Scientific Reports
https://doi.org/10.1038/s41598-026-61980-y
Article in Press

Germany's youth city versus rural dwellers engage in more moderate-to-vigorous physical activity

Received: 26 August 2024
Accepted: 8 July 2026
Published online: 17 July 2026

Cite this article as: Reichert M., Nigg C., Fiedler J. *et al.* Germany's youth city versus rural dwellers engage in more moderate-to-vigorous physical activity. *Sci Rep* (2026). https://doi.org/10.1038/s41598-026-61980-y

Markus Reichert, Carina Nigg, Janis Fiedler, Sarah Brüßler, Alexander Burchartz, Darko Jekauc, Matthias F. Limberger, Janina Krell-Roesch, Birte Haaren-Mack, Ulrich W. Ebner-Priemer, Claudia Niessner, Jasper Schipperijn & Alexander Woll

Germany's Youth City vs. Rural Dwellers Engage in More Moderate to Vigorous Physical Activity

Markus Reichert, PhD*[1,2,3], Carina Nigg, PhD*[2,4], Janis Fiedler, PhD[2], Sarah Brüßler, MSc[2], Alexander Burchartz, MSc[2], Darko Jekauc, PhD[2], Matthias Limberger, MSc.[2], Janina Krell-Rösch, PhD[2], Birte von Haaren-Mack, PhD[2], Ulrich Ebner-Priemer, PhD[2], Claudia Niessner, PhD[2], Jasper Schipperijn, PhD[5], Alexander Woll, PhD[2]

[1] Department of Sport and Exercise Science, Faculty of Natural and Life Sciences, University Salzburg, Austria

[2] Institute of Sports and Sports Science, Karlsruhe Institute of Technology, Germany

[3] Department of Psychiatry and Psychotherapy, Central Institute of Mental Health, Medical Faculty/University of Heidelberg, Germany

[4] Institute of Social and Preventive Medicine (ISPM), University of Bern, Switzerland

[5] Department of Sport Science and Clinical Biomechanics, University of Southern Denmark, Denmark

Corresponding authors*:

Markus Reichert, Department of Sport and Exercise Science, Faculty of Natural and Life Sciences, University Salzburg, Schlossallee 49, 5400 Hallein, Austria.

Email: markus.reichert@plus.ac.at

Carina Nigg, Institute of Social and Preventive Medicine, University of Bern, Mittelstrasse 43, 3012 Bern, Switzerland. Email: carina.nigg2@unibe.ch

Germany's Youth City vs. Rural Dwellers Engage in More Moderate to Vigorous Physical Activity

Abstract

Rapid urbanization poses the question how city living impacts human physical activity, especially in the population of vulnerable youth. This study aimed to examine urban-rural differences in moderate-to-vigorous physical activity (MVPA) among children and adolescents in

Germany in a large German national study, across two independent samples (Discovery study: *N* = 2,734; Replication study: *N* = 1,196) of children and adolescents (6-17 years), with accelerometer-assessed MVPA, and across two different urbanicity assessments. In both studies, city youth engaged in more total MVPA than rural youth and were more likely to comply with the physical activity guidelines of the World Health Organization. While city living and total MVPA were independent of age and gender, age groups differed regarding physical activity guideline compliance. These results point towards a potential positive implication of urbanization for physical activity and suggest actions to target rural areas for physical activity promotion, if findings are validated towards causality in future studies.

Keywords: children, adolescents, physical activity guidelines, urbanization, cities

Germany's Youth City vs. Rural Dwellers Engage in More Moderate to Vigorous Physical Activity

Both nature and nurture shape human health. Global urbanization in the 21st is the most large-scale reorganization of environments humanity has faced in the last centuries, with two-thirds of the global population expected to live in cities by 2050[1].

However, the issue of how urban living impacts physical activity in children and adolescents remains under-investigated. This is especially relevant when considering that 81% of children and adolescents are engaging in less than 60 minutes of moderate-to-vigorous physical activity (MVPA) per day, thus failing to achieve health-enhancing physical activity levels as recommended by the World Health Organization[2]. As physical activity is positively related to behavioral, mental, and physical health[3,4], while insufficient physical activity is constituting an enormous economic burden with an estimate of INT$48 billion annual health care costs[5], understanding and promoting determinants of physical activity remains a major societal challenge. While the exact dose-response effects of MVPA increases on physical and mental health benefits in children and adolescents remain subject of future investigations, general positive health effects are well-evidenced, e.g., on cardiovascular disease risk, cardiorespiratory fitness, and body composition[6,7].

To tackle the problem of physical activity, the World Health Organization considers creating active environments as one of four key strategies in its global action plan on physical activity.[8] This assumption is supported by ecological models of health behavior, which emphasize the impact of environmental features on physical activity; for example, public sports facilities, traffic safety, and stimulating natural environments may foster engagement in physical activity.[9] While previous studies investigated associations between city living's environmental characteristics and physical activity in adults[10,11], studies in children and adolescents are sparse. Moreover and taking an international perspective, Rogers and colleagues just recently stated as an central finding of their review "that the examination of physical activity resources/opportunities in rural communities is lacking"[12], a view that had already been presented in the Global Matrix 4.0 investgation on physical activity indicators of children and adolecents[12] and had been concluded by previous reviews, see e.g., Aubert and colleagues[13]. Looking at empirical evidence in children and adolescents, previous studies found that in general, park and playground equipment, mixed land use, short distances to facilities, better walkability, and infrastructure for walking and cycling to be associated with youth's physical activity[14,15] – features that are commonly more prevalent in urban areas[16]. Indeed, a study in Italy found that children in Italy children living in cities attended schools showing a higher Walk Score® compared to children living in rural areas[17], and Reimers and colleagues report as a result of their study conducted in Germany that "adolescent girls living in rural areas participation in indoor sports activities was positively associated with gym proximity"[18].

In general taking a translational perspective against the background of potential future public health interventions, Rogers and colleagues emphasize a study revealing that "outdoor public open spaces and amenities for physical activity, such as trails, are lacking in rural communities, and those that do exist are often poorly maintained or informal"[12]. In particular, Germany's rural areas are experiencing demographic changes with an aging population and people with higher education moving to urban areas, which is associated with changes in the rural infrastructure, such as fewer schools, education opportunities, public transport options, and shopping and leisure facilities, which may have deteriorated physical activity opportunities for children and adolescents[19].

Summarizing the evidence on the issue of how urbanization relates to MVPA in youth, to date a highly heterogenous picture arises: in McCormack and Meendering's[20] review, five studies did not find differences between urban and rural adolescents for moderate-to-vigorous physical activity, nine studies reported higher moderate-to-vigorous physical activity in rural youth, and one study in urban youth. In 2014, McCrorie et al. found adolescents living in more densely populated areas were slightly more likely to be physically active[21], but in 2020, they could not find significant differences in MVPA[22]. Fan and Cao[23] reported boys in urban areas were 14% more likely to meet the physical activity WHO physical activity guidelines than their rural peers, a finding that was not true for girls.

However, existing studies are limited in various domains such as the use of (a) self-report instead of reliable device-based measures (b) small non-representative samples, including (c) restricted age ranges in youth, and, (d) inconsistent and rough definitions of urban and rural areas. Therefore, in this study, our main goal was to investigate how urban and rural living relates to MVPA in children and adolescents in a large representative sample of German children and adolescents aged six to 17 years. We used reliable device-based measures and two different systems to assess urbanicity. Following ecological models (e.g., Sallis and Owen[9]), we hypothesized an increased volume of MVPA in children living in more urban areas; second, we hypothesized an increased likelihood of meeting the WHO physical activity guidelines[2].

Method

Procedures

For this study, data was obtained from the Motorik-Modul (MoMo) Study[24] follow-ups T3 and T4, an in-depth study within the German Health Interview and Examination Survey for Children and Adolescents (KIGGS) conducted by the Robert Koch Institute[25,26]. In general, the MoMo study is dedicated to study physical activity in a nationwide, representative cohort of children and youth in Germany; thus, it applied broad inclusion and minimal exclusion criteria, for example considering ethical, practical, and test specific medical criteria. The sample size was determined by the sampling design. For details on the MoMo methodology, see [24,27,28].

