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The association between neighbourhood greenspace and type 2 diabetes in a large cross-sectional study

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Abstract

Objective: To investigate the relationship between neighbourhood greenspace and type 2 diabetes.

Design: Cross-sectional.

Setting: Three diabetes screening studies conducted in Leicestershire, UK in 2004-2011. The percentage of greenspace in the participant's home neighbourhood (3km radius around home postcode) was obtained from a Land Cover Map. Demographic and biomedical variables were measured at screening.

Participants: 10,476 individuals (6200 from general population; 4276 from high-risk population) aged 20-75 years (mean 59 years); 47% female; 21% non-white ethnicity.

Main outcome measure: Screen-detected type 2 diabetes (WHO 2011 criteria).

Results: Increased neighbourhood greenspace was associated with significantly lower levels of screen-detected type 2 diabetes. The ORs (95% CI) for screen-detected type 2 diabetes were 0.97 (0.80 to 1.17), 0.78 (0.62 to 0.98) and 0.67 (0.49 to 0.93) for increasing quartiles of neighbourhood greenspace compared with the lowest quartile after adjusting for ethnicity, age, sex, social deprivation score and urban/rural status (P_{trend} = 0.01). This association remained upon further adjustment for body mass index, physical activity, fasting glucose, 2-hour glucose and cholesterol (OR [95% CI] for highest vs lowest quartile: 0.53 [0.35 to 0.82]; P_{trend} = 0.01).

Conclusions: Neighbourhood greenspace was inversely associated with screen-detected type 2 diabetes, highlighting a potential area for targeted screening as well as a possible public health area for diabetes prevention. However, none of the risk factors that we considered appeared to explain this association, and thus further research is required to elicit underlying mechanisms.

Keywords: Diabetes Mellitus; Environment; Epidemiology; Greenspace; Public Health

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Strengths and limitations of this study

- Evidence regarding the association between greenspace and type 2 diabetes is limited since only two cross-sectional studies have investigated this association, and while they showed an inverse association, both used self-reported measures of diabetes.
- A major strength of this study was that robust measures of type 2 diabetes, greenspace, and potential confounders were used.
- Other strengths include the large sample size, robust detailed analysis, and the multi-ethnic population.
- The limitations include the cross-sectional nature of the study, that only screen-detected diabetes was included rather than all prevalent cases, and it is not possible to determine from the available data which areas of greenspace were publicly accessible.
- We found that neighbourhood greenspace was inversely associated with screen-detected type 2 diabetes, with 11% prevalence of undiagnosed type 2 diabetes in the lowest quartile of greenspace compared with 6% prevalence in the highest quartile of greenspace.

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Introduction

Prevalence of type 2 diabetes mellitus, a chronic long term condition, is rapidly increasing, and it is estimated that there are 175 million cases undiagnosed worldwide.[1] This may be largely due to environmental/behavioural factors.[2, 3] Individual-level interventions that encourage healthy lifestyles can lead to increased physical activity and improved diet, which in turn lower glucose levels to reduce type 2 diabetes risk or improve type 2 diabetes control.[4] However, public health solutions, such as changes to local environments, are also required to tackle the type 2 diabetes epidemic.[5] Accordingly, policymakers have been urged to provide greenspace, such as parks and natural areas, to facilitate physical activity, encourage other healthy behaviours, and reduce type 2 diabetes risk.[5, 6]

Only two studies have however investigated relationships between neighbourhood greenspace and type 2 diabetes.[7, 8] Both used self-reported diabetes, and found that greenspace was inversely related to diabetes.[7, 8] The knowledge gap highlighted by this limited evidence base is gaining even more importance with the increasing urbanisation worldwide. Additionally, the underlying factors explaining any relationship between greenspace and type 2 diabetes are unclear. For example, physical activity could explain the purported relationship between greenspace and morbidity,[9] but this has not been clearly shown in all studies.[7] This might be because, to our knowledge, no studies have used objective measures of greenspace in conjunction with objective diagnoses of type 2 diabetes and measures of its risk factors.

We therefore investigated whether neighbourhood greenspace was associated with type 2 diabetes in a large multi-ethnic population characterised using robust, objective measurements. The primary objective was to investigate the relationship between neighbourhood greenspace and screen-detected type 2 diabetes, and the secondary objective was to explore possible explanations underlying this relationship.

Materials and Methods

Participants

Three type 2 diabetes screening studies were conducted in Leicestershire, UK, using identical standard operating procedures: ADDITION-Leicester (NCT00318032), Let's Prevent Diabetes ("Let's Prevent"; NCT00677937), and Walking Away from Diabetes ("Walking Away"; NCT00941954). This work only included cross-sectional data from the screening stage of each study. Ethical approval was from the University Hospitals of Leicester and Leicestershire Primary Care Research Alliance (ADDITION-Leicester) or the Nottingham (Walking Away/Let's Prevent) Research Ethics Committees. All participants gave written informed consent.

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Full study descriptions are available elsewhere.[10-12] Briefly, ADDITION-Leicester (2004-2009) was a population-based study which screened people for type 2 diabetes.[10] Individuals selected at random from participating general practices who met the eligibility criteria were invited. Eligibility criteria included age 40-75 years (white Europeans) or 25-75 years (other ethnicities), and no diabetes diagnosis, thus all type 2 diabetes cases are screen-detected. Recruitment methods and inclusion criteria were similar in Let's Prevent (2009-2011)[11] and Walking Away (2010),[12] except that individuals in both Let's Prevent and Walking Away were at high risk of type 2 diabetes based on the Leicester Practice Risk Score,[13] and Walking Away had wider age inclusion criteria (18-74 years). Participants were excluded from the current analyses if their postcode was missing or invalid. If they took part in more than one of the studies then their most recent record was kept. In all three studies, participants attended a clinic visit where they provided a fasting sample, underwent an oral glucose tolerance test, had anthropometric measurement recorded, and completed questionnaires.

Outcome

Type 2 diabetes diagnosis was based on WHO 2011 criteria, using gold-standard oral glucose tolerance tests (fasting glucose ≥7.0mmol/l or 2 hour glucose ≥11.1mmol/l) or HbA1c (≥6.5%; 48mmol/mol).[14]

Explanatory variables

The main explanatory variable was the percentage of greenspace in the participant's home neighbourhood, and this was categorised into quartiles for the analyses. ArcGIS 9.3 (ESRI 2009), a geographic information system, was used.[15] To delineate neighbourhood boundaries, the postcode of each participant was geo-located using the UK Ordnance Survey Code-Point® database (2004-2013),[16] which provides a set of coordinates depicting the average latitude and longitude of all mail delivery locations within each postcode, which contains 15 addresses on average. Neighbourhood was delineated based on distance around these coordinates. Neighbourhoods are typically defined as the area within 800m (approximating to a ten minute walk) of a home location.[17] However, recent research from studies employing global positioning systems to track movement suggests that this may be overly conservative,[18] and that individuals typically travel greater distances to access resources and be physically active, therefore we used a distance of 3km.[19] We used a circular buffer because greenspaces are often accessible via footpaths and cut-throughs rather than roads. In sensitivity analyses, we also defined neighbourhood based on radii of 800m and 5km, and using road network buffers.

Estimates of greenspace were from the Centre for Ecology and Hydrology Land Cover Map of the UK (2007),[20] which is derived from satellite images and digital cartography, and records the dominant land use type, based on a 23 class typology, per 25m by 25m grid cell. Broadleaved and coniferous

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woodland, arable, improved grassland, semi-natural grassland, mountain, heath, bog, and freshwater (including rural lakeland environments) were classed as greenspace. Each participant's exposure was computed by overlaying the mapped greenspace with the neighbourhood boundaries in the geographic information system software to calculate the percentage of each neighbourhood area that contained these land cover types.

Other explanatory variables were treated as confounders, including age, sex, social deprivation score (Index of Multiple Deprivation score), and urban/rural location.[21] Ethnicity was self-reported using Census categories and grouped as White European, South Asian and Other due to the small number of participants in some ethnic groups. Trained staff measured weight and height to the nearest 0.1kg and 0.5cm, respectively. BMI was calculated as weight (kg) / height (m) squared. Cholesterol was measured in the fasting blood sample. Self-reported physical activity was obtained using the International Physical Activity Questionnaire (IPAQ). Published standards were used to calculate the number of metabolic equivalents (METS) per day for total activity.[22] Objective physical activity (average number of steps per day) was also available in Let's Prevent (sealed piezoelectric pedometer, NL-800, New Lifestyles, USA) and Walking Away (tri-axial accelerometer, GT3X, ActiGraph, USA). Participants wore the devices during waking hours for seven consecutive days on the right anterior axillary line of their trunks.

Statistical Analysis

Participant characteristics were summarised by study and overall as mean (standard deviation [SD]) for continuous variables and percentage for categorical variables. The mean (SD) percentage of neighbourhood greenspace was summarised by subgroup of participant demographics and compared using one-way ANOVA. Generalised estimating equations with a binary outcome were used to investigate whether quartiles of neighbourhood greenspace were associated with type 2 diabetes, with a term for clustering by postcode. Quartiles were defined as ≤30%, 31-59%, 60-77%, and ≥78% based on the data. Three models were fitted. Model 1 was adjusted for ethnicity, age, sex, social deprivation score, and urban/rural status. Model 2 was adjusted for all variables in Model 1 plus body mass index and physical activity (total METS). Model 3 was adjusted for all variables in Model 2 plus fasting glucose, 2 hour glucose, and total cholesterol. Tests for trend were performed by fitting the greenspace quartiles as a continuous variable. Missing data were imputed in all models. Missing type 2 diabetes values were replaced as no type 2 diabetes, and missing ethnicity as white European, as these were overwhelmingly the modal values for those variables. All other missing values were replaced using multiple imputation with type 2 diabetes, age, sex and ethnicity as the predictor variables. Model 3 was also fitted using an objective measure of physical activity (average number of steps per day), rather than a subjective one (total METS reported via IPAQ), but this measure was only available in Walking Away and Let's Prevent, so missing data for average number of steps per

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day were not imputed due to the large quantity of such data. Sensitivity analysis involved fitting the fully adjusted model (Model 3) for different neighbourhood definitions. Analyses were performed in Stata v13. P-values <0.05 were treated as statistically significant.

Results

Participants

The three studies screened 11,032 people (6749 ADDITION-Leicester, 3450 Let's Prevent, 833 Walking Away), of whom 300 were excluded because their postcode was missing (all ADDITION-Leicester), and 12 because it was invalid (6 ADDITION-Leicester, 5 Let's Prevent, 1 Walking Away). There were 244 people who participated in multiple studies; therefore, these analyses included 10,476 participants, whose characteristics are in Table 1. The mean age was 59 years, 47% were female, 21% were of non-white ethnicity, and 16% lived in a rural location. There were some differences between the studies, primarily because ADDITION-Leicester screened the general population, whereas the other two screened high risk populations.

Amount of neighbourhood greenspace

Percentage of greenspace varied by neighbourhood definition, however all measures were strongly correlated (Table 2). The remainder of the manuscript pertains to the circular 3km buffer unless otherwise stated.

Neighbourhoods comprised 57% (SD 26%) greenspace on average (Table 3). The amount of neighbourhood greenspace was higher for participants who were older (P<0.001), male (P<0.001), of White European ethnicity (P<0.001), lived in rural locations (P<0.001), and had low social deprivation (P<0.001).

