**Neighbourhood and physical activity in German adolescents: GINIplus and LISAplus**

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**Abstract**

**Introduction:** Epidemiological studies on neighbourhood and physical activity (PA) are scarce in adolescents. Moreover, only few have used objectively measured exposures and outcomes data. Therefore we investigated the association between objectively measured both neighbourhood characteristics and PA in 15-year-old German adolescents.

**Methods:** Data were available from 747 adolescents residing in the urban Munich area and 542 from the rural Wesel area from the GINIplus and LISAplus birth cohorts. Neighbourhood was defined as a circular 500-m buffer around the residence. Greenness was calculated as 1) the mean Normalized Difference Vegetation Index (NDVI), and as 2) percent tree cover. Neighbourhood green spaces and sport and leisure facilities were defined as present or absent in a neighbourhood (data only available for Munich). Data on PA were collected from one-week triaxial accelerometry (hip-worn ActiGraph GT3X). Minutes of PA were classified into moderate-to-vigorous (MVPA), lifestyle and sedentary using Romanzini’s triaxial cutoffs, and averaged over the recording period. Activity diaries were used for differentiation between school and leisure (total minus school) PA. Area-specific associations were assessed by adjusted negative binomial regressions.

**Results:** The only consistent observed associations were in Munich, between neighbourhood sport facilities and both leisure MVPA (rate ratio=1.09 (95% confidence interval=1.01-1.18)) and total MVPA (1.09 (1.01-1.17)). None of the two greenness metrics was consistently associated with any PA variable in Munich or Wesel, except that NDVI was associated with increased MVPA among Wesel females. In Munich, residing in a neighbourhood with green spaces and leisure facilities was not associated with PA.

**Conclusion:** There is indication that neighbourhood sport facilities could promote MVPA in German adolescents residing in urban areas, while higher greenness may encourage MVPA in rural females.

**Key words:** accelerometry, built environment, greenness, NDVI, green spaces, sport facilities

**Introduction**

Physical inactivity and low levels of physical activity (PA) are estimated to be among the ten leading risk factors for global disease burden, especially for noncommunicable diseases such as cardiovascular disease, diabetes and cancer (15). According to guidelines of World Health Organization (WHO), 81% of adolescents worldwide were insufficiently physically active in 2010, indicating that this group is especially vulnerable (32).

A well-planned and aesthetically pleasing neighbourhood with many trees and other vegetation that provides good access to green spaces and recreational facilities is important for promoting PA (25). A recent systematic review (10) provides some evidence (five of nine studies showed positive effect) that opening a new urban green space or improving an existing one (e.g., building new pedestrian paths) might increase PA levels in neighbouring residents. However, the reviewed studies were limited almost entirely to adults in the USA and Australia, and addressed only green spaces rather than other neighbourhood features. Thus, it is not clear whether neighbourhood and PA are actually linked, and whether it applies across different countries, age groups, and rural versus urban settings.

Epidemiological studies based on objectively assessed characteristics of both the neighbourhood and PA are very scarce in adolescents. A comprehensive review (6) concluded that recreational facility access was associated with PA in children and adolescents. However, 95 of the 103 reviewed papers were based on questionnaire-derived either PA or neighbourhood characteristics, or were conducted in children. As there is poor agreement between perceived and objective measurements of both neighbourhood (5,14) and PA (27) in adolescents, caution is needed when interpreting findings based on mainly self-reported information. A more recent systematic review and meta-analysis (20) that included studies with only objectively assessed PA and neighbourhood concluded that neighbourhood features such as recreational facilities, gyms, parks and sport venues increased moderate-to-vigorous PA (MVPA) in adolescents. Still, the review by McGrath and colleagues focused only on MVPA due to the lack of studies investigating lifestyle (light) and sedentary PA.

Because of the public health importance of the topic, the lack of epidemiological studies in adolescents and the scarcity of objective data on different PA levels (especially lifestyle and sedentary PA) we investigated whether neighbourhood characteristics such as vegetation level (greenness), green spaces and sport and leisure facilities were associated with different PA levels in urban and rural 15-year-olds in Germany. In this study, exposure and outcome variables were objectively assessed: neighbourhood characteristics in Geographic Information System (GIS) by using satellite images and land use datasets, and total and leisure PA by accelerometry.

**Methods**

**Study population.** The GINIplus study (German Infant Study on the Influence of Nutrition Intervention plus Environmental and Genetic Influences on Allergy Development) and the LISAplus study (Influence of Life-Style Factors on the Development of the Immune System and Allergies in East and West Germany plus the Influence of Traffic Emissions and Genetics) are ongoing birth cohorts that recruited healthy full-term neonates with a normal birth weight. Briefly, GINIplus participants were recruited in the cities of Munich (n=2,949) and Wesel (n=3,042) between 1995 and 1998. This cohort consists of two study groups: one is an observation group and the second includes a nutritional intervention conducted during the first four months of life, in which a randomised, double-blind controlled trial compared the effect of three hydrolysed formulas versus cow's milk formula on allergy development. Newborns with a family history of allergy were invited for the intervention group. Participants with a negative family history or a positive family history but who declined to participate in the intervention trial were included in the observation group (31). LISAplus is a population based cohort recruited in the cities of Munich (n=1,467), Leipzig (n=976), Wesel (n=348) and Bad Honnef (n=306) between 1997 and 1999 (33). As the GINIplus and LISAplus birth cohorts have nearly identical study designs at later follow-ups, data were pooled and are analysed by study area.

