BMJ Open

Inner-city green space and its association with body mass index and prevalent type 2 diabetes: a cross-sectional study in an urban German city

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ABSTRACT

Objective The accessibility of green space is an important aspect of the urban residential environment and has been found to be beneficial for health and well-being. This study investigates the association between different indicators of green space and the outcomes body mass index (BMI) and prevalent type 2 diabetes in an urban population.

Design Population-based cross-sectional study.

Setting Dortmund, a city located in the industrial Ruhr area in Western Germany.

Participants 1312 participants aged 25–74 years from the Dortmund Health Study.

Methods The participants' addresses were geocoded and shapefiles of statistical districts, road network and land use, as well as data on neighbourhood characteristics were obtained at baseline. Three indicators of green space were constructed using geographical information systems: proportion of green space, recreation location quotient (RLQ) weighted by population and distance to the next park or forest. Multilevel linear and logistic regression analyses on the association of green space with BMI and type 2 diabetes were performed, adjusted by individual-level characteristics and neighbourhood unemployment rate.

Results The multilevel regression analyses showed no association between green space and BMI. In contrast, the three indicators of green space were significantly associated with type 2 diabetes. Residents of neighbourhoods with a low RLQ had a 2.44 (95% CI 1.01 to 5.93) times higher odds to have type 2 diabetes compared with residents of high RLQ neighbourhoods. Likewise, residing more than 0.8 km away from the nearest park or forest increased the odds of type 2 diabetes (OR 1.71, 95% CI 1.05 to 2.77).

Conclusions This study indicates that green space and its spatial accessibility might play a role in the development of type 2 diabetes. Further research is needed to clarify this association.

INTRODUCTION

Recent publications suggest that obesity as well as type 2 diabetes are associated with socioeconomic characteristics of the residential environment.[1–6] A potential mechanism operating in the relationship between neighbourhood socioeconomic characteristics and

Strengths and limitations of this study

► The study focuses on the analysis of green space and its association with body mass index and type 2 diabetes in an urban city setting.
► Three different indicators of green space based on detailed land use data were applied in this analysis, addressing different dimensions of green space and its accessibility.
► The application of multilevel tools allows modelling the effects of individual-level and neighbourhood-level variables on health.
► Neighbourhoods were defined based on administrative districts, which differ significantly in size and population count, and may not entirely correspond to the residential environment of the study participants.
► The study is based on a cross-sectional design and therefore cannot establish a causal relationship.

health is related to differences in available resources of a neighbourhood.[7] Referring to the 'collective resources model', wealthy neighbourhoods offer their residents more collective resources that promote health and well-being.[8]

The built environment can affect health directly through pathological effects of exposure to biological and chemical substances and indirectly through characteristics of the physical and social environment.[9] Green space in the residential environment has been positively associated with health and well-being.[10] Although causal mechanisms relating green space and health are not clearly understood, the following potential pathways are discussed[11–13]: green space supports regeneration from exhaustion and stress,[14] offers space and opportunities for social interactions and physical activity,[11 15] reduces noise and noise annoyance,[16] and improves air quality.[11 17]

So far, only few studies investigated the relationship between green space and type 2

diabetes.[11 18–21] Most of these studies assessed the green space exposure as the proportion of green space in a defined radius around the participant's home, whereas the definition of the radius differed between studies (800 m,[18 20] 1 km,[11 19] 3 km,[11 18 20] 5 km[18 20]). All of these studies suggested an inverse association, namely lower odds of type 2 diabetes in greener areas.[11 18–20] A current study by Ngom *et al*[21] further investigated the role of proximity (distance from the participant's home to the nearest green space boundary) and type of green space in relation to diabetes.[21] In this study, a higher diabetes prevalence rate was reported for the participants with the highest distance to the next green space compared with those with the lowest distance, but this relationship was only present for green space providing sport facilities.[21]

