Access to green space, physical activity and mental health: a twin study

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ABSTRACT

Background Increasing global urbanisation has resulted in a greater proportion of the world's population becoming exposed to risk factors unique to urban areas, and understanding these effects on public health is essential. The aim of this study was to examine the association between access to green space and mental health among adult twin pairs.

Methods We used a multilevel random intercept model of same-sex twin pairs (4338 individuals) from the community-based University of Washington Twin Registry to analyse the association between access to green space, as measured by the Normalised Difference Vegetation Index and self-reported depression, stress, and anxiety. The main parameter of interest was the within-pair effect for identical (monozygotic, MZ) twins because it was not subject to confounding by genetic or shared childhood environment factors. Models were adjusted for income, physical activity, neighbourhood deprivation and population density.

Results When treating twins as individuals and not as members of a twin pair, green space was significantly inversely associated with each mental health outcome. The association with depression remained significant in the within-pair MZ univariate and adjusted models; however, there was no within-pair MZ effect for stress or anxiety among the models adjusted for income and physical activity.

Conclusions These results suggest that greater access to green space is associated with less depression, but provide less evidence for effects on stress or anxiety. Understanding the mechanisms linking neighbourhood characteristics to mental health has important public health implications. Future studies should combine twin designs and longitudinal data to strengthen causal inference.

INTRODUCTION

Mental disorders represent a considerable proportion of the global burden of disease.[1] In the USA, prevalence of major depression is 8% among adults, costing society 97 billion dollars annually in healthcare utilisation and lost productivity.[1–3] Anxiety disorders affect approximately 7% of the global population, with a prevalence over 10% in many Western countries, including the US.[4]

Residential neighbourhoods have a profound effect on health. One neighbourhood feature that has been studied in association with mental health is access to green space.[5] Green space is thought to influence mental health through an increase in physical activity, by providing a place for neighbourhood residents to meet, facilitating social ties, and by alleviating stress and mental fatigue (figure 1).

Findings from green space-mental health studies have been mixed.[5–9] Most have been cross-sectional, and are thus subject to reverse causality. However, at least two longitudinal studies in England provided evidence that individuals living in greener areas had better mental health outcomes over time,[10 11] while a study in Sweden found an additive protective effect of green space and physical activity on mental health among women.[6] In a study recently published in this journal, Astell-Burt *et al* explored the trajectory between green space and minor psychiatric morbidity across the life-course. The authors reported a protective effect that emerged in early adulthood for men, and followed a positive linear pattern in which greater green space was associated with greater mental health benefit.[12] In contrast, the benefit of green space for women emerged later in adulthood, and followed a parabolic pattern in which women with moderate access to green space derived greater mental health benefit than those residing in the most or least green areas.

Despite the advantages of longitudinal designs, concerns about unmeasured confounds remain, most notably the inability to control for non-random selection of residents into neighbourhoods. Twin designs are an optimal way to address this self-selection problem because they provide a method of controlling genetic and environmental confounds.[13] Twins raised together share their childhood environment, and this shared upbringing may influence both residential selection and mental health. There are known genetic influences on mental health outcomes, and there may additionally be genetic influences on residential self-selection. A previous study assessing the contributions of genetic and environmental factors to residential selection found that although the largest contributions came from shared and unique environments, genetic factors did play a role.[14]

The aim of this study was to establish the association between access to green space and mental health among and within adult twin pairs. We hypothesised that greater access to green space would be associated with better mental health outcomes, controlling for genetic and shared environmental confounds within twin pairs.

MATERIALS AND METHODS

Study population

We conducted a cross-sectional analysis using same-sex twin pairs from the University of Washington Twin Registry (UWTR), 2008–2014. Registry construction has been published elsewhere.[15] Briefly, the UWTR is a community-based sample of twins reared together identified by the Washington State Department of Licensing. Twins