In particular, we only used data obtained in the second follow-up (T3, named “discovery study” in the following) and the third follow-up (T4 prior to the Covid-19 pandemic, named “replication study” in the following) as accelerometer-data was only collected in those study waves. Of note, MoMo[24] baseline data (T1) was collected between 2003 and 2006, with the first follow-up between 2009 and 2012 (T2), the second follow-up between 2015 and 2017 (T3), and the third follow-up between 2018 and 2022 (T4). In addition to the participants examined longitudinally, a representative of children and adolescents between four and 17 years was recruited based on census tract data on age, gender, migration, and social status at each follow-up. The study was conducted according to the Declaration of Helsinki. For MoMo, ethics approval was granted by the ethics committee of the Karlsruhe Institute of Technology on September 23rd, 2014. For measurement purposes, participants were invited to examination rooms within proximity to their homes, where they filled out a questionnaire and received the accelerometer. Participants and their parents were informed in detail about the study and data management. Written informed consent was provided by participants above 15 years of age or legal guardians (if participants were 15 years or younger). For participants under the age of 18 years, the presence of a legal guardian was mandatory.

Participants

Study participants were selected based on a multi-stage sampling approach from the KiGGS study with two evaluation levels.[29] First, a systematic sample of 167 primary MoMo test sites was selected from an inventory of German communities stratified according to the classification system that measures the level of urbanization and geographic distribution; that is, at 167 MoMo test sites data for the study had been acquired. Second, based on the official registers of local residents, an age-stratified sample of randomly selected children and adolescents was drawn; see also [24,27,28].

To be eligible for the discovery study, participants had to be part of the second follow-up study of MoMo (2015-2017; T3), participate in the accelerometry-measurement, and be younger than 18 years.

To be eligible for the replication study, participants had to be part of the third follow-up of MoMo (T4; 2018-2022 prior to the pandemic), participate in the accelerometry-measurement, and be younger than 18 years. Due to the Covid-19 pandemic, data could not be collected at all 167 MoMo test sites but had to be interrupted after 128 sampling points were completed. All data used in this study (2018-2020) had been collected prior to the first Covid-19 related lockdown in Germany in March 2020[30,31].

For the here presented analyses, no participants have been included who did follow up throughout T1-T4. In particular, the MoMo study comprises both cross-sectional and longitudinal participants, and we excluded the longitudinal participants for reasons of potential confounding by dependent data for a subset of the sample. Of note, the longitudinal participants had not been considered when drawing the representative sample for the MoMo project. In other words, a representative sample was drawn for each study wave, while individuals who had previously participated were invited again on top of that. For details on the recruitment procedure of MoMo project see[28].

Measures

Socio-demographic and health variables

For each participant, gender, age, socio-economic status, and weight status were assessed and included as covariates into the regression models, see below. The socio-economic status includes information about the parents' education, monthly household income, and job qualification and level. This information is used to create a score between three and 21, with higher values representing a higher socio-economic status. In particular, from both parents, occupational status as well as education level were assessed (scores ranging from 1 to 7 points, respectively). The higher score of the two parents was applied; for single-parent households, we considered the occupational status and education level of the parent residing with the child. The disposable household income was standardized and transformed to scores ranging from 1 to 7 points. Finally, the three scores were summed up[32]. Towards BMI assessment, height and weight were measured by trained research staff and the weight status of participants was determined based on the cut-off points of the International Obesity Task Force [IOTF].[33,34]

***Physical activity*.**

Participants were asked to wear an accelerometer (ActiGraph GT3x+ or ActiGraph wGT3X-BT; physical dimensions: 4.6×3.3×1×5 centimeters; weight: 19 grams) for eight consecutive days. The deviced included a three-axial acceleration sensor (sensitivity: 3milli-g; range: ±6g; resolution: 30-100 Hertz; epoch lengths: 1-240 seconds). The devices were handed out to participants by qualified research assistants with important aspects being summarized on a leaflet to take home. For example, the devices should not be worn during bedtime, and when swimming or showering. Participants were instructed to place the accelerometer laterally on the right hip (above the right anterior superior iliac spine; closure to the top), which was supervised by a research assistant. To minimize the Hawthorne effect, where participants may alter their behavior due to being observed, we excluded the first day of accelerometer wear from the analysis.[35] Data was sampled using a frequency of 30 Hz. The software ActiLife (version 6.13.3) was used to convert the downloaded data into 1-second-epochs. Data were further processed into 15-second-epochs using the software "MATLAB". We chose small epoch lengths to consider potential sporadic activity of children and youth. Non-wear time was defined as 90 minutes without consecutive zero/non-zero counts based on the Choi algorithm.[36] Two-minute intervals of non-zero counts with the up- /downstream 30-minute consecutive zero count windows were allowed to detect artificial movements[36]. To be considered a valid dataset, participants had to wear the device for more than eight hours on at least four weekdays and one weekend day. To classify physical activity intensity, we applied different established cut-off points depending on the age groups researched; in particular, for this study, two cut-off point systems were applied that are commonly used for the specific age groups of six to ten-year-olds[37] and for eleven to 17-year-olds[37]. A detailed description of the use of accelerometers including a description of data preprocessing in the MoMo study is available elsewhere[24].

Urbanicity**.** In the discovery study, the participant's address data was not available for data protection issues. Hence, we assessed the level of urbanicity based on the German national categorization system for political community sizes, a categorization system that is used to investigate influences on mobility.[38] While there is no consensus on political community sizes, the following categorization has been commonly applied in federal reports and statistics.[38] 1) city (≥ 100,000 citizens); 2) medium-sized town (20,000 – 99,999); 3) small town (5,000 – 19,999), and 4) rural (< 5,000 citizens). We decided to use this system to allow for policy-relevant conclusions of our study and comparability with previous studie[38].

In the replication study, we obtained data on the degree of urbanization (DEGURBA) from the German Federal Statistics Office's community information system. The DEGURBA classification is a European-wide classification system that uses a combination of geographical contiguity and minimum population density threshold applied to 1 km^2 population grid cells to determine the urbanization degree for local administrative units – usually communes. Based on these grid cells, three urbanicity levels are determined: 1) Cities, representing densely populated areas, with at least 50% of the population living in urban clusters; 2) Towns and suburbs, representing intermediate densely populated areas, with at least 50% of the population living in urban cluster and less than 50% living in urban centers, and 3) Rural areas, with at least 50% of the population living in rural grid cells.[39,40] Using ArcGIS Pro (version 2.8.0), we calculated the closest (sub-)community to the participant's home address and matched the urbanicity degree of the corresponding community with the participant.[31] The DEGURBA classification was selected for the replication study as it provides a standardized, European-wide framework for defining urbanicity based on population density and geographical contiguity. Unlike the national administrative boundary-based approach used in the discovery study, DEGURBA offers greater precision in capturing gradients of urbanicity.

Please insert Figure 1 around here

Statistical analysis

All analysis was conducted using R Studio (version 4.2.2)[41] For descriptive statistics, we report means, standard deviations (SD) and absolute frequencies stratified by urban-rural status, including this information on predictors, outcomes and covariates (e.g., age, socio-economic status, accelerometer wear time, and MVPA). Group differences between urban-rural groups were tested using one-way ANOVA for continuous variables and chi-square tests for categorical variables. To investigate the relationship between urbanicity and MVPA, we used multiple linear regression models. We entered urbanicity degree as predictor of interest for MVPA, with rural areas being the reference category. To assess the relationship between urbanicity and the WHO guidelines, we used logistic regression models.

First, we plotted the relationship between the variables included in the model and our outcome. As the plotting revealed a non-linear association between age and MVPA, we formed three age groups based on the data plotting and theoretical assumptions: 6-10 years, which is the typical age during which children attend primary school; 11-13 years as the early adolescent years, and 14-17 years as the adolescent years.