Studies on obesity and green space have been published more often, but their results are also more contradictory.[10 22] For example, Lachowycz and Jones[22] systematically reviewed 13 studies investigating the association between green space and weight. Only 3 of these 13 studies reported a clear association indicating lower weight or lower weight gain in individuals from greener areas.[22] The most common green space measures in the reviewed articles were distance to the nearest green space or the percentage of green space within a defined area.[22] Since then, further studies have been published, but results on the relationship between green space and weight status are still mixed.[10]

The aim of the present study was to evaluate the relationship between green space and the outcomes body mass index (BMI) and type 2 diabetes by applying different measurement approaches of green space and its accessibility. For this purpose, we combined data from a population-based study with administrative data on neighbourhood characteristics and green space.

METHODS
Dortmund Health Study
The Dortmund Health Study (DHS)[23] is a population-based study conducted in Dortmund, a city located in the industrial Ruhr area in Western Germany with 585 000 inhabitants at the time of data collection. Baseline data were collected between October 2003 and September 2004. A gender-stratified and 5-year age group-stratified sample of 3820 individuals aged 25–74 years was drawn from the population registry. After corrections for deaths, language difficulties and recent relocations, 3425 individuals were eligible and invited to standardised face-to-face interviews and physical examinations to collect information on the prevalence of chronic diseases, health-related behaviours and sociodemographic characteristics. Overall, 2291 individuals participated in the DHS (response rate 66.9%) of which 1312 participants completed an interview and examination in the study centre and 979 participants answered a reduced postal questionnaire that was otherwise identical with the interview. In the present analysis, we included

the 1312 interview participants. To allow spatial analyses, participants' addresses at baseline were geocoded and linked to statistical districts, referred to as proxy neighbourhoods (n=62). Informed consent was obtained from all participants included in the study.[23]

Indicators of green space
Geographical data were obtained from different sources. Shapefiles of statistical districts were provided by the Survey and Land Registration Bureau of the city of Dortmund (approval 07/04/2011; statistical districts' mean area size=4.53 km², range 1.29–10.23 km²). Data on population per statistical district was obtained from the statistical office of the city of Dortmund for the year of DHS data collection. The road network was obtained from the OpenStreetMap contributors (accessed 28/04/2014). Data on land use mapping was provided by the Regional Association Ruhr for the year 2009. The land use maps (vector with spatial resolution of <3 m) were derived from different sources including orthophotos and the German basic map (Deutsche Grundkarte, DGK5, 1:5000) and recorded 150 different land use types. For this analysis, all green space areas including private and public gardens, parks, cemeteries, zoos, road planting and forests were considered. The smallest green space unit included in this analysis was 19 m². The data set was prepared and analysed using geographical information systems (ArcMap 10.0 Esri Deutschland GmbH; Grass GIS 7.0.0beta2).

We conceptualised two indicators to operationalise green space on the level of proxy neighbourhoods (based on the statistical districts): First, we calculated the proportion of green space within the total area for each neighbourhood. Second, a recreation location quotient (RLQ) weighted by the population was adapted to measure relative differences in the availability of green space between neighbourhoods.[24] The RLQ is calculated with the following equation[24]:

$$RLQ_s = \frac{\left(\frac{r_s}{pop_s}\right)}{\left(\frac{r_n}{pop_n}\right)}$$

where r denotes area of green space, pop population, s neighbourhood and n reference region. The reference region is the city in total (ie, the city of Dortmund, Germany). The RLQ quantifies the area of green space available to a resident of a specific neighbourhood relative to the city's total population. Values >1 indicate higher and values <1 indicate lower green space resources relative to the city's average; for instance, a value of 0.1 indicates a 90% lower green space availability in a specific neighbourhood compared with the city's average availability. In contrast to the crude proportion of green space, the RLQ enables to evaluate green space in relation to population size in a neighbourhood. We assume that the population size in a neighbourhood modifies the impact of green space on health. For instance, even with a large proportion of green space could the availability of green space for recreation be limited if it is a dense populated

neighbourhood; further, the function of green space as absorber of noise, for instance, could work less effectively in a dense populated neighbourhood. In respect to the first two variables (proportion of green space and RLQ), we decided to consider all kinds of green space because there are pathways linking green space and health that do not depend on their accessibility, for instance, green space can reduce noise and increase air quality. The variables were categorised into tertiles including an equal number of neighbourhoods to be able to show a potential dose–response relationship between green space and BMI/diabetes.