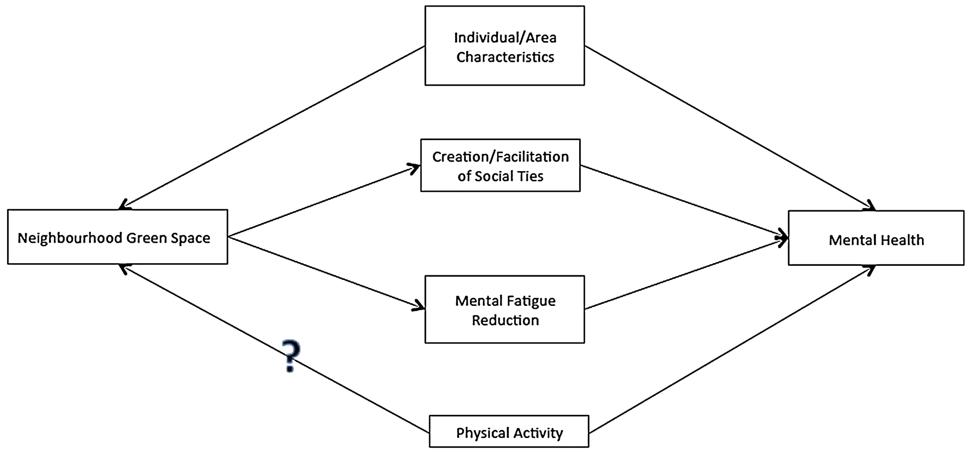

Figure 1 Directed acyclical graph showing the proposed association between variables in the model. Neighbourhood green space can affect mental health through creation of social ties and reduction of mental fatigue. Traditional individual and area characteristics (eg, income, neighbourhood deprivation) act as confounders. Physical activity is also conceptualised as a confounder, with desire for physical activity driving self-selection into greener areas. However, previous work has also conceptualised physical activity as a mediator, suggesting that greener areas impact mental health by encouraging more physical activity.

completed a brief recruitment survey on initial contact, and a follow-up survey in 2010. Both surveys collected information on sociodemographics, health behaviours, and health conditions. Addresses were geocoded to create a series of environmental exposures. Twins were classified as identical (monozygotic, MZ) or fraternal (dizygotic, DZ) using standard questions about childhood similarity that determine zygosity with greater than 90% accuracy when compared with DNA-based methods.[16 17]

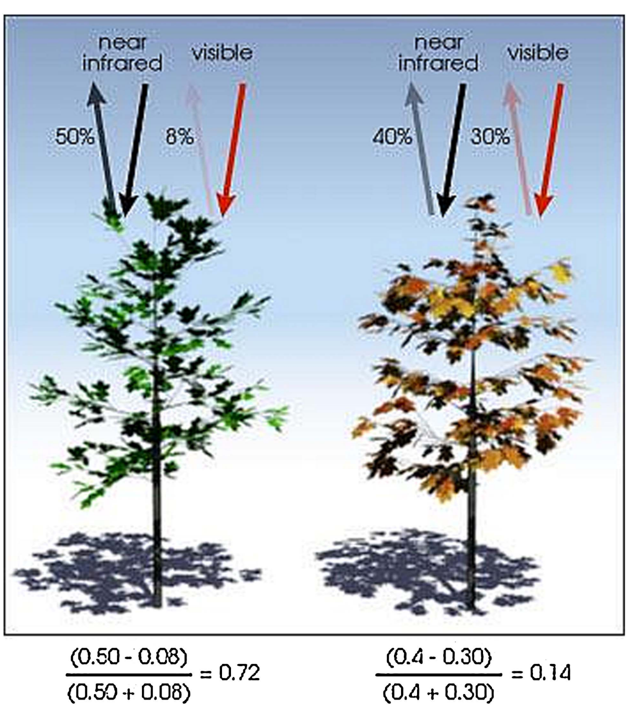

Figure 2 Healthy vegetation reflects a substantial portion of the near-infrared light that hits it, and absorbs visible light. By contrast, unhealthy or scarce vegetation absorbs more near-infrared light and reflects more visible light. The Normalised Difference Vegetation Index is calculated from the amount of near-infrared and visible light reflected in a specified geographic area: (NIR−VIS)/(NIR+VIS). (illustration by Robert Simmon, http://earthobservatory.nasa.gov/Features/MeasuringVegetation/).

A total of 4338 twins were included in this study. Although most twins currently live or have lived in Washington State at some point in their life (73.5%), twins living in the District of Columbia and all 50 states except Alaska, Delaware, Hawaii and Vermont are included.

Written informed consent was provided as approved by the university's institutional review board.

