Epidemiology, BIPS, Bremen, Germany; Tkaczick is with the Institute of Geography, University of Bremen, Bremen, Germany; Pitsiladis is with the College of Medical, Veterinary and Life Sciences, Institute of Cardiovascular and Medical Sciences, University of Glasgow, Glasgow, UK; Pitsiladis is with the School of Sport and Service Management, University of Brighton, Eastbourne, UK; Bourdehaudhuij is with the Department of Movement and Sports Sciences, Ghent University, Ghent, Belgium; Reisch is with the Department of Intercultural Communication and Management, Copenhagen Business School, Copenhagen, Denmark; Ahrens is with the Faculty of Mathematics and Computer Science, University of Bremen, Bremen, Germany.

Correspondence: Christoph Buck, Leibniz Institute for Prevention Research and Epidemiology, BIPS, Bremen, Germany. (E-mail: buck@bips.uni-bremen.de)

playground density ($\hat{\beta} = 0.014, p = 0.008$) or by public open space density ($\hat{\beta} = 0.014, p = 0.007$), but no effects of urban measures and moveability indices were found in pre-school children. The final moveability indices capture relevant opportunities for PA in school children. Particularly, availability of public open spaces seems to be a strong predictor of MVPA. Future studies involving children should consider quantitative assessment of public recreational facilities in larger cities or urban sprawls in order to investigate the influence of the moveability on childhood PA in a broader sample.

KEYWORDS Accelerometry, Built environment, Children, IDEFICS study, Moderate-to-vigorous physical activity, Walkability

INTRODUCTION

Features of the built environment can positively influence physical activity (PA) levels in adults and are commonly assessed using objective measures such as residential density, land use mix, and street connectivity.^{1,2} To assess the overall walkability of urban areas, these measures are typically combined to a so-called walkability index which captures possibilities for PA through walking in everyday life of adults.^{1,3} Moreover, the walkability index can be extended to capture additional features for instance using public transit density to capture the impact of public transit on reported PA in adults.⁴

Most previous studies employing the walkability index were conducted in the USA and Australia, where environmental features and transport mode choices significantly differ from those in Europe and Germany, in particular.⁵ Moreover, studies of the walkability concept focused on physical activity in adults and it is not evident that urban measures of the walkability index assess built environment characteristics that influence PA in children. With regard to children, some studies showed that walkability measures are applicable to investigate the effect of the built environment on PA,^{6,7} but other findings strongly differ and found no effect of walkability on PA.⁸

Hence, the idea to extend the walkability index and to create indices to assess the playability or the moveability of the urban environment has recently been discussed.^{8–11} Since the walkability index does not capture recreational facilities that reflect opportunities for PA in children in leisure time, additional features of the built environment that have particular relevance for children and adolescents have to be studied.⁶ Particularly, time spent outdoors for example on green spaces can positively influence moderate-to-vigorous physical activity (MVPA) in children^{12,13} and the spatial availability of recreational facilities such as playgrounds and parks is an important aspect of the built environment in the neighborhood that influences PA in children.^{14–16}

A moveability index that is based on the walkability index and extended by additional components such as the density of recreational facilities or playgrounds possibly allows to investigate the effect of the built environment on PA in children.^{8,10,11} In a previous study, we investigated the built environment on a macro-level in a German study region and found a small but significant influence of features such as playground density, residential density, and intersection density on reported PA of school children. We developed a first moveability index considering

all types of recreational facilities to extend the walkability index and also found small effects of the moveability index on reported PA of school children.¹¹ However, it is unclear if only specific recreational facilities should be considered for extending the walkability index and if the walkability index itself can be used without changes in the original components.^{10,11}

To investigate the impact of the built environment on PA levels in children, we use data from the IDEFICS study (Identification and prevention of Dietary- and lifestyle-induced health EFfects In Children and infantS) of one German study region \cite{Ahrens10tic}. In detail, we investigate the influence of common walkability measures and different types of recreational areas such as playgrounds, green spaces, and parks within individual network-dependent neighborhoods³ to extend the walkability index to a *moveability index* and analyze the effect of the built environment on accelerometer-based MVPA of pre-school and primary school children.