Model assumptions were visually inspected using the package "performance" for both linear and logistic regression[42]. If assumptions seemed to be violated, we used the package "robustbase" to obtain robust regression estimates.[43] The results were compared to the non-robust regression estimates.[42] We report the results of the non-robust model if the results remained substantially unchanged with the robust method.

Based on previous findings, we included age group (reference category: six to ten-year-olds), gender (reference category: boys), socioeconomic status, and weight status (reference category: normal weight) as covariates in the model[7,30,43,44]. For details on the assessment of the potential confounders, see section “Socio-demographic and health variables” above. As associations between environmental features and physical activity may vary based on age and gender[45], we calculated interactions between the urbanicity degree and gender and age in the linear regression models and stratified the analysis by gender and age group in the logistic regression model. To generate result tables, we used the package “sjPlot”[46].

To examine the influence of missing data on our results, we imputed missing data in a sensitivity analysis including all participants in both the discovery and replication study who had agreed to wear an accelerometer. For each participant who did not fulfill the weartime conditions to be considered as a valid accelerometer dataset, we set accelerometer weartime and MVPA as missing data. For imputation, we used the Multivariate Imputation via Chained Equations (MICE) package[47], which can handle data missing at random or missing completely at random. For each variable containing missing values, an imputation model was specified and the algorithm iteratively imputed the missing values with multiple possible values to account for the uncertainty of the missing value imputation and increase the plausibility for missing at random[48]. We generated 20 datasets with 20 iterations, using predictive mean matching (pmm) for continuous variables and polytomous regression (polyreg) imputation for categorical variables. The imputation model included all covariates (agegroup, gender, socio-economic status, weight status, and accelerometer weartime) as well as the outcome (MVPA). Fullfillment of WHO guidelines was calculated from the imputed MVPA results. All analyses were were repeated with the 20 data sets imputated and pooled results were compared to the results of the complete-case analysis.

Results

Descriptives

In the discovery study, a total of N = 2,190 participants had complete information regarding the variables that were included in our statistical models for the discovery study, while in the replication study, a total of N = 923 participants had complete data that were included in our statistical models for the replication study, with the information presented in *Table 1*.

For details regarding socio-demographic information stratified by urban-rural status, see *appendix Table A.1 and Table A.2*. Missing data accounted for 0–20% of all variables. A detailed breakdown of missing values and their imputation is provided in the supplementary materials.

Please insert Table 1 about here

Association between urbanicity and average MVPA per day

Table 2 presents the results of the multiple linear regression model of the discovery study (Adjusted R^2 = 0.31, $F(11, 2178)$ = 90.94, $p < .001$) and the replication study (Adjusted R^2 = 0.31, $F(10, 912)$ = 41.53, $p < .001$). In the discovery study, children in cities engaged on average in 7.12 minutes more MVPA per day than children from rural areas (β = 0.30, $p < .001$). There was also a tendency that children in small towns (β = 0.09, p = .075) and medium-sized towns (β = 0.10, p = .068) engaged in more MVPA per day compared to children and adolescents from rural areas. These findings were confirmed in the replication study, with children and adolescents living in cities engaging on average in 5.73 minutes more MVPA per day than children from rural areas (β = 0.24, p = .002).

In both the discovery and the replication study, we investigated interactions with age and gender, however, none of them turned out to be significant (results not shown).

Please insert Table 2 about here

Association between urbanicity and compliance with the WHO[2] physical activity guidelines

Table 3 presents the results of the logistic regression model for the discovery study (Nagelkerke's R^2 = 0.28) and the replication study (Nagelkerke's R^2 = 0.33). In the discovery study, children and adolescents living in a medium-sized town (OR = 1.43, p = .024) or in a city (OR = 2.04, p < .001) were more likely to meet the physical activity guidelines compared to children and adolescents living in rural areas. In the replication study, children and adolescents living in cities were more likely to meet the physical activity guidelines (OR = 1.20, p = .006). A similar, but non-significant direction was also observed for children and adolescents in towns and suburbs (OR = 1.41; p = .079).

Please insert Table 3 around here

A stratified analysis in the discovery study showed similar results for boys and girls. However in the replication study, when stratified by gender, only girls in cities were more likely to meet the physical activity guidelines (OR = 2.09, p = .023), while for boys, a similar, but non-significant association was observed (OR = 1.72; p = .069).

Moreover, a stratified analysis in the discovery study by age group revealed differences: Adolescents between 14 and 17 years living in a medium-sized town (OR = 2.10, p = .033) or city (OR = 3.81, p < .001) were more likely to meet the physical activity guidelines than their rural counterparts. For six to ten-year-old children, the association was in a similar direction, but non-significant (medium-sized town: OR = 1.67 p = 0.054); city: OR = 1.82, p = .065). For 11-13-year-old adolescents, no evidence for urban-rural differences was observed. However for the replication study, when stratified by age group, the results revealed that city living was only associated with an increased likelihood of meeting the guidelines in six-to-ten-year-old children (OR = 2.03, p = .020), but not in adolescents aged 11-13 (p = 0.165) or 14-17 years (p = .122). The detailed results can be found in the *appendix*, *Table A.3, A.4, A.5 and A.6.*

Sensitivity analysis

Including all participants who agreed to wear an accelerometer in the analysis resulted in N = 2,734 participants in the discovery study (n = 465 participants without valid accelerometer data; *n* = 88 with missing information on sociodemographic characteristics or weight status) and *N* = 1,192 participants in the replication study (*n* = 245 participants without valid accelerometer data; *n* = 28 with missing information on sociodemographic characteristics or weight status). That is, data of *N* = 2,734 participants in the discovery study was used for our sensitivity analyses using data imputation, for details see Table A.10. We found statistical differences between original sample valid data and missing data (i.e., for age; see Appendix results A.1 and table A.9) which may point towards a potential hidden bias; yet, there was no significant difference in sociodemographic characteristics between valid and missing cases, see Appendix table A.9. To test for potential confounding by this missing data, we recomputed the main models (i.e., the multiple linear regression with MVPA as outcome and the logistic regression on the compliance with the WHO[2] physical activity guidelines for both the discovery and replication study, respectively) using an dataset with imputed data for the missing values. The result patterns remained similar when missing data were imputed (see *appendix Tables A.7* and *A.8*).

Discussion

In two large samples of children and adolescents across Germany applying device-based assessment of physical activity with two different assessments of urbanicity, both our discovery and replication study showed that compared to rural areas, children and adolescents in cities spent more time in MVPA, independent of gender and age. Children and adolescents from urban areas were more likely to meet the WHO[2] physical activity guidelines, with gender and age differences being observed. This provides high-quality evidence on the association of urbanicity and physical activity, therewith contributing to a research discussion of utmost importance. The greatest difference was observed between children living in cities versus those residing in rural areas. These findings extend previous results from a study that investigated urban-rural physical activity trends in Germany's children and adolescents based on self-report, showing that rural areas have been experiencing a physical activity decline over the last 15 years[31].

Our finding of heightened MVPA in urban youth may be explained by more MVPA-opportunities in urban compared to rural areas. From an ecological perspective, our finding that urban youth engage in more MVPA may trace back to the fact that there may be more opportunities for MVPA in urban areas compared to rural areas. For example, Yousefian et. al.[49] report about a lack or poor maintenance of outdoor spaces for physical activity, e.g., trails in rural communities[50], an observation which matches large-scale global reports of Sallis et al.[16]. In particular, Germany's rural areas are experience changes in their infrastructure resulting, e.g., in fewer schools, education opportunities, public transport options, and shopping and leisure facilities[19], for a detailed insight see, e.g.[19]. This may link to deteriorated physical activity opportunities for children and adolescents, for example, on their way to school or gyms. On a related note, in one study, children in rural areas were four times more likely to report they couldn't exercise because parks and playgrounds were too far from their homes or because sidewalks and bike lanes were missing, compared to children from suburban large towns.[51]

However, during times of crisis, such as the Covid-19 pandemic, rural living seems conducive for physical activity: In a study conducted during the first Covid-19 lockdown in Germany, children and adolescents in less densely populated areas increased their self-reported daily life physical activity by about 45 minutes per day, while children and adolescents in highly densely populated areas increased their daily life physical activity by only ten minutes per day[31]. This may be explained by the fact that during the lockdown, the physical activity opportunities obtained through urban living were restricted (e.g., public play and sports ground closures) whilst rural areas may have offered more open space for playing outside with a safe distance to other people[31].