A third indicator measures the accessibility of green space on the individual level. We conducted a network analysis based on the street network providing measures for the minimum distance from the participants' residential addresses to the closest park or forest.[25] For this approach, representing an indicator of green space accessibility in the participants' home neighbourhoods, the analysis was limited to parks and forests because they are easily accessible for everyone, their use is free of charge, and they offer sufficient space for physical activity (min. $10\,000\,m^2$). We dichotomised the distance indicator with an 800 m cut-off. The cut-off of 800 m was chosen because previous studies suggested that this distance represents an area which can be accessed in approximately 10 min walking time.[26]

Outcomes
Weight and height were measured during physical examination and were used to calculate BMI (kg/m^2). Type 2 diabetes was defined based on the self-reported physician diagnosis of diabetes. To avoid the inclusion of type 1 diabetes cases, we excluded participants reporting an age of diagnosis younger than 31 years of age or without information (n=6) on the age of diagnosis (DIAB-CORE definition[27]). Participants who did not report a diabetes diagnosis but reported to take antidiabetic medication were also classified as prevalent type 2 diabetes cases. In order to identify participants with potentially unknown diabetes, participants with elevated levels of glycated haemoglobin (HbA1c ≥6.5%) were classified as additional cases. The HbA1c is a measure of glycaemic control and has been established as a screening biomarker for type 2 diabetes.[28]

Covariates
Individual social attributes need to be taken into account to investigate a person's interaction with his or her environment.[9] According to the literature, low educated, poor individuals or individuals belonging to ethnic minorities show a higher risk for type 2 diabetes.[29 30] Therefore, we adjusted the analysis for a number of individual variables, including age, sex, education, income, living with or without a partner and migrational background, as well as unemployment rate as a neighbourhood level variable.

Information on the highest level of school education and professional training was operationalised applying the 1997 International Standard Classification of Education (ISCED-97) from the United Nations Educational, Scientific and Cultural Organization. The educational background was summarised in three groups of low (no education, (pre)primary education and lower secondary education; ISCED-97 levels 0–2), medium (upper secondary education and postsecondary non-tertiary education; ISCED-97 levels 3–4) and high education (first and second stage tertiary education; ISCED-97 levels 5–6).[31] Based on information on household income and the number of household members, we calculated the net equivalent income with the following equation: $\frac{net\ household\ income}{number\ of\ household\ members^{0.36}}$, adapted from the Luxembourg income study.[32 33] The equivalent income was coded in four categories: income group 1 (<60% of the median income), income group 2 (60% of the median income to median income), income group 3 (>median income to 150% of median income) and income group 4 (>150% of median income).[33] Data on neighbourhood unemployment rate was provided by the statistical office of the city of Dortmund for the year of DHS data collection (2003). We considered overall unemployment rate as a covariate on the neighbourhood level, allowing adjustment for the socioeconomic status of the neighbourhood.

Statistical analysis
First, descriptive statistics were used to analyse the association between the outcomes BMI and type 2 diabetes, the independent individual-level variables and the measures of green space on an individual level. Group differences were tested via Pearson's χ^2 test, Fisher's exact test and analysis of variance.