The current cross-sectional analyses are restricted to participants who resided in in the city of Munich and the adjacent regions of Upper Bavaria and Swabia (predominantly urban part of the region; hereafter referred to as Munich area; see Supplemental figure 1) and in the city of Wesel and the adjacent regions of Münster and Düsseldorf (predominantly rural part of the region; hereafter referred to as Wesel area; see Supplemental figure 1) both at birth and at the 15-year follow-up, and who provided valid accelerometry data. The final study population comprised of 747 participants from the Munich area and 542 participants from the Wesel study area. Detailed flow chart of the participants enrolled into the current analyses is provided in Supplemental figure 2.

The GINIplus and LISAplus studies have been approved by their local ethics committees and informed consent was obtained from all parents of participants.

**Exposure assessment.** In line with many other studies (1,3,4,8,19,21), a neighbourhood was defined as a circular 500-m buffer around the residence, and all exposure variables were derived for this area.

**Greenness.** Greenness was defined as 1) the mean Normalized Difference Vegetation Index (NDVI) and as 2) percent tree cover. NDVI refers to all vegetation, and it is calculated based on the knowledge that plants strongly absorb visible red light (RED) for use in photosynthesis while strongly reflecting near-infrared light (NIR) to prevent overheating; the equation for NDVI is based on spectral reflectance measurements acquired in corresponding light wavelengths: NDVI=(NIR–RED)/(NIR+RED). These reflectances are ratios of the reflected over absorbed light and their values range from 0 to +1, therefore NDVI values range from −1 to +1, with +1 indicating a highly vegetated area (31). For our NDVI calculations, we used cloud-free Landsat 5 Thematic Mapper (TM) satellite images at a resolution of 30 m (<http://earthexplorer.usgs.gov/>), obtained during spring and summer months in 2011 (April for the Wesel area and July for the Munich area, as cloud-free images for the same month were not available for both study areas). We excluded negative pixels from the calculated NDVI maps before assigning the neighbourhood NDVI because they are not vegetation-informative, and represent mainly water features. Neighbourhood NDVI is visualized in Supplemental figure 3A.

Tree cover refers to the annual averaged percentage of surface covered by woody vegetation that is higher than 5 m. Percent tree cover in the neighbourhood was obtained from freely available Landsat Vegetation Continuous Fields (VCF) maps at a resolution of 30 m for the year 2005 (<http://glcfapp.glcf.umd.edu/data/landsatTreecover/>) as a neighbourhood mean (each 30-m pixel contains information on percent tree cover; visualized in Supplemental figure 3B). These maps were developed based on all seven reflectance bands of Landsat 5 TM or Landsat 7 Enhanced TM (ETM) (26).

**Green spaces and sport and leisure facilities (Munich area only).** Neighbourhood urban green spaces (parks and gardens), sport facilities (swimming pools, sports complexes and stadiums), leisure facilities (open air museums, open air theatres, recreation centres, amusement parks, safari-parks, game reserves, zoos) and forests (representing natural green spaces in contrast to urban green spaces) were defined as present or absent in a neighbourhood (visualized in Supplemental figure 3C). Data for these calculations were obtained from the local Bavarian land use dataset (vector with spatial resolution of <5 m) from the Bavarian Survey Office for the year 2008, and were available only for the Munich area.

Geographic data management and calculations were conducted using the ArcGIS 10.1 Geographical Information System (GIS) (ESRI, Redlands, CA) and Geospatial Modelling Environment (GME) (Spatial Ecology LLC) softwares.

**Physical activity.** A detailed description of PA measurements by accelerometry and activity diaries is provided by Pfitzner et al. (23) and Smith and Schulz (28). Briefly, time spent in PA was obtained from one week hip-worn triaxial accelerometers (ActiGraph GT3X, Pensacola, Florida) and stored in “activity count units” at 1 Hz (resampled from 30 Hz). PA was then classified according to number of accelerometer counts per minute, into sedentary, lifestyle, and moderate-to-vigorous PA (MVPA), using newly published triaxial ActiGraph cutoffs for adolescents by Romanzini et al. (24). Detailed activity diaries filled by participants during wearing accelerometers were used for quality control (in total 16% of participants who completed accelerometry were excluded at this stage mainly due to non-wear time issues, see Supplemental figure 2), and for differentiation between school and leisure PA. Valid PA data for at least 10 hours per day over at least three weekdays and one weekend day had to be available for a participant to be included into analyses. Total and leisure (total PA minus school PA) minutes of each type of PA (sedentary, lifestyle, and MVPA) per day were averaged over the recording period and rounded to the nearest integer to be further used in the regression analyses. Furthermore, number of days with more than 60 min/day of MVPA (according to WHO recommendations) was also calculated for each participant and used as an outcome variable. Thus, a total of seven outcome variables were utilized in the current analyses. All exposure and outcome variables as well as their units of measurements are summarized in Supplemental figure 4.

**Statistical analyses.** Differences between the study population and the original birth cohorts were assessed using Pearson’s Chi-square test.

