Landscape and Urban Planning 247 (2024) 105068

Contents lists available at ScienceDirect

Landscape and Urban Planning

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

Associations between green space availability and youth's physical activity in urban and rural areas across Germany

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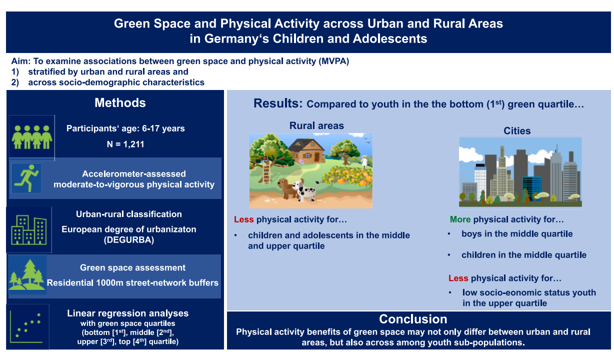
HIGHLIGHTS

- Green space – physical activity (PA) associations explored across urbanicity levels.
- Green space and urbanicity assessed with geospatial methods.
- Accelerometer-assessed PA for 1,211 youth (6–17 years)
- Youth in rural areas engage in less PA with more green space.
- Green space – PA associations in cities depend on age, gender, and social status.

GRAPHICAL ABSTRACT



ARTICLE INFO

Keywords:
Built environment
Urban planning
Epidemiology
Natural environment
GIS

ABSTRACT

Green space may be an important physical activity facilitator for children and adolescents. However, to date, most studies focused on urban green space, and few studies investigated associations between green space and physical activity across urban and rural areas, which was the goal of this study. Data were obtained from a German cohort study, including 1,211 youth aged 6–17 years. Residential green space was assessed within a 1000 m street-network buffer using land cover and land use data and divided into quartiles, urbanicity using the European Urbanization Degree, and moderate-to-vigorous physical activity (MVPA) using accelerometers. Associations were investigated via linear regression analysis stratified by urbanicity degree, controlling for relevant confounders. We found that in rural areas, compared to youth in the bottom green quartile, those within the middle (2nd) and upper (3rd) green quartiles engaged in less MVPA. This relationship was not observed for youth in towns and cities. Interactions occurred between green space and socio-demographic characteristics for children and adolescents in cities: Compared to the bottom green quartile, boys or younger children within the middle green quartile engaged in more MVPA. However, socially disadvantaged children and adolescents in cities engaged in less MVPA in the upper compared to the bottom green quartile. Our results show that

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https://doi.org/10.1016/j.landurbplan.2024.105068
Received 28 March 2023; Received in revised form 2 February 2024; Accepted 20 March 2024

associations between green space and MVPA do not only differ between urban and rural areas but also among youth sub-populations. These findings are important to consider for planning policies to create inclusive active living environments across urban and rural areas.

1. Introduction

Physical inactivity is a major societal challenge, predicted to lead to 500 million new cases of non-communicable diseases (e.g., hypertension) and mental disorders (e.g., depression) between 2020 and 2030, incurring health care costs of US$ 27 billion annually (WHO, 2022). Since physical activity is positively associated with mental, physical, and behavioral health (Chaput et al., 2020), the World Health Organization (WHO) recommends that children and adolescents engage in an average of 60 min of moderate to vigorous physical activity (MVPA) daily (WHO, 2020). However, only 20–26 % of children and adolescents meet these physical activity recommendations globally and in Germany (Aubert et al., 2022).

To tackle physical inactivity, the WHO (2018) set up the Global Action Plan on Physical Activity. This action plan builds on socio-ecological models (Sallis & Owen, 2015), emphasizing the importance of creating active environments to facilitate physical activity engagement. Specifically, the WHO (2018) calls for action to strengthen access to public green space for physical activity promotion. From a conceptual point of view, green space is expected to enhance human health via three pathways, including mitigation through harm reduction (e.g., heat reduction), mental restoration through restoring capacities (e.g., via stress recovery), and in this context most importantly, prevention through building capacities, such as engagement in physical activity (Markevych et al., 2017). Hence, conceptually, it is expected that green space facilitates physical activity of children and adolescents.

However, recent systemic reviews synthesizing the evidence on green space and physical activity in children and adolescents show mixed findings (Jia et al., 2021; Nordbø, Nordh, Raanaas, & Aamodt, 2020; Prince et al., 2022). While methodological heterogeneity regarding green space definition as well as buffer types and sizes may be one reason for this (Nigg, Niessner, Burchartz, Woll, & Schipperijn, 2022), another reason could be that the green space context has been neglected. More specifically, the association between green space and physical activity may vary across urban and rural areas due to their different characteristics. For example, compared to metropolitan areas, rural areas have less developed public open green space, referring to areas that primarily consist of vegetation but also have some construction compared to undeveloped green space (King & Clarke, 2015). To date, studies investigating the built environment in relation to children's and adolescent's physical activity focused predominantly on urban green space (Buck et al., 2015; Hinckson et al., 2017; Janssen & Rosu, 2015; Klinker, Schipperijn, Kerr, Ersbøll Kjær, & Troelsen, 2014; Prins et al., 2011), while green space studies across the urban–rural continuum are rare (Hansen, Umstattd Meyer, Lenardson, & Hartley, 2015; Prince et al., 2022). This seems to be even more important since some studies show that children and adolescents from rural areas engage in less physical activity than their urban counterparts (Rainham et al., 2012) and show decreasing physical activity levels (Corder et al., 2015; Nigg et al., 2022). Neighborhood characteristic differences seem to be partially responsible for those differences (Christiana, Bouldin, & Battista, 2021). Drawing upon the few studies that investigated associations between green space and physical activity along the urban–rural continuum, a study with US adolescents between 12 and 17 years showed that park accessibility was associated with regular physical activity for urban, but not rural adolescents (Babey, Hastert, Yu, & Brown, 2008). Similar results were found in another study with ten-year-old children in England, where perceived park availability predicted physical activity in urban, but not semi-urban and rural children (Craggs et al., 2011). In a study with older adolescents in Germany, vegetation cover (assessed via the normalized differentiated vegetation index – NDVI) was associated with more total MVPA for adolescents in urban, but not rural areas in the Wesel region, while in the Munich area, green space was unrelated to MVPA in both urban and rural regions (Markevych et al., 2016).