Next, multilevel regression techniques were applied to analyse the relation between green space and the outcomes of interest. This model strategy allows controlling for the hierarchical structure of the data set. Level 1 includes 1312 study participants, which are nested in 62 proxy neighbourhoods on level 2. Multilevel logistic regression was applied for dichotomous outcomes (type 2 diabetes). Median ORs (MORs) were provided to assess '[…] the variation between clusters (the second-level variation) by comparing two persons from two randomly chosen, different clusters'.[34] Multilevel linear regression was conducted for metric outcomes (BMI) and intraclass correlation (ICC) was given as measure of variance. The models were stepwise adjusted by a set of individual-level variables and neighbourhood unemployment rate as a potential confounder on the neighbourhood level. We conducted a complete case analysis. Effect modification by sex as well as by education was tested for each measurement approach in the analysis of BMI and type 2 diabetes, but no indication for effect modification was observed.

Table 1 Characteristics of the study participants and distribution of body mass index (BMI) and type 2 diabetes by individual-level characteristics

	Total	BMI (kg/m^2)		Type 2 diabetes		
				Yes	No	
Participants (n)	1312	1309		112	1194	
	% (n)	Mean (SD)	P value*	% (n)	% (n)	P value†
Age						
25–40	23.2 (304)	25.5 (4.7)	<0.0001	4.5 (5)	24.8 (296)	<0.0001
40–60	42.2 (554)	27.7 (5.1)		28.6 (32)	43.6 (521)	
60–75	34.6 (454)	28.7 (4.5)		67.0 (75)	31.6 (377)	
Sex						
Women	52.9 (694)	27.0 (5.4)	<0.0001	43.8 (49)	53.7 (641)	0.04
Men	47.1 (618)	28.2 (4.4)		56.3 (63)	46.3 (553)	
Education						
Low	14.6 (191)	29.2 (5.4)	<0.0001	27.7 (31)	13.2 (157)	<0.0001
Medium	59.1 (775)	27.7 (5.0)		62.5 (70)	59.0 (704)	
High	26.4 (346)	26.3 (4.3)		9.8 (11)	27.9 (333)	
Net equivalent income						
Income group 1 (poor)	13.9 (182)	27.7 (5.2)	0.0001	16.0 (17)	14.6 (164)	0.001
Income group 2	35.1 (461)	28.0 (5.2)		49.1 (52)	36.0 (406)	
Income group 3	25.0 (328)	27.9 (5.0)		26.4 (28)	26.4 (298)	
Income group 4 (wealthy)	20.4 (268)	26.3 (4.2)		8.5 (9)	23.0 (259)	
Migration background						
No	84.0 (1102)	27.4 (5.0)	0.10	83.0 (93)	84.0 (1003)	0.79
Yes	16.0 (210)	28.0 (4.8)		17.0 (19)	16.0 (191)	
Living with a partner						
Yes	75.5 (991)	27.8 (4.9)	0.003	74.1 (83)	75.8 (903)	0.69
No	24.2 (318)	26.8 (5.1)		25.9 (29)	24.2 (288)	

*Group differences tested via analysis of variance.
†Group differences tested via χ^2 test or Fisher's exact test.

Statistical analyses were performed with STATA SE V.13.0 (StataCorp, College Station, Texas, USA).

RESULTS

The study population (n=1312) had a mean age of 52.6 years, and 52.9% of the participants were women (table 1). Mean BMI was 27.5 kg/m^2 (95% CI 27.3 to 27.8) and the crude prevalence of type 2 diabetes was 8.6% (95% CI 7.1% to 10.2%). The proportion of green space per total neighbourhood area varied between 5.1% and 75.5% with an average of 26.7%. The RLQ, which quantifies the area of green space available to a resident of a specific neighbourhood relative to the city's total population, differed between 0.1 and 25.9 with a mean of 1.0. The minimum distance between the participants' homes

to the closest park or forest differed between 0.01 and 3.1 km and had its mean at 1.1 km.

Table 1 reports the distribution of BMI and type 2 diabetes by individual-level characteristics. BMI was significantly associated with individual-level variables except migrational background. We observed an increasing BMI with higher ages as well as a higher BMI in men, in individuals with low education and low income, and in individuals living with a partner. Type 2 diabetes was more prevalent in the highest age group and in individuals with lower education and lower income.