Exposure measure

Access to green space was measured by the Normalised Difference Vegetation Index (NDVI).[18] The NDVI uses satellite remote sensors to estimate visible and near-infrared light reflected by vegetation within a specified distance around a residential address (in this study, a 1 km buffer around the geocoded home location).[19] Healthy vegetation reflects near-infrared (NIR) light while absorbing visible (VIS) light (figure 2). The NDVI is calculated by dividing the difference of NIR and visible radiation by the sum of NIR and visible radiation: NDVI=(NIR−VIS)/(NIR+VIS). Values for NDVI range from −1.0 to +1.0; very low values (0.1 and below) correspond to barren areas of rock, sand or snow. Moderate values represent shrub and grassland (0.2–0.3), while high values indicate temperate and tropical rainforests (0.6–0.8). A value of −1 indicates water; twins living within a 1 km buffer identified as water were excluded from the analysis. NDVI has been used to investigate associations between greenness and physical activity,[20 21] cardiovascular disease,[22] pregnancy outcomes, 7 and mortality.[23]

Outcome measures

Mental health outcomes included depression, using a modified 2-item Patient Health Questionnaire (PHQ-2);[24] stress, using the Perceived Stress Scale (PSS);[25] and anxiety, using the Brief Symptom Inventory (BSI).[26] The modified PHQ-2 includes questions about depressed mood, feeling tired and anhedonia (inability to experience pleasure). The measure has been validated against the Diagnostic and Statistical Manual Fourth Edition (DSM-IV).[24] The PSS measures the degree to which an individual's life is perceived as stressful, and has good validity using life-event scores, depressive symptoms, physical symptoms, healthcare utilisation and social anxiety as criteria.[25] The BSI is a modified version of the longer Symptom Checklist 90, and shows good correlation to the more complete scale, as well as good convergent and construct validity.[26] All three measures record responses on a 4-point Likert scale. The total scale ranges from 0 to 9 for the modified PHQ-2, 0–40 for the PSS, and 0–24 for the BSI.

Covariate measures

Based on the literature, we decided a priori that household income and physical activity were potential confounders. Income can drive neighbourhood self-selection[27 28] and both income and physical activity are associated with mental health and green space access.[5 29–31] Income was categorised in increments of \$10 000, beginning with 'less than \$20 000' and increasing to 'greater than or equal to \$80 000'. Physical activity was measured as moderate-to-vigorous physical activity (MVPA) and walking in the home neighbourhood. MVPA was assessed by combing two questions: 'how many days during a typical week did you exercise moderately for at least 30 minutes?' and 'how many days during a typical week did you exercise vigorously for at least 20 minutes?' Total MVPA was rescaled to hours/week for the analysis. In a sample of 102 twins, MVPA correlated with objectively measured activity via accelerometry ($r=0.46$, $p<0.001$).

Twins also reported how many days during a typical week they walked in their neighbourhood, with a follow-up question about the number of minutes spent in each walking bout. Responses of less than 15 min were coded as 10 min, whereas responses of 90 or more minutes were top coded as 90 min. As with MVPA, walking was rescaled to hours/week for the analysis. Finally, transit use was assessed as the number of days in a typical week respondents used transit services including bus, ferry and commuter rail. The use of transit frequently requires walking to and from transit stops, therefore contributing to total activity levels beyond leisure activity.[32]

We included two additional measures of the neighbourhood environment: population density (people/square mile) and neighbourhood deprivation. Both were measured at the census tract level; census tracts are small geographical areas within a county that average approximately 4000 residents. Neighbourhood deprivation was measured using the Singh Index, which combines 2010 census data on education, employment, income and income disparity, poverty, characteristics of the home and home, vehicle, and telephone ownership.[33 34] Higher index scores indicate greater levels of deprivation. Both area based variables were considered potential confounders because they are associated with area greenness and mental health.[5 31]

Statistical analysis

We used a multilevel random intercept model to account for correlation of the data which would otherwise bias SE estimates. There are two types of correlation in this study: between twins within a pair, and between individuals living within the same census tract.

Each mental health outcome was first regressed on NDVI score to estimate the phenotypic association (non-genetically informed). This model treats each twin as a singleton, and although it accounts for the correlated nature of the data, it does not estimate within-pair effects.