Associations with type 2 diabetes

Increased neighbourhood greenspace was associated with significantly lower levels of screen-detected type 2 diabetes. In the lowest greenspace quartile, 281 (10.7%) of people had type 2 diabetes; the analogous figures were 236 (9.0%), 159 (6.1%) and 161 (6.1%) for the second, third and fourth quartile respectively. ORs suggested that inverse relationship was significant (Figure 1). The OR (95% CI) for screen-detected type 2 diabetes was 0.67 (0.49, 0.93) in the highest compared with the lowest quartile after adjusting for ethnicity, age, sex, social deprivation score and urban/rural status (P_{trend} = 0.01). This pattern remained upon further adjustment for body mass index and physical activity (Figure 1). After further adjustment for fasting glucose, 2-hour glucose and cholesterol, the dose-response relationship weakened, but the inverse association between greenspace and type 2 diabetes remained (P_{trend} = 0.01; Figure 1).

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The effect sizes were similar in analyses stratified by recruitment type (fully adjusted OR [95% CI] for highest vs lowest quartile: population-based 0.48 [0.23, 1.01]; high-risk studies 0.47 [0.27, 0.81]; data not in Table). When objectively-measured physical activity was included in Model 3, rather than subjectively-measured physical activity, the inverse association between greenspace and type 2 diabetes remained (fully adjusted OR [95% CI] for highest vs lowest quartile: 0.45 [0.24, 0.82]; $P_{trend} < 0.01$; N = 3541; data not in Table).

Sensitivity analysis

Table 4 shows the fully adjusted analyses (Model 3) for different neighbourhood definitions. When a distance of 800m was used to define the neighbourhood, there was not a significant association between type 2 diabetes and greenspace, regardless of whether a circular or road network buffer was used. Conversely, when a distance of 3km or 5km was used, there was a significant inverse association between greenspace and type 2 diabetes regardless of the type of buffer used.

Discussion

In this large cross-sectional study, older age, male sex, White European ethnicity, higher socio-economic status and rural locations were associated with having more neighbourhood greenspace. After adjustment for these and other factors, increasing amounts of greenspace were associated with lower prevalence of screen-detected type 2 diabetes. Sensitivity analyses suggested that this inverse association was somewhat dependent on neighbourhood definition.

Our study has major strengths. Notably, the objective measures of greenspace, type 2 diabetes and potential confounders, the large sample size, robust detailed analysis, and the multi-ethnic population, mean that we are able to add novel, robust information to an emerging area of type 2 diabetes prevention. Furthermore, the diverse ethnic, socioeconomic and geographical distribution of this population means that our results are generalisable to other populations. This study also has limitations. The most important is that the cross-sectional nature of the study means that we are unable to infer causality from our findings. Other limitations are likely to have weakened the association between greenspace and type 2 diabetes, and so it may be stronger than observed. These limitations are that only screen-detected diabetes was included rather than all prevalent cases, and it is not possible to determine from the available data which areas of greenspace were publicly accessible. Finally, we were not able to assess the quality of greenspace, and there is some evidence that better quality spaces, for example those free from vandalisms and with better accessibility, are more health promoting.[23]

Our finding that neighbourhood greenspace might be associated with lower screen-detected type 2 diabetes prevalence can be interpreted in two ways due to the cross-sectional nature of our study.

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First, it could suggest that areas with a low amount of greenspace would benefit from targeted screening programmes since these areas tend to have a higher number of undiagnosed type 2 diabetes cases. This could have important implications in terms of resource allocation, and might suggest that a general population screening programme is best suited to urban areas with low greenspace availability, whereas in areas with more greenspace then only those at high-risk of type 2 diabetes would need to be screened. It also suggests that areas with a low density of greenspace might benefit from community interventions, such as mass media campaigns, to raise awareness of type 2 diabetes and its prevention.

Second, it could suggest that greenspace might be protective for type 2 diabetes if the association between undiagnosed type 2 diabetes and greenspace is the same as that between overall type 2 diabetes and greenspace, which seems likely to be the case particularly after adjustment for socio-economic status, ethnicity and other demographic factors that are likely to lead to earlier diagnosis. The idea that greenspace might be protective for type 2 diabetes supports the findings of two other large cross-sectional studies, both of which used self-reported measures of type 2 diabetes,[7, 8] as well as emerging evidence that more walkable neighbourhoods are associated with fewer diabetes cases.[24] Maas et al used similar methods to ours to quantify greenspace in a Dutch population,[8] and found that greenspace was inversely associated with diabetes in a 1km, but not a 3km, radius. Conversely, our results tended towards a stronger association when a larger radius was used. Differences depending on the neighbourhood definition used may occur for a number of reasons. For example, people living on the edge of urban developments may be linked with a small percentage of greenspace based on a road network buffer, and with a much larger percentage based on a circular buffer. Therefore, some neighbourhood definitions may better capture the amount of greenspace that people access than others. Astell-Burt et al also recently reported that greater access to greenspace was associated with lower diabetes risk in Australian adults aged 45 years and older.[7] Our work extends the limited evidence in this area by demonstrating that the association between greenspace and screen-detected type 2 diabetes appears also to be present in multi-ethnic populations and when robust type 2 diabetes diagnoses are used. We estimated that people living in neighbourhoods with the highest quartiles of greenspace had a 47% lower odds ratio of type 2 diabetes compared with those in the lowest quartile. These quartiles relate to ≥78% and ≤30% neighbourhood greenspace, respectively, suggesting that those with the lowest prevalence of type 2 diabetes have access to approximately three times as much greenspace as those with the highest prevalence. It is also notable that those with the lowest neighbourhood greenspace had demographic patterns congruent with those of people at highest risk of type 2 diabetes, for example those of south Asian ethnicity, suggesting that public health guidance to increase greenspace access to prevent or delay type 2 diabetes would potentially be of greatest benefit to those at highest risk if it were to be implemented.[5, 6]

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Intuitively, the most likely reason that greenspace might be associated with type 2 diabetes prevalence seems to be that increased greenspace might encourage healthy behaviours, particularly physical activity, which is known to decrease type 2 diabetes risk.[25] However, we found little evidence to support this; adjusting for subjectively and objectively measured physical activity did not attenuate the association between greenspace and type 2 diabetes. This supports another observational study in England, which found that greenspace was not significantly related to the types of physical activity normally associated with greenspace.[26] Possible explanations of this are that seven days of measurement may not reflect seasonal variation in physical activity and might bias towards the null any relationship between physical activity and greenspace,[27, 28] and that we were only able to measure participation in physical activity without reference to where it occurs, such as in greenspace, the gym or at home. Astell-Burt et al also found that physical activity did not appear to explain the inverse relationship between greenspace and diabetes.[7] Indeed, the association between greenspace and type 2 diabetes was not explained by any of the type 2 diabetes risk factors that we accounted for in the analyses. This could mean that they are not causally associated, or that these associations are due to confounding with an unmeasured factor. Similarly, other studies have found that the potential mediators that they examined did not explain the association between health and greenspace.[7, 29] They therefore concluded that other unmeasured pathways might explain the association, such as air pollution,[7] quality of sleep, or psychosocial factors,[29] which seems highly plausible. Another potential pathway is through diet (for example, deficiency of metabolically active micronutrients analogous with modern dietary intake), but we could not explore this as there was not a consistent diet measure across the studies that we included.

In conclusion, these data support the hypothesis that access to greenspace is inversely associated with screen-detected type 2 diabetes, thus highlighting a potential area to be considered for targeted screening programmes and type 2 diabetes prevention. However, none of the confounders that we considered appeared to explain this association, which highlights that more research is needed in this area before public health policies are generated. Future research areas that would be of particular interest would be to incorporate dietary indicators, and to subjectively delineate quality of greenspace.

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Competing Interests

All authors have completed the Unified Competing Interest form at www.icmje.org/coi_disclosure.pdf (available on request from the corresponding author) and declare that all authors have no relationships with companies that might have an interest in the submitted work in the previous 3 years; their spouses, partners, or children have no financial relationships that may be relevant to the submitted work; and (4) all authors have no non-financial interests that may be relevant to the submitted work.

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Contribution statement

KK, MD, LG, TY and SH designed and conducted the Let's Prevent Diabetes study. KK, MD, DW, and LG designed and conducted the ADDITION-Leicester study. KK, MD, TY, CE and LG designed and conducted the Walking Away from Diabetes study. DB, GO, AD and AJ conceived and designed

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the current analyses. DB conducted and is responsible for the data analysis. DB wrote the first draft of the manuscript with GO. All authors contributed to interpreting the data, revising the manuscript, and approved the final version. DB is the guarantor for the study. DB affirms that the manuscript is an honest, accurate, and transparent account of the study being reported; that no important aspects of the study have been omitted, and that any discrepancies from the study as planned have been explained. All authors had full access to all the data in the study and can take responsibility for the integrity of the data and the accuracy of the data analysis.

Data sharing

No additional data available.

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Table 1. Participant characteristics by study and for the entire sample combined.

Variable	ADDITION-Leicester	Let's Prevent Diabetes	Walking Away from Diabetes	All
Age, years	56.2 (10.8)	63.2 (8.2)	63.1 (8.2)	59.0 (10.4)
Social deprivation score	19.7 (14.1)	17.3 (15.0)	20.2 (16.3)	19.0 (14.6)
Total METS	3376.2 (3579.6)	2293.5 (3038.0)	3380.0 (3949.8)	3007.3 (3475.3)
Average steps per day[a]	-	6544.1 (3100.0)	6610.3 (3210.9)	6557.6 (3122.7)
Body mass index, kg/m^2	28.0 (5.0)	32.4 (5.7)	32.5 (5.6)	29.8 (5.7)
Waist, cm	93.7 (13.2)	108.8 (12.9)	101.8 (12.4)	99.4 (14.8)
Fasting glucose, mmol/l	5.2 (0.9)	5.3 (0.8)	5.3 (0.8)	5.2 (0.9)
2 hour glucose, mmol/l	6.0 (2.4)	6.6 (2.5)	6.5 (2.4)	6.3 (2.5)
HbA1c, %	5.7 (0.6)	5.9 (0.5)	5.9 (0.6)	5.8 (0.6)
Total cholesterol, mmol/l	5.5 (1.1)	5.1 (1.0)	5.1 (1.1)	5.4 (1.1)
Female	53.1	39.1	36.5	47.2
South Asian	23.5	10.7	8.1	18.0
Other ethnicity	2.6	2.6	3.5	2.6
Rural location	11.7	24.5	17.5	16.3
Type 2 diabetes mellitus	6.2	10.9	9.4	8.0
Total	**6200**	**3444**	**832**	**10476**

Data are mean (standard deviation) or percentage.

Missing data: 0 Age and Sex, 21 Social deprivation score, 1481 Total METS, 208 Body mass index, 33 Fasting glucose, 81 2 hour glucose, 149 HbA1c, 108 Total cholesterol, 190 Ethnicity, 21 Rural location, 13 Type 2 diabetes.

[a] Measured using pedometers in Let's Prevent Diabetes and using accelerometers in Walking Away from Diabetes (735 missing values).

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Table 2. Average percentage of greenspace and correlations between percentage of greenspace according to neighbourhood definition.

			Correlations					
			Circular buffer			Road network buffer		
		Mean (SD) % of greenspace	800m	3km	5km	800m	3km	5km
Circular buffer	**800m**	38 (27)	1					
	3km	57 (26)	0.81	1				
	5km	65 (22)	0.74	0.97	1			
Road network buffer	**800m**	33 (28)	0.94	0.72	0.65	1		
	3km	50 (27)	0.85	0.97	0.92	0.77	1	
	5km	58 (24)	0.77	0.98	0.98	0.69	0.96	1

Abbreviations: SD, Standard Deviation.