The outcome variables – the minutes of PA or number of days with more than 60 min/day of MVPA (Supplemental figure 4) – were count data with over-dispersion, as identified by descriptive statistics (the variance greater than the mean). Therefore, typical in such cases Poisson regression could not be used and the associations between each exposure and outcome variable pair were assessed by negative binomial regression. Negative binomial regression has the same mean structure as Poisson regression but models the over-dispersion by an additional parameter. The natural logarithm of the number of days with valid PA measurements was fitted as an offset in models where number of days with more than 60 min/day of MVPA was used as an outcome variable. Betas (ß) and their 95% confidence intervals (CI) were exponentiated to obtain rate ratios (RR). Crude models were adjusted for study (GINIplus observation / GINIplus intervention / LISAplus), sex (male / female), exact age at the time of accelerometry (years), and season of accelerometry readings (winter / spring / summer / autumn). Main models were additionally corrected for body mass index (BMI, kg/m²), and for maternal and paternal education level (low for < 10 years of school / medium for 10 / high for > 10, according to the German education system). Finally, urbanisation-adjusted models additionally accounted for degree of urbanisation, assessed by urban index, which reflects the proportion of land use with predominantly sealed soil such as residential areas, roads or airports (according to CORINE land cover data, EEA 2006) within a radius of 2 km (11,12). Several studies have been reported that the degree of urbanisation may confound and/or modify associations with greenness or green spaces (18, 22), which might also be the case for other neighbourhood features.

Since sex difference in activity levels are well known and were also observed in our cohorts (28), we tested for effect modification by sex using an interaction term between each of exposure variables and sex and by stratifying urbanisation-adjusted models by sex.

Moreover, since Romanzini’s triaxial cutoffs have been published very recently (24), for better comparability with other studies, we replicated all aforementioned analyses by using more common uniaxial cutoffs for activity levels published by Freedson et al. (9).

To test whether the choice of satellite images taken during different months for two study areas (April for Wesel and July for Munich) did not change the results, an alternative set of cloud-free images for the same month (July 2003) for both study areas was used for calculation of NDVI, and the analyses were re-run.

To examine whether the size of an urban green space or forest is an influential factor on the studied associations, we limited urban green spaces and forests to those with a land area greater or equal to 5,000 m², as has been recommended by the European Commission (16).

For all analyses, the statistical significance level was considered at p < 0.05.

All analyses were conducted by using Statistical Analysis Software (SAS Institute Inc., Cary, NC, USA), version 9.2.

**Results**

**Study population**

Study participants’ characteristics are provided by study area in Table 1. The Wesel participants were different from the Munich participants in almost all characteristics: they had higher BMI (21.2 *vs.* 20.5 kg/m²), there were more females (57.9 *vs.* 49.5%) and more participants from families with low and medium education level.

Compared to the original cohorts, adolescents included in the current study were more likely to have participated in the GINIplus intervention group than in the GINIplus observation group or LISAplus cohort (38 *vs.* 29%), to be female (53 *vs.* 48%), and to have both parents with high education level (mothers: 52 *vs*. 46%, fathers: 59 *vs.* 53%).

**Neighbourhood characteristics**

The Wesel participants resided in less urbanised neighbourhoods as defined by urban index and with higher tree cover than Munich participants (Table 1). As it was not possible to obtain cloud-free images for the same month for both study areas, comparing NDVI is therefore not appropriate. Spearman’s correlations coefficients (ρ) between two greenness variables and urbanisation for each study area are provided in Supplemental table 2. In both areas, moderate negative correlation (ρ=-0.62 and ρ =-0.64 for Munich and Wesel, respectively) was observed between NDVI and degree of urbanisation while negligible correlation (ρ=-0.13 and ρ=0.22 for Munich and Wesel, respectively) was observed between tree cover and degree of urbanisation. There was low (ρ=0.43) positive correlation between NDVI and tree cover in the Munich area; in the Wesel area this correlation was negligible (ρ=-0.22).

53.7% of Munich adolescents had urban green spaces in the neighbourhood, 45.2% had sport facilities, 21.7% had leisure facilities and 50.6% had forests (Table 1). The bivariate associations between neighbourhood green spaces, sport and leisure facilities and greenness variables as well as degree of urbanisation are given in Supplemental table 3. Neighbourhoods with urban green spaces had both lower NDVI and tree cover while being located in areas with higher degree of urbanisation compared to neighbourhoods without urban green spaces; the opposite was true for neighbourhoods with forests. No such clear picture was observed for sport and leisure facilities. Thus, we could see that urban green spaces are more common land use types in more urbanised areas, while forests are more typical in rural areas. This justifies additionally adjusting regression models for degree of urbanisation to account for possible confounding.

**Physical activity variables**

Adolescents residing in the Munich study area received more MVPA (47 *vs.* 43 min) and sedentary activity (654 *vs.* 645 min) while the Wesel participants received more lifestyle activity minutes (189.9 min *vs.* 178.0 min), as defined by Romanzini’s cutoffs (Table 1). Time spent in leisure activity (together for sedentary, lifestyle and MVPA) was 74% of total activity time in both study areas. 50% of participants (median) in both study areas had 28.6% of days with more than 60 min/day of MVPA (Table 1). Spearman’s correlations coefficients between activity variables for each study area are provided in Supplemental table 1. Total and leisure activity variables were highly correlated (ρ>0.7) in both areas. Low to moderate negative correlations (ρ=-0.3 to -0.7) were observed between lifestyle and sedentary variables as well as between MVPA and sedentary activity, and low positive correlations (ρ=0.3 to 0.5) were observed between MVPA and lifestyle activity variables.