We then used the following model to take full advantage of the twin design (genetically informed):[35]

$$y_{ij} = \beta_0 + (\beta_B \times x_j) + (\beta_W \times (x_{ij} - x_j)) + (\beta_3 \times g_Z) + (\beta_4 \times g_Z \times (x_{ij} - x_j)) + \mu_k + \mu_j + e_{ij}$$

where x_j is the average access to green space for twin pair j, x_{ij} is the individual access to green space for twin i in pair j, and g_z is the zygosity for pair j (coded 0 MZ, 1 DZ). In this model, μ_k and μ_j represent the random intercepts for the specific census tract and pair j, respectively and e_{ij} represents the individual error for twin i in pair j.

The within-pair effect for MZ twins (β_W) is the main coefficient of interest because it is not subject to genetic or shared environment confounding. It can be interpreted as the difference in risk of the outcome associated with a one-unit difference in NDVI score within a MZ twin pair, conditional on the mean NDVI score of the twin pair.[35] The inclusion of the between-pair effect (β_B) allows for an individual's risk of outcome to be influenced by the mean NDVI for the twin pair.

Additionally, comparing the within-pair effect for MZ and DZ twins (β_4) can indicate if there is potential genetic confounding. The two within-pair effects control equally for any childhood environment confounders, but the DZ effect only controls half as well for genetic confounders. A significantly different within-pair effect for MZ and DZ twins suggests genetic confounding in the relationship between green space and mental health.

Finally, the Interclass Correlation Coefficient (ICC) is the proportion of the total unaccounted variance in mental health outcome that is attributable to genetic and environmental factors shared between twins within a pair. Assuming that MZ twins share all their genes and DZ twins share, on average, 50% of their genes, ICCs estimate the additive genetic (A), shared environment (C) and unique environment (E) influences on the relationship between access to green space and mental health. Additive genetic influences are estimated as twice the difference between the MZ and DZ ICCs ($A=2\times(ICC_{MZ}-ICC_{DZ})$). Shared environment influences are estimated as the difference between the MZ ICC and the additive genetic influences ($C=ICC_{MZ}-A$), and unique environment influences can be estimated as $1-ICC_{MZ}$.[35]

We first constructed an unadjusted model (model A) that contained access to green space and the mental health outcome. Each of the four subsequent models (models B–E) included income as a covariate. Models C and D also included the physical activity measures; model C included activity that could take place anywhere (MVPA) while model D included activity specific to the respondent's neighbourhood (walking in the neighbourhood and transit use). Model E included all individual level covariates, as well as tract-level Singh Index and population density. Age, sex and race/ethnicity are not included in the models because they are inherently controlled for in the twin design. All probability values were 2-sided, and the significant level was set at 0.05.

RESULTS

The sample included 4338 twins; NDVI ranged from 0.08 to 0.89, with a mean of 0.57 (SD 0.15), indicating moderate to high vegetation density. Select sample characteristics are given in table 1, stratified by NDVI for illustrative purposes. Twins who lived in greener areas tended to have higher annual incomes, and were less likely to identify as Hispanic/Latino or to use transit. Greener areas were more likely to have lower Singh Index scores and lower population density.

Phenotypic (non-genetically informed) models

All three phenotypic models showed a significant inverse association between access to green space and mental health ($p<0.05$; data not shown). Among MZ twins, a one unit difference in NDVI was associated with a 0.39 lower modified PHQ-2 score, a 2.02 lower PSS score, and a 0.68 lower BSI score. The

Table 1 Select characteristics of adult twins in the University of Washington Twin Registry, stratified by access to green space*, 2008–2012

	Number (%)	
Characteristic	**NDVI <0.57 N=2061**	**NDVI ≥0.57 N=2277**
Male	668 (32.4)	722 (31.7)
Age (years)†	38.7±16.4	39.7±17.1
White	1875 (91.0)	2111 (92.7)
Hispanic	107 (5.3)	69 (3.1)
Income		
Less than $50 000	943 (46.9)	925 (42.0)
$50 000 or greater	1068 (53.1)	1279 (58.0)
Total MVPA (minutes/week)†	113.7±90.6	113.1±87.4
Total walking (minutes/week)†	89.0±101.1	87.4±101.9
Transit users	377 (18.3)	244 (10.8)
Singh Index†‡	−0.3 (0.8)	−0.4 (0.7)
Population density†	6294.8 (10 179.6)	2129.7 (2265.5)
Modified PHQ-2†	1.8±1.9	1.6±1.8
PSS†	13.5±6.8	13.2±6.8
BSI†	2.5±3.3	2.4±3.3