Existing pre-Covid studies on urban-rural differences in physical activity differed in numerous aspects from the here presented investigation. In particular, the age-ranges of children and adolescents investigated were highly different (e.g.[22,52,53]), the measurement of urbanicity and rurality were diverse, ranging from urban influence codes to population density measures[20] the measurement of physical activity from self-reports to device-based assessment, and the conduct ranged across the last two decades, a time of rapid urbanization processes and land use changes (e.g.[22,54–56]).

Nonetheless, our finding in a large sample of children and adolescents across the age range from six to 17 years using device-based assessment of physical activity and GIS system-based assessment of urbanicity is in line with results from studies applying self-reported[57] and accelerometer-measured physical activity assessment[58]. In contrast, one study with accelerometer-measurement reported no differences in MVPA between urban and rural youth[22], and Machado-Rodrigues et al.[52] , as well as Moore et al.[53] found less MVPA in urban girls compared to their rural counterparts, respectively.

Regarding the results of meeting the physical activity guidelines, the main results differ from studies conducted in Canada[59] and China[60], where no differences between urban and rural youth were observed. However, the study in Canada was conducted with adolescents between twelve and 17 years[59], an age range for which we also did mostly not find support for differences in the likelihood of meeting the guidelines between urban and rural areas when stratifying the analysis by age group. A potential reason for this could be that physical activity opportunities in urban areas are no longer attractive to adolescents as other aspects, such as being active on social media, are becoming increasingly important. Hence, physical activity levels of urban and rural adolescents may converge, leading to overall low physical activity levels in Germany's adolescents[61].

In addition, results of the replication study revealed that urbanicity degree was only associated with an enhanced likelihood of meeting the guidelines in girls, but not in boys. While these gender disparities are not well understood, in our study, this might indicate that especially girls in Germany, who have on average lower physical activity levels than boys[24], a finding in line with Brazilian Cohort Studies[62], benefit from urban living regarding physical activity. However, given that this disparity was only observed in one of our two studies and given that both of our studies are of pure observational nature precluding any causal interpretation, this topic remains subject to future investigations.

For future research, there are promising paths to gain more specific insights to inform policy, health guidelines, and interventions on how to further improve MVPA in children and adolescents living in cities and especially youth living in rural environments. First, information about the physical activity type, e.g., whether children and adolescents achieved the MVPA-levels by running to the school bus (active transport) versus by playing soccer with friends (sports and exercises)[63] would help to assess the relation with physical activity to target interventions. Therefore, future studies can combine accelerometry with real-time assessment of the physical activity types, e.g., via electronic diaries prompting participants directly after their physical activity engagement therewith combining device-based intensity measurement with an ecologically valid assessment of physical activity types. Second, to design environments that promote physical activity in children and adolescents, it is important to understand how the features of the urban environment relate to their physical activity. To allow conclusions about relevant characteristics of physical activity and the environment, combining global positioning systems (GPS), global information systems (GIS), and accelerometry is a promising approach.[64–66] This approach can contribute to inform urban and rural policy and interventions thereby following suggestions of the World Health Organization to create active environments[8]; e.g., it may built upon ecological models of health behavior emphasizing the impact of environmental features such as public sports facilities, traffic safety, and stimulating natural environments on physical activity[11], upon empirical evidence of previous studies in children and adolescents showing that in general, park and playground equipment, mixed land use, short distances to facilities, better walkability, and infrastructure for walking and cycling shown to be associated with youth's physical activity[14,15], and upon specific recommendations to enhance "outdoor public open spaces and amenities for physical activity, such as trails"[12]. Third, future research should prioritize longitudinal designs to examine changes over time and to shed light on the causality of associations between urbanicity and physical activity, e.g., applying within-person encouragement designs using just-in-time adaptive interventions[67,68]. Fourth, because age is a continuous variable and related to physical activity engagement, this is an interesting account for future research. While we formed three age groups based on the data plotting and theoretical assumptions and received age-dependent results, future studies may model age using polynomial terms and spline-based methods.

Some aspects of our work require further refinement in future research. First, our cross-sectional design does not at all allow for causal conclusions. Therefore, to enable insights above the sole association of urbanicity and physical activity, e.g., into the directionality of effects and potential third (moderation) variables, future studies can make use of longitudinal designs and experimental approaches (see e.g.[68]). Second, socioeconomic status was not equally distributed across participants from rural versus urban environments, which may posit a potential bias to the results. However, all models included socioeconomic status as a covariate, which yielded no significant effects on physical activity. Third, we focused our analysis on MVPA against the background of current public health recommendations and established evidence linking MVPA to health outcomes[2]. However, future studies should research associations of urban-rural differences in light physical activity to knowledge on further activity types. Fourth, we found statistical differences between original sample valid data and imputation data (i.e., for age and gender; see Appendix) which may point towards a potential hidden bias. However, the study findings remained robust across both original sample and imputation data. Fifth, accelerometry may be subject to underestimation of certain activities, such as swimming or cycling; it does not provide contextual information about activity type or location. Further, intensity thresholds may differ by algorithms, which could affect comparability. However, accelerometry remains the gold standard approach for physical activity estimation in epidemiological research[63]. Sixth, the methodology between our discovery and replication study differed. That is, in the discovery study urbanicity was parametrized based on the political categorization of urbanicity, and, in the replication study, urbanicity was parameterized via the European-wide DEGURBA degree. The method applied in our discovery study can be questioned regarding its limited sensitivity. In our replication study, we applied a parameterization using the European-wide DEGURBA degree. Unlike the national administrative boundary-based approach used in the discovery study, DEGURBA offers greater precision in capturing gradients of urbanicityl; still, its potential to oversimplify mixed-density areas, such as peri-urban zones, may introduce classification biases. However, despite the use of different methodology and in independent data, we received the same pattern of results in both the discovery and replication study, which strengthens the robustness of our findings. Finally, the clinical and public health relevance of the reported magnitude of differences in PA between rural and urban youth (approximately 6–7 minutes of MVPA per day) should be considered in light of recent evidence for health benefits of MVPA, see e.g. [4,69,70].

Conclusion

We here provide novel and robust evidence that youth city dwellers in Germany engage in more MVPA than their rural counterparts. While global physical inactivity makes physical activity promotion necessary across all geographical areas our findings suggest that rural communities should be explicitly targeted to prevent adverse health events and address urban-rural inequalities. For example, since in the school setting, similar urban-rural physical activity developments have been observed across the last 15 years[39], this context poses a promising starting point to reach children and adolescents across geographical areas.

Given the outstanding value of physical activity engagement for human's physical and mental health[3,4], our finding of significantly heightened MVPA levels in Germany's youth city dwellers comes with positive implications for ongoing urbanization yet raises critical future research questions to inform policy and city planning: While heightened MVPA in city dwellers can benefit youth health in times of urbanization, studies researching which specific features of the urban environment are associated with which kind of human physical activity are critical for targeted interventions aiming to sustainably increase physical activity.

Here, rapid digitization offers highly promising tools such as unobtrusive geolocation sensing via smartphone apps and advanced geoinformatics methods such as lidar data to extract environmental features. Combinations with further advanced ambulatory research tools (e.g., electronic diaries on smartphones, smartphone sensing) can open avenues to more comprehensive insights into health behaviors and specific health indicators of youth's everyday life in both the rural and urban context.

Author contributions statement:

MR and CN conceptualized the study and wrote the original draft. CN and JF analyzed the data. DJ and LM provided input on the statistical analysis. AB was responsible for project administration and data curation. AW acquired funding and developed the overall study idea of the project underlying this study. AW and JS supervised this study. SB, JF, JKR, BvH, UEP and CN, and all other others provided critical input on the manuscript.