In summary, research investigating associations between green space and physical activity along the urban–rural gradient is scarce. Existing research focused on park access and park availability in adolescents while there is a lack of studies investigating associations between land-cover based green space and physical activity across a broad age range of children and adolescents (McGrath, Hopkins, & Hinckson, 2015). In addition, research was mainly conducted in North America (Nordbø et al., 2020). The objectives of this study were to a) investigate associations between green space and children's and adolescent's physical activity across urban and rural areas in Germany, and b) explore if these associations are moderated by socio-demographic characteristics. We hypothesize that associations between green space and physical activity would differ across urban and rural areas.

2. Methods

We used data from the Motorik-Modul (MoMo) study. The MoMo study is a nationally representative study in Germany that investigates physical activity, physical fitness, and health indicators in children and adolescents aged four to 17 years using a cohort-sequence design (Woll et al., 2021). We utilized cross-sectional data from survey period "Wave 3 (2018–2022)" as this was the only wave for which we could obtain the address data of the participants.

2.1. Participants and procedures

To select participants for the survey period "Wave 3 (2018–2022)", a nationwide multi-stage sampling approach was used with two evaluation levels to ensure representativeness (Woll et al., 2021). First, a systematic sample of 167 primary sampling units was chosen from an inventory of German communities stratified by urbanization and geographic distribution (Kamtsiuris, Lange, & Schaffrath, 2007), with the probability of selection proportional to the number of citizens younger than 18 years in each community. Second, an age-stratified sample of randomly selected children and adolescents was drawn from the official registers of residents.

Due to the Covid-19 pandemic, data collection had to be interrupted after 128 of 167 sampling points were completed. All data used in this study were collected before the first Covid-19 lockdown in March 2020. The spatial distribution of the participants taking part in the study until then is displayed in the *appendix* (Figure S1). Participants were invited to nearby examination rooms for measurement purposes. Study participation was voluntary with written consent obtained from participants' parents or guardians. Parents or guardians of children under the age of eleven years were asked to fill in the questionnaire together with their children. The study was conducted in accordance with the Declaration of Helsinki and ethics approval was obtained from the ethics committee of (Woll et al., 2021).

2.2. Measures

2.2.1. Socio-demographic characteristics and body-mass-index (BMI)

The study collected information on age, gender, and socio-economic status. The latter was determined by a multidimensional score computed based on both parents' occupation, education, and net income data (Lampert, Müters, Stolzenberg, & Kroll, 2014). Trained staff assessed participants' height and weight to establish BMI categories using the International Obesity Task Force's cut-off points (Cole, Bellizzi, Flegal, & Dietz, 2000; Cole, Flegal, Nicholls, & Jackson, 2007).

2.2.2. Urbanicity

From the German Federal Statistics Office community information system, we obtained data on the degree of urbanization (DEGURBA). The DEGURBA classification system is used across Europe to determine the level of urbanization in local administrative units, typically municipalities. It combines geographical contiguity and a minimum population density threshold applied to 1 km^2 population grid cells to assess the degree of urbanization. Based on this assessment, the system assigns three urbanicity levels to each local administrative unit: 1) Rural areas, with over 50 % of the population living in rural grid cells, 2) Towns and suburbs, representing intermediate densely populated areas with over 50 % of the population living in urban clusters and less than 50 % living in urban centers, and 3) Cities, representing densely populated areas with over 50 % of the population living in urban clusters (EU, FAO, UN-Habitat, OECD, & The World Bank, 2021). Using ArcGIS Pro (version 2.8.0), we identified the closest municipality to each participant's home address and matched the corresponding community's urbanicity degree with the participant (Nigg, Oriwol, Wunsch, Burchartz, Kolb, Worth, … Niessner, 2021).