The distribution of BMI and type 2 diabetes by the indicators of green space is presented in table 2. RLQ and distance to the nearest park or forest were significantly related to BMI showing the lowest mean BMI in neighbourhoods with a high RLQ (26.9 kg/m^2) and in

Table 2 Distribution of BMI and type 2 diabetes by indicators of green space

	Tertile 1	Tertile 2	Tertile 3	P value*
Proportion of green space in %	<23	23–31	>31	
N (total n=1312), %	33.4	33.7	32.9	
BMI (n=1309), mean (95% CI)	27.6 (27.2 to 28.1)	27.7 (27.2 to 28.1)	27.3 (26.8 to 27.7)	0.42
Prevalence type 2 diabetes (n=1306), % (95% CI)	10.3 (7.6 to 13.6)	9.5 (7.0 to 12.7)	5.8 (3.8 to 8.5)	0.04
RLQ weighted by population	<0.70	0.70–1.27	>1.28	
N (total n=1312), %	46.9	36.4	16.8	
BMI (n=1309), mean (95% CI)	27.4 (27.0 to 27.8)	28.0 (27.5 to 28.5)	26.9 (26.4 to 27.5)	0.02
Prevalence type 2 diabetes (n=1306), % (95% CI)	10.0 (7.7 to 12.6)	9.0 (6.6 to 12.0)	3.7 (1.6 to 7.1)	0.02
	Category 1	Category 2	P value*	
Distance to park or forest in km	≤0.8	>0.8		
N (total n=1312), %	38.3	61.6		
BMI (n=1309), mean (95% CI)	27.1 (26.7 to 27.5)	27.8 (27.5 to 28.2)	0.01	
Prevalence type 2 diabetes (n=1306), % (95% CI)	5.6 (3.7 to 8.0)	10.4 (8.4 to 12.8)	0.002	

*Group differences tested via χ^2 test, mean BMI by ANOVA.
ANOVA, analysis of variance; BMI, body mass index; RLQ, recreation location quotient.

participants living in a maximum distance of 800 m to the next park or forest ($27.1\,kg/m^2$). All three indicators of green space were associated with the prevalence of type 2 diabetes. While the prevalence of type 2 diabetes was 10.3% (95% CI 7.6 to 13.6%) in neighbourhoods with a low proportion of green space and 10.0% (95% CI 7.7% to 12.6%) in neighbourhoods with a low RLQ, the diabetes prevalence decreased to 5.8% (95% CI 3.8% to 8.5%) and 3.7% (95% CI 1.6% to 7.1%) in neighbourhoods with a high proportion of green space and high RLQ, respectively. Similar results were found for the distance to the nearest park or forest.

Table 3 presents the results of the stepwise linear two-level regression models on the relationship between green space and BMI. We found no associations between the proportion of green space or RLQ and BMI. In the age-adjusted and sex-adjusted model (model 2), individuals residing further than 0.8 km away from the next park or forest had a higher BMI compared with individuals living close by. Further adjustment for individual and neighbourhood social characteristics explained this relationship.

Additional analyses using logistic regression examining the relationship between the three indicators of green space and obesity (BMI $\geq30\,kg/m^2$) also showed no associations in the final models (data not shown).

In contrast, we found associations between all three indicators of green space and prevalent type 2 diabetes (table 4). In the univariate analysis (model 1), the highest odds to have type 2 diabetes were observed in individuals residing in neighbourhoods with the lowest proportion of green space (OR 1.86, 95% CI 1.12 to 3.10) and with the lowest values of RLQ (OR 2.92, 95% CI 1.37 to 6.22). With