*Access to green space assessed by the Normalised Difference Vegetation Index (NDVI), a measure of 'greenness' using satellites to assess the density of vegetation in the target area.
†Mean±SD.
‡Singh Index, a measure of neighbourhood deprivation which combines data on education, employment, income and income disparity, poverty, characteristics of the home and home, vehicle, and telephone ownership.
BSI, Brief Symptom Inventory, a measure of anxiety on a scale of 0–24; MVPA, moderate-vigorous physical activity; PHQ-2, 2-item Patient Health Questionnaire, a measure of depressive symptoms on a scale of 0–9; PSS, Perceived Stress scale, a measure of stress on a scale of 0–40.

magnitude of the association between NDVI and each mental health outcome changed slightly for DZ twins; however, the difference between MZ and DZ associations was not significant.

Random intercept (genetically informed) models

Depression

There was a significant within-pair association between access to green space and depression in the crude model among MZ twins (−0.44, 95% CI −0.74 to −0.14; table 2). The association was inverse such that within MZ pairs, the twin with the higher NDVI had a lower risk of depression. This difference remained significant in all four adjusted models. Furthermore, in the crude model and the models adjusted for income only and income and MVPA, MZ twins had a significantly different inverse within-pair effect than DZ twins (crude model: 0.29, 95% CI 0.01 to 0.56).

The ICCs were similar in magnitude across all models (data not shown), though consistently higher for MZ compared to DZ twins (roughly 0.23 vs 0.02, respectively). There were no shared environment effects. The estimated additive genetic influences on the observed association were 42%, with unique environment influences 58%.

Stress

Similar to depression, there was a significant inverse within-pair association between access to green space and stress within MZ twins in the crude model ($p<0.05$; −2.79, 95% CI −4.90 to −0.68). However, this association was not significant in the adjusted models (data not shown). Further, there was no significant difference in the within-pair effect between MZ and DZ twins.

As with depression, ICCs were similar in magnitude across all models (data not shown) and consistently higher for MZ compared to DZ twins (roughly 0.38 vs 0.16, respectively). Likewise, there were no shared environment effects. The estimated additive genetic and unique environment influences on the association were 44% and 56%, respectively.

Anxiety

Unlike depression and stress, there was no significant within-pair effect among MZ twins between access to green space and anxiety in any model; nor was there a significant difference in the within-pair effect between MZ and DZ twins ($p>0.05$, data not shown). The ICCs estimated in the anxiety analysis were similar in magnitude across all models (data not shown) and consistently slightly higher for MZ compared to DZ twins (roughly 0.28 vs 0.26, respectively). The estimated additive genetic influences were 4%; the shared environment influences were 24%; and the unique environment influences were 72%.

DISCUSSION

This study supports the hypothesis that greater access to residential green space is associated with less depression, but provides less evidence of an association between green space and stress or anxiety. Each of the three phenotypic models showed significant inverse associations between green space and mental health. However, only the association with depression remained significant in within-pair MZ univariate and adjusted models. Since there were no within-pair MZ effects for anxiety, any association between green space and anxiety is likely driven by unshared characteristics between twin pairs. Further, because the within-pair effect for MZ twins between green space and stress became non-significant when adjusted for confounders, the stress differences within pairs were likely due to these measured and possibly unmeasured confounds, and not access to green space.

Descriptively, a one-unit difference in NDVI represents the difference between a barren area of rock or stone and a rainforest. The MZ within-pair effect in the unadjusted model for depression (table 2) suggests that, on average, people who live in or around dense vegetation have a 0.44 (on a scale of 0–9) lower depression score than those who live in a location without any access to green space. A 0.25 unit difference in NDVI, comparing barren rock to grassland, would therefore be associated with a difference in modified PHQ-2 score of 0.11. Further, the unadjusted within-pair effect for DZ twins can be calculated as the result of solving for x in: $x-(-0.44)=0.29$, which gives −0.15. Thus the unadjusted within-pair effect is more negative for MZ twins than DZ twins (−0.44 vs −0.15, table 2), suggesting the presence of genetic confounds that attenuate the green space-depression association.