2.2.3. Green space assessment

The development and processing of geospatial data to operationalize the natural environment in this study have been described previously (Nigg, Niessner, Burchartz, Woll, & Schipperijn, 2022). Briefly, we obtained digital land cover and land use data (DE-LBM2018) from the Federal Agency for Cartography and Geodesy which was transformed by the Federal Agency to comply with the European CORINE land cover classification (CLC). We decided to use land cover and land use data instead of vegetation-based green measures (e.g., NDVI), since we assumed from a conceptual perspective that green space facilitates physical activity via green space use, with the overall vegetation cover playing a minor role and as non-usable green space is also included in vegetation-based measures. In addition, we obtained street network data from the dataset Basis-DLM that contains topographical objects with an accuracy of -/+ 3 m. For our purposes, we excluded highways and federal streets as they are only accessible with a motorized vehicle and thus irrelevant for physical activity. Next, we operationalized green space as vegetated and semi-natural areas, such as forests, green urban areas, or pastures, but excluded agricultural areas since they are often not accessible (Matthews, Taylor, Sherwood, Tucker, & Melanie, 2000). Blue space, such as wetlands and water bodies were excluded since previous study results indicate that blue and green space have distinct relationships with health (Nutsford, Pearson, Kingham, & Reitsma, 2016). For a detailed overview which environmental features were included, please see the *appendix* (Table S2). Next, based on the street data, we computed 1000 m-street network buffers around the participant's residential address using the service area solver within the Network Analyst extension of ArcGIS Pro (version 2.6.3). We intersected the 1000 m-street network buffers with the green space layer to calculate the percentage of green space within each network buffer (range: 0–1). Based upon conceptual and geospatial considerations (Nigg, Niessner, Burchartz, Woll, & Schipperijn, 2022), we decided to use a 1000 m-street-network buffer distance since this is considered as a walkable neighborhood distance (Millward, Spinney, & Scott, 2013), thus being practically relevant to emerging climate-friendly and active living design concepts, such as the 15-minute-city (Allam, Bibri, Chabaud, & Moreno, 2022). Additionally, established studies investigating associations between the built environment and physical activity, such as the International Physical Activity and Environment Network (IPEN) Adolescent Study (Cain et al., 2021), used this buffer type and size, facilitating comparability (Nordbø et al., 2020).

2.2.4. Moderate-to-vigorous physical activity (MVPA)

A detailed explanation regarding accelerometer use in this study can be found elsewhere (Burchartz et al., 2020). Participants were instructed to wear an accelerometer (ActiGraph GT3x + or ActiGraph wGT3X-BT) for eight consecutive days, with the first day not being included in the analysis. The devices were provided to participants by qualified research assistants together with a leaflet summarizing important aspects of device placement and handling. Supervised by a research assistant, participants were instructed to place the accelerometer on the right hip and to wear it during waking hours. The data was sampled using a frequency of 30 Hz, downloaded into 1-second epoch length, and re-integrated into 15-second epoch length. Participants were required to wear the device for more than eight hours on at least four weekdays and one weekend day for their data to be considered valid. Two cut-off point systems were used to determine physical activity intensity for specific age groups: six to ten-year-olds (Evenson, Catellier, Gill, Ondrak, & McMurray, 2008) and eleven to 17-year-olds (Romanzini, Petroski, Ohara, Dourado, & Reichert, 2014).

2.3. Statistical analysis

All analyses were conducted using R Studio (version 4.2.2). To investigate the relationship between green space and MVPA, we used multiple linear regression models based upon green space quartiles (bottom [1st] quartile; middle [2nd] quartile; upper [3rd] quartile; top [4th] quartile) and stratified by urbanicity degree. We decided to use green space quartiles due to limited variability, an approach applied in previous environment and physical activity studies (Foster, Giles-Corti, & Knuiman, 2014; Villeneuve, Jerrett, Su, Weichenthal, & Sandler, 2018). We grouped green space into quartiles for each urbanicity category (see *appendix* Table S1 for threshold and mean values for each quartile). The bottom quartile was set as the reference category in all analyses. Since previous studies showed physical differences based on the socio-demographic characteristics age, gender, socioeconomic status, and weight status, we included these variables as co-variates in each model (Elmesmari, Martin, Reilly, & Paton, 2018; Sterdt, Liersch, & Walter, 2014). For weight status, we collapsed the categories "overweight" and "obese" into one category due to too low case numbers in the latter one. Since data plotting revealed a non-linear association between age and MVPA, we formed two age groups based on the data plotting and theoretical assumptions, with one category including six to ten-year-olds (children in primary school) and the other category including eleven to 17-year-olds (adolescents in secondary school). In addition, we included accelerometer wear time as covariate as well as the season during which accelerometer data were collected since MVPA may depend on seasonal characteristics, such as temperatures (Turrisi et al., 2021). Based upon the German meteorological weather service, we assigned each month to a season: spring (March-May), summer (June-August), autumn (September-November), and winter (December-February).

Furthermore, results of previous studies indicate that associations between green space and physical activity may vary between population groups, such as age, gender, and socio-economic status (Rigolon, Browning, McAnirlin, & Yoon, 2021; Sanders, Feng, Fahey, Lonsdale, & Astell-Burt, 2015; Young et al., 2014). Hence, within each urbanicity level, we calculated interactions between green quartiles and age group, gender, and socio-economic status. Model assumptions were visually inspected using the package "performance" (Lüdecke, Ben-Shachar, Patil, Waggoner, & Makowski, 2021).