respect to the proportion of green space, the pattern of a dose–response relationship was attenuated after further adjustment. In the fully adjusted model, only the residents in the medium tertile 2 had an elevated odds of type 2 diabetes and there was no longer a statistically significant trend across the tertiles. With respect to the RLQ, the significant association between RLQ and type 2 diabetes remained present in the fully adjusted model. Residents of neighbourhoods in tertile 1 had a 2.44 (95% CI 1.01 to 5.93) times higher odds to have type 2 diabetes than residents in tertile 3. Furthermore, residing more than 0.8 km away from the nearest park or forest roughly doubled the odds of type 2 diabetes in the basic model. The association was slightly attenuated after adjustment for individual-level variables and neighbourhood unemployment rate in model 4 but remained statistically significant (OR 1.71, 95% CI 1.05 to 2.77). According to the MOR (empty model: MOR=1.28; fully adjusted model: MOR=1.00; table 4), the variation in type 2 diabetes prevalence was low and could be statistically explained by the considered variable set.

DISCUSSION
In a population-based study, we examined the association of green space with BMI and type 2 diabetes in adults aged 25–74 years living in a large German city. In line with previous findings, the results indicate that green space may be an important resource in the residential environment. A lack of green space almost doubled the odds of type 2 diabetes, varying by the applied green space indicator. In contrast, the relation between green space and BMI appeared to be less clear with only a small difference

Table 3 Results of the multilevel linear regression: coefficient and corresponding 95% CIs for body mass index by indicators of green space

Indicators of green space	Coefficient (95% CI)			
	Model 1 (n=1309)*	Model 2 (n=1309)†	Model 3 (n=1233)‡	Model 4 (n=1233)§
Proportion of green space				
T1 (5.13–23.16)	0.45 (−0.36 to 1.27)	0.61 (−0.18 to 1.40)	0.28 (−0.37 to 0.93)	−0.09 (−0.79 to 0.60)
T2 (23.37–30.95)	0.49 (−0.32 to 1.29)	0.73 (−0.05 to 1.51)	0.50 (−0.15 to 1.15)	0.31 (−0.35 to 0.97)
T3 (31.38–75.48)	Reference	Reference	Reference	Reference
Test for trend P value	0.28	0.13	0.41	0.78
ICC (SE)¶	0.02 (0.1)	0.02 (0.1)	0	0
RLQ weighted by population				
T1 (0.08–0.70)	0.43 (−0.42 to 1.28)	0.43 (−0.42 to 1.28)	0.23 (−0.52 to 0.99)	−0.44 (−1.29 to 0.41)
T2 (0.70–1.27)	**1.09 (0.20 to 1.97)**	0.88 (−0.01 to 1.76)	0.63 (−0.15 to 1.41)	0.25 (−0.56 to 1.06)
T3 (1.28–25.86)	Reference	Reference	Reference	Reference
Test for trend P value	0.71	0.58	0.94	0.12
ICC (SE)¶	0.01 (0.1)	0.02 (0.1)	0	0
Distance to park or forest				
≤800 m	Reference	Reference	Reference	Reference
>800 m	**0.71 (0.12 to 1.30)**	**0.61 (0.04 to 1.18)**	0.45 (−0.09 to 0.99)	0.33 (−0.21 to 0.88)
ICC (SE)	0.01 (0.01)	0.02 (0.1)	0	0

The bold values represent statistically significant results.
*Model 1: unadjusted.
†Model 2: adjusted for age and sex.
‡Model 3: adjusted for age, sex, migration background, living with a partner, education, income.
§Model 4: adjusted for age, sex, migration background, living with a partner, education, income, neighbourhood unemployment rate.
¶ICC (SE) was estimated to be 0.02 (0.1) in the empty model.
ICC, intraclass correlation coefficient; RLQ, recreation location quotient.

in BMI between residents of neighbourhoods with a relatively large and those with a small area of green space.