These findings partially support previous studies reporting associations between greener neighbourhood environments and improved mental health.[10 11 36–41] It is important to note differences in conceptual models used to link green space and mental health in each of the studies, and in particular how physical activity is thought to influence this association. The present study tested for a direct association between green space and mental health, treating physical activity as a confounder. In this model, physical activity is directly associated with better mental health, while a desire for greater physical activity drives self-selection into greener neighbourhoods. The association between desire for more walking and choosing environments supporting

Table 2 Associations between access to green space and depression* among twin pairs in the University of Washington Twin Registry, 2008–2012

	Model A		Model B		Model C		Model D		Model E	
	Coef	**95% CI**	**Coef**	**95% CI**	**Coef**	**95% CI**	**Coef**	**95% CI**	**Coef**	**95% CI**
Fixed effects										
NDVI†										
Between-pair effect (β_B)	−0.17	−0.36 to 0.03	−0.12	−0.31 to 0.07	−0.12	−0.31 to 0.08	−0.12	−0.31 to 0.08	−0.11	−0.37 to 0.02
MZ within-pair effect (β_W)	−0.44	−0.74 to −0.14	−0.39	−0.70 to −0.09	−0.39	−0.70 to −0.09	−0.38	−0.68 to −0.07	−0.44	−0.80 to −0.25
DZ—MZ within-pair effect (β_B)	0.29	0.01 to 0.56	0.28	0.01 to 0.56	0.29	0.01 to 0.56	0.27	−0.01 to 0.55	0.27	−0.08 to 0.45
Zygosity	−0.04	−0.11 to 0.03	−0.04	−0.34 to 0.26	−0.04	−0.34 to 0.03	−0.05	−0.12 to 0.02	−0.04	−0.12 to 0.00
Income			−0.05	−0.06 to −0.04	−0.05	−0.06 to −0.04	−0.05	−0.06 to −0.04	−0.05	−0.06 to −0.04
MVPA					−0.03	−0.05 to −0.01			−0.02	−0.04 to 0.00
Walking in neighbourhood‡							−0.03	−0.04 to −0.01	−0.01	−0.03 to 0.01
Transit use							0.00	−0.02 to 0.02	−0.01	−0.02 to 0.01
Singh Index§									0.00	−0.05 to 0.03
Population density									0.00	0 to 0
Random effects										
Census tract	0		0		0.00	0 to 0	0.00	0 to 0	0.00	0 to 0
Between MZ pair	0.21	0.16 to 0.26	0.19	0.15 to 0.24	0.20	0.15 to 0.24	0.20	0.16 to 0.25	0.19	0.13 to 0.22
Within MZ pair	0.68	0.63 to 0.73	0.67	0.62 to 0.72	0.67	0.62 to 0.72	0.66	0.61 to 0.71	0.68	0.62 to 0.71
Between DZ pair	0.02	−0.06 to 0.10	0.02	−0.07 to 0.10	0.02	−0.07 to 0.11	0.03	−0.05 to 0.12	0.01	−0.09 to 0.06
Within DZ pair	0.92	0.81 to 1.02	0.91	0.80 to 1.02	0.91	0.80 to 1.02	0.90	0.79 to 1.00	0.91	0.78 to 0.97

*Measured by the modified 2-item Patient Health Questionnaire.
†Access to green space assessed by the Normalised Difference Vegetation Index (NDVI), a measure of ‘greenness’ using satellites to assess the density of vegetation in the target area.
‡Walking rescaled to hours/week.
§Neighbourhood deprivation assessed by the Singh Index, which combines data on education, employment, income and income disparity, poverty, characteristics of the home and home, vehicle, and telephone ownership.
DZ, dizygotic; MVPA, moderate-vigorous physical activity (rescaled to hours/week); MZ, monozygotic.

walking is supported in the literature.[42] Similarly, people who preferred walkable areas were likely to walk wherever they moved and were likely to select into walkable areas.[43] In contrast, previous studies primarily conceptualised physical activity as an effect modifier or mediator. For example, Astell-Burt *et al*[37] found that green space only had a mental health benefit among middle-aged adults who were more active. Similarly, Annerstedt *et al*[6] reported a synergistic protective effect of physical activity and access to serene green areas on mental health. In contrast, Richardson *et al*[40] found that physical activity partially mediated green space-health associations. These different conceptualisations may also reflect the type and variety of green areas used in each study. Fan *et al*[44] found that park size can affect stress by promoting physical activity while general greenness, operationalised by NDVI, was not directly associated with physical activity, but rather influenced stress through other mechanisms. Further work should tease apart the different mechanisms through which green areas influence health.