**Associations between neighbourhood greenness and PA**

Associations between neighbourhood greenness’ variables and minutes of PA levels are presented by study area in Table 2. No consistent associations were observed in either Munich or Wesel participants. Despite the expectations, associations between NDVI and MVPA even tended to be slightly negative in the Munich adolescents before correcting for urbanisation degree. In Wesel adolescents, this tendency was opposite and the RRs were statistically significant before accounting for urbanisation. Very similar, non-significant estimates were observed when more than 60 min/day of MVPA in any of the study areas was considered as an outcome (Table 4).

Interaction terms between tree cover and sex were non-significant in either area. Three interaction terms were significant for NDVI: with leisure lifestyle activity minutes in Munich, and with both total and leisure MVPA minutes in Wesel. Sex-stratified associations between neighbourhood greenness and activity variables are presented in Supplemental tables 4 and 6. Positive significant associations between NDVI and total and leisure MVPA were observed in the Wesel females while negative associations (significant for total MVPA only) were observed for males. No difference was observed for lifestyle activity in Munich adolescents when the models were sex-stratified.

Associations were similar when Freedson’s cutoffs for activity levels were used and when NDVI was calculated based on an alternative set of images for July 2003 (data not shown).

**Associations between neighbourhood green spaces, sport and leisure facilities and PA (Munich area only)**

Table 3 presents associations between neighbourhood green spaces and facilities and minutes of PA in Munich adolescents. Adolescents with sport facilities in the neighbourhood achieved on average 9% more total and leisure MVPA (4.8 min/day and 3.8 min/day, respectively) compared to those with no neighbourhood sport facilities, which was the only consistent association. Still, neighbourhood sport facilities were not associated with achieving the recommended 60 min/day of MVPA (Table 4). In main models, there was association between sedentary activity and neighbourhood urban green spaces, however after accounting for urbanisation it became non-significant. PA was not associated with neighbourhood forests and leisure facilities.

None of the interaction terms between neighbourhood green spaces, sport and leisure facilities and sex was significant. Sex-stratified associations between neighbourhood green spaces, sport and leisure facilities and activity variables are presented in Supplemental tables 5 and 6. No differential associations by sex were observed, except for positive but not significant associations between green spaces and MVPA in females.

Associations were similar when Freedson’s cutoffs for activity levels were used and after green spaces smaller than 5,000 m² were excluded (data not shown).

**Discussion**

In this cross-sectional analysis of a population sample of 15-year-olds residing in two areas in Germany, we found evidence to support an association between objectively assessed neighbourhood sport facilities and accelerometer-derived total and leisure MVPA in urban adolescents. There is also indication that higher vegetation level as assessed by NDVI may promote MVPA in rural females. Higher neighbourhood tree cover, urban and natural green spaces and leisure facilities were not associated with PA. None of the neighbourhood characteristics was significantly associated with achieving the minimal MVPA level recommended by WHO.

Despite the recent growth in epidemiological literature investigating potential beneficial roles of the neighbourhood in encouraging PA, adolescents are so far under-investigated. What is more, such studies rarely combine accelerometric PA with GIS-measured neighbourhood characteristics. When they do, there is between-studies heterogeneity in the neighbourhood characteristics considered, assessment methods and definitions of “neighbourhood” (20).

To our knowledge, there is only one study in adolescents that investigated the effects of the neighbourhood NDVI on PA (1), and no studies considering tree cover. Several studies have utilized greenness as a characteristic of green spaces, and have found that a park’s greater greenness or presence of the trees providing shade was associated with PA (7,29). In our study, in line with Almanza et al. (1), we did not find any consistent associations between all vegetation (NDVI) or trees and PA in general population in either of study areas. The observed positive association in Wesel females between NDVI and MVPA in contrast to negative in Wesel males could be due to sex differences in time spent in the neighbourhood and type of activity conducted. It might also be that higher NDVI reflects lower urbanisation (as supported by correlation analysis), and thus poorer infrastructure. Poor infrastructure might discourage walking to amenities or visiting friends, which could affect adolescent males from being engaged in PA more than it does females. In rural areas, which generally have less sport-promoting amenities, it may be crucial. Nevertheless, we did not have necessary data to verify this hypothesis.

More studies have investigated the associations of adolescents’ PA with play-encouraging neighbourhood venues, such as parks, recreation facilities, gyms and sports complexes. The results of a meta-analysis (20) supported a promoting, though rather minor role of such venues on MVPA. The results of our study are partially in line with this meta-analysis’ conclusion, indicating that sport facilities in the neighbourhood could be beneficial for adolescents’ higher engagement in doing MVPA. Such facilities are not very costly and therefore are affordable for most Germans; therefore, building more sport venues is a potentially good sport-promoting intervention in adolescents.