METHODS

IDEFICS Study

We assessed features of the built environment in one German study region, the city of Delmenhorst, and linked these to individual data obtained from 400 2- to 9-year-old children that were collected during the baseline survey of the IDEFICS study, which took place between September 2007 and May 2008.¹⁷ Delmenhorst is located in Lower Saxony, Germany and covers an area of about 62 km² with about 77,300 residents in 2008. The IDEFICS study is a European multicenter study that was conducted from 2006 to 2012 to investigate the etiology of lifestyle- and nutrition-related diseases and disorders in 16,228 2-to 9-year-old children from eight European countries.¹⁸ Measurements included anthropometry, food intake, PA, and other lifestyle factors.¹⁷

Individual data included body mass index (BMI), accelerometer measurements, and education of parents assessed by the International Standard Classification of Education (ISCED). Reported safety concerns of the parents that restricted PA of the children were identified using two items derived from the parental questionnaire, “I restrict my child’s outdoor activities for safety reasons.”, and “I don’t like to let my child walk/cycle to kindergarten, pre-school or school for safety reasons.” to which parents could agree or disagree.

Environmental Data

Geographic data on land use and number of residents within the study region were provided by the land registry office of Lower Saxony. Geographic line data of the footpath network were obtained from the OpenStreetMap project and validated using data of the municipal geospatial information system (Kommunales Raumbezogenes Informationssystem (KRIS)) of the city of Delmenhorst. Bus stops and recreational facilities, i.e., playgrounds, and parks, were digitalized based on available maps and lists provided by the public transit company and the civil service for green space of Delmenhorst, respectively. Mainly, playgrounds and parks, that are under responsibility of the municipality, are considered with regard to opportunities for leisure time PA \cite{Roemmich06aoa,holt09npa}. Geographic data of these features can easily be obtained from public authorities, though these data do not capture all accessible opportunities for PA in an urban environment. Other green spaces, particularly in

apartment housing areas that are not under public responsibility, could provide the same opportunities for PA in leisure time as public open spaces. Based on land use maps and imagery data provided in *ArcGIS 10.0*,^{*} we assessed and digitalized green spaces that were larger than 100 m² and located in or adjacent to residential areas but that were not defined as public. We ensured the accessibility of recreational facilities and green spaces via field surveys resulting in 103 playgrounds, 45 park areas, and 103 green spaces that were considered as points in our analyses. We processed and digitalized geographic data in *ArcGIS 10.0*.

Study Data

In our study region, Delmenhorst, 1,179 children participated in the baseline survey of the IDEFICS study.¹⁷ Due to budgetary constraints, accelerometer devices were not available for all children. A random sample of children was asked to wear an accelerometer device of whom 460 children agreed. Anonymized address coordinates of these children were geocoded within the study area of whom we excluded 34 children who lived in the rural peripheral area of Delmenhorst to focus on children living in an urban environment. Due to missing values of questionnaire information, 26 children were additionally excluded resulting in a total sample of 400 2- to 9-year-old children. Age- and sex-specific BMI z-scores and categories for overweight and obesity were calculated according to Cole and Lobstein.¹⁹ Accelerometer measurements of 15 s epochs covered at least three consecutive days with at least 8 h of valid wear time each after exclusion of all intervals of at least 30 min of consecutive zeros. MVPA was defined using the cutoff value of 2,298 counts per minute (cpm) that was proposed by Evenson.²⁰ In addition, we considered hours of valid wear time and the season of accelerometer measurement as a confounder. Assessments that took place in September 2007 and from March to May 2008 were categorized as spring/summer and measurements from October 2007 until February 2008 were categorized as autumn/winter where the majority of the assessments took place (70.5 %). The categorization of the seasonal variable was also verified based on mean temperature per month.[†]

Moveability Indices

We calculated objective measures of the built environment within individual network-dependent neighborhoods based on a distance of 1 km per child, i.e., the neighborhood captures an area that can be reached within 1 km around the home location depending on the street network.³ Due to data protection requirements, it was not allowed to use the exact address coordinates to calculate individual neighborhoods. Therefore, we proposed a spatial blurring based on a Gaussian error that was inversely proportional to the underlying residential density.^{21,22} According to Cassa et al.²², the anonymization of address data using a Gaussian error only slightly affects spatial cluster analyses. In our analyses, the spatial blurring shifted the coordinates by about 50 to 100 m on average and a simulation study showed only small differences of walkability measures after spatial blurring.²¹ We conducted the network analyses using the *network analyst* in *ArcGIS 10.0* and calculated the spatial blurring in R 3.0.1²³ using the *rnorm* function.