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Table 3. The percentage of neighbourhood greenspace by participant characteristics.

Variable	Category	N	Mean (SD) percentage of greenspace	P-value
Age, years	<55	3208	51 (26)	
	55-64	3548	58 (25)	
	≥65	3720	60 (25)	<0.001
Sex	Male	5534	58 (26)	
	Female	4942	55 (25)	<0.001
Ethnicity	White European	8167	62 (24)	
	South Asian	1847	35 (17)	
	Other	272	33 (20)	<0.001
Urban/rural location	Urban	8749	50 (22)	
	Rural	1706	91 (06)	<0.001
Social deprivation score	Low	5872	68 (21)	
	High	4583	41 (23)	<0.001
Total		**10476**	**57 (26)**	

Abbreviations: SD, Standard deviation.

P-values test for a difference in the percentage of greenspace across the categories and were estimated using one-way analysis of variance.

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Table 4. Sensitivity analyses considering different definitions of neighbourhood for the risk of type 2 diabetes mellitus in relation to quartiles of neighbourhood green space in 10,476 participants.[a]

	Adjusted[b] Odds Ratio (95% CI) of outcome			
Greenspace definition	**Quartile 2**	**Quartile 3**	**Highest Quartile**	**P for trend**
Circular 800m	0.96 (0.73, 1.27)	0.98 (0.72, 1.32)	1.00 (0.68, 1.47)	0.990
Circular 3km	0.71 (0.54, 0.93)	0.76 (0.54, 1.05)	0.53 (0.35, 0.82)	0.008
Circular 5km	0.65 (0.50, 0.85)	0.79 (0.56, 1.09)	0.65 (0.44, 0.95)	0.041
Road network 800m	1.07 (0.82, 1.40)	0.92 (0.69, 1.24)	1.03 (0.73, 1.45)	0.888
Road network 3km	0.71 (0.55, 0.93)	0.67 (0.49, 0.93)	0.48 (0.30, 0.77)	0.001
Road network 5km	0.67 (0.51, 0.88)	0.75 (0.54, 1.05)	0.58 (0.39, 0.86)	0.013

Note: Lowest quartile is referent category.

Abbreviations: CI, Confidence Interval; Q2, Quartile 2; Q3, Quartile 3.

[a] Missing data were imputed so analyses included all participants.

[b] Odds ratios were adjusted for ethnicity, age, sex, social deprivation score, urban/rural status, body mass index, physical activity (total METS), fasting glucose, 2 hour glucose, and total cholesterol.

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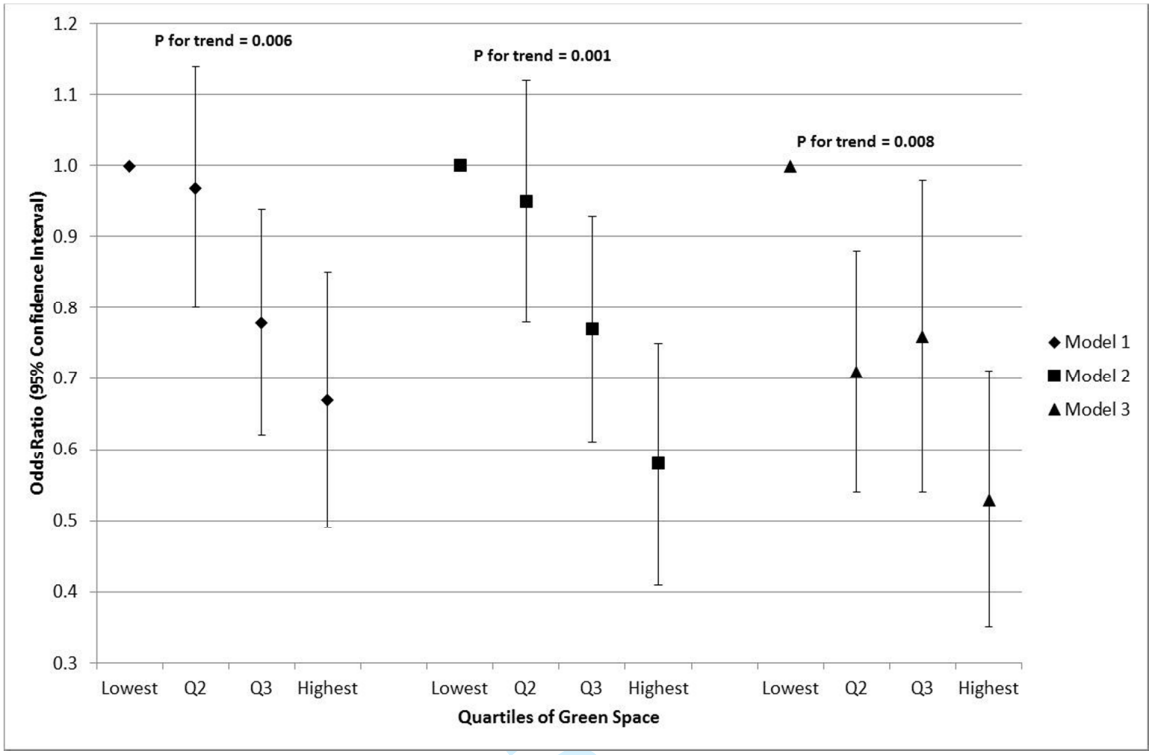
Figure 1. Odds ratios of screen-detected type 2 diabetes mellitus in relation to quartiles of neighbourhood greenspace in 10,476 participants.[a]



[a] Missing data were imputed so analyses included all participants.

Note: Lowest quartile is referent category.

Abbreviations: Q2, Quartile 2; Q3, Quartile 3.

Model 1 was adjusted for ethnicity, age, sex, social deprivation score, and urban/rural status.

Model 2 was adjusted for all variables in Model 1 plus body mass index and physical activity (total METS).

Model 3 was adjusted for all variables in Model 2 plus fasting glucose, 2 hour glucose, and total cholesterol.

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STROBE Statement—checklist of items that should be included in reports of observational studies

	Item No	Recommendation
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract Page 1
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found Page 2
Introduction		
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported Page 4
Objectives	3	State specific objectives, including any prespecified hypotheses Page 4
Methods		
Study design	4	Present key elements of study design early in the paper Pages 4-5
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection Pages 4-6
Participants	6	(*a*) *Cohort study*—Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up *Case-control study*—Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls *Cross-sectional study*—Give the eligibility criteria, and the sources and methods of selection of participants Page 5
		(*b*) *Cohort study*—For matched studies, give matching criteria and number of exposed and unexposed *Case-control study*—For matched studies, give matching criteria and the number of controls per case
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable Pages 5-6
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group Page 5
Bias	9	Describe any efforts to address potential sources of bias Page 6
Study size	10	Explain how the study size was arrived at Page 7
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why Pages 5-6
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding Pages 6-7
		(*b*) Describe any methods used to examine subgroups and interactions Page 8
		(*c*) Explain how missing data were addressed Pages 6-7
		(*d*) *Cohort study*—If applicable, explain how loss to follow-up was addressed *Case-control study*—If applicable, explain how matching of cases and controls was addressed *Cross-sectional study*—If applicable, describe analytical methods taking account of sampling strategy N/A
		(*e*) Describe any sensitivity analyses Page 7

Continued on next page

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Results		
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed Page 7
		(b) Give reasons for non-participation at each stage Page 7
		(c) Consider use of a flow diagram N/A
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders Page 7 and Table 1
		(b) Indicate number of participants with missing data for each variable of interest Table 1
		(c) *Cohort study*—Summarise follow-up time (eg, average and total amount) N/A
Outcome data	15*	*Cohort study*—Report numbers of outcome events or summary measures over time
		Case-control study—Report numbers in each exposure category, or summary measures of exposure
		Cross-sectional study—Report numbers of outcome events or summary measures Page 7
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included Figure 1
		(*b*) Report category boundaries when continuous variables were categorized Page 6
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period N/A
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses Page 8
Discussion		
Key results	18	Summarise key results with reference to study objectives Page 8
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias Page 8
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence Pages 8-10
Generalisability	21	Discuss the generalisability (external validity) of the study results Page 8
Other information		
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based Page 11

*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.

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The association between neighbourhood greenspace and type 2 diabetes in a large cross-sectional study

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Manuscripts

The association between neighbourhood greenspace and type 2 diabetes in a large cross-sectional study

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Running Head: Greenspace and type 2 diabetes

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Abstract

Objective: To investigate the relationship between neighbourhood greenspace and type 2 diabetes.

Design: Cross-sectional.

Setting: Three diabetes screening studies conducted in Leicestershire, UK in 2004-2011. The percentage of greenspace in the participant's home neighbourhood (3km radius around home postcode) was obtained from a Land Cover Map. Demographic and biomedical variables were measured at screening.

Participants: 10,476 individuals (6200 from general population; 4276 from high-risk population) aged 20-75 years (mean 59 years); 47% female; 21% non-white ethnicity.

Main outcome measure: Screen-detected type 2 diabetes (WHO 2011 criteria).

Results: Increased neighbourhood greenspace was associated with significantly lower levels of screen-detected type 2 diabetes. The ORs (95% CI) for screen-detected type 2 diabetes were 0.97 (0.80 to 1.17), 0.78 (0.62 to 0.98) and 0.67 (0.49 to 0.93) for increasing quartiles of neighbourhood greenspace compared with the lowest quartile after adjusting for ethnicity, age, sex, area social deprivation score and urban/rural status (P_{trend} = 0.01). This association remained upon further adjustment for body mass index, physical activity, fasting glucose, 2-hour glucose and cholesterol (OR [95% CI] for highest vs lowest quartile: 0.53 [0.35 to 0.82]; P_{trend} = 0.01).

Conclusions: Neighbourhood greenspace was inversely associated with screen-detected type 2 diabetes, highlighting a potential area for targeted screening as well as a possible public health area for diabetes prevention. However, none of the risk factors that we considered appeared to explain this association, and thus further research is required to elicit underlying mechanisms.

Keywords: Diabetes Mellitus; Environment; Epidemiology; Greenspace; Public Health

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Strengths and limitations of this study

- Evidence regarding the association between greenspace and type 2 diabetes is limited since only two cross-sectional studies have investigated this association, and while they showed an inverse association, both used self-reported measures of diabetes.
- A major strength of this study was that robust measures of type 2 diabetes, greenspace, and potential confounders were used.
- Other strengths include the large sample size, robust detailed analysis, and the multi-ethnic population.
- The limitations include the cross-sectional nature of the study, that only screen-detected diabetes was included rather than all prevalent cases, and it is not possible to determine from the available data which areas of greenspace were publicly accessible.
- We found that neighbourhood greenspace was inversely associated with screen-detected type 2 diabetes, with 11% prevalence of undiagnosed type 2 diabetes in the lowest quartile of greenspace compared with 6% prevalence in the highest quartile of greenspace.