Despite our expectations, the same was not true for venues encouraging other MVPA and/or light PA, namely leisure facilities and green spaces. The latter have been often demonstrated to be positively associated with PA in different adult populations (13). Of course, it might be that in our study, the power was insufficient to detect this association, presumably small in size, as confirmed by significant positive results from main models (Table 3).

The first major strength of this study is spatial distribution of participants over two study areas that substantially differed by degree of urbanisation. A further strength is objective assessment of PA by accelerometry and by diary records, which allowed differentiation between school and leisure activity. As estimates for total PA were mainly driven by leisure PA, we suggest that at least in this age group total PA might be used as a proxy for leisure PA if the latter is not available. Since our findings were not affected by the spatial resolution of acceleration for PA measurements – triaxial (Romanzini) vs. uniaxial (Freedson) - and choice of cutoffs for activity levels, it speaks in favour of their reliability.

The standardized objective assessment of several neighbourhood characteristics based on good resolution satellite images and detailed land use dataset is a further strength. Of course, this approach is not without limitations. In particular, cloud-free Landsat images close in time to PA data collection were not available for both study areas for the same month, so we had to choose images taken during different months. Nevertheless, we analyzed the associations by study area. Furthermore, using the alternative NDVI variable based on same-month images taken several years earlier did not change our findings. Lastly, our definition of neighbourhood as a 500-m circular buffer around the residence, referring to the distance easily reachable on foot within 10 minutes, could have caused some misclassification, since we were not able to account for walkability. However, this definition is quite standard (1,3,4,8,19,21). Moreover, neighbourhoods in Germany are safe and designed for walking: for example roads generally have pavements and pedestrian crossings. Thus, walkability level should not confound the associations of interest.

GINIplus and LISAplus cohorts were not designed to assess the specific association between the neighbourhood and PA. Despite of prospective collection of the personal characteristics and PA data, which minimizes recall bias, current analysis is cross-sectional and thus purely descriptive. Moreover, residual confounding due to time spent in the neighbourhood, quality characteristics and frequency of use of green spaces, sport and leisure facilities, sports club membership and having an own garden could have taken place. Location of PA with help of GPS would have helped looking closer into the studied association, but these data were also not available.

The generalizability of our findings is limited as there are several sources of selection bias. First of all, only German-speaking families were initially recruited to participate in the GINIplus and LISAplus cohorts, which is not representative of the entire German population. Moreover, families with a lower socioeconomic status (SES) were less likely to be initially recruited and further participate in the 15-year follow-up of both cohorts. Thus, adolescents with low SES that could potentially benefit more from their neighbourhood (2,17) are under-represented in this analysis. Nevertheless, as it has been reported in the review by McGrath et al. (20), SES does not influence studied association. Still, we cautiously adjusted for mother’s and father’s educational level as a proxy of SES, and it did not change our findings.

**Conclusions**

Our findings suggest that in German adolescents, neighbourhood sport facilities could promote MVPA in urban neighborhoods while higher greenness could encourage MVPA in rural neighborhoods, only for females. We suggest that adolescents’ PA may be encouraged by building more sports facilities in residential areas. To achieve greater effects, other approaches are likely needed than mere reshaping of the built environment. Moreover, males and females might require different interventions because of possible different activity preferences, which should be more investigated.

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**Conflicts of interests**

All co-authors have no conflicts of interest.