To examine the influence of missing data on our results, we imputed missing data in a sensitivity analysis including all participants who had agreed to wear an accelerometer ($N = 1{,}211$). For participants not fulfilling the accelerometer wear time conditions, wear time and MVPA were set as missing. Using the Multivariate Imputation via Chained Equations (MICE) package (Van Buuren & Groothuis-Oudshoorn, 2011), for each variable containing missing values, an imputation model was specified, with the algorithm iteratively imputing multiple possible values for the missing values, accounting for the uncertainty of the missing value imputation and increasing the plausibility for missing at random. Data were imputed for each urbanicity level separately. For each urbanicity level, we used polytomous regression (polyreg) imputation for categorical variables and predictive mean matching (pmm) for continuous variables to generate 20 datasets with 10 iterations. We included all predictors and co-variates as well as the outcome (MVPA) in the imputation model.

3. Results

3.1. Descriptive statistics

Overall, 2,357 children and adolescents between six and 17 years participated in the study wave. Of those, 1,211 children and adolescents participated in the accelerometer assessment, with 949 of them providing valid accelerometer data. We included only those participants in the analysis that had complete data on all variables including co-variates, resulting in *N* = 923. Comparing those with complete data (*N* = 923) to those without complete data and who did not participate in the accelerometer assessment (N = 1,434) revealed some statistically significant differences: Those with complete data were slightly older, had slightly higher socio-economic status scores, had a slightly higher proportion of children and adolescents with normal weight status, and were more likely to be from rural areas or small towns. No statistically significant differences emerged for gender and green space. Although some differences were statistically significant, effect sizes indicated that differences were small to negligible (strongest effect size: Cohen's *d* = 0.19 for age differences). For a detailed overview, see *appendix* Table S3.

Participants with complete data (*N* = 923) were on average 11.22 (*SD* = 3.34) years old, 50.05 % were girls, and 14.19 % were categorized as overweight or obese. Thirty-five percent lived in rural areas, 42 % in towns and suburbs, and 23 % in cities. A detailed overview of socio-demographic information, weight status, and study variable descriptive results for participants with complete data can be found in Table 1 and for all participants that participated in the accelerometer assessment (*N* = 1,211) in the *appendix* (Table S8).

Table 1
Descriptive Information about the Study Sample.

	Rural areas (*N* = 324)	Town/ suburb (*N* = 391)	Cities (*N* = 208)	Overall (*N* = 923)
Gender				
Boys	164 (50.62 %)	195 (49.87 %)	102 (49.04 %)	461 (49.95 %)
Girls	160 (49.38 %)	196 (50.13 %)	106 (50.96 %)	462 (50.05 %)
Age in years (*Mean, SD*)	11.55 (3.38)	10.99 (3.40)	11.00 (3.14)	11.19 (3.34)
Age groups				
6–10 years	155 (47.84 %)	212 (54.22 %)	113 (54.33 %)	480 (52.00 %)
11–17 years	169 (52.16 %)	179 (45.78 %)	95 (45.67 %)	443 (48.00 %)
BMI				
Underweight	34 (10.49 %)	31 (7.93 %)	21 (10.10 %)	86 (9.32 %)
Normal weight	236 (72.84 %)	306 (78.26 %)	164 (78.85 %)	706 (76.49 %)
Overweight/obese	54 (16.67 %)	54 (13.81 %)	23 (11.06 %)	131 (14.19 %)
Socio-economic status (*Mean, SD*)	14.73 (3.06)	15.97 (3.33)	15.99 (3.31)	15.54 (3.28)
Season				
Summer	63 (19.44 %)	36 (9.21 %)	31 (14.90 %)	130 (14.08 %)
Autumn	117 (36.11 %)	104 (26.60 %)	62 (29.81 %)	283 (30.66 %)
Winter	81 (25.00 %)	167 (42.71 %)	57 (27.40 %)	305 (33.04 %)
Spring	63 (19.44 %)	84 (21.48 %)	58 (27.88 %)	205 (22.21 %)
Greenspace (0–1)				
Mean (SD)	0.14 (0.15)	0.13 (0.11)	0.14 (0.10)	0.14 (0.13)
Min, Max	0.00, 0.94	0.00, 0.59	0.00, 0.45	0.00, 0.94
Accelerometer wear time in min/day (*Mean, SD*)	823.38 (111.97)	811.58 (102.97)	827.11 (124.75)	819.22 (111.43)
MVPA in min/day (*Mean, SD*)	51.88 (23.79)	55.61 (24.18)	59.43 (23.57)	55.16 (24.05)

3.2. Associations between green space and physical activity (MVPA min/day)

Regression results of the main effects are displayed in Table 2. Results showed that green space was negatively related to physical activity in rural areas, but not in small towns/suburbs, or cities. More specifically, in rural areas, compared to children and adolescents in the bottom quartile, children and adolescents in the middle quartile spent 6.74 (95 %CI [-13.02;-0.46]) and in the upper quartile 6.77 (95 %CI [-13.05;-0.50]) minutes less in MVPA per day. There was no statistically significant difference for the top quartile.

3.3. Interaction effects between green space and socio-demographic characteristics regarding MVPA (min/day)

Interaction analysis revealed statistically significant interactions only for cities, but not for rural areas or small towns (see also *appendix* Tables S4-S6). Hence, all following result presentations refer to cities only.