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Introduction

Prevalence of type 2 diabetes mellitus, a chronic long term condition, is rapidly increasing, and it is estimated that there are 175 million cases undiagnosed worldwide.[1] This may be largely due to environmental/behavioural factors.[2, 3] Individual-level interventions that encourage healthy lifestyles can lead to increased physical activity and improved diet, which in turn lower glucose levels to reduce type 2 diabetes risk or improve type 2 diabetes control.[4] However, public health solutions, such as changes to local environments, are also required to tackle the type 2 diabetes epidemic.[5] In public health, ecological models describe people's interactions with their physical and sociocultural surroundings.[6] The physical environment (built and natural), social environment, and policy environment are regarded as important influences on behaviour that may be changed in order to increase physical activity[7] and reduce obesity,[8] which are major modifiable risk factors for type 2 diabetes.[9, 10] Accordingly, urban designers and planners have been urged to provide greenspace, such as parks and natural areas, to facilitate physical activity, encourage other healthy behaviours, and reduce type 2 diabetes risk.[5, 11]

Only two studies have however investigated relationships between neighbourhood greenspace and type 2 diabetes.[12, 13] Both used self-reported diabetes, and found that greenspace was inversely related to diabetes.[12, 13] The knowledge gap highlighted by this limited evidence base is gaining even more importance with the increasing urbanisation worldwide. Additionally, the underlying factors explaining any relationship between greenspace and type 2 diabetes are unclear. For example, physical activity could explain the purported relationship between greenspace and morbidity,[14] but this has not been clearly shown in all studies.[12] This might be because, to our knowledge, no studies have used objective measures of greenspace in conjunction with objective diagnoses of type 2 diabetes and measures of its risk factors. The use of objective measures in the present study is noteworthy because the measurement error associated with self-reported diabetes[15, 16] and self-reported physical activity[17] may bias towards the null.

We therefore investigated whether neighbourhood greenspace was associated with type 2 diabetes in a large multi-ethnic population characterised using robust, objective measurements. The primary objective was to investigate the relationship between neighbourhood greenspace and screen-detected type 2 diabetes, and the secondary objective was to explore possible explanations underlying this relationship.

Materials and Methods

Participants

Three type 2 diabetes screening studies were conducted in Leicestershire, UK, using identical standard operating procedures: ADDITION-Leicester (ClinicalTrials.gov registration number:

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NCT00318032), Let's Prevent Diabetes ("Let's Prevent"; NCT00677937), and Walking Away from Diabetes ("Walking Away"; NCT00941954). This work only included cross-sectional data from the screening stage of each study. Ethical approval was from the University Hospitals of Leicester and Leicestershire Primary Care Research Alliance (ADDITION-Leicester) or the Nottingham (Walking Away/Let's Prevent) Research Ethics Committees. All participants gave written informed consent.

Full study descriptions are available elsewhere.[18-20] Briefly, ADDITION-Leicester (2004-2009) was a population-based study which screened people for type 2 diabetes.[18] Individuals selected at random from participating general practices who met the eligibility criteria were invited. Eligibility criteria included age 40-75 years (white Europeans) or 25-75 years (other ethnicities), and no diabetes diagnosis, thus all type 2 diabetes cases are screen-detected. Recruitment methods and inclusion criteria were similar in Let's Prevent (2009-2011)[19] and Walking Away (2010),[20] except that individuals in both Let's Prevent and Walking Away were at high risk of type 2 diabetes based on the Leicester Practice Risk Score,[21] and Walking Away had wider age inclusion criteria (18-74 years). Participants were excluded from the current analyses if their postcode was missing or invalid. If they took part in more than one of the studies then their most recent record was kept. In all three studies, participants attended a clinic visit where they provided a fasting sample, underwent an oral glucose tolerance test, had anthropometric measurement recorded, and completed questionnaires.

Outcome

Type 2 diabetes diagnosis was based on WHO 2011 criteria, using gold-standard oral glucose tolerance tests (fasting glucose ≥7.0mmol/l or 2 hour glucose ≥11.1mmol/l) or HbA1c (≥6.5%; 48mmol/mol).[22]

Explanatory variables

The main explanatory variable was the percentage of greenspace in the participant's home neighbourhood, and this was categorised into quartiles for the analyses. ArcGIS 9.3, a geographic information system, was used.[23] To delineate neighbourhood boundaries, the postcode of each participant was geo-located using the UK Ordnance Survey Code-Point® database (2004-2013),[24] which provides a set of coordinates depicting the average latitude and longitude of all mail delivery locations within each postcode, which contains 15 addresses on average. Neighbourhood was delineated based on distance around these coordinates. Neighbourhoods are typically defined as the area within 800m (approximating to a ten minute walk) of a home location.[25] However, recent research from studies employing global positioning systems to track movement suggests that this may be overly conservative,[26] and that individuals typically travel greater distances to access resources and be physically active, therefore we used a straight-line distance of 3km.[27] In sensitivity analyses, we also defined neighbourhood based on radii of 800m and 5km, and using road network buffers.

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Estimates of greenspace were from the Centre for Ecology and Hydrology Land Cover Map of the UK (2007),[28] which is derived from satellite images and digital cartography, and records the dominant land use type, based on a 23 class typology, per 25m by 25m grid cell. Broadleaved and coniferous woodland, arable, improved grassland, semi-natural grassland, mountain, heath, bog, and freshwater (including rural lakeland environments) were classed as greenspace. Each participant's exposure was computed by overlaying the mapped greenspace with the neighbourhood boundaries in the geographic information system software to calculate the percentage of each neighbourhood area that contained these land cover types.

Other explanatory variables were treated as confounders, including age, sex, urban/rural location.[29] and area social deprivation score (The English Indices of Deprivation 2010 provides a relative measure of deprivation at small area level across England, and its measure of multiple deprivation was used in the present study).[30] Ethnicity was self-reported using Census categories and grouped as White European, South Asian and Other due to the small number of participants in some ethnic groups. Trained staff measured weight and height to the nearest 0.1kg and 0.5cm, respectively. BMI was calculated as weight (kg) / height (m) squared. Cholesterol was measured in the fasting blood sample. Self-reported physical activity was obtained using the International Physical Activity Questionnaire (IPAQ). Published standards were used to calculate the number of metabolic equivalents (METS) per day for total activity.[31] Objective physical activity (average number of steps per day) was also available in Let's Prevent (sealed piezoelectric pedometer, NL-800, New Lifestyles, USA) and Walking Away (tri-axial accelerometer, GT3X, ActiGraph, USA). Participants wore the devices during waking hours for seven consecutive days on the right anterior axillary line of their trunks.

Statistical Analysis

Participant characteristics were summarised by study and overall as mean (standard deviation [SD]) for continuous variables and percentage for categorical variables. The mean (SD) percentage of neighbourhood greenspace was summarised by subgroup of participant demographics and compared using one-way ANOVA. Generalised estimating equations with a binary outcome were used to investigate whether quartiles of neighbourhood greenspace were associated with type 2 diabetes, with a term for clustering by postcode. Quartiles were defined as ≤30%, 31-59%, 60-77%, and ≥78% based on the data. Three models were fitted. Model 1 was adjusted for ethnicity, age, sex, social deprivation score, and urban/rural status. Model 2 was adjusted for all variables in Model 1 plus body mass index and physical activity (total METS). Model 3 was adjusted for all variables in Model 2 plus fasting glucose, 2 hour glucose, and total cholesterol. Models 2 and 3 were added to allow us to consider the influence of groups of covariates. Model 2 allowed us to consider the influence of lifestyle factors

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associated with type 2 diabetes.[9, 10] Model 3 allowed us to consider the influence of blood borne variables associated with type 2 diabetes.[32-35] Tests for trend were performed by fitting the greenspace quartiles as a continuous variable. Missing data were imputed in all models. Missing type 2 diabetes values were replaced as no type 2 diabetes, and missing ethnicity as white European, as these were overwhelmingly the modal values for those variables. All other missing values were replaced using multiple imputation with type 2 diabetes, age, sex and ethnicity as the predictor variables. Model 3 was also fitted using an objective measure of physical activity (average number of steps per day), rather than a subjective one (total METS reported via IPAQ), but this measure was only available in Walking Away and Let's Prevent, so missing data for average number of steps per day were not imputed due to the large quantity of such data. Sensitivity analysis involved fitting the fully adjusted model (Model 3) for different neighbourhood definitions. Analyses were performed in Stata v13. P-values <0.05 were treated as statistically significant.

Results

Participants

The three studies screened 11,032 people (6749 ADDITION-Leicester, 3450 Let's Prevent, 833 Walking Away), of whom 300 were excluded because their postcode was missing (all ADDITION-Leicester), and 12 because it was invalid (6 ADDITION-Leicester, 5 Let's Prevent, 1 Walking Away). There were 244 people who participated in multiple studies; therefore, these analyses included 10,476 participants, whose characteristics are in Table 1. The mean age was 59 years, 47% were female, 21% were of non-white ethnicity, and 16% lived in a rural location. There were some differences between the studies, primarily because ADDITION-Leicester screened the general population, whereas the other two screened high risk populations.

Amount of neighbourhood greenspace

Percentage of greenspace varied by neighbourhood definition, however all measures were strongly correlated (Table 2). The remainder of the manuscript pertains to the circular 3km buffer unless otherwise stated.

Neighbourhoods comprised 57% (SD 26%) greenspace on average (Table 3). The amount of neighbourhood greenspace was higher for participants who were older (P<0.001), male (P<0.001), of White European ethnicity (P<0.001), lived in rural locations (P<0.001), and had low area social deprivation (P<0.001).

Associations with type 2 diabetes

Increased neighbourhood greenspace was associated with significantly lower levels of screen-detected type 2 diabetes. In the lowest greenspace quartile, 281 (10.7%) of people had type 2 diabetes; the

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analogous figures were 236 (9.0%), 159 (6.1%) and 161 (6.1%) for the second, third and fourth quartile respectively. ORs suggested that inverse relationship was significant (Figure 1). The OR (95% CI) for screen-detected type 2 diabetes was 0.67 (0.49, 0.93) in the highest compared with the lowest quartile after adjusting for ethnicity, age, sex, area social deprivation score and urban/rural status (P_{trend} = 0.01). This pattern remained upon further adjustment for body mass index and physical activity (Figure 1). After further adjustment for fasting glucose, 2-hour glucose and cholesterol, the dose-response relationship weakened, but the inverse association between greenspace and type 2 diabetes remained (P_{trend} = 0.01; Figure 1).

The effect sizes were similar in analyses stratified by recruitment type (fully adjusted OR [95% CI] for highest vs lowest quartile: population-based 0.48 [0.23, 1.01]; high-risk studies 0.47 [0.27, 0.81]; data not in Table). When objectively-measured physical activity was included in Model 3, rather than subjectively-measured physical activity, the inverse association between greenspace and type 2 diabetes remained (fully adjusted OR [95% CI] for highest vs lowest quartile: 0.45 [0.24, 0.82]; P_{trend} < 0.01; N = 3541; data not in Table).

Sensitivity analysis

Table 4 shows the fully adjusted analyses (Model 3) for different neighbourhood definitions. When a distance of 800m was used to define the neighbourhood, there was not a significant association between type 2 diabetes and greenspace, regardless of whether a circular or road network buffer was used. Conversely, when a distance of 3km or 5km was used, there was a significant inverse association between greenspace and type 2 diabetes regardless of the type of buffer used.

Discussion

In this large cross-sectional study, older age, male sex, White European ethnicity, higher socio-economic status and rural locations were associated with having more neighbourhood greenspace. After adjustment for these and other factors, increasing amounts of greenspace were associated with lower prevalence of screen-detected type 2 diabetes. Sensitivity analyses suggested that this inverse association was somewhat dependent on neighbourhood definition.

Our study has major strengths. Notably, the objective measures of greenspace, type 2 diabetes and potential confounders, the large sample size, robust detailed analysis, and the multi-ethnic population, mean that we are able to add novel, robust information to an emerging area of type 2 diabetes prevention. Furthermore, the diverse ethnic, socioeconomic and geographical distribution of this population means that our results are generalisable to other populations. This study also has limitations. The most important is that the cross-sectional nature of the study means that we are unable to infer causality from our findings. Other limitations are likely to have weakened the

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association between greenspace and type 2 diabetes, and so it may be stronger than observed. These limitations are that only screen-detected diabetes was included rather than all prevalent cases, and it is not possible to determine from the available data which areas of greenspace were publicly accessible. We only had information on area deprivation and, whilst individual and area deprivation are known to be strongly associated, not all residents of deprived areas will be deprived themselves.