**Table 1.** Characteristics of study population and exposure levels

|  |  |  |  |
| --- | --- | --- | --- |
| **Variable** | **Munich**  (n=747) | **Wesel**  (n=542) | **p-value§** |
| **Personal characteristics** |  |  |  |
| Study\*  GINIplus observation  GINIplus intervention  LISAplus | 214 (28.7)  269 (36.0)  264 (35.3) | 268 (49.5)  221 (40.7)  53 (9.8) | <.0001 |
| Sex\*  female  male | 370 (49.5)  377 (50.5) | 314 (57.9)  228 (42.1) | 0.0028 |
| Age (years)\*\* | 15.6 ± 0.5 | 15.6 ± 0.6 | 0.1942 |
| BMI (kg/m²)\*\*  missing | 20.5 ± 2.8  13 | 21.2 ± 3.3  6 | <.0001 |
| Maternal school education (years)\*  ≤ 9  10  > 10  missing | 52 (7.3)  202 (28.2)  462 (64.5)  31 | 66 (12.7)  259 (49.7)  196 (37.6)  21 | <.0001 |
| Paternal school education (years)\*  ≤ 9  10  > 10  missing | 86 (12.2)  124 (17.5)  498 (70.3)  39 | 170 (33.1)  137 (26.7)  206 (40.2)  29 | <.0001 |
|  |  |  |  |
| **Neighbourhood characteristics** |  |  |  |
| Urban index\*\* | 0.44 ± 0.28 | 0.26 ± 0.21 | <.0001 |
| Neighbourhood NDVI\*\* | 0.41 ± 0.09 | 0.33 ± 0.08 | <.0001 |
| Neighbourhood tree cover (%)\*\*\* | 1.0 [0.4 – 3.4] | 6.4 [4.2 – 9.6] | <.0001 |
| Neighbourhood urban green spaces\*  yes  no | 401 (53.7)  346 (46.3) | NA  NA | NA |
| Neighbourhood sport facilities\*  yes  no | 338 (45.2)  409 (54.8) | NA  NA | NA |
| Neighbourhood leisure facilities\*  yes  no | 162 (21.7)  585 (78.3) | NA  NA | NA |
| Neighbourhood forests\*  yes  no | 378 (50.6)  369 (49.4) | NA  NA | NA |
|  |  |  |  |
| **Physical activity** |  |  |  |
| Season of wearing a monitor\*  winter  spring  summer  autumn | 182 (24.4)  173 (23.1)  95 (12.7)  297 (39.8) | 156 (28.8)  164 (30.3)  97 (17.9)  125 (23.0) | <.0001 |
| Number of days with valid PA data\*  4  5  6  7 | 27 (3.6)  124 (16.6)  228 (30.5)  368 (49.3) | 31 (5.7)  73 (13.5)  161 (29.7)  277 (51.1) | 0.6096 |
| Total time in activity (min/day)\*\* | 885.0 ± 49.9 | 883.1 ± 52.9 | 0.5182 |
| Leisure time in activity (min/day)\*\* | 652.8 ± 68.4 | 651.1 ± 71.7 | 0.6830 |
| Total MVPA (min/day)\*\*\* | 47 [34 – 65] | 43 [30 – 59] | 0.0002 |
| Leisure MVPA (min/day)\*\*\* | 38 [26 – 54] | 34 [23 – 49] | 0.0003 |
| Total sedentary activity (min/day)\*\* | 654.0 ± 70.2 | 645.0 ± 72.8 | 0.0191 |
| Leisure sedentary activity (min/day)\*\* | 469.6 ± 69.2 | 459.9 ± 73.0 | 0.0160 |
| Total lifestyle activity (min/day)\*\* | 178.0 ± 41.9 | 189.9 ± 44.8 | <.0001 |
| Leisure lifestyle activity (min/day)\*\* | 141.0 ± 35.9 | 152.6 ± 40.3 | <.0001 |
| Days with more than 60 min/day of MVPA (%)\*\*\* | 28.6 [14.3 – 50.0] | 28.6 [14.3 – 42.9] | 0.0003 |

**\*** n (%); \*\* Mean ± standard deviation; \*\*\* Median [1st quartile – 3rd quartile]

**§** Two-tailedMann–Whitney *U* test or Chi-Square test

PA levels classified according to triaxial Romanzini’s cutoffs (24); all activity variables averaged over the recording period

MVPA – moderate-to-vigorous physical activity

NDVI – Normalized Difference Vegetation Index. Wesel images to calculate NDVI were obtained for April 2011; Munich images were obtained for July 2011

BMI – body mass index

**Table 2.** Rate ratios with 95% confidence intervals of neighbourhood **NDVI and tree cover** (interquartile increase\*) and average minutes per day of moderate-to-vigorous physical activity (MVPA), sedentary and lifestyle activities estimated by negative binomial regression. Significant associations (p<0.05) are written in bold font.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Study area /**  **Outcome variable** | **Exposure variable** | **Crude model\*\*** | **Main model\*\*\*** | **Urbanisation-adjusted model \*\*\*\*** |
|  |  |  |  |  |
| **Munich** |  | (n=747) | (n=688) | (n=688) |
|  |  |  |  |  |
| Total MVPA | NDVI | 0.98 (0.93 – 1.02) | 0.98 (0.94 – 1.03) | 1.00 (0.94 – 1.06) |
|  | Tree cover | 1.01 (0.99 – 1.02) | 1.01 (0.99 – 1.03) | 1.01 (1.00 – 1.03) |
|  |  |  |  |  |
| Leisure MVPA | NDVI | 0.96 (0.92 – 1.01) | 0.97 (0.92 – 1.02) | 0.99 (0.93 – 1.06) |
|  | Tree cover | 1.01 (0.99 – 1.03) | 1.01 (0.99 – 1.03) | 1.01 (1.00 – 1.03) |
|  |  |  |  |  |
| Total sedentary activity | NDVI | 1.01 (1.00 – 1.02) | 1.01 (0.99 – 1.02) | 0.99 (0.98 – 1.01) |
|  | Tree cover | 1.00 (1.00 – 1.00) | 1.00 (1.00 – 1.01) | 1.00 (1.00 – 1.00) |
|  |  |  |  |  |
| Leisure sedentary activity | NDVI | 1.01 (0.99 – 1.02) | 1.01 (0.99 – 1.02) | 1.00 (0.98 – 1.02) |
|  | Tree cover | 1.00 (1.00 – 1.01) | 1.00 (1.00 – 1.01) | 1.00 (0.99 – 1.01) |
|  |  |  |  |  |
| Total lifestyle activity | NDVI | 0.99 (0.97 – 1.01) | 0.99 (0.97 – 1.01) | 1.00 (0.97 – 1.03) |
|  | Tree cover | 1.00 (0.99 – 1.01) | 1.00 (0.99 -1.01) | 1.00 (1.00 – 1.01) |
|  |  |  |  |  |
| Leisure lifestyle activity | NDVI | 0.99 (0.97 – 1.01) | 0.99 (0.97 – 1.02) | 1.00 (0.97 – 1.04) |
|  | Tree cover | 1.00 (1.00 – 1.01) | 1.00 (1.00 – 1.01) | 1.01 (1.00 – 1.01) |
|  |  |  |  |  |
|  |  |  |  |  |
| **Wesel** |  | (n=542) | (n=504) | (n=504) |
|  |  |  |  |  |
| Total MVPA | NDVI | **1.05 (1.00 – 1.11)** | **1.05 (1.00 – 1.11)** | 1.04 (0.98 – 1.11) |
|  | Tree cover | 0.99 (0.94 – 1.04) | 0.99 (0.94 – 1.04) | 1.00 (0.95 – 1.05) |
|  |  |  |  |  |
| Leisure MVPA | NDVI | **1.06 (1.00 – 1.12)** | 1.05 (1.00 – 1.12) | 1.04 (0.97 – 1.11) |
|  | Tree cover | 0.97 (0.92 – 1.02) | 0.97 (0.92 – 1.03) | 0.98 (0.92 – 1.03) |
|  |  |  |  |  |
| Total sedentary activity | NDVI | 1.00 (0.99 – 1.01) | 1.00 (0.98 – 1.01) | **0.98 (0.97 – 1.00)** |
|  | Tree cover | 1.00 (0.99 – 1.01) | 1.00 (0.99 – 1.01) | 1.00 (0.99 – 1.01) |
|  |  |  |  |  |
| Leisure sedentary activity | NDVI | 1.01 (0.99 – 1.02) | 1.00 (0.99 – 1.02) | 0.99 (0.97 – 1.01) |
|  | Tree cover | 1.00 (0.99 – 1.02) | 1.00 (0.99 – 1.02) | 1.00 (0.99 – 1.02) |
|  |  |  |  |  |
| Total lifestyle activity | NDVI | 1.02 (0.99 – 1.04) | 1.02 (0.99 – 1.04) | 1.03 (1.00 – 1.06) |
|  | Tree cover | 0.99 (0.97 – 1.01) | 0.99 (0.97 – 1.01) | 0.99 (0.97 – 1.01) |
|  |  |  |  |  |
| Leisure lifestyle activity | NDVI | 1.02 (0.99 – 1.05) | 1.02 (0.99 – 1.05) | 1.03 (0.99 – 1.06) |
|  | Tree cover | 0.98 (0.96 – 1.01) | 0.99 (0.96 – 1.01) | 0.99 (0.96 – 1.01) |