Regarding gender differences, boys and girls displayed similar MVPA levels in the bottom green quartile. Girls showed similar MVPA levels across green quartiles. However, boys in the middle green quartile engaged in 14.58 (95 %CI [3.27;25.90]) more MVPA than those in bottom green quartile, leading to gender differences for MVPA in the middle green quartile (*B* = -19.96, 95 %CI [-34.94;-4.97]): Boys spent 76.73 (95 %CI [66.81, 86.65]) and girls only 55.89 (95 %CI [45.65, 66.14]) minutes in MVPA in the middle green quartile (see also Fig. 1*A*; Appendix Table S4).

Regarding age group differences, in the bottom green quartile, adolescents (eleven to 17 years) engaged in 15.99 (95 %CI [-26.99;-4.99]) minutes less MVPA than children (six to ten years). Adolescents showed similar MVPA levels across green quartiles. Compared to children (six to ten years) in the bottom green quartile, children in the middle green quartile engaged in 10.13 (95 %CI [0.26;20.00]) more MVPA minutes, leading to even more pronounced age group differences (*B* = -16.34, 95 %CI [-31.55;-1.12]): Children engaged in 75.48 (95 %CI [65.79, 85.17]) MVPA minutes in the middle green quartile, but adolescents only in 43.15 (95 %CI [32.83, 53.48]) (see also Fig. 1*B*; *appendix* Table S5).

Regarding socio-economic status differences, a higher socio-economic status was related to less MVPA in the bottom green quartile (see also *appendix* Table S6). Green space and socio-economic status interacted for youth in the upper (*B* = 3.40, 95 %CI [1.18;5.62]) and top (*B* = 2.57, 95 %CI [0.30;4.84]) green quartile. To allow for more robust conclusions, we split city youth into socio-economic status tertiles (1st tertile: low, 2nd tertile: medium, 3rd tertile: high) and calculated an additional model. Results revealed that in the bottom green quartile, youth with a medium and high socio-economic status spent less time in MVPA compared to youth with low socio-economic status. In the upper green quartile, youth with a low socio-economic status spent 20.26 (95 %CI [-34.05;-6.48]) minutes less in MVPA compared to low socio-economic status youth in the bottom green quartile. For the upper and top green quartile, the differences between the socio-economic status groups vanished (see also Fig. 2*; appendix* Table S7).

Result patterns were similar when missing data was imputed and

Table 2
Multiple Linear Regression Analysis with Green Space Stratified by Urbanicity Level Predicting MVPA (Minutes/Day).

	Rural areas					Small towns and suburbs					Cities				
	B	*SE*	*β*	*95 %CI*	*p*	*B*	*SE*	*β*	*95 %CI*	*p*	*B*	*SE*	*β*	*95 %CI*	*p*
(Intercept)	70.73	3.64	0.79	63.56;77.90	<0.001	74.41	4.42	0.78	65.71;83.11	<0.001	68.06	4.36	0.37	59.45;76.67	<0.001
Green space (reference: Bottom [1st] quartile)															
Middle [2nd] quartile	−6.74	3.19	−0.28	−13.02;-0.46	0.035	−0.27	2.94	−0.01	−6.05;5.51	0.927	3.29	3.87	0.14	−4.34;10.92	0.396
Upper [3rd] quartile	−6.77	3.19	−0.28	−13.05;-0.50	0.035	−0.35	3.02	−0.01	−6.28;5.59	0.909	0.20	3.86	0.01	−7.41;7.81	0.958
Top [4th] quartile	−6.01	3.17	−0.25	−12.25;0.22	0.059	1.22	3.04	0.05	−4.76;7.20	0.689	−0.05	3.87	−0.00	−7.69;7.59	0.990
Gender (ref. boys)	−0.52	0.37	−0.07	−1.26;0.21	0.164	0.42	0.32	0.06	−0.21;1.05	0.189	−0.49	0.41	−0.07	−1.30;0.33	0.238
Age group (ref. 6–10 years)	−8.81	2.29	−0.37	−13.32;-4.30	<0.001	−11.48	2.09	−0.48	−15.60;-7.37	<0.001	−12.38	2.78	−0.53	−17.87;-6.90	<0.001
Socio-economic status	−23.49	2.35	−0.99	−28.11;-18.87	<0.001	−21.67	2.17	−0.90	−25.93;-17.41	<0.001	−23.41	2.85	−0.99	−29.04;-17.78	<0.001
BMI (ref. normal weight)															
Underweight	0.97	3.73	0.04	−6.37;8.30	0.795	−4.44	3.91	−0.18	−12.13;3.25	0.257	−3.14	4.63	−0.13	−12.28;5.99	0.498
Overweight/obese	−8.96	3.10	−0.38	−15.05;-2.86	0.004	−11.47	3.07	−0.47	−17.51;-5.43	<0.001	−7.97	4.41	−0.34	−16.66;0.72	0.072
Season (ref. summer)															
Autumn	6.41	3.19	0.27	0.14;12.68	0.045	−4.04	4.11	−0.17	−12.13;4.04	0.326	14.48	4.39	0.61	5.82;23.13	0.001
Winter	0.78	3.38	0.03	−5.87;7.44	0.817	−2.87	3.79	−0.12	−10.32;4.58	0.449	8.30	4.41	0.35	−0.39;16.99	0.061
Spring	7.76	3.66	0.33	0.56;14.97	0.035	4.49	4.13	0.19	−3.62;12.61	0.277	7.60	4.36	0.32	−0.99;16.19	0.082
Wear time	0.02	0.01	0.08	−0.00;0.04	0.086	0.02	0.01	0.09	−0.00;0.04	0.051	0.00	0.01	0.02	−0.02;0.03	0.783
N	324					391					208				
R^2 / R^2 adjusted	0.32 / 0.30					0.31 / 0.29					0.38 / 0.34				

Note: For better interpretability of the intercept, socio-economic status and accelerometer wear time were grand-mean centered. BMI = body-mass-index; ref. = reference.

included in the analysis (see *appendix* Table S9-S12*)*.