There is some evidence that better quality greenspaces are more health promoting, such as those free from vandalism and with better accessibility.[36] Indeed, some research has suggested that objective measures of greenspace availability may differ from how such spaces are perceived and actually used.[37, 38] In the absence of such information, we used a measure of neighbourhood greenness based on detailed land cover information, using circular buffers to indicate the maximum potential accessible greenspace. The use of such buffers is consistent with the work of others.[39] The buffer size we used (3 km) is inevitably somewhat arbitrary, but it was based on evidence of mobility patterns from the literature and we tested the sensitivity of our findings to this definition by examining larger and smaller buffers. Road network buffers have been used in some studies, but we deemed them inappropriate in the present study because greenspaces are not necessarily accessed by road. Whilst other measures of greenspace have been used in other studies, such as distance to nearest greenspace or number and size of greenspaces around a home location,[11] these are based on a range of assumptions around greenspace use. In the absence of clear, causal mechanisms linking greenspace use with diabetes risk we did not test them. A clear limitation of our work was that we had no information about actual use of greenspaces among study participants. Studies utilising wearable tracking devices such as global positioning systems will help to reveal patterns of use, and thus provide more robust evidence to inform understanding of potential causal mechanisms.

Our finding that neighbourhood greenspace might be associated with lower screen-detected type 2 diabetes prevalence can be interpreted in two ways due to the cross-sectional nature of our study. First, it could suggest that areas with a low amount of greenspace would benefit from targeted screening programmes since these areas tend to have a higher number of undiagnosed type 2 diabetes cases. This could have important implications in terms of resource allocation, and might suggest that a general population screening programme is best suited to urban areas with low greenspace availability, whereas in areas with more greenspace then only those at high-risk of type 2 diabetes would need to be screened. It also suggests that areas with a low density of greenspace might benefit from community interventions, such as mass media campaigns, to raise awareness of type 2 diabetes and its prevention.

Second, it could suggest that greenspace might be protective for type 2 diabetes if the association between undiagnosed type 2 diabetes and greenspace is the same as that between overall type 2

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diabetes and greenspace, which seems likely to be the case particularly after adjustment for socio-economic status, ethnicity and other demographic factors that are likely to lead to earlier diagnosis. The idea that greenspace might be protective for type 2 diabetes supports the findings of two other large cross-sectional studies, both of which used self-reported measures of type 2 diabetes,[12, 13] as well as emerging evidence that more walkable neighbourhoods are associated with fewer diabetes cases.[40] Maas et al used similar methods to ours to quantify greenspace in a Dutch population,[13] and found that greenspace was inversely associated with diabetes in a 1km, but not a 3km, radius. Conversely, our results tended towards a stronger association when a larger radius was used. Differences depending on the neighbourhood definition used may occur for a number of reasons. For example, people living on the edge of urban developments may be linked with a small percentage of greenspace based on a road network buffer, and with a much larger percentage based on a circular buffer. Therefore, some neighbourhood definitions may better capture the amount of greenspace that people access than others. Astell-Burt et al also recently reported that greater access to greenspace was associated with lower diabetes risk in Australian adults aged 45 years and older.[12] Our work extends the limited evidence in this area by demonstrating that the association between greenspace and screen-detected type 2 diabetes appears also to be present in multi-ethnic populations and when robust type 2 diabetes diagnoses are used. We estimated that people living in neighbourhoods with the highest quartiles of greenspace had a 47% lower odds ratio of type 2 diabetes compared with those in the lowest quartile. These quartiles relate to ≥78% and ≤30% neighbourhood greenspace, respectively, suggesting that those with the lowest prevalence of type 2 diabetes have access to approximately three times as much greenspace as those with the highest prevalence. It is also notable that those with the lowest neighbourhood greenspace had demographic patterns congruent with those of people at highest risk of type 2 diabetes, for example those of south Asian ethnicity, suggesting that public health guidance to increase greenspace access to prevent or delay type 2 diabetes would potentially be of greatest benefit to those at highest risk if it were to be implemented.[5, 11]

Intuitively, the most likely reason that greenspace might be associated with type 2 diabetes prevalence seems to be that increased greenspace might encourage healthy behaviours, particularly physical activity, which is known to decrease type 2 diabetes risk.[41] However, we found little evidence to support this; adjusting for subjectively and objectively measured physical activity did not attenuate the association between greenspace and type 2 diabetes. This supports another observational study in England, which found that greenspace was not significantly related to the types of physical activity normally associated with greenspace.[42] Possible explanations of this are that seven days of measurement may not reflect seasonal variation in physical activity and might bias towards the null any relationship between physical activity and greenspace,[43, 44] and that we were only able to measure participation in physical activity without reference to where it occurs, such as in greenspace, the gym or at home. Astell-Burt et al also found that physical activity did not appear to explain the inverse

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relationship between greenspace and diabetes.[12] Indeed, the association between greenspace and type 2 diabetes was not explained by any of the type 2 diabetes risk factors that we accounted for in the analyses. This could mean that they are not causally associated, or that these associations are due to confounding with an unmeasured factor. Similarly, other studies have found that the potential mediators that they examined did not explain the association between health and greenspace.[12] They therefore concluded that other unmeasured pathways might explain the association, such as air pollution,[12] quality of sleep, or psychosocial factors,[45] which seems highly plausible.

In conclusion, these data support the hypothesis that access to greenspace is inversely associated with screen-detected type 2 diabetes, thus highlighting a potential area to be considered for targeted screening programmes and type 2 diabetes prevention. Whilst these data are in keeping with calls for urban designers and planners to provide more greenspace, more research is required to explain the inverse association between greenspace and type 2 diabetes.

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Competing Interests

All authors have completed the Unified Competing Interest form at www.icmje.org/coi_disclosure.pdf (available on request from the corresponding author) and declare that all authors have no relationships with companies that might have an interest in the submitted work in the previous 3 years; their spouses, partners, or children have no financial relationships that may be relevant to the submitted work; and (4) all authors have no non-financial interests that may be relevant to the submitted work.

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Contribution statement

KK, MD, LG, TY and SH designed and conducted the Let's Prevent Diabetes study. KK, MD, DW, and LG designed and conducted the ADDITION-Leicester study. KK, MD, TY, CE and LG designed and conducted the Walking Away from Diabetes study. DB, GO, AD and AJ conceived and designed

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the current analyses. DB conducted and is responsible for the data analysis. DB wrote the first draft of the manuscript with GO. All authors contributed to interpreting the data, revising the manuscript, and approved the final version. DB is the guarantor for the study. DB affirms that the manuscript is an honest, accurate, and transparent account of the study being reported; that no important aspects of the study have been omitted, and that any discrepancies from the study as planned have been explained. All authors had full access to all the data in the study and can take responsibility for the integrity of the data and the accuracy of the data analysis.

Data sharing

No additional data available.

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Table 1. Participant characteristics by study and for the entire sample combined.

Variable	ADDITION-Leicester	Let's Prevent Diabetes	Walking Away from Diabetes	All
Age, years	56.2 (10.8)	63.2 (8.2)	63.1 (8.2)	59.0 (10.4)
Area social deprivation score	19.7 (14.1)	17.3 (15.0)	20.2 (16.3)	19.0 (14.6)
Total METS	3376.2 (3579.6)	2293.5 (3038.0)	3380.0 (3949.8)	3007.3 (3475.3)
Average steps per day[a]	-	6544.1 (3100.0)	6610.3 (3210.9)	6557.6 (3122.7)
Body mass index, kg/m^2	28.0 (5.0)	32.4 (5.7)	32.5 (5.6)	29.8 (5.7)
Waist, cm	93.7 (13.2)	108.8 (12.9)	101.8 (12.4)	99.4 (14.8)
Fasting glucose, mmol/l	5.2 (0.9)	5.3 (0.8)	5.3 (0.8)	5.2 (0.9)
2 hour glucose, mmol/l	6.0 (2.4)	6.6 (2.5)	6.5 (2.4)	6.3 (2.5)
HbA1c, %	5.7 (0.6)	5.9 (0.5)	5.9 (0.6)	5.8 (0.6)
Total cholesterol, mmol/l	5.5 (1.1)	5.1 (1.0)	5.1 (1.1)	5.4 (1.1)
Female	53.1	39.1	36.5	47.2
South Asian	23.5	10.7	8.1	18.0
Other ethnicity	2.6	2.6	3.5	2.6
Rural location	11.7	24.5	17.5	16.3
Type 2 diabetes mellitus	6.2	10.9	9.4	8.0
Total	**6200**	**3444**	**832**	**10476**

Data are mean (standard deviation) or percentage.

Missing data: 0 Age and Sex, 21 Social deprivation score, 1481 Total METS, 208 Body mass index, 33 Fasting glucose, 81 2 hour glucose, 149 HbA1c, 108 Total cholesterol, 190 Ethnicity, 21 Rural location, 13 Type 2 diabetes.

[a] Measured using pedometers in Let's Prevent Diabetes and using accelerometers in Walking Away from Diabetes (735 missing values).

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Table 2. Average percentage of greenspace and correlations between percentage of greenspace according to neighbourhood definition.

			Correlations					
			Circular buffer			Road network buffer		
		Mean (SD) % of greenspace	800m	3km	5km	800m	3km	5km
Circular buffer	**800m**	38 (27)	1					
	3km	57 (26)	0.81	1				
	5km	65 (22)	0.74	0.97	1			
Road network buffer	**800m**	33 (28)	0.94	0.72	0.65	1		
	3km	50 (27)	0.85	0.97	0.92	0.77	1	
	5km	58 (24)	0.77	0.98	0.98	0.69	0.96	1

Abbreviations: SD, Standard Deviation.

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Table 3. The percentage of neighbourhood greenspace by participant characteristics.

Variable	Category	N	Mean (SD) percentage of greenspace	P-value
Age, years	<55	3208	51 (26)	
	55-64	3548	58 (25)	
	≥65	3720	60 (25)	<0.001
Sex	Male	5534	58 (26)	
	Female	4942	55 (25)	<0.001
Ethnicity	White European	8167	62 (24)	
	South Asian	1847	35 (17)	
	Other	272	33 (20)	<0.001
Urban/rural location	Urban	8749	50 (22)	
	Rural	1706	91 (06)	<0.001
Area social deprivation score	Low	5872	68 (21)	
	High	4583	41 (23)	<0.001
Total		**10476**	**57 (26)**	

Abbreviations: SD, Standard deviation.

P-values test for a difference in the percentage of greenspace across the categories and were estimated using one-way analysis of variance.

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Table 4. Sensitivity analyses considering different definitions of neighbourhood for the risk of type 2 diabetes mellitus in relation to quartiles of neighbourhood green space in 10,476 participants.[a]

	Adjusted[b] Odds Ratio (95% CI) of outcome			
Greenspace definition	**Quartile 2**	**Quartile 3**	**Highest Quartile**	**P for trend**
Circular 800m	0.96 (0.73, 1.27)	0.98 (0.72, 1.32)	1.00 (0.68, 1.47)	0.990
Circular 3km	0.71 (0.54, 0.93)	0.76 (0.54, 1.05)	0.53 (0.35, 0.82)	0.008
Circular 5km	0.65 (0.50, 0.85)	0.79 (0.56, 1.09)	0.65 (0.44, 0.95)	0.041
Road network 800m	1.07 (0.82, 1.40)	0.92 (0.69, 1.24)	1.03 (0.73, 1.45)	0.888
Road network 3km	0.71 (0.55, 0.93)	0.67 (0.49, 0.93)	0.48 (0.30, 0.77)	0.001
Road network 5km	0.67 (0.51, 0.88)	0.75 (0.54, 1.05)	0.58 (0.39, 0.86)	0.013

Note: Lowest quartile is referent category.