PA levels classified according to triaxial Romanzini’s cutoffs (24)

NDVI – Normalized Difference Vegetation Index

\* Interquartile ranges are area-specific. Munich: NDVI = 0.122, tree cover = 3.03; Wesel: NDVI = 0.100, tree cover = 5.35

\*\*Adjusted for study, sex, age and season

\*\*\*Adjusted for study, sex, age, season, BMI, maternal and parental education

\*\*\*\* Adjusted for study, sex, age, season, BMI, maternal and parental education and urban index

**Table 3.** Rate ratios with 95% confidence intervals of neighbourhood **green spaces, sport and leisure facilities** and average minutes per day of moderate-to-vigorous physical activity (MVPA), sedentary and lifestyle activities estimated by negative binomial regression for Munich area. Reference is no green spaces or sport facilities or leisure facilities in the neighbourhood. Significant associations (p<0.05) are written in bold font.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Outcome variable** | **Exposure variable** | **Crude model\***  (n=747) | **Main model\*\***  (n=688) | **Urbanisation-adjusted model \*\*\*** (n=688) |
| Total MVPA | Urban green spaces | 1.06 (0.99 - 1.13) | 1.05 (0.98 – 1.13) | 1.03 (0.94 – 1.12) |
|  | Sport facilities | **1.09 (1.02 – 1.17)** | **1.09 (1.02 – 1.18)** | **1.09 (1.01 – 1.17)** |
|  | Leisure facilities | 1.05 (0.97 – 1.14) | 1.07 (0.98 – 1.17) | 1.07 (0.98 – 1.17) |
|  | Forests | 1.00 (0.93 – 1.07) | 1.01 (0.94 – 1.09) | 1.04 (0.96 - 1.12) |
|  |  |  |  |  |
| Leisure MVPA | Urban green spaces | **1.08 (1.00 – 1.16)** | 1.06 (0.99 – 1.15) | 1.04 (0.95 – 1.14) |
|  | Sport facilities | **1.10 (1.02 - 1.18)** | **1.10 (1.02 – 1.19)** | **1.09 (1.01 – 1.18)** |
|  | Leisure facilities | 1.07 (0.98 – 1.17) | 1.09 (0.99 – 1.20) | 1.09 (1.00 – 1.20) |
|  | Forests | 0.99 (0.92 – 1.07) | 1.02 (0.94 – 1.10) | 1.05 (0.96 – 1.14) |
|  |  |  |  |  |
| Total sedentary activity | Urban green spaces | **0.98 (0.96 – 0.99)** | **0.98 (0.96 – 0.99)** | 0.98 (0.97 – 1.00) |
|  | Sport facilities | 0.98 (0.97 – 1.00) | 0.99 (0.97 – 1.00) | 0.99 (0.97 – 1.00) |
|  | Leisure facilities | 1.01 (0.99 – 1.03) | 1.01 (0.99 – 1.03) | 1.00 (0.99 – 1.02) |
|  | Forests | 1.01 (1.00 – 1.03) | 1.01 (1.00 – 1.03) | 1.00 (0.99 – 1.02) |
|  |  |  |  |  |
| Leisure sedentary activity | Urban green spaces | **0.98 (0.96 – 1.00)** | **0.97 (0.95 – 1.00)** | 0.98 (0.95 – 1.01) |
|  | Sport facilities | **0.97 (0.95 – 1.00)** | 0.98 (0.96 – 1.00) | 0.98 (0.96 – 1.00) |
|  | Leisure facilities | 1.01 (0.99 – 1.04) | 1.01 (0.98 – 1.04) | 1.01 (0.98 – 1.03) |
|  | Forests | 1.01 (0.99 – 1.04) | 1.01 (0.99 – 1.04) | 1.01 (0.98 – 1.03) |
|  |  |  |  |  |
| Total lifestyle activity | Urban green spaces | 1.00 (0.97 – 1.04) | 1.01 (0.97 – 1.04) | 0.99 (0.95 – 1.03) |
|  | Sport facilities | 1.02 (0.98 – 1.05) | 1.02 (0.98 – 1.05) | 1.02 (0.98 – 1.05) |
|  | Leisure facilities | 0.99 (0.95 – 1.03) | 1.00 (0.96 – 1.04) | 1.00 (0.96 – 1.04) |
|  | Forests | 1.00 (0.97 – 1.03) | 1.00 (0.97 – 1.04) | 1.01 (0.98 – 1.05) |
|  |  |  |  |  |
| Leisure lifestyle activity | Urban green spaces | 1.00 (0.97 – 1.04) | 1.00 (0.97 – 1.04) | 0.98 (0.94 – 1.03) |
|  | Sport facilities | 1.02 (0.98 – 1.05) | 1.02 (0.99 – 1.06) | 1.02 (0.98 – 1.06) |
|  | Leisure facilities | 0.98 (0.94 – 1.02) | 0.98 (0.94 – 1.03) | 0.98 (0.94 – 1.03) |
|  | Forests | 1.00 (0.97 – 1.04) | 1.01 (0.97 – 1.05) | 1.02 (0.98 – 1.06) |