The lack of an association between green space and self-reported stress is in contrast with the hypothesised conceptualisation of emotional restoration as a mediator in the pathway between green space and mental health (figure 1). This mechanism has been supported by previous work finding links between green space and biomarkers of stress. Two studies in Scotland found that viewing green areas, either as images or by walking through them, increased levels of meditation and decreased levels of arousal.[45 46] Two other studies, both conducted in the UK, found that higher levels of green space were associated with decreased stress, measured by mean levels and diurnal patterns of cortisol, as well as self-reported stress, in residents of socio-economically deprived neighbourhoods.[47 48]

However, the current study is consistent with a study examining associations between green space, depression, anxiety and stress of residents in Wisconsin that found depression showed the strongest relationship with green space, even after adjusting for different confounders.[49]

The main strength of this study is the use of a large sample of adult twins from a community-based registry, which controls for confounding due to unmeasured genetic and shared environment factors. The use of a randomised experiment to study the green space-mental health association is not practical or ethical; therefore, the twin design is the best approximation to an experimental design to overcome the concerns regarding self-selection into neighbourhoods.

Despite this strength, twin designs do not account for all factors that may affect residential self-selection, such as the desire to live close to work or the influence of a spouse. The cross-sectional study design limits our ability to draw causal inferences because it does not address reverse causation. In addition, our results may not be generalisable to other populations because over 90% of twins were white. There was, however, diversity in income. A further assumption of this analysis is that results of twin studies are generalisable to the non-twin population. Although little research has addressed this issue, previous studies have suggested that twin-based results may be generalisable across a variety of outcomes including cardiovascular disease and antisocial behaviour.[50 51] Additionally, twins residing in areas deemed 'water' were excluded from the analysis. This exclusion presents two limitations. First, these twins most likely lived on waterfront property and, given the generally higher property values of waterfront homes, this may have resulted in the exclusion of wealthier twins. Second, previous studies have linked living near the coast to improvements in health and well-being and decreases in mental distress.[52–54] However, not all twins who lived in such areas lived on the coast: many lived on inland lakes, and the link between lakes and mental health has been less clear.[52] Finally, the NDVI is a non-specific measure of green space and does not distinguish between different types of green area such as tree canopy or parks. As noted above, different types of green space may influence mental health through different mechanisms.[44] The UWTR does not currently have measures of park space or tree canopy, thereby limiting the ability to investigate differential effects on mental health by green space type.

CONCLUSION

The results of this study suggest that greater access to green space in the home neighbourhood is associated with less depression, even when controlling for genetic and shared environmental confounds. Future studies should combine twin designs and longitudinal data to further address neighbourhood self-selection and reverse causality. This will strengthen our ability to make causal inferences that could facilitate specific efforts to modify the environment in which we live in order to benefit our health.

What is already known on this subject

It is plausible that access to residential green space can affect mental health. Epidemiological research on this association has yielded mixed results. Causal inference is further limited by concerns about unmeasured confounds including genetic influences and residents' non-random self-selection into neighbourhoods.

What this study adds

This paper uses a twin design to address concerns about unmeasured genetic and environmental confounds. Our findings suggest that observed associations between access to green space and stress and anxiety are most likely driven by genetic and childhood environment confounds. However, the association between access to green space and depression remained significant even when controlling for genetics, childhood environment, income and moderate-to-vigorous physical activity. These findings highlight the need for a more complete understanding of the mechanisms linking neighbourhood characteristics to mental health outcomes in order to make specific modifications to the residential environment to improve health.

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Contributors All three authors were involved in the study design, data analysis and interpretation, and drafting, revising and final approval of the manuscript.

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