*ESRI 2011. ArcGIS Desktop:Release 10. Redlands, CA: Environmental Systems Research Institute.

[†]<http://www.wetteronline.de/wetterdaten/delmenhorst>

In each individual 1-km network-dependent neighborhood, we constructed two versions of a walkability index first including residential density, i.e., number of residents per km², land use mix, calculated as the entropy of land use types, and intersection density which assesses the street connectivity,^{1,3} and second an extended index that also comprises the density of public transit stations.⁴ In recent studies, the retail floor area, i.e., the ratio of retail floor area to retail land use area, has also been used to describe the car dependency of commercial areas that is associated with car use in adults.^{1,4} However, data on retail floor areas were not available in our study region, and since we focused on opportunities for PA in children, we did not consider the retail floor area ratio in the index construction. We calculated intersection density and public transit density as number of points per area based on the simple density approach.^{2,3} For the construction of both walkability indices, we standardized all measures using *z*-scores. Indices were constructed as non-weighted sums of *z*-scores of (1) three measures, i.e., residential density, land use mix, and intersection density,¹ and (2) four measures, i.e., residential density, land use mix, intersection density, and additionally public transit density.⁴

We accounted for urban opportunities for leisure time PA in children by constructing an extended walkability index and calculated the intensity of all point characteristics such as intersections, public transit stations, and midpoints of recreational areas based on a kernel approach which was already used in previous analyses.¹¹ To assess point patterns in a varying urban environment, the use of a kernel approach is recommended to assess the intensity, i.e., availability, of a point process.^{11,24} For each cell of a 2×2 m raster, the intensity is the weighted sum of point characteristics, where the weights depend on the distance from the point of observation and decrease for an increasing distance based on a Gaussian kernel.^{25,26} We then calculated environmental variables of point characteristics as mean intensity, i.e., number per km², of cells per neighborhood. The mean intensity of points such as recreational facilities, public transit stations, and intersections serves as our density measure. Figure 1 exemplarily illustrates the playground density in the study region calculated by the kernel approach.

Eventually, we constructed three different moveability indices to account for different types of recreational facilities and added the standardized *z*-score of the mean intensity of (1) only playgrounds, (2) playgrounds and parks, called public open spaces, and (3) all playgrounds, parks, and green spaces, which we named open spaces.

To illustrate the spatial distribution of the built environment measures, we calculated the four-dimensional walkability index and the moveability index that includes public open spaces based on *z*-scores of raster cells within the study area (Fig. 2).

We calculated all environmental variables with the *spatstat* package²⁵ in the statistical software *R* 3.0.1.²³ Particularly, we implemented the kernel density approach using the *density.ppp* function in the *spatstat* package (version 1.31.1) that is based on a Gaussian kernel and a fixed bandwidth of $\sigma=500$ m.

Statistical Analyses

We first performed descriptive analyses stratified by pre-school and school children to reveal potential differences in environmental variables. In a second step, we investigated the influence of environmental variables on MVPA. For this purpose, we calculated a gamma log-regression model as a basic model without any environmental variables and considered linear and non-linear effects of continuous

FIG. 1 Density of playgrounds as number per km² assessing the availability within individual neighborhoods. As an example, four individual neighborhoods are depicted in yellow.

variables such as age and BMI z-score as well as single effects of categorical variables, e.g. sex or education level, to optimize the goodness of fit based on Akaike's information criterion (AIC). We stratified each model by pre-school children including 2 to <6 years old (25 %) and school children from 6 to 9 years old. Please note that the estimated effects are derived from a cross-sectional study and should therefore not be interpreted as causal. To be more specific, we modeled age as

FIG. 2 Raster values of the walkability index including four dimensions (*left*) and the moveability index including public open space density (*right*) in the study area of Delmenhorst.

a linear and a quadratic term to account for a known plateau effect of age, but due to the small age range, the linear and quadratic term for age were not considered in the stratified models. The basic model was also adjusted for sex, BMI *z*-score, education level of parents, valid wear time of accelerometer devices, and season of assessment. Then, we separately included environmental variables as single environmental features and the indices into the basic model to investigate the effect of each environmental variable on children's MVPA (two-sided test at $\alpha=0.05$). Statistical analyses were performed using SAS 9.2 and the *glimmix* procedure,* in particular.