PA levels classified according to triaxial Romanzini’s cutoffs (24)

\* Adjusted for study, sex, age and season

\*\*Adjusted for study, sex, age, season, BMI, maternal and parental education

\*\*\* Adjusted for study, sex, age, season, BMI, maternal and parental education and urban index

**Table 4.** Incident rate ratios with 95% confidence intervals of neighbourhood NDVI and tree cover (interquartile increase\*) as well as neighbourhood green spaces and sport and leisure facilities\*\* and **number of days with more than 60 min/day of** **moderate-to-vigorous physical activity (MVPA)** estimated by negative binomial regression. Significant associations (p<0.05) are written in bold font.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Study area** | **Exposure variable** | **Crude model\*\*\*** | **Main model\*\*\*\*** | **Urbanisation-**  **adjusted model \*\*\*\*\*** |
|  |  |  |  |  |
| **Munich** |  | (n=747) | (n=688) | (n=688) |
|  |  |  |  |  |
|  | NDVI | 0.98 (0.91 – 1.05) | 0.98 (0.91 – 1.06) | 1.01 (0.91 – 1.11) |
|  | Tree cover | 1.01 (0.98 – 1.04) | 1.01 (0.98 – 1.04) | 1.02 (0.99 – 1.04) |
|  | Urban green spaces | 1.08 (0.96 – 1.20) | 1.09 (0.97 – 1.23) | 1.08 (0.94 – 1.25) |
|  | Sport facilities | **1.14 (1.02 – 1.28)** | 1.12 (1.00 – 1.26) | 1.12 (1.00 – 1.26) |
|  | Leisure facilities | 1.04 (0.91 – 1.19) | 1.04 (0.90 – 1.20) | 1.04 (0.91 – 1.20) |
|  | Forests | 1.03 (0.92 – 1.15) | 1.03 (0.92 – 1.16) | 1.06 (0.94 – 1.20) |
|  |  |  |  |  |
| **Wesel** |  | (n=542) | (n=504) | (n=504) |
|  |  |  |  |  |
|  | NDVI | 1.05 (0.96 – 1.15) | 1.05 (0.96 – 1.15) | 0.99 (0.88 – 1.11) |
|  | Tree cover | 0.99 (0.91 – 1.07) | 0.98 (0.90 – 1.06) | 0.99 (0.91 – 1.07) |

Days with more than 60 min/day of MVPA classified according to triaxial Romanzini’s cutoffs (24)

NDVI – Normalized Difference Vegetation Index

\*Interquartile ranges are area-specific. Munich: NDVI=0.113, tree cover=2.87; Wesel: NDVI=0.102, tree cover=5.19

\*\* Reference is no green spaces or sport facilities or leisure facilities in the neighbourhood.

\*\*\*Adjusted for study, sex and age

\*\*\*\*Adjusted for study, sex, age, BMI, maternal and parental education

\*\*\*\*\* Adjusted for study, sex, age, BMI, maternal and parental education and urban index