Data availability statement:

Due to ethical, legal, and data protection restrictions associated with participant-level data, the underlying dataset cannot currently be shared publicly or transferred to external parties. The study data contain sensitive information and are subject to German and European data protection regulations (GDPR) as well as the consent agreements obtained from study participants. Upon reasonable request, researchers may access the data on-site through a supervised guest researcher workstation at the Karlsruhe Institute of Technology (KIT), Institute of Sports and Sports Science (IfSS), Germany, under controlled conditions and in accordance with applicable data protection requirements. Requests should be submitted to the corresponding authors MR and CN. The statistical analyses scripts comprising the documentation of analytical procedures used in the study are publicly available at https://osf.io/4xr7e/overview?view_only=d3e067252ac34a529a890d7d51e8e56c.

Additional information:

Ulrich W. Ebner-Priemer reports a consulting relationship with Boehringer Ingelheim GmbH. All other authors have no interests to disclose.

Funding Declaration:

This work was supported 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).

Tables:

Table 1

Sample information

	Discovery study (N = 2,190)	Replication study (N = 923)
Urbanicity discovery study		
Rural	449 (20.5%)	
Small town	822 (37.5%)	
Medium-sized town	587 (26.8%)	
City	332 (15.2%)	
Urbanicity replication study		
Rural areas (thinly populated areas)		324 (35.1%)
Towns and suburbs (intermediate density areas)		391 (42.4%)
Cities (densely populated areas)		208 (22.5%)
Gender		
Boys	1031 (47.1%)	461 (49.9%)
Girls	1159 (52.9%)	462 (50.1%)
Age group		

	Discovery study (N = 2,190)	Replication study (N = 923)
6-10 years	584 (26.7%)	392 (42.5%)
11-13 years	818 (37.4%)	313 (33.9%)
14-17 years	788 (36.0%)	218 (23.6%)
Age in years Mean (SD)	12.40 (3.30)	11.20 (3.34)
Socio-economic status score Mean (SD)	14.1 (3.81)	15.5 (3.28)
Weight status		
Underweight	203 (9.3%)	86 (9.3%)
Normal weight	1617 (73.8%)	706 (76.5%)
Overweight	288 (13.2%)	111 (12.0%)
Obese	82 (3.7%)	20 (2.2%)
MVPA Mean minutes/day (SD)	51.6 (23.7)	55.2 (24.0)
WHO guidelines		
Not fulfilled	1502 (68.6%)	596 (64.6%)
Fulfilled	688 (31.4%)	327 (35.4%)

Table 2

Multiple linear regression results with moderate-to-vigorous physical activity (MVPA) as outcome.

	Discovery Study (N = 2,190)					**Replication Study (N = 923)**				
Predictors	*B*	*SE*	*95%CI*	*β*	*p*	*B*	*SE*	*95%CI*	*β*	*p*
(Intercept)	74.84	1.29	72.30;77.38	0.98	**<.001**	72.53	1.56	69.46;75.59	0.72	**<.001**
Urbanicity discovery study (ref. rural)										
Small town	2.07	1.16	-0.21;4.35	0.09	.075					
Medium-sized town	2.28	1.25	-0.17;4.73	0.10	.068					
Cities	7.12	1.46	4.26;9.97	0.30	**<.001**					
Urbanicity replication study (ref. rural areas)										
Towns and suburbs						2.42	1.53	-0.58;5.43	0.10	.114

City						5.73	1.81	2.18;9.27	0.24	**.002**
Age group (ref. 6-10 years)										
11-13 years	-21.50	1.09	-23.64;-19.35	-0.91	**<.001**	-19.73	1.56	-22.79;-16.68	-0.82	**<.001**
14-17 years	-30.34	1.16	-32.61;-28.08	-1.28	**<.001**	-26.59	1.77	-30.07;-23.11	-1.11	**<.001**
Gender (ref. boys)										
Girls	-11.43	0.85	-13.09;-9.77	-0.48	**<.001**	-10.32	1.33	-12.93;-7.72	-0.43	**<.001**
Socio-economic status	0.16	0.12	-0.06;0.39	0.03	.162	-0.07	0.21	-0.47;0.34	-0.01	.752
BMI (ref. normal)										
Underweight	-0.18	1.47	-3.06;2.71	-0.01	.905	-2.58	2.29	-7.08;1.93	-0.11	.262
Overweight	-3.65	1.27	-6.14;-1.16	-0.15	**.004**	-8.68	2.07	-12.74;-4.62	-0.36	**<.001**
Obese	-5.95	2.25	-10.35;-1.54	-0.25	**.008**	-11.40	4.57	-20.36;-2.44	-0.47	**.013**
Accelerometer weartime	0.04	0.01	0.03;0.06	0.15	**<.001**	0.02	0.01	0.01;0.03	0.08	**.005**

Please note: For better interpretability of the intercept, accelerometer weartime and socio-economic status were centered on the sample's mean.

Table 3

Logistic regression results regarding compliance with the WHO (2020) physical activity guidelines.

	Discovery study (*N* = 2,190)			**Replication study (*N* = 923)**		
Predictors	*Odds Ratios*	*95%CI*	*p*	*Odds Ratios*	*95%CI*	*p*
(Intercept)	2.51	1.85;3.41	**<.001**	2.10	1.45;3.03	**<.001**
Urbanicity discovery study (ref. rural)						
Small town	1.18	0.88;1.58	.275			
Medium sized town	1.43	1.05;1.95	**.024**			
City	2.04	1.44;2.90	**<.001**			
Urbanicity replication study (ref. rural areas)						
Towns and suburbs				1.41	0.96;2.08	.079
Cities				1.87	1.20;2.91	**.006**
Gender (ref. boys)						
Girls	0.35	0.28;0.43	**<.001**	0.39	0.28;0.54	**<.001**

Socio-economic status	1.01	0.98;1.04	.580	1.01	0.96;1.06	.666
BMI (ref. normal)						
Underweight	1.28	0.91;1.80	.157	0.84	0.49;1.45	.534
Overweight	0.63	0.45;0.86	**.005**	0.29	0.15;0.55	**<.001**
Obese	0.52	0.28;0.92	**.029**	0.08	0.01;0.68	**.021**
Agegroup (ref. 6-10 years)						
11-13 years	0.18	0.14;0.23	**<.001**	0.17	0.12;0.25	**<.001**
14-17 years	0.08	0.06;0.11	**<.001**	0.07	0.04;0.13	**<.001**
Accelerometer weartime	1.003	1.001;1.004	**<.001**	1.002	1.001;1.004	**.011**

Please note: for the replication study, the robust model results are reported

Figures:

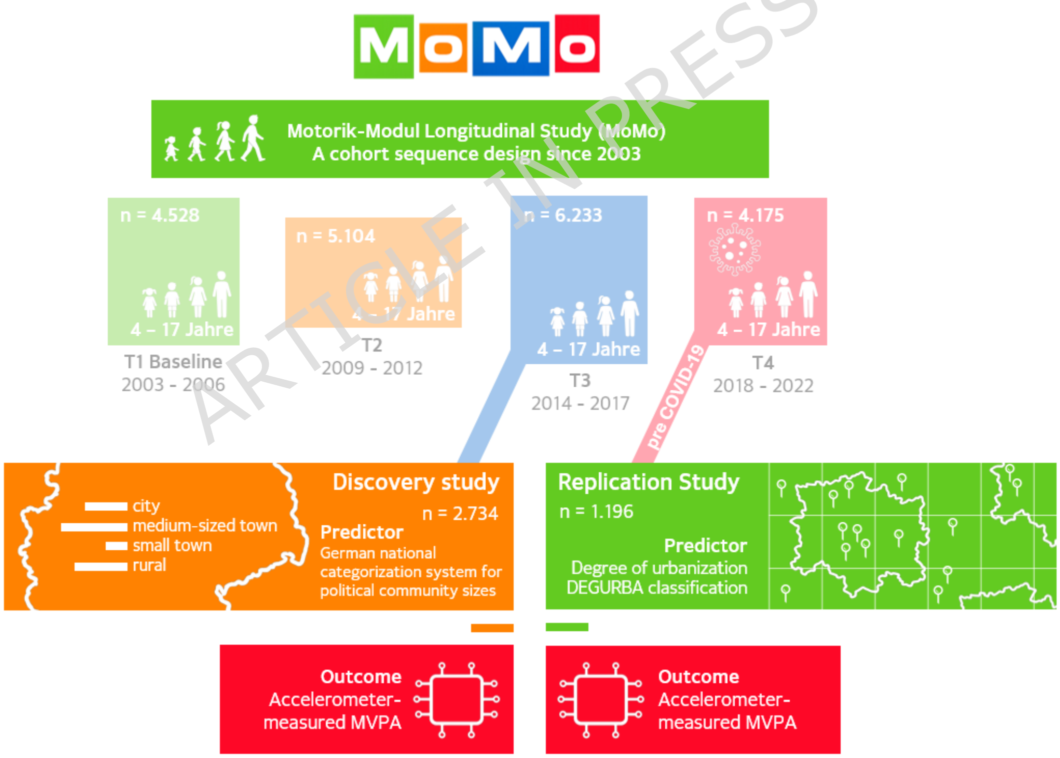

Figure 1. Schematic overview of study design.