RESULTS

Overall, 16.3 % of the children were overweight or obese and mean MVPA was 60.2 min per day with lower mean MVPA in pre-school than in school children (55.4 min/day vs. 61.8 min/day). Mean age was 6.7 years, and overall 51.8 % were girls. Characteristics of the study sample are presented in Table 1 for all children and stratified by pre-school and school children.

Table 2 presents descriptive statistics stratified by pre-school and school children. Mean intensity of recreational facilities was about the same for playgrounds and green spaces with higher variability in green spaces, but maximum intensity was highest for green spaces with 11.7 areas per km². Parks showed a low availability per neighborhood with 0.9 parks per km² on average ranging from 0 to only 2.6. Overall, environmental variables and indices showed about the same mean and standard deviation in both pre-schoolers and school children.

Results for the basic model that only included individual variables are presented in Table 3. In all children, age showed a positive plateau effect on MVPA as a combination of the linear and the quadratic term ($\hat{\beta}_{\text{age}} = 0.367, p < 0.001; \hat{\beta}_{\text{age}^2} = -0.027, p < 0.001$). In school children, girls were less active with significantly lower levels of MVPA

*PROC GLIMMIX; SAS version 9.2, SAS Institute Inc, Cary, NC

TABLE 1 Characteristics of the study sample in the study region, Delmenhorst, Germany

N (%)						
	All		Pre-school children		School children	
Sample size	400	(100)	100	(25.0)	300	(75.0)
Weight status ^a						
Thinness	27	(6.8)	11	(11.0)	16	(5.3)
Normal weight	308	(77.0)	79	(79.0)	229	(76.3)
Overweight	47	(11.8)	6	(6.0)	41	(13.7)
Obesity	18	(4.5)	4	(4.0)	14	(4.7)
ISCED level ^b						
Low	80	(20.0)	12	(12.0)	68	(22.7)
High	320	(80.0)	88	(88.0)	232	(77.3)
Safety concerns of parents						
No	249	(62.3)	54	(54.0)	195	(65.0)
Yes	151	(37.8)	46	(46.0)	105	(35.0)
Season of MVPA assessment						
Autumn/winter	282	(70.5)	69	(69.0)	213	(71.0)
Spring/summer	118	(29.5)	31	(31.0)	87	(29.0)
Mean (SD)						
MVPA (min/day)	60.2	(23.1)	55.4	(22.8)	61.8	(23.0)
Age	6.7	(1.7)	4.2	(0.8)	7.5	(0.8)
BMI z-score ^a	0.32	(1.1)	0.02	(1.1)	0.4	(1.0)
Valid weartime (h) ^c	11.5	(1.2)	11.1	(1.0)	11.6	(1.3)

^aAccording to Cole and Lobstein¹⁹
^bMax. ISCED level of both parents, low: level 1 and 2 relates to lower secondary education and less
^cWeartime of accelerometers after exclusion of 30 min of consecutive zeros

($\hat{\beta} = -0.216, p < 0.001$) and BMI z-score showed a negative effect on MVPA ($\hat{\beta} = -0.037, p = 0.08$), but in pre-school children, the effect of BMI z-score was reverse ($\hat{\beta} = 0.036, p = 0.37$) and no difference between boys and girls was found. Higher levels of MVPA were observed in spring and summer months ($\hat{\beta} = 0.156, p < 0.001$) in both pre-schoolers and school children. In particular, the negative effect of safety concerns of parents was more pronounced in pre-school children ($\hat{\beta} = -0.136, p = 0.11$) than in school children ($\hat{\beta} = -0.027, p = 0.52$).

The estimated effects of all environmental variables are summarized in Table 4. In school children, playground density ($\hat{\beta} = 0.048, p = 0.01$) and density of public open spaces, i.e., playgrounds and parks combined ($\hat{\beta} = 0.040, p = 0.01$), revealed a positive effect on MVPA, but no effect was found for green space density and density of open spaces that also included green spaces ($\hat{\beta} = 0.005, p = 0.39$). Particularly, including playground density or public open space density revealed the best goodness of fit (see AIC in Table 4).