Abbreviations: CI, Confidence Interval; Q2, Quartile 2; Q3, Quartile 3.

[a] Missing data were imputed so analyses included all participants.

[b] Odds ratios were adjusted for ethnicity, age, sex, social deprivation score, urban/rural status, body mass index, physical activity (total METS), fasting glucose, 2 hour glucose, and total cholesterol.

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Figure 1. Odds ratios of screen-detected type 2 diabetes mellitus in relation to quartiles of neighbourhood greenspace in 10,476 participants.[a]

[Figure]

[a] Missing data were imputed so analyses included all participants.

Note: Lowest quartile is referent category.

Abbreviations: Q2, Quartile 2; Q3, Quartile 3.

Model 1 was adjusted for ethnicity, age, sex, area social deprivation score, and urban/rural status.

Model 2 was adjusted for all variables in Model 1 plus body mass index and physical activity (total METS).

Model 3 was adjusted for all variables in Model 2 plus fasting glucose, 2 hour glucose, and total cholesterol.

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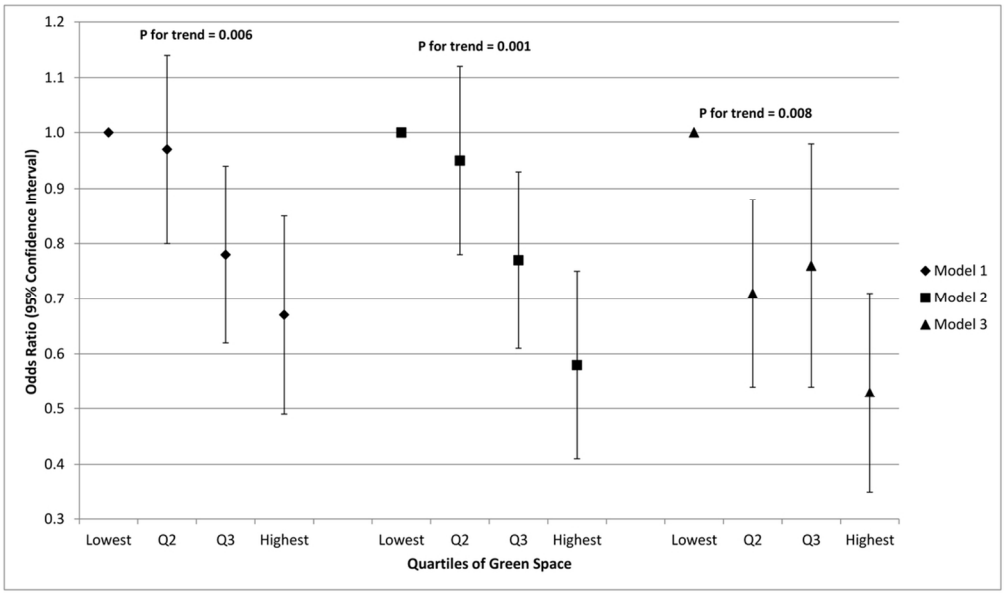

Odds ratios of screen-detected type 2 diabetes mellitus in relation to quartiles of neighbourhood greenspace in 10,476 participants
102x60mm (300 x 300 DPI)

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The association between neighbourhood greenspace and type 2 diabetes in a large cross-sectional study

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Abstract

Objective: To investigate the relationship between neighbourhood greenspace and type 2 diabetes.

Design: Cross-sectional.

Setting: Three diabetes screening studies conducted in Leicestershire, UK in 2004-2011. The percentage of greenspace in the participant's home neighbourhood (3km radius around home postcode) was obtained from a Land Cover Map. Demographic and biomedical variables were measured at screening.

Participants: 10,476 individuals (6200 from general population; 4276 from high-risk population) aged 20-75 years (mean 59 years); 47% female; 21% non-white ethnicity.

Main outcome measure: Screen-detected type 2 diabetes (WHO 2011 criteria).

Results: Increased neighbourhood greenspace was associated with significantly lower levels of screen-detected type 2 diabetes. The ORs (95% CI) for screen-detected type 2 diabetes were 0.97 (0.80 to 1.17), 0.78 (0.62 to 0.98) and 0.67 (0.49 to 0.93) for increasing quartiles of neighbourhood greenspace compared with the lowest quartile after adjusting for ethnicity, age, sex, area social deprivation score and urban/rural status (P_{trend} = 0.01). This association remained upon further adjustment for body mass index, physical activity, fasting glucose, 2-hour glucose and cholesterol (OR [95% CI] for highest vs lowest quartile: 0.53 [0.35 to 0.82]; P_{trend} = 0.01).

Conclusions: Neighbourhood greenspace was inversely associated with screen-detected type 2 diabetes, highlighting a potential area for targeted screening as well as a possible public health area for diabetes prevention. However, none of the risk factors that we considered appeared to explain this association, and thus further research is required to elicit underlying mechanisms.

Keywords: Diabetes Mellitus; Environment; Epidemiology; Greenspace; Public Health

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Strengths and limitations of this study

- Evidence regarding the association between greenspace and type 2 diabetes is limited since only two cross-sectional studies have investigated this association, and while they showed an inverse association, both used self-reported measures of diabetes.
- A major strength of this study was that robust measures of type 2 diabetes, greenspace, and potential confounders were used.
- Other strengths include the large sample size, robust detailed analysis, and the multi-ethnic population.
- The limitations include the cross-sectional nature of the study, that only screen-detected diabetes was included rather than all prevalent cases, and it is not possible to determine from the available data which areas of greenspace were publicly accessible.
- We found that neighbourhood greenspace was inversely associated with screen-detected type 2 diabetes, with 11% prevalence of undiagnosed type 2 diabetes in the lowest quartile of greenspace compared with 6% prevalence in the highest quartile of greenspace.

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Introduction

Prevalence of type 2 diabetes mellitus, a chronic long term condition, is rapidly increasing, and it is estimated that there are 175 million cases undiagnosed worldwide.[1] This may be largely due to environmental/behavioural factors.[2, 3] Individual-level interventions that encourage healthy lifestyles can lead to increased physical activity and improved diet, which in turn lower glucose levels to reduce type 2 diabetes risk or improve type 2 diabetes control.[4] However, public health solutions, such as changes to local environments, are also required to tackle the type 2 diabetes epidemic.[5] In public health, ecological models describe people's interactions with their physical and sociocultural surroundings.[6] The physical environment (built and natural), social environment, and policy environment are regarded as important influences on behaviour that may be changed in order to increase physical activity[7] and reduce obesity,[8] which are major modifiable risk factors for type 2 diabetes.[9, 10] Accordingly, ~~policymakers~~ urban designers and planners have been urged to provide greenspace, such as parks and natural areas, to facilitate physical activity, encourage other healthy behaviours, and reduce type 2 diabetes risk.[5, 11]

Only two studies have however investigated relationships between neighbourhood greenspace and type 2 diabetes.[12, 13] Both used self-reported diabetes, and found that greenspace was inversely related to diabetes.[12, 13] The knowledge gap highlighted by this limited evidence base is gaining even more importance with the increasing urbanisation worldwide. Additionally, the underlying factors explaining any relationship between greenspace and type 2 diabetes are unclear. For example, physical activity could explain the purported relationship between greenspace and morbidity,[14] but this has not been clearly shown in all studies.[12] This might be because, to our knowledge, no studies have used objective measures of greenspace in conjunction with objective diagnoses of type 2 diabetes and measures of its risk factors. The use of objective measures in the present study is noteworthy because the measurement error associated with self-reported diabetes[15, 16] and self-reported physical activity[17] may bias towards the null.

We therefore investigated whether neighbourhood greenspace was associated with type 2 diabetes in a large multi-ethnic population characterised using robust, objective measurements. The primary objective was to investigate the relationship between neighbourhood greenspace and screen-detected type 2 diabetes, and the secondary objective was to explore possible explanations underlying this relationship.

Materials and Methods

Participants

Three type 2 diabetes screening studies were conducted in Leicestershire, UK, using identical standard operating procedures: ADDITION-Leicester (ClinicalTrials.gov registration number:

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NCT00318032), Let's Prevent Diabetes ("Let's Prevent"; NCT00677937), and Walking Away from Diabetes ("Walking Away"; NCT00941954). This work only included cross-sectional data from the screening stage of each study. Ethical approval was from the University Hospitals of Leicester and Leicestershire Primary Care Research Alliance (ADDITION-Leicester) or the Nottingham (Walking Away/Let's Prevent) Research Ethics Committees. All participants gave written informed consent.

Full study descriptions are available elsewhere.[18-20] Briefly, ADDITION-Leicester (2004-2009) was a population-based study which screened people for type 2 diabetes.[18] Individuals selected at random from participating general practices who met the eligibility criteria were invited. Eligibility criteria included age 40-75 years (white Europeans) or 25-75 years (other ethnicities), and no diabetes diagnosis, thus all type 2 diabetes cases are screen-detected. Recruitment methods and inclusion criteria were similar in Let's Prevent (2009-2011)[19] and Walking Away (2010),[20] except that individuals in both Let's Prevent and Walking Away were at high risk of type 2 diabetes based on the Leicester Practice Risk Score,[21] and Walking Away had wider age inclusion criteria (18-74 years). Participants were excluded from the current analyses if their postcode was missing or invalid. If they took part in more than one of the studies then their most recent record was kept. In all three studies, participants attended a clinic visit where they provided a fasting sample, underwent an oral glucose tolerance test, had anthropometric measurement recorded, and completed questionnaires.

Outcome

Type 2 diabetes diagnosis was based on WHO 2011 criteria, using gold-standard oral glucose tolerance tests (fasting glucose ≥7.0mmol/l or 2 hour glucose ≥11.1mmol/l) or HbA1c (≥6.5%; 48mmol/mol).[22]

Explanatory variables

The main explanatory variable was the percentage of greenspace in the participant's home neighbourhood, and this was categorised into quartiles for the analyses. ArcGIS 9.3 ~~(ESRI 2009)~~, a geographic information system, was used.[23] To delineate neighbourhood boundaries, the postcode of each participant was geo-located using the UK Ordnance Survey Code-Point® database (2004-2013),[24] which provides a set of coordinates depicting the average latitude and longitude of all mail delivery locations within each postcode, which contains 15 addresses on average. Neighbourhood was delineated based on distance around these coordinates. Neighbourhoods are typically defined as the area within 800m (approximating to a ten minute walk) of a home location.[25] However, recent research from studies employing global positioning systems to track movement suggests that this may be overly conservative,[26] and that individuals typically travel greater distances to access resources and be physically active, therefore we used a straight-line distance of 3km.[27] ~~We used a circular buffer because greenspaces are often accessible via footpaths and cut-throughs rather than roads.~~ In

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sensitivity analyses, we also defined neighbourhood based on radii of 800m and 5km, and using road network buffers.