References

1. United Nations Department of Economic and Social Affairs. *World Urbanization Prospects: The 2018 Revision* (UN, 2019).

2. Bull, F. C. *et al.* World Health Organization 2020 guidelines on physical activity and sedentary behaviour. *British journal of sports medicine* **54,** 1451–1462; 10.1136/bjsports-2020-102955 (2020).

3. Biddle, S. J., Ciaccioni, S., Thomas, G. & Vergeer, I. Physical activity and mental health in children and adolescents: An updated review of reviews and an analysis of causality. *Psychology of Sport and Exercise* **42,** 146–155; 10.1016/j.psychsport.2018.08.011 (2019).

4. Chaput, J.-P. *et al.* 2020 WHO guidelines on physical activity and sedentary behaviour for children and adolescents aged 5-17 years: summary of the evidence. *The international journal of behavioral nutrition and physical activity* **17,** 141; 10.1186/s12966-020-01037-z (2020).

5. *Global Status Report on Physical Activity 2022.* 1st ed. (World Health Organization, Geneva, 2022).

6. Guthold, R., Stevens, G. A., Riley, L. M. & Bull, F. C. Global trends in insufficient physical activity among adolescents: a pooled analysis of 298 population-based surveys with 1·6 million participants. *The Lancet. Child & adolescent health* **4,** 23–35; 10.1016/S2352-4642(19)30323-2 (2020).

7. Sallis, J. F. *et al.* Progress in physical activity over the Olympic quadrennium. *Lancet (London, England)* **388,** 1325–1336; 10.1016/S0140-6736(16)30581-5 (2016).

8. Organization, W. H. *Global Action Plan on Physical Activity 2018-2030. More Active People for a Healthier World* (World Health Organization, Geneva, 2019).

9. Sallis, J. F., Owen, N. & Fisher, E. B. Ecological models of health behavior. In *Health behavior: Theory, research, and practice,* edited by K. Glanz, B. K. Rimer & K. V. Viswanath. 5th ed. (2015), pp. 43–64.

10. Cerin, E. *et al.* Determining thresholds for spatial urban design and transport features that support walking to create healthy and sustainable cities: findings from the IPEN Adult study. *The Lancet. Global health* **10,** e895-e906; 10.1016/S2214-109X(22)00068-7 (2022).

11. Sallis, J. F. *et al.* Built Environment, Physical Activity, and Obesity: Findings from the International Physical Activity and Environment Network (IPEN) Adult Study. *Annual review of public health* **41,** 119–139; 10.1146/annurev-publhealth-040218-043657 (2020).

12. Rogers, A. E. *et al.* Indicators of community physical activity resources and opportunities and variation by community sociodemographic characteristics: A scoping review. *Preventive medicine reports* **40,** 102656; 10.1016/j.pmedr.2024.102656 (2024).

13. Aubert, S. *et al.* Global Matrix 3.0 Physical Activity Report Card Grades for Children and Youth: Results and Analysis From 49 Countries. *Journal of physical activity & health* **15,** S251-S273; 10.1123/jpah.2018-0472 (2018).

14. Nordbø, E. C. A., Nordh, H., Raanaas, R. K. & Aamodt, G. Promoting activity participation and well-being among children and adolescents: a systematic review of neighborhood built-environment determinants. *JBI evidence synthesis* **18,** 370–458; 10.11124/JBISRIR-D-19-00051 (2020).

15. Smith, M. *et al.* Systematic literature review of built environment effects on physical activity and active transport - an update and new findings on health equity. *The international journal of behavioral nutrition and physical activity* **14,** 158; 10.1186/s12966-017-0613-9 (2017).

16. Sallis, J. F. *et al.* Use of science to guide city planning policy and practice: how to achieve healthy and sustainable future cities. *Lancet (London, England)* **388,** 2936–2947; 10.1016/S0140-6736(16)30068-X (2016).

17. Gallotta, M. C. *et al.* Influence of Geographical Area and Living Setting on Children's Weight Status, Motor Coordination, and Physical Activity. *Frontiers in pediatrics* **9,** 794284; 10.3389/fped.2021.794284 (2021).

18. Reimers, A. K. *et al.* Proximity to sports facilities and sports participation for adolescents in Germany. *PloS one* **9,** e93059; 10.1371/journal.pone.0093059 (2014).

19. Bundesministerium für Ernährung und Landwirtschaft. Das Land lebt! Dritter Bericht der Bundesregierung zur Entwicklung der ländlichen Räume. Available at https://www.bmleh.de/SharedDocs/Downloads/DE/_laendliche-Regionen/regierungsbericht-laendliche-raeume-2020.pdf?__blob=publicationFile&v=5 (2020).

20. McCormack, L. A. & Meendering, J. Diet and Physical Activity in Rural vs Urban Children and Adolescents in the United States: A Narrative Review. *Journal of the Academy of Nutrition and Dietetics* **116,** 467–480; 10.1016/j.jand.2015.10.024 (2016).

21. McCrorie, P. R. W., Fenton, C. & Ellaway, A. Combining GPS, GIS, and accelerometry to explore the physical activity and environment relationship in children and young people - a review. *The international journal of behavioral nutrition and physical activity* **11,** 93; 10.1186/s12966-014-0093-0 (2014).

22. McCrorie, P. *et al.* The relationship between living in urban and rural areas of Scotland and children's physical activity and sedentary levels: a country-wide cross-sectional analysis. *BMC public health* **20,** 304; 10.1186/s12889-020-8311-y (2020).

23. Fan, X. & Cao, Z.-B. Physical activity among Chinese school-aged children: National prevalence estimates from the 2016 Physical Activity and Fitness in China-The Youth Study. *Journal of sport and health science* **6,** 388–394; 10.1016/j.jshs.2017.09.006 (2017).

24. Woll, A. *et al.* Cohort Profile Update: The Motorik-Modul (MoMo) Longitudinal Study-physical fitness and physical activity as determinants of health development in German children and adolescents. *International journal of epidemiology* **50,** 393–394; 10.1093/ije/dyaa281 (2021).

25. Hölling, H. *et al.* Die KiGGS-Studie. Bundesweit repräsentative Längs- und Querschnittstudie zur Gesundheit von Kindern und Jugendlichen im Rahmen des Gesundheitsmonitorings am Robert Koch-Institut. *Bundesgesundheitsblatt, Gesundheitsforschung, Gesundheitsschutz* **55,** 836–842; 10.1007/s00103-012-1486-3 (2012).

26. Kurth, B.-M. *et al.* The challenge of comprehensively mapping children's health in a nation-wide health survey: design of the German KiGGS-Study. *BMC public health* **8,** 196; 10.1186/1471-2458-8-196 (2008).

27. Woll, A., Albrecht, C. & Worth, A. Motorik-Module (MoMo) - the KiGGS Wave 2 module to survey motor performance and physical activity. *Journal of health monitoring* **2,** 63–70; 10.17886/RKI-GBE-2017-110 (2017).