Furthermore, positive effects on MVPA of school children were found for public transit density ($\hat{\beta} = 0.037, p = 0.01$), intersection density ($\hat{\beta} = 0.003, p = 0.04$),

TABLE 2 Descriptive statistics of environmental variables stratified by age groups

Mean (SD) min/max						
Environmental variables	all		pre-school children		School children	
Residents per km ²	2535 (884)	211/4173	2587 (757)	596/3940	2517 (919)	211/4173
Land use mix	0.63 (0.18)	0/0.98	0.63 (0.18)	0/0.98	0.64 (0.18)	0/0.98
Playgrounds per km ²	3.3 (1.1)	0.3/5.6	3.3 (0.9)	1.0/5.4	3.3 (1.1)	0.3/5.6
Green spaces per km ²	2.7 (2.8)	0/11.7	3.2 (3.1)	0.1/11.7	2.6 (2.7)	0/11.7
Parks per km ²	0.9 (0.5)	0/2.6	0.8 (0.5)	0/2.1	0.9 (0.6)	0/2.6
Intersections per km ²	59.3 (15.3)	20.8/91.1	59.6 (13.9)	24.2/86.6	59.2 (15.7)	20.8/91.1
Public transit stops per km ²	4.6 (1.4)	1.0/7.0	4.6 (1.4)	1.2/7.0	4.6 (1.4)	1.0/6.9
Walkability index (three-dimensions) ^a	-0.07 (1.8)	-4.9/5.6	-0.00 (1.5)	-3.4/3.5	-0.09 (1.9)	-4.9/5.6
Walkability index (four-dimensions) ^a	-0.07 (2.5)	-6.8/6.8	0.08 (2.2)	-5.0/4.7	-0.12 (2.6)	-6.8/6.8
Moveability index (incl. playgrounds)	-0.09 (3.8)	-9.8/9.0	0.07 (3.5)	-8.7/9.0	-0.14 (4.0)	-9.8/8.9
Moveability index (incl. POS) ^b	-0.09 (3.8)	-10.0/8.4	0.07 (3.5)	-8.7/8.4	-0.14 (4.0)	-10.0/8.4
Moveability index (incl. OS) ^c	-0.12 (3.7)	-9.2/7.1	0.13 (3.5)	-8.5/6.8	-0.20 (3.7)	-9.2/7.1

^aExcluding retail floor area ratio^{1,4}^bPublic open spaces: playgrounds and parks^cOpen spaces: playgrounds, parks, and green spaces

and residential density ($\hat{\beta} = 0.5 \cdot 10^{-4}, p = 0.02$), while land use mix showed a negative effect on MVPA ($\hat{\beta} = -0.173, p = 0.13$). Thus, we constructed the final moveability indices based on the unweighted sum of standardized z -scores of residential density, public transit density, intersections density, and density of recreational facilities minus the z -score of land use mix. All three versions of a moveability index showed significantly positive effects on MVPA (Table 4), and the strongest effect was found including density of public open spaces ($\hat{\beta} = 0.014, p = 0.007$). In particular, goodness of fit was best including playground density or public open space density (see Table 4). However, no effects of walkability indices or moveability indices on MVPA were found in pre-school children, though in both pre-school and school children, goodness of fit slightly improved using the moveability indices compared to the walkability indices. Environmental variables showed the same effect in the overall sample, but in pre-school children, effects were smaller and not statistically significant compared to school children.

DISCUSSION

Based on our results of the micro-level analyses, the extension of the walkability index to a moveability index seems to be an appropriate approach to investigate opportunities for PA, particularly in school children. Environmental features that

TABLE 3 Basic log-gamma regression model including all factors influencing MVPA without environmental variables in all children and stratified for age groups