Estimates of greenspace were from the Centre for Ecology and Hydrology Land Cover Map of the UK (2007),[28] which is derived from satellite images and digital cartography, and records the dominant land use type, based on a 23 class typology, per 25m by 25m grid cell. Broadleaved and coniferous woodland, arable, improved grassland, semi-natural grassland, mountain, heath, bog, and freshwater (including rural lakeland environments) were classed as greenspace. Each participant's exposure was computed by overlaying the mapped greenspace with the neighbourhood boundaries in the geographic information system software to calculate the percentage of each neighbourhood area that contained these land cover types.

Other explanatory variables were treated as confounders, including age, sex, ~~social deprivation score (Index of Multiple Deprivation score), and~~ urban/rural location,~~.~~[29] and area social deprivation score (The English Indices of Deprivation 2010 provides a relative measure of deprivation at small area level across England, and its measure of multiple deprivation was used in the present study).[30] Ethnicity was self-reported using Census categories and grouped as White European, South Asian and Other due to the small number of participants in some ethnic groups. Trained staff measured weight and height to the nearest 0.1kg and 0.5cm, respectively. BMI was calculated as weight (kg) / height (m) squared. Cholesterol was measured in the fasting blood sample. Self-reported physical activity was obtained using the International Physical Activity Questionnaire (IPAQ). Published standards were used to calculate the number of metabolic equivalents (METS) per day for total activity.[31] Objective physical activity (average number of steps per day) was also available in Let's Prevent (sealed piezoelectric pedometer, NL-800, New Lifestyles, USA) and Walking Away (tri-axial accelerometer, GT3X, ActiGraph, USA). Participants wore the devices during waking hours for seven consecutive days on the right anterior axillary line of their trunks.

Statistical Analysis

Participant characteristics were summarised by study and overall as mean (standard deviation [SD]) for continuous variables and percentage for categorical variables. The mean (SD) percentage of neighbourhood greenspace was summarised by subgroup of participant demographics and compared using one-way ANOVA. Generalised estimating equations with a binary outcome were used to investigate whether quartiles of neighbourhood greenspace were associated with type 2 diabetes, with a term for clustering by postcode. Quartiles were defined as ≤30%, 31-59%, 60-77%, and ≥78% based on the data. Three models were fitted. Model 1 was adjusted for ethnicity, age, sex, social deprivation score, and urban/rural status. Model 2 was adjusted for all variables in Model 1 plus body mass index and physical activity (total METS). Model 3 was adjusted for all variables in Model 2 plus fasting

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glucose, 2 hour glucose, and total cholesterol. Models 2 and 3 were added to allow us to consider the influence of groups of covariates. Model 2 allowed us to consider the influence of lifestyle factors associated with type 2 diabetes.[9, 10] Model 3 allowed us to consider the influence of blood borne variables associated with type 2 diabetes.[32-35] Tests for trend were performed by fitting the greenspace quartiles as a continuous variable. Missing data were imputed in all models. Missing type 2 diabetes values were replaced as no type 2 diabetes, and missing ethnicity as white European, as these were overwhelmingly the modal values for those variables. All other missing values were replaced using multiple imputation with type 2 diabetes, age, sex and ethnicity as the predictor variables. Model 3 was also fitted using an objective measure of physical activity (average number of steps per day), rather than a subjective one (total METS reported via IPAQ), but this measure was only available in Walking Away and Let's Prevent, so missing data for average number of steps per day were not imputed due to the large quantity of such data. Sensitivity analysis involved fitting the fully adjusted model (Model 3) for different neighbourhood definitions. Analyses were performed in Stata v13. P-values <0.05 were treated as statistically significant.

Results

Participants

The three studies screened 11,032 people (6749 ADDITION-Leicester, 3450 Let's Prevent, 833 Walking Away), of whom 300 were excluded because their postcode was missing (all ADDITION-Leicester), and 12 because it was invalid (6 ADDITION-Leicester, 5 Let's Prevent, 1 Walking Away). There were 244 people who participated in multiple studies; therefore, these analyses included 10,476 participants, whose characteristics are in Table 1. The mean age was 59 years, 47% were female, 21% were of non-white ethnicity, and 16% lived in a rural location. There were some differences between the studies, primarily because ADDITION-Leicester screened the general population, whereas the other two screened high risk populations.

Amount of neighbourhood greenspace

Percentage of greenspace varied by neighbourhood definition, however all measures were strongly correlated (Table 2). The remainder of the manuscript pertains to the circular 3km buffer unless otherwise stated.

Neighbourhoods comprised 57% (SD 26%) greenspace on average (Table 3). The amount of neighbourhood greenspace was higher for participants who were older (P<0.001), male (P<0.001), of White European ethnicity (P<0.001), lived in rural locations (P<0.001), and had low area social deprivation (P<0.001).

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Associations with type 2 diabetes

Increased neighbourhood greenspace was associated with significantly lower levels of screen-detected type 2 diabetes. In the lowest greenspace quartile, 281 (10.7%) of people had type 2 diabetes; the analogous figures were 236 (9.0%), 159 (6.1%) and 161 (6.1%) for the second, third and fourth quartile respectively. ORs suggested that inverse relationship was significant (Figure 1). The OR (95% CI) for screen-detected type 2 diabetes was 0.67 (0.49, 0.93) in the highest compared with the lowest quartile after adjusting for ethnicity, age, sex, area social deprivation score and urban/rural status (P_{trend} = 0.01). This pattern remained upon further adjustment for body mass index and physical activity (Figure 1). After further adjustment for fasting glucose, 2-hour glucose and cholesterol, the dose-response relationship weakened, but the inverse association between greenspace and type 2 diabetes remained (P_{trend} = 0.01; Figure 1).

The effect sizes were similar in analyses stratified by recruitment type (fully adjusted OR [95% CI] for highest vs lowest quartile: population-based 0.48 [0.23, 1.01]; high-risk studies 0.47 [0.27, 0.81]; data not in Table). When objectively-measured physical activity was included in Model 3, rather than subjectively-measured physical activity, the inverse association between greenspace and type 2 diabetes remained (fully adjusted OR [95% CI] for highest vs lowest quartile: 0.45 [0.24, 0.82]; P_{trend} < 0.01; N = 3541; data not in Table).

Sensitivity analysis

Table 4 shows the fully adjusted analyses (Model 3) for different neighbourhood definitions. When a distance of 800m was used to define the neighbourhood, there was not a significant association between type 2 diabetes and greenspace, regardless of whether a circular or road network buffer was used. Conversely, when a distance of 3km or 5km was used, there was a significant inverse association between greenspace and type 2 diabetes regardless of the type of buffer used.

Discussion

In this large cross-sectional study, older age, male sex, White European ethnicity, higher socio-economic status and rural locations were associated with having more neighbourhood greenspace. After adjustment for these and other factors, increasing amounts of greenspace were associated with lower prevalence of screen-detected type 2 diabetes. Sensitivity analyses suggested that this inverse association was somewhat dependent on neighbourhood definition.

Our study has major strengths. Notably, the objective measures of greenspace, type 2 diabetes and potential confounders, the large sample size, robust detailed analysis, and the multi-ethnic population, mean that we are able to add novel, robust information to an emerging area of type 2 diabetes prevention. Furthermore, the diverse ethnic, socioeconomic and geographical distribution of this

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population means that our results are generalisable to other populations. This study also has limitations. The most important is that the cross-sectional nature of the study means that we are unable to infer causality from our findings. Other limitations are likely to have weakened the association between greenspace and type 2 diabetes, and so it may be stronger than observed. These limitations are that only screen-detected diabetes was included rather than all prevalent cases, and it is not possible to determine from the available data which areas of greenspace were publicly accessible. We only had information on area deprivation and, whilst individual and area deprivation are known to be strongly associated, not all residents of deprived areas will be deprived themselves.

~~Finally, we were not able to assess the quality of greenspace, and there is some evidence that better quality spaces, for example those free from vandalisms and with better accessibility, are more health promoting.[23]~~

There is some evidence that better quality greenspaces are more health promoting, such as those free from vandalism and with better accessibility.[36] Indeed, some research has suggested that objective measures of greenspace availability may differ from how such spaces are perceived and actually used.[37, 38] In the absence of such information, we used a measure of neighbourhood greenness based on detailed land cover information, using circular buffers to indicate the maximum potential accessible greenspace. The use of such buffers is consistent with the work of others.[39] The buffer size we used (3 km) is inevitably somewhat arbitrary, but it was based on evidence of mobility patterns from the literature and we tested the sensitivity of our findings to this definition by examining larger and smaller buffers. Road network buffers have been used in some studies, but we deemed them inappropriate in the present study because greenspaces are not necessarily accessed by road. Whilst other measures of greenspace have been used in other studies, such as distance to nearest greenspace or number and size of greenspaces around a home location,[11] these are based on a range of assumptions around greenspace use. In the absence of clear, causal mechanisms linking greenspace use with diabetes risk we did not test them. A clear limitation of our work was that we had no information about actual use of greenspaces among study participants. Studies utilising wearable tracking devices such as global positioning systems will help to reveal patterns of use, and thus provide more robust evidence to inform understanding of potential causal mechanisms.

Our finding that neighbourhood greenspace might be associated with lower screen-detected type 2 diabetes prevalence can be interpreted in two ways due to the cross-sectional nature of our study. First, it could suggest that areas with a low amount of greenspace would benefit from targeted screening programmes since these areas tend to have a higher number of undiagnosed type 2 diabetes cases. This could have important implications in terms of resource allocation, and might suggest that a general population screening programme is best suited to urban areas with low greenspace

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availability, whereas in areas with more greenspace then only those at high-risk of type 2 diabetes would need to be screened. It also suggests that areas with a low density of greenspace might benefit from community interventions, such as mass media campaigns, to raise awareness of type 2 diabetes and its prevention.

Second, it could suggest that greenspace might be protective for type 2 diabetes if the association between undiagnosed type 2 diabetes and greenspace is the same as that between overall type 2 diabetes and greenspace, which seems likely to be the case particularly after adjustment for socio-economic status, ethnicity and other demographic factors that are likely to lead to earlier diagnosis. The idea that greenspace might be protective for type 2 diabetes supports the findings of two other large cross-sectional studies, both of which used self-reported measures of type 2 diabetes,[12, 13] as well as emerging evidence that more walkable neighbourhoods are associated with fewer diabetes cases.[40] Maas et al used similar methods to ours to quantify greenspace in a Dutch population,[13] and found that greenspace was inversely associated with diabetes in a 1km, but not a 3km, radius. Conversely, our results tended towards a stronger association when a larger radius was used. Differences depending on the neighbourhood definition used may occur for a number of reasons. For example, people living on the edge of urban developments may be linked with a small percentage of greenspace based on a road network buffer, and with a much larger percentage based on a circular buffer. Therefore, some neighbourhood definitions may better capture the amount of greenspace that people access than others. Astell-Burt et al also recently reported that greater access to greenspace was associated with lower diabetes risk in Australian adults aged 45 years and older.[12] Our work extends the limited evidence in this area by demonstrating that the association between greenspace and screen-detected type 2 diabetes appears also to be present in multi-ethnic populations and when robust type 2 diabetes diagnoses are used. We estimated that people living in neighbourhoods with the highest quartiles of greenspace had a 47% lower odds ratio of type 2 diabetes compared with those in the lowest quartile. These quartiles relate to ≥78% and ≤30% neighbourhood greenspace, respectively, suggesting that those with the lowest prevalence of type 2 diabetes have access to approximately three times as much greenspace as those with the highest prevalence. It is also notable that those with the lowest neighbourhood greenspace had demographic patterns congruent with those of people at highest risk of type 2 diabetes, for example those of south Asian ethnicity, suggesting that public health guidance to increase greenspace access to prevent or delay type 2 diabetes would potentially be of greatest benefit to those at highest risk if it were to be implemented.[5, 11]