4. Discussion

Using device-based physical activity and objective green space assessment, we found that associations between green space and health-enhancing physical activity (MVPA) differed across urban and rural areas in a large sample of children and adolescents across Germany. For children and adolescents in cities, relationships were moderated by socio-demographic characteristics.

More specifically, for the whole sample, we found that in rural areas, green space was associated with less physical activity for children and adolescents in the middle and upper green quartiles. For towns and cities, no such relationships emerged. The negative association for rural areas compared to towns and cities may be the result of the green space context and quality being different in rural compared to more urban areas. For example, two qualitative studies with rural parents, adolescents, and children in North America investigated physical activity opportunities and barriers, and showed that parks were predominantly mentioned as a place that was unsafe for physical activity due to train tracks close by as well as drug and gang activities (Findholt, Michael, Jerofke, & Brogoitti, 2011; Hennessy et al., 2010). Beyond safety aspects, other characteristics seem to play a role to use green space for physical activity, which includes physical characteristics, such as green space infrastructure (e.g., parking lots, bike racks; Schipperijn, Bentsen, Troelsen, Toftager, & Stigsdotter, 2013), but also social aspects such as a community feeling and the presence of other people as a protective network (Noël, Landschoot, Vanroelen, & Gadeyne, 2021). In urban green space studies, such features have been summarized and analyzed in terms of availability, accessibility, and attractiveness (Biernacka et al., 2020). Features beneficial for green space availability, accessibility, and attractiveness are typical for developed green space that contain some elements of construction (King & Clarke, 2015), but less present for undeveloped green space. With rural areas having more undeveloped green space (King & Clarke, 2015), such features are probably less prevalent in rural green space. This may be another explanation for our findings. For towns and suburbs, green space was consistently unrelated to physical activity, with the reasons for this remaining to be further investigated.

Or results indicate that the association between green space and physical activity varied based on socio-demographic characteristics. Children between six and ten years in cities in the middle green quartile showed enhanced MVPA engagement, reinforcing age group differences. For adolescents, MVPA engagement was similar across green quartiles. This supports previous results regarding distinct green space-physical activity associations across urban and rural areas in children (Craggs et al., 2011) and adolescents (Babey et al., 2008). A reason for this may be that compared to adolescents, children collect more MVPA through outdoor play (Nigg, Niessner, Nigg, Oriwol, Schmidt, & Woll, 2021). Thus, green space may be more important for them as an outdoor play location. The converse associations between green space and MVPA in rural areas and cities may be again explained by the type of green space exposure. For example, a study with parents of children between six and twelve years focusing on play environments showed that undeveloped natural spaces, e.g., forests, are less used by children than developed outdoor green spaces, such as playgrounds (Gundersen, Skår, O'Brien, Wold, & Follo, 2016). Since developed green space is more likely in cities than in rural areas (King & Clarke, 2015), this may explain the distinct associations between green space and physical activity in cities and rural areas. Practically speaking, this means that the availability of abundant undeveloped green space in rural areas does not compensate for the lower availability of developed green spaces in relation to children's physical activity. For that reason, it is important to also provide high quality developed green spaces in rural areas.

The same pattern as for age group was observed for gender: City boys in the middle quartile show increased physical activity engagement,