Variable	All		Pre-school children		School children	
	(n=400, AIC=3569)		(n=100, AIC=907.1)		(n=300, AIC=2679)	
	β	p value	β	p value	β	p value
Age	0.367	<0.001				
Age ²	-0.027	<0.001				
BMI z-score ^a	-0.019	0.27	0.036	0.37	-0.037	0.08
Sex (ref: male)	-0.187	<0.001	-0.067	0.44	-0.216	<0.001
Valid weartime (h) ^b	0.028	0.07	0.058	0.18	0.032	0.06
ISCED ^c (ref: low)	0.016	0.73	-0.057	0.67	0.048	0.34
Season (ref: autumn/winter)	0.156	<0.001	0.217	0.01	0.151	0.001
Safety concerns (ref: no)	-0.043	0.25	-0.136	0.11	-0.027	0.52

^aAccording to Cole and Lobstein¹⁹
^bWeartime of accelerometers after exclusion of 30 min of consecutive zeros
^cMax. ISCED level of both parents, low: level 1 and 2 relates to lower secondary education and less

were used to construct walkability indices such as residential density, intersection density, and public transit density showed a positive effect on MVPA. However, land use mix was found to influence PA negatively which was the only observation that is in contrast to findings in adults.^{3,1,4} Thus, the construction of the moveability index was based on the sum of z-scores of residential density, intersection density, and public transit density according to the walkability indices,^{3,4} but land use mix was subtracted.

Adding information about the spatial availability of opportunities for PA in leisure time and taking into account the negative influence of land use mix on MVPA provided a feasible index that can be used to predict MVPA levels particularly in school children. Overall, neighborhoods characterized by a high moveability index (index value >0) provided more opportunities for PA in children that resulted in higher amounts of MVPA (results not shown). These neighborhoods were mainly residential providing single or apartment housing with low values of land use mix and included more public recreational facilities. Moreover, these neighborhoods were particularly not located in or adjacent to the center of the city, whereas in adults, high-walkable neighborhoods are mainly located in the city center providing highly connected walking facilities and a mix of different land use types.^{1,4}

Furthermore, the density of public open space, i.e., playgrounds and parks, showed a positive impact on MVPA in children as found previously.^{14,16} Considering different types of recreational facilities, our analyses revealed that mainly public open spaces such as playgrounds and parks need to be considered as opportunities for PA, but the spatial availability of non-public green spaces did not seem to influence physical activity levels neither in pre-school children nor in school children.

The assessment of green spaces based on imagery and land use data, particularly within high-populated areas, was more laborious than assessing parks and playgrounds that were provided by the municipality and that could be digitalized using listed addresses or street names. Moreover, in our analyses, green spaces did not turn out as an environmental factor explaining MVPA in pre-school and primary school children. Thus, in the setting that we investigated, it seems to be

TABLE 4 Influence of environmental variables and indices on MVPA separately calculated using the basic log-gamma regression model adjusted for non-environmental factors in all children and stratified for age groups

Variable	All (n=400)				Pre-school children (n=100)				School children (n=300)			
	β	p value	AIC		β	p value	AIC		β	p value		AIC
Playground density	0.053	0.002	3561		0.061	0.17	907.1		0.048	0.01		2674
Green space density	0.003	0.62	3571		0.004	0.82	909.0		-0.001	0.87		2681
Park density	0.048	0.18	3569		0.074	0.38	908.3		0.032	0.43		2681
Public open space density ^a	0.045	0.002	3561		0.051	0.14	906.9		0.040	0.01		2675
Open space density ^b	0.008	0.14	3569		0.006	0.56	908.7		0.005	0.39		2680
Intersection density	0.002	0.09	3568		0.001	0.70	908.9		0.003	0.04		2677
Public transit density	0.030	0.02	3566		0.019	0.52	908.7		0.037	0.01		2675
Residential density	0.00005	0.01	3565		0.00006	0.28	907.9		0.00005	0.02		2676
Land use mix	-0.197	0.049	3567		-0.155	0.50	908.6		-0.173	0.13		2679
Walkability index (three-dimensions) ^c	0.008	0.45	3570		0.002	0.93	909.1		0.013	0.26		2680
Walkability index (four-dimensions) ^c	0.010	0.20	3569		0.005	0.81	909.0		0.013	0.13		2679
Moveability index (incl. playgrounds)	0.013	0.005	3563		0.012	0.29	908.0		0.014	0.008		2674
Moveability index (incl. POS) ^a	0.014	0.004	3562		0.013	0.28	907.9		0.014	0.007		2674
Moveability index (incl. OS) ^b	0.013	0.009	3564		0.010	0.37	908.3		0.014	0.015		2675