28. Woll, A. *et al.* The German national cohort study on the development of motor performance, physical activity and health in children and adolescents: the MoMo 2.0-Study protocol. *BMJ open* **15,** e094895; 10.1136/bmjopen-2024-094895 (2025).

29. Kamtsiuris, P., Lange, M. & Schaffrath Rosario, A. Der Kinder- und Jugendgesundheitssurvey (KiGGS): Stichprobendesign, Response und Nonresponse-Analyse. *Bundesgesundheitsblatt, Gesundheitsforschung, Gesundheitsschutz* **50,** 547–556; 10.1007/s00103-007-0215-9 (2007).

30. Schmidt, S. C. E. *et al.* Physical activity and screen time of children and adolescents before and during the COVID-19 lockdown in Germany: a natural experiment. *Scientific reports* **10,** 21780; 10.1038/s41598-020-78438-4 (2020).

31. Nigg, C. *et al.* Population density predicts youth's physical activity changes during Covid-19 - Results from the MoMo study. *Health & place* **70,** 102619; 10.1016/j.healthplace.2021.102619 (2021).

32. Lampert, T., Müters, S., Stolzenberg, H. & Kroll, L. E. Messung des sozioökonomischen Status in der KiGGS-Studie : Erste Folgebefragung (KiGGS Welle 1). *Bundesgesundheitsblatt, Gesundheitsforschung, Gesundheitsschutz* **57,** 762–770; 10.1007/s00103-014-1974-8 (2014).

33. Cole, T. J., Bellizzi, M. C., Flegal, K. M. & Dietz, W. H. Establishing a standard definition for child overweight and obesity worldwide: international survey. *BMJ (Clinical research ed.)* **320,** 1240–1243; 10.1136/bmj.320.7244.1240 (2000).

34. Cole, T. J., Flegal, K. M., Nicholls, D. & Jackson, A. A. Body mass index cut offs to define thinness in children and adolescents: international survey. *BMJ (Clinical research ed.)* **335,** 194; 10.1136/bmj.39238.399444.55 (2007).

35. McCambridge, J., Witton, J. & Elbourne, D. R. Systematic review of the Hawthorne effect: new concepts are needed to study research participation effects. *Journal of clinical epidemiology* **67,** 267–277; 10.1016/j.jclinepi.2013.08.015 (2014).

36. Choi, L., Liu, Z., Matthews, C. E. & Buchowski, M. S. Validation of accelerometer wear and nonwear time classification algorithm. *Medicine and science in sports and exercise* **43,** 357–364; 10.1249/MSS.0b013e3181ed61a3 (2011).

37. Romanzini, M., Petroski, E. L., Ohara, D., Dourado, A. C. & Reichert, F. F. Calibration of ActiGraph GT3X, Actical and RT3 accelerometers in adolescents. *European journal of sport science* **14,** 91–99; 10.1080/17461391.2012.732614 (2014).

38. Wittwer, R. *Raumstrukturelle Einflüsse auf das Verkehrsverhalten - Nutzbarkeit der Ergebnisse großräumiger und lokaler Haushaltsbefragungen für makroskopische Verkehrsplanungsmodelle* (Dresden, 2008).

39. World Intellectual Property Organization (WIPO). WIPO Mediation Rules. Available at https://www.wipo.int/amc/en/mediation/rules (2021).

40. Eurostat. Degree of urbanisation: Methodology. Available at https://ec.europa.eu/eurostat/web/degree-of-urbanisation/methodology.

41. R Core Team. R: A language and environment for statistical computing. Available at http://www.R-project.org/ (2022).

42. Lüdecke, D., Ben-Shachar, M., Patil, I., Waggoner, P. & Makowski, D. performance: An R Package for Assessment, Comparison and Testing of Statistical Models. *JOSS* **6,** 3139; 10.21105/joss.03139 (2021).

43. Maechler, M. *et al. CRAN: Contributed Packages* (2006).

44. Sterdt, E., Liersch, S. & Walter, U. Correlates of physical activity of children and adolescents: A systematic review of reviews. *Health Education Journal* **73,** 72–89; 10.1177/0017896912469578 (2014).

45. Kowaleski-Jones, L., Fan, J. X., Wen, M. & Hanson, H. Neighborhood Context and Youth Physical Activity: Differential Associations by Gender and Age. *American journal of health promotion : AJHP* **31,** 426–434; 10.1177/0890117116667353 (2017).

46. Daniel Lüdecke. *sjPlot - Data Visualization for Statistics in Social Science* (Zenodo, 2018).

47. van Buuren, S. & Groothuis-Oudshoorn, K. mice : Multivariate Imputation by Chained Equations in R. *J. Stat. Soft.* **45**; 10.18637/jss.v045.i03 (2011).

48. Zhang, Z. Multiple imputation with multivariate imputation by chained equation (MICE) package. *Annals of translational medicine* **4,** 30; 10.3978/j.issn.2305-5839.2015.12.63 (2016).

49. Yousefian, A. *et al.* Development of the rural active living assessment tools: Measuring rural environments. *Preventive medicine* **50,** S86-S92; 10.1016/j.ypmed.2009.08.018 (2010).

50. Abildso, C. G. *et al.* Environmental Factors Associated with Physical Activity in Rural U.S. Counties. *International journal of environmental research and public health* **18**; 10.3390/ijerph18147688 (2021).

51. Taylor, L. G., Clark, A. F. & Gilliland, J. A. Context Matters: Examining children's perceived barriers to physical activity across varying Canadian environments. *Health & place* **54,** 221–228; 10.1016/j.healthplace.2018.10.002 (2018).

52. Machado-Rodrigues, A. M. *et al.* Urban-rural contrasts in fitness, physical activity, and sedentary behaviour in adolescents. *Health promotion international* **29,** 118–129; 10.1093/heapro/das054 (2014).

53. Moore, J. B., Beets, M. W., Morris, S. F. & Kolbe, M. B. Comparison of objectively measured physical activity levels of rural, suburban, and urban youth. *American journal of preventive medicine* **46,** 289–292; 10.1016/j.amepre.2013.11.001 (2014).

54. Salvati, L., Zambon, I., Chelli, F. M. & Serra, P. Do spatial patterns of urbanization and land consumption reflect different socioeconomic contexts in Europe? *The Science of the total environment* **625,** 722–730; 10.1016/j.scitotenv.2017.12.341 (2018).

55. Springer, A. E., Hoelscher, D. M. & Kelder, S. H. Prevalence of Physical Activity and Sedentary Behaviors in US High School Students by Metropolitan Status and Geographic Region. *Journal of physical activity & health* **3,** 365–380; 10.1123/jpah.3.4.365 (2006).

56. Stathakis, D., Tselios, V. & Faraslis, I. Urbanization in European regions based on night lights. *Remote Sensing Applications: Society and Environment* **2,** 26–34; 10.1016/j.rsase.2015.10.001 (2015).

57. Liu, J., Bennett, K. J., Harun, N. & Probst, J. C. Urban-rural differences in overweight status and physical inactivity among US children aged 10-17 years. *The Journal of rural health : official journal of the American Rural Health Association and the National Rural Health Care Association* **24,** 407–415; 10.1111/j.1748-0361.2008.00188.x (2008).

58. Moore, J. B., Brinkley, J., Crawford, T. W., Evenson, K. R. & Brownson, R. C. Association of the built environment with physical activity and adiposity in rural and urban youth. *Preventive medicine* **56,** 145–148; 10.1016/j.ypmed.2012.11.019 (2013).

59. Manyanga, T. *et al.* A Comparison of Meeting Physical Activity and Screen Time Recommendations between Canadian Youth Living in Rural and Urban Communities: A Nationally Representative Cross-Sectional Analysis. *International journal of environmental research and public health* **19**; 10.3390/ijerph19074394 (2022).

60. Zhu, Z. *et al.* Physical activity, screen viewing time, and overweight/obesity among Chinese children and adolescents: an update from the 2017 physical activity and fitness in China-the youth study. *BMC public health* **19,** 197; 10.1186/s12889-019-6515-9 (2019).