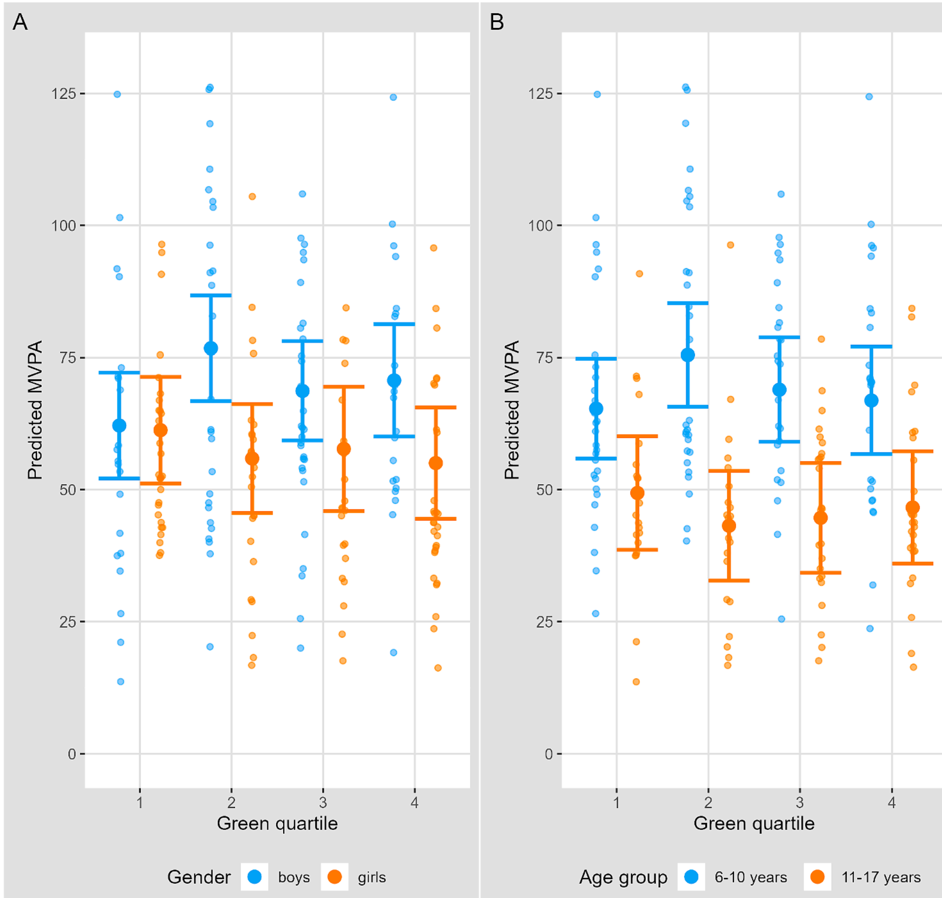

Fig. 1. Gender (A) and age group (B) moderating the association between green space and MVPA in cities. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

girls displayed similar MVPA engagement across green quartiles. While these effects may be partially confounded by the fact that younger children were also more likely to be boys in our sample, another reason may also be that boys spend in general more time outdoors than girls (Klinker, Schipperijn, Kerr, Ersbøll Kjær, & Troelsen, 2014), and engage in more independent mobility than girls, especially in urban areas (Stone, Faulkner, Mitra, & Buliung, 2014). Thus, they may have more opportunities to use green space for physical activity. The negative associations between green space and physical activity may be also reinforced by decreasing levels of independent mobility in rural areas (Kyttä, Hirvonen, Rudner, Pirjola, & Laatikainen, 2015). Interestingly, the benefits of green space for MVPA in cities were only observed for the middle green quartile. This may indicate again that for green space to be beneficial for MVPA, it must be combined with other physical and social environment characteristics instead of only providing abundant green space (Findholt et al., 2011; Hennessy et al., 2010; Noël et al., 2021; Schipperijn, Bentsen, Troelsen, Toftager, & Stigsdotter, 2013).

Finally, we found that associations between physical activity and green space were moderated by socio-economic status for city youth: City youth with a low socio-economic engaged in most MVPA in the bottom green quartile, which was not the case for youth with medium and high socio-economic status. However, with low socio-economic status youth tending to engage in less physical activity with more green space, physical activity levels assimilated across socio-economic status groups. Although a recent systematic review found that most studies exhibited stronger health benefits of green space for people with low socio-economic status, the same review also showed that associations between green space and health benefits varied across socio-economic status groups (Rigolon et al., 2021). In our study, this finding may be the result of gentrification, referring to the process in which neighborhoods of lower socio-economic status receive an increased influx and investment of residents with higher socio-economic status (Hwang & Lin, 2016). This problem has also been encountered in the urban greening context (Sax, Nesbitt, & Quinton, 2022), showing that equal provision of neighborhood green space does not guarantee the same health benefits for all neighborhood residents (Lennon, Douglas, & Scott, 2019). More specifically, urban green space is often targeting the needs of middle- and higher-income residents, with the needs of less privileged residents being neglected (Anguelovski et al., 2019; Haase et al., 2017). This may reflect also in our results, with green space not fulfilling the needs of low socio-economic status youth, leading to displacement (Sax et al., 2022) and thus to less green space use and physical activity. Institutions and policy makers should ensure green space availability, accessibility, and attractiveness (Biernacka & Kronenberg, 2018; Biernacka, Łaszkiewicz, & Kronenberg, 2022), especially for vulnerable and marginalized groups (Anguelovski et al., 2020). Complementing formal green areas (e.g., parks) with informal green areas in cities (e.g., along streets or between housing units) may be one option to especially target vulnerable groups in cities (Sikorska, Łaszkiewicz, Krauze, & Sikorski, 2020). Another explanation for those results could be the deprivation amplification hypothesis, stating that poorer populations live in contextually disadvantaged areas (Nogueira, 2010). This hypothesis was for example confirmed in one playground study, showing that poorer children also had lower quality playgrounds (Buck, Bolbos, & Schneider, 2019), Transferred to our study, this may indicate that poorer children are exposed to more low-quality green space compared to youth with medium or high socio-economic status, which may lead to less green space use.