This study supports the knowledge on the relation between green space and type 2 diabetes in an urban context. So far, only few studies investigated this research question.[11 18–21] As described before, most of the previous studies assessed the green space exposure as the proportion of green space in a defined radius around the participants' homes. In line with our study, all prior studies presented significant associations between green space and type 2 diabetes, suggesting a positive impact of a green residential environment.[11 18–20] For example, Dalton et al reported a 19% lower risk of incident diabetes for individuals living in the greenest neighbourhoods compared with those living in the least green areas.[20] Our work supports these results and adds to the literature by applying additional indicators of green space, in particular RLQ. A study by Ngom et al[21] further examined the role of specific types of green space in relation to diabetes and other cardiovascular endpoints.[21] In their analysis, particularly green space providing sport facilities was shown to be beneficial in relation to diabetes, with a 9% higher prevalence rate in the group with the highest distance to this type of green space compared with the group with the lowest distance.[21] This study suggests that it may be important for further studies to consider the type and quality of green space. Reports on the relation between green space and weight status are more frequent but present heterogeneous results up to now.[10 22] Our study results do not support a clear association between green space and BMI, independently of the applied green space measurement.

A variety of potential pathways linking green space and health outcomes such as obesity and diabetes have been discussed in the literature (for comprehensive reviews please see Markevych et al and Hartig et al[12 13]). With respect to obesity, it is questioned how the residential environment promotes high caloric food intake and prevents physical activity. In this context, environmental aspects such as the access to fast food or grocery stores, access to recreational facilities and green space, neighbourhood walkability and street connectivity were examined.[9] Auchincloss et al[35] presented a reduction of 10% in the incidence of obesity by a modest improvement in neighbourhood resources promoting a healthy diet and walking.[35] Green space provides space and opportunities for physical activity,[36] which is associated with lower weight and is also an important aspect in the prevention of type 2 diabetes.[37] The published literature on the relation between green space and physical activity suggests a moderately positive association[10] but is not entirely consistent.[22]

Table 4 Results of the multilevel logistic regression: OR and corresponding 95% CIs for type 2 diabetes by indicators of green space

Indicators of green space	OR (95% CI)			
	Model 1 (n=1306)*	Model 2 (n=1306)†	Model 3 (n=1230)‡	Model 4 (n=1230)§
Proportion of green space				
T1 (5.13–23.16)	**1.86 (1.12 to 3.10)**	**2.13 (1.26 to 3.60)**	1.73 (0.99 to 3.03)	1.54 (0.86 to 2.78)
T2 (23.37–30.95)	**1.71 (1.02 to 2.86)**	**2.09 (1.23 to 3.56)**	**2.03 (1.16 to 3.54)**	**1.89 (1.07 to 3.33)**
T3 (31.38–75.48)	Reference	Reference	Reference	Reference
Test for trend P value	0.02	0.006	0.07	0.21
MOR¶	1.00	1.00	1.00	1.00
RLQ weighted by population				
T1 (0.08–0.70)	**2.92 (1.37 to 6.22)**	**3.10 (1.43 to 6.71)**	**2.79 (1.22 to 6.39)**	**2.44 (1.01 to 5.93)**
T2 (0.70–1.27)	**2.62 (1.21 to 5.69)**	**2.40 (1.09 to 5.30)**	2.22 (0.96 to 5.16)	2.07 (0.88 to 4.88)
T3 (1.28–25.86)	Reference	Reference	Reference	Reference
Test for trend P value	0.01	0.004	0.02	0.07
MOR¶	1.06	1.13	1.00	1.00
Distance to park or forest				
≤800 m	Reference	Reference	Reference	Reference
>800 m	**1.97 (1.26 to 3.07)**	**1.91 (1.20 to 3.04)**	**1.80 (1.12 to 2.91)**	**1.71 (1.05 to 2.77)**
MOR	1.07	1.23	1.00	1.00

The bold values represent statistically significant results.

*Model 1: unadjusted.

†Model 2: adjusted for age and sex.

‡Model 3: adjusted for age, sex, migration background, living with a partner, education, income.

§Model 4: adjusted for age, sex, migration background, living with a partner, education, income, neighbourhood unemployment rate.

¶MOR was estimated to be 1.28 in the empty model.

MOR, median OR; RLQ, recreation location quotient.