61. Burchartz, A. *et al.* Comparison of self-reported & device-based, measured physical activity among children in Germany. *BMC public health* **21**, 1081; 10.1186/s12889-021-11114-y (2021).

62. Pinto, A. A. *et al.* Physical Activity Levels in Brazilian Adolescents: A Secular Trend Study (2007-2017/18). *International journal of environmental research and public health* **19**; 10.3390/ijerph192416901 (2022).

63. Burchartz, A. *et al.* Assessing physical behavior through accelerometry – State of the science, best practices and future directions. *Psychology of Sport and Exercise* **49,** 101703; 10.1016/j.psychsport.2020.101703 (2020).

64. Jankowska, M. M., Schipperijn, J. & Kerr, J. A framework for using GPS data in physical activity and sedentary behavior studies. *Exercise and sport sciences reviews* **43,** 48–56; 10.1249/JES.0000000000000035 (2015).

65. Reichert, M. *et al.* Studying the impact of built environments on human mental health in everyday life: methodological developments, state-of-the-art and technological frontiers. *Current opinion in psychology* **32,** 158–164; 10.1016/j.copsyc.2019.08.026 (2020).

66. Reichert, M. *et al.* Ambulatory Assessment for Physical Activity Research: State of the Science, Best Practices and Future Directions. *Psychology of Sport and Exercise* **50**; 10.1016/j.psychsport.2020.101742 (2020).

67. Klasnja, P. *et al.* Microrandomized trials: An experimental design for developing just-in-time adaptive interventions. *Health psychology: official journal of the Division of Health Psychology, American Psychological Association* **34S,** 1220–1228; 10.1037/hea0000305 (2015).

68. Schmiedek, F. & Neubauer, A. B. Experiments in the Wild: Introducing the Within-Person Encouragement Design. *Multivariate behavioral research* **55,** 256–276; 10.1080/00273171.2019.1627660 (2020).

69. Ekelund, U., Tarp, J., Ding Ding, M. A. S.-L. *et al.* Deaths potentially averted by small changes in physical activity and sedentary time: an individual participant data meta-analysis of prospective cohort studies. *The Lancet* **407**, 339–49 (2026). https://doi.org/10.1016/S0140-6736(25)02219-6

70. Ekelund, U., Luan, J., Sherar, L. B. *et al.* Moderate to vigorous physical activity and sedentary time and cardiometabolic risk factors in children and adolescents. *JAMA* **307(7**), 704–712 (2012). https://doi.org/10.1001/jama.2012.156

Tables:

Table 1

Sample information

	Discovery study (*N* = 2,190)	Replication study (*N* = 923)
Urbanicity discovery study		
Rural	449 (20.5%)	
Small town	822 (37.5%)	
Medium-sized town	587 (26.8%)	
City	332 (15.2%)	
Urbanicity replication study		
Rural areas (thinly populated areas)		324 (35.1%)
Towns and suburbs (intermediate density areas)		391 (42.4%)
Cities (densely populated areas)		208 (22.5%)
Gender		
Boys	1031 (47.1%)	461 (49.9%)
Girls	1159 (52.9%)	462 (50.1%)
Age group		
6-10 years	584 (26.7%)	392 (42.5%)
11-13 years	818 (37.4%)	313 (33.9%)
14-17 years	788 (36.0%)	218 (23.6%)
Age in years Mean (SD)	12.40 (3.30)	11.20 (3.34)
Socio-economic status score Mean (SD)	14.1 (3.81)	15.5 (3.28)
Weight status		
Underweight	203 (9.3%)	86 (9.3%)
Normal weight	1617 (73.8%)	706 (76.5%)
Overweight	288 (13.2%)	111 (12.0%)
Obese	82 (3.7%)	20 (2.2%)
MVPA Mean minutes/day (SD)	51.6 (23.7)	55.2 (24.0)
WHO guidelines		
Not fulfilled	1502 (68.6%)	596 (64.6%)

	Discovery study (N = 2,190)	Replication study (N = 923)
Fulfilled	688 (31.4%)	327 (35.4%)

Table 2

Multiple linear regression results with moderate-to-vigorous physical activity (MVPA) as outcome.

	Discovery Study (N = 2,190)					Replication Study (N = 923)				
Predictors	*B*	*SE*	*95%CI*	*β*	*p*	*B*	*SE*	*95%CI*	*β*	*p*
(Intercept)	74.84	1.29	72.30;77.38	0.98	**<.001**	72.53	1.56	69.46;75.59	0.72	**<.001**
Urbanicity discovery study (ref. rural)										
Small town	2.07	1.16	-0.21;4.35	0.09	.075					
Medium-sized town	2.28	1.25	-0.17;4.73	0.10	.068					
Cities	7.12	1.46	4.26;9.97	0.30	**<.001**					
Urbanicity replication study (ref. rural areas)										
Towns and suburbs						2.42	1.53	-0.58;5.43	0.10	.114
City						5.73	1.81	2.18;9.27	0.24	**.002**
Age group (ref. 6-10 years)										
11-13 years	-21.50	1.09	-23.64;-19.35	-0.91	**<.001**	-19.73	1.56	-22.79;-16.68	-0.82	**<.001**
14-17 years	-30.34	1.16	-32.61;-28.08	-1.28	**<.001**	-26.59	1.77	-30.07;-23.11	-1.11	**<.001**
Gender (ref. boys)										
Girls	-11.43	0.85	-13.09;-9.77	-0.48	**<.001**	-10.32	1.33	-12.93;-7.72	-0.43	**<.001**
Socio-economic status	0.16	0.12	-0.06;0.39	0.03	.162	-0.07	0.21	-0.47;0.34	-0.01	.752
BMI (ref. normal)										
Underweight	-0.18	1.47	-3.06;2.71	-0.01	.905	-2.58	2.29	-7.08;1.93	-0.11	.262
Overweight	-3.65	1.27	-6.14;-1.16	-0.15	**.004**	-8.68	2.07	-12.74;-4.62	-0.36	**<.001**
Obese	-5.95	2.25	-10.35;-1.54	-0.25	**.008**	-11.40	4.57	-20.36;-2.44	-0.47	**.013**
Accelerometer weartime	0.04	0.01	0.03;0.06	0.15	**<.001**	0.02	0.01	0.01;0.03	0.08	**.005**

Please note: For better interpretability of the intercept, accelerometer weartime and socio-economic status were centered on the sample's mean.

Table 3

Logistic regression results regarding compliance with the WHO (2020) physical activity guidelines.

	Discovery study (*N* = 2190)			Replication study (*N* = 923)		
Predictors	*Odds Ratios*	*95%CI*	*p*	*Odds Ratios*	*95%CI*	*p*
(Intercept)	2.51	1.85;3.41	**<.001**	2.10	1.45;3.03	**<.001**
Urbanicity discovery study (ref. rural)						
Small town	1.18	0.88;1.58	.275			
Medium sized town	1.43	1.05;1.95	**.024**			
City	2.04	1.44;2.90	**<.001**			
Urbanicity replication study (ref. rural areas)						
Towns and suburbs				1.41	0.96;2.08	.079
Cities				1.87	1.20;2.91	**.006**
Gender (ref. boys)						
Girls	0.35	0.28;0.43	**<.001**	0.39	0.28;0.54	**<.001**
Socio-economic status	1.01	0.98;1.04	.580	1.01	0.96;1.06	.666
BMI (ref. normal)						
Underweight	1.28	0.91;1.80	.157	0.84	0.49;1.45	.534
Overweight	0.63	0.45;0.86	**.005**	0.29	0.15;0.55	**<.001**
Obese	0.52	0.28;0.92	**.029**	0.08	0.01;0.68	**.021**
Agegroup (ref. 6-10 years)						
11-13 years	0.18	0.14;0.23	**<.001**	0.17	0.12;0.25	**<.001**
14-17 years	0.08	0.06;0.11	**<.001**	0.07	0.04;0.13	**<.001**
Accelerometer weartime	1.003	1.001;1.004	**<.001**	1.002	1.001;1.004	**.011**

Please note: for the replication study, the robust model results are reported