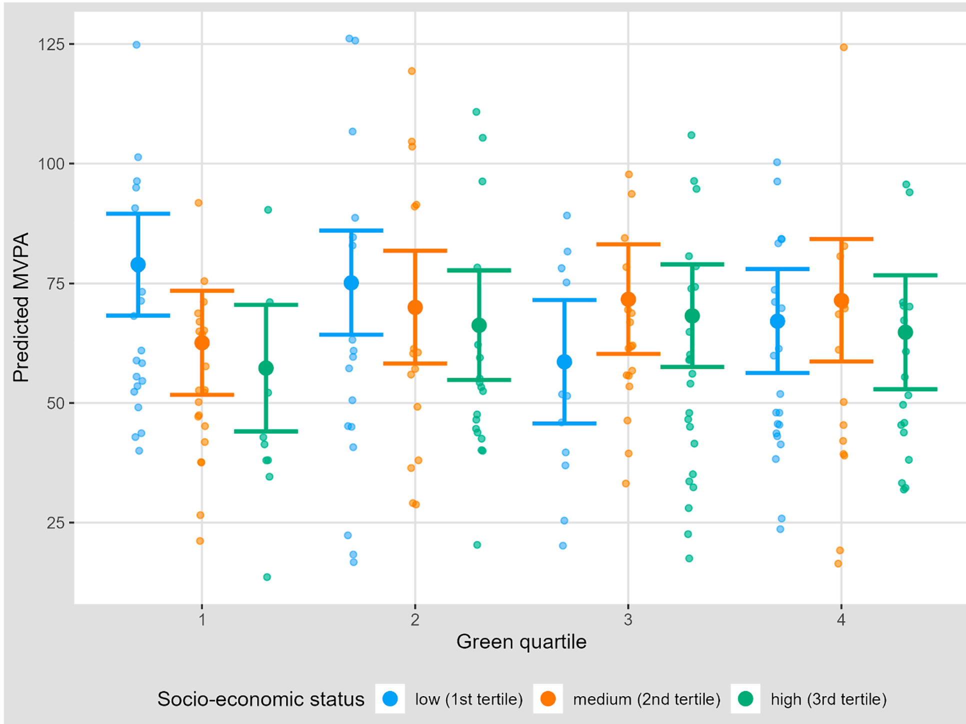

Fig. 2. Socio-economic status moderating the association between green space and MVPA for city youth. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

4.1. Strengths, limitations, and future research directions

A strength of our study is that we investigated associations between objectively assessed green space via individual-level street-network buffers and device-based assessed physical activity across urban and rural areas in a broad age range of children and adolescents with varying socio-demographic characteristics, while previous studies focused predominantly on children or adolescents in urban areas within a limited age range or within a specific sub-population (e.g., Babey et al., 2008; Craggs et al., 2011; Markevych et al., 2016; Oreskovic et al., 2014; Young et al., 2014).

However, our study does not come without limitations. First, the cross-sectional character of our study limits any causal conclusions. Second, we calculated green space based on land cover and land use data, which merely considers the quantitative amount of green space, while qualitative characteristics of green space were neglected. Evaluating specific green space characteristics could provide valuable information to explain distinct associations between green space and physical activity for urban and rural areas well as for different subpopulations. This includes green space type (Hunter et al., 2019) as well as green space infrastructure both from a facilitator-perspective, such as playground or sports fields, walking paths, barbeques, and public access toilets (Edwards, Hooper, Knuiman, Foster, & Giles-Corti, 2015) and from a barrier-perspective (e.g., noise, air pollution, fences; Biernacka, Kronenberg, and Łaszkiewicz (2020). Such information could also be used to guide green space planning for active living in both urban and rural areas. We focused on general health-enhancing physical activity, operationalized as MVPA, but did not assess specific activity domains. For example, a previous study with rural children showed that parks were negatively related to active commuting, but unrelated to total daily MVPA (Oreskovic et al., 2014), whereas other studies emphasize natural environments as being facilitators for active recreational and exercise activities (Findholt et al., 2011; Hennessy et al., 2010). Furthermore, while we selected green space, buffer type, and buffer size based on conceptual and practical considerations as well as previous evidence (Nigg et al., 2022), we cannot be sure that our metrics were relevant to our study sample, known as the uncertain geographic context problem (Kwan, 2012). Hence, using ambulatory assessment methods via combining accelerometers for physical activity assessment with geolocation tracking in future studies would allow for capturing individual's activity space as well as green space utilization information (Jankowska, Schipperijn, & Kerr, 2015).

5. Conclusion

Our study found that green space and physical activity show distinct associations across rural areas and cities, with green space in rural areas being associated with less physical activity. In cities, boys or children may benefit from some green space. Socially disadvantaged children and adolescents in cities engaged in less physical activity with more green space. Further studies should investigate green space quality characteristics and how they relate to physical activity across urban and rural areas. Our findings are important to support planning policies for creating inclusive active living environments across urban and rural areas.

Funding

This work has been developed within the Motorik-Modul Longitudinal Study (MoMo) (2009 – 2022): Physical fitness and physical activity as determinants of health development in children and adolescents. MoMo is funded by the Federal Ministry of Education and Research (funding reference number: 01ER1503) within the research program ‚long-term studies' in public health research. Carina Nigg gratefully acknowledges funding from the German Academic Scholarship Foundation (Studienstiftung des deutschen Volkes).

CRediT authorship contribution statement

Carina Nigg: Formal analysis, Methodology, Visualization, Writing –

original draft. **Janis Fiedler:** Formal analysis, Writing – review & editing. **Alexander Burchartz:** Conceptualization, Funding acquisition, Methodology, Writing – review & editing. **Markus Reichert:** Supervision, Writing – review & editing. **Claudia Niessner:** Conceptualization, Methodology, Writing – review & editing. **Alexander Woll:** Conceptualization, Funding acquisition, Methodology, Writing – review & editing. **Jasper Schipperijn:** Methodology, Supervision, Writing – review & editing.

Data availability

Data will be made available on request.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.landurbplan.2024.105068.

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