With respect to type 2 diabetes, next to physical activity some other potential mechanisms have been suggested. Green space has also been discussed as offering places and opportunities for social contacts. Maas *et al* investigated this hypotheses and found lower availability of green space associated with perceived loneliness, a perceived lack of social support and a mediating effect in the relation of green space and health but not a higher frequency in contacts to neighbours or more received social support.[38] Further, green space has been found to be beneficial for mental health. Roe *et al*[14] found that higher levels of green space in the neighbourhood are associated with lower perceived stress and a healthier diurnal decline of cortisol.[14] Perceived stress in turn has been related to an increased risk of type 2 diabetes.[39] Likewise, literature suggested air pollution as a potential underlying mechanism between green space and type 2 diabetes, as recent studies found that air pollution may be an important risk factor for type 2 diabetes.[40 41]

Our present study has several strengths and limitations that need to be discussed. One important strength is the application of different indicators of green space, which were based on accurate and detailed land use data as well as a network analysis, addressing different dimensions of green space including its accessibility.

Aside from one of the simplest approaches, the proportion of green space, which had been the measure of choice in most of the previous studies, we additionally considered the RLQ as a standardised measure taking into account the potential local demand of green space and enabling regional comparisons.[24] Additionally, the network analysis provides an accurate picture of individual accessibility of green space.[42] Another strength of our analysis is the application of multilevel tools, which allow modelling the effects of individual-level and neighbourhood-level variables on the outcomes of interest. This model strategy takes account of the hierarchical structure of our data set,[9] including individual characteristics of the DHS participants as well as area-level characteristics (ie, unemployment rate). In terms of the outcome assessment, the weight status has a high reliability because BMI was calculated with objectively measured weight and height. Type 2 diabetes was assessed via self-reported physician diagnoses, and thus the prevalence might be underestimated. However, we identified additional type 2 diabetes cases by classifying individuals with HbA1c ≥6.5% or with antidiabetic medication.

Drawing conclusions on a causal relationship between green space, weight status and type 2 diabetes is limited due to the cross-sectional design of this study.

We cannot exclude reverse causation, that is, better off individuals with a low odds of having a high BMI and type 2 diabetes live more often in green neighbourhoods or close to parks or forests, although we tried to limit this bias by adjusting the analysis for educational level and income.[43] Moreover, observational studies cannot completely rule out residual confounding. In particular, residual confounding can be present on area-level, as considering only unemployment rate may not comprehensively cover the socioeconomic status of neighbourhoods.

The conceptualisation and construction of indicators measuring green space and its accessibility is manifold. We assessed the quantity of as well as the distance to green space but had no information on the quality of green space,[43] including details on the actual use of green space, activity opportunities or walkability. Another limitation is that we have no information on the length of exposure. We and others assume that positive impact of green space has a long-term effect, which cannot be investigated applying a cross-sectional study.[43] Furthermore, for two of the three green space indicators neighbourhoods were defined based on the administrative areas/statistical districts (proxy neighbourhoods), which differ significantly in size and population count, and may not correspond to the actual home neighbourhoods of the study participants. Due to this fact, the two indicators measured on the level of statistical districts might miss to explore the residential environment correctly. This refers also to the 'container effect', which assumes that all residents have equal access to green space in their residential neighbourhood but no access to green spaces across borders.[44] Moreover, the spatial distribution of green space in respect to the participants cannot be taken into account.[42] These biases are avoided in the network analysis based on the street network, which draws a more accurate picture of the accessibility of green space than buffer analysis or straight lines between participants' address and green space.[25]

CONCLUSIONS

From a public health perspective, it is essential to evaluate the importance of the built environment including the availability of green space for obesity and type 2 diabetes because it may be a promising basis for the development of prevention programmes on the community level.[9] The present analysis highlights a potential association between green space and type 2 diabetes on a cross-sectional level. However, longitudinal studies, which allow drawing causal inferences in the relation between green space and health, as well as studies examining underlying mechanisms are needed to justify the focus of prevention programmes towards the expansion of a green space policy.[43]

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