Intuitively, the most likely reason that greenspace might be associated with type 2 diabetes prevalence seems to be that increased greenspace might encourage healthy behaviours, particularly physical activity, which is known to decrease type 2 diabetes risk.[41] However, we found little evidence to support this; adjusting for subjectively and objectively measured physical activity did not attenuate

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the association between greenspace and type 2 diabetes. This supports another observational study in England, which found that greenspace was not significantly related to the types of physical activity normally associated with greenspace.[42] Possible explanations of this are that seven days of measurement may not reflect seasonal variation in physical activity and might bias towards the null any relationship between physical activity and greenspace,[43, 44] and that we were only able to measure participation in physical activity without reference to where it occurs, such as in greenspace, the gym or at home. Astell-Burt et al also found that physical activity did not appear to explain the inverse relationship between greenspace and diabetes.[12] Indeed, the association between greenspace and type 2 diabetes was not explained by any of the type 2 diabetes risk factors that we accounted for in the analyses. This could mean that they are not causally associated, or that these associations are due to confounding with an unmeasured factor. Similarly, other studies have found that the potential mediators that they examined did not explain the association between health and greenspace.[12] They therefore concluded that other unmeasured pathways might explain the association, such as air pollution,[12] quality of sleep, or psychosocial factors,[45] which seems highly plausible. ~~Another potential pathway is through diet (for example, deficiency of metabolically active micronutrients analogous with modern dietary intake), but we could not explore this as there was not a consistent diet measure across the studies that we included.~~

In conclusion, these data support the hypothesis that access to greenspace is inversely associated with screen-detected type 2 diabetes, thus highlighting a potential area to be considered for targeted screening programmes and type 2 diabetes prevention. Whilst these data are in keeping with calls for urban designers and planners to provide more greenspace, more research is required to explain the inverse association between greenspace and type 2 diabetes. ~~However, none of the confounders that we considered appeared to explain this association, which highlights that more research is needed in this area before public health policies are generated. Future research areas that would be of particular interest would be to incorporate dietary indicators, and to subjectively delineate quality of greenspace.~~

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Competing Interests

All authors have completed the Unified Competing Interest form at www.icmje.org/coi_disclosure.pdf (available on request from the corresponding author) and declare that all authors have no relationships with companies that might have an interest in the submitted work in the previous 3 years; their spouses, partners, or children have no financial relationships that may be relevant to the submitted work; and (4) all authors have no non-financial interests that may be relevant to the submitted work.

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Contribution statement

KK, MD, LG, TY and SH designed and conducted the Let's Prevent Diabetes study. KK, MD, DW, and LG designed and conducted the ADDITION-Leicester study. KK, MD, TY, CE and LG designed and conducted the Walking Away from Diabetes study. DB, GO, AD and AJ conceived and designed

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the current analyses. DB conducted and is responsible for the data analysis. DB wrote the first draft of the manuscript with GO. All authors contributed to interpreting the data, revising the manuscript, and approved the final version. DB is the guarantor for the study. DB affirms that the manuscript is an honest, accurate, and transparent account of the study being reported; that no important aspects of the study have been omitted, and that any discrepancies from the study as planned have been explained. All authors had full access to all the data in the study and can take responsibility for the integrity of the data and the accuracy of the data analysis.

Data sharing

No additional data available.

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Table 1. Participant characteristics by study and for the entire sample combined.

Variable	ADDITION-Leicester	Let's Prevent Diabetes	Walking Away from Diabetes	All
Age, years	56.2 (10.8)	63.2 (8.2)	63.1 (8.2)	59.0 (10.4)
~~Social~~ Area social deprivation score	19.7 (14.1)	17.3 (15.0)	20.2 (16.3)	19.0 (14.6)
Total METS	3376.2 (3579.6)	2293.5 (3038.0)	3380.0 (3949.8)	3007.3 (3475.3)
Average steps per day[a]	-	6544.1 (3100.0)	6610.3 (3210.9)	6557.6 (3122.7)
Body mass index, kg/m^2	28.0 (5.0)	32.4 (5.7)	32.5 (5.6)	29.8 (5.7)
Waist, cm	93.7 (13.2)	108.8 (12.9)	101.8 (12.4)	99.4 (14.8)
Fasting glucose, mmol/l	5.2 (0.9)	5.3 (0.8)	5.3 (0.8)	5.2 (0.9)
2 hour glucose, mmol/l	6.0 (2.4)	6.6 (2.5)	6.5 (2.4)	6.3 (2.5)
HbA1c, %	5.7 (0.6)	5.9 (0.5)	5.9 (0.6)	5.8 (0.6)
Total cholesterol, mmol/l	5.5 (1.1)	5.1 (1.0)	5.1 (1.1)	5.4 (1.1)
Female	53.1	39.1	36.5	47.2
South Asian	23.5	10.7	8.1	18.0
Other ethnicity	2.6	2.6	3.5	2.6
Rural location	11.7	24.5	17.5	16.3
Type 2 diabetes mellitus	6.2	10.9	9.4	8.0
Total	**6200**	**3444**	**832**	**10476**

Data are mean (standard deviation) or percentage.

Missing data: 0 Age and Sex, 21 Social deprivation score, 1481 Total METS, 208 Body mass index, 33 Fasting glucose, 81 2 hour glucose, 149 HbA1c, 108 Total cholesterol, 190 Ethnicity, 21 Rural location, 13 Type 2 diabetes.

[a] Measured using pedometers in Let's Prevent Diabetes and using accelerometers in Walking Away from Diabetes (735 missing values).

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Table 2. Average percentage of greenspace and correlations between percentage of greenspace according to neighbourhood definition.

			Correlations					
			Circular buffer			Road network buffer		
		Mean (SD) % of greenspace	800m	3km	5km	800m	3km	5km
Circular buffer	**800m**	38 (27)	1					
	3km	57 (26)	0.81	1				
	5km	65 (22)	0.74	0.97	1			
Road network buffer	**800m**	33 (28)	0.94	0.72	0.65	1		
	3km	50 (27)	0.85	0.97	0.92	0.77	1	
	5km	58 (24)	0.77	0.98	0.98	0.69	0.96	1

Abbreviations: SD, Standard Deviation.

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Table 3. The percentage of neighbourhood greenspace by participant characteristics.

Variable	Category	N	Mean (SD) percentage of greenspace	P-value
Age, years	<55	3208	51 (26)	
	55-64	3548	58 (25)	
	≥65	3720	60 (25)	<0.001
Sex	Male	5534	58 (26)	
	Female	4942	55 (25)	<0.001
Ethnicity	White European	8167	62 (24)	
	South Asian	1847	35 (17)	
	Other	272	33 (20)	<0.001
Urban/rural location	Urban	8749	50 (22)	
	Rural	1706	91 (06)	<0.001
~~Social~~ Area social deprivation score	Low	5872	68 (21)	
	High	4583	41 (23)	<0.001
Total		**10476**	**57 (26)**	

Abbreviations: SD, Standard deviation.

P-values test for a difference in the percentage of greenspace across the categories and were estimated using one-way analysis of variance.

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Table 4. Sensitivity analyses considering different definitions of neighbourhood for the risk of type 2 diabetes mellitus in relation to quartiles of neighbourhood green space in 10,476 participants.[a]

	Adjusted[b] Odds Ratio (95% CI) of outcome			
Greenspace definition	**Quartile 2**	**Quartile 3**	**Highest Quartile**	**P for trend**
Circular 800m	0.96 (0.73, 1.27)	0.98 (0.72, 1.32)	1.00 (0.68, 1.47)	0.990
Circular 3km	0.71 (0.54, 0.93)	0.76 (0.54, 1.05)	0.53 (0.35, 0.82)	0.008
Circular 5km	0.65 (0.50, 0.85)	0.79 (0.56, 1.09)	0.65 (0.44, 0.95)	0.041
Road network 800m	1.07 (0.82, 1.40)	0.92 (0.69, 1.24)	1.03 (0.73, 1.45)	0.888
Road network 3km	0.71 (0.55, 0.93)	0.67 (0.49, 0.93)	0.48 (0.30, 0.77)	0.001
Road network 5km	0.67 (0.51, 0.88)	0.75 (0.54, 1.05)	0.58 (0.39, 0.86)	0.013

Note: Lowest quartile is referent category.

Abbreviations: CI, Confidence Interval; Q2, Quartile 2; Q3, Quartile 3.

[a] Missing data were imputed so analyses included all participants.

[b] Odds ratios were adjusted for ethnicity, age, sex, social deprivation score, urban/rural status, body mass index, physical activity (total METS), fasting glucose, 2 hour glucose, and total cholesterol.

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Figure 1. Odds ratios of screen-detected type 2 diabetes mellitus in relation to quartiles of neighbourhood greenspace in 10,476 participants.[a]

[Figure]

[a] Missing data were imputed so analyses included all participants.

Note: Lowest quartile is referent category.

Abbreviations: Q2, Quartile 2; Q3, Quartile 3.

Model 1 was adjusted for ethnicity, age, sex, area social deprivation score, and urban/rural status.

Model 2 was adjusted for all variables in Model 1 plus body mass index and physical activity (total METS).

Model 3 was adjusted for all variables in Model 2 plus fasting glucose, 2 hour glucose, and total cholesterol.

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STROBE Statement—checklist of items that should be included in reports of observational studies

	Item No	Recommendation
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract Page 1
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found Page 2
Introduction		
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported Page 4
Objectives	3	State specific objectives, including any prespecified hypotheses Page 4
Methods		
Study design	4	Present key elements of study design early in the paper Pages 4-5
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection Pages 4-6
Participants	6	(*a*) *Cohort study*—Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up *Case-control study*—Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls *Cross-sectional study*—Give the eligibility criteria, and the sources and methods of selection of participants Page 5
		(*b*) *Cohort study*—For matched studies, give matching criteria and number of exposed and unexposed *Case-control study*—For matched studies, give matching criteria and the number of controls per case
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable Pages 5-6
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group Page 5
Bias	9	Describe any efforts to address potential sources of bias Pages 6-7
Study size	10	Explain how the study size was arrived at Page 7
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why Pages 5-7
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding Pages 6-7
		(*b*) Describe any methods used to examine subgroups and interactions Page 8
		(*c*) Explain how missing data were addressed Pages 6-7
		(*d*) *Cohort study*—If applicable, explain how loss to follow-up was addressed *Case-control study*—If applicable, explain how matching of cases and controls was addressed *Cross-sectional study*—If applicable, describe analytical methods taking account of sampling strategy N/A
		(*e*) Describe any sensitivity analyses Page 7

Continued on next page

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Results		
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed Page 7
		(b) Give reasons for non-participation at each stage Page 7
		(c) Consider use of a flow diagram N/A
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders Page 7 and Table 1
		(b) Indicate number of participants with missing data for each variable of interest Table 1
		(c) *Cohort study*—Summarise follow-up time (eg, average and total amount) N/A
Outcome data	15*	*Cohort study*—Report numbers of outcome events or summary measures over time
		Case-control study—Report numbers in each exposure category, or summary measures of exposure
		Cross-sectional study—Report numbers of outcome events or summary measures Page 8
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included Figure 1
		(*b*) Report category boundaries when continuous variables were categorized Page 6
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period N/A
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses Page 8
Discussion		
Key results	18	Summarise key results with reference to study objectives Page 8
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias Pages 8-9
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence Pages 8-11
Generalisability	21	Discuss the generalisability (external validity) of the study results Pages 8-9
Other information		
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based Page 12

*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.

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