^aPublic open spaces: playgrounds and parks
^bOpen spaces: playgrounds, parks, and green spaces
^cExcluding retail floor area ratio^{1,4}

sufficient to consider availability of playgrounds or parks to assess the moveability of urban neighborhoods.¹⁴ Previous studies in adolescents suggested that this association is different and parks are the main public open spaces that provide opportunities for PA in leisure time for this age group.¹⁶ For example, Wheeler et al.¹² found based on GPS and accelerometry data of children that particularly in boys, high intensity PA is more likely when located on parks. Since in our study the moveability index including public open space density, i.e., number of playgrounds and parks, was also a strong predictor of MVPA, this index may present a compromise providing a tool to assess opportunities for PA in both children and adolescents.

Due to the large proportion of school children, effects of environmental variables were similar in the overall sample compared to our findings in school children. However, in pre-school children, effects of environmental variables on MVPA were smaller and not significant. The reduced sample size of pre-school children may have been too small to detect effects of playground and park density or moveability indices which were slightly smaller than in school children. Moreover, parents of pre-school children showed higher percentage of safety concerns, and the effect on MVPA was more pronounced compared to school children. Hence, the contribution of environmental moveability and particularly effects of the transport network on PA levels in young children seem to be mediated by parental safety perceptions which were also observed in recent studies.^{27,28} Since independent mobility increases with age,²⁷ the effect of environmental variables such as intersection density and public transit density can also be observed in older children of our study.

Some limitations have to be considered. Primarily, the study sample was slightly biased including more children whose parents had high education levels (65.0 %) or high household income (62.1 %). Moreover, the reported results may be influenced by the spatial blurring that had to be conducted to use anonymized individual address coordinates, although we found that the Gaussian blurring does only slightly affect environmental analyses. With regard to the recent literature, strengths of our study are the use of objective measurements of environmental variables based on geographic data as well as of objectively measured PA of study participants using accelerometry. Furthermore, the link of individual data to geographic data based on individual network-dependent neighborhoods allowed to assess all opportunities around a child's home, instead of averaging values in larger districts or artificial areas.³ The use of the kernel approach improved the assessment of point patterns as it was described previously.¹¹ However, the kernel density was implemented based on a fixed bandwidth. Therefore, possible methodological improvements such as the use of cross-validation to choose an optimal bandwidth or the use of an adaptive bandwidth to consider environmental variability in the underlying residential density²⁹ have to be investigated.

Besides multiple determinants of physical activity in children that exist on the individual level, our study supports the evidence that physical activity of children is also influenced by built environment characteristics. Well-designed public open spaces and particularly playgrounds offer opportunities for children to be physically active in addition to sport activities that are promoted in schools or kindergartens. Moreover, safely designed public open spaces might also reduce parental concerns. This would encourage children to have more leisure time outdoor activities and increase their independent mobility. Public health practitioners and health policy makers should therefore consider urban planning as an additional discipline that needs to be involved in the promotion of a healthy environment for children providing safe and well-designed public open spaces in the urban neighborhood of children.

CONCLUSION

The moveability index turned out to be a useful tool to capture opportunities for PA on a micro-level in the urban neighborhood of school children in everyday life. Environmental features showed a significant effect on PA levels in children and could be combined to a moveability index. Moreover, availability of public open space and particularly playgrounds were positive predictors while other features that were commonly used to build the walkability index showed similar effects on PA levels for school children as for adults, except for land use mix. However, studies involving larger study areas, e.g. major cities or urban sprawls, as well as the assessment of regions in other countries are needed to further generalize these findings by quantitatively assessing recreational facilities. To also consider PA in leisure time of adults or adolescents, recreational facilities such as fitness centers or sports clubs should also be used to adapt the index in the same way as it was presented in our study. In addition, questionnaires assessing the perceived environment and its influence on PA levels may still be useful to identify motivational factors and to gain more insight into the association of the environment and the PA behavior of residents, besides objective measures of the urban neighborhood. In the long run, a validated quantitative moveability index may offer a valuable tool for urban planners to assess the communities where children live. Safe and well-designed public open spaces may encourage children to be more physically active and create a healthy environment to counteract the worrying lack of physical activity.

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