Assessing Green Space as a Correlate of Physical Activity Among Twins

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Abstract

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Background: The health benefits of regular physical activity are well established. However, the contribution of natural and "built" environmental factors, including access to green space, to physical activity levels remains uncertain. In this study we use walking, moderate-to-vigorous physical activity (MVPA), public transit use, and neighborhood green space data from twin pairs in Washington State to elucidate this relationship. Twin pairs were used in this analysis to control for the genetic contribution to physical activity participation and self-selection into environments with more (or less) green space. We hypothesized that an increased density of green space around a subject's home would be associated with an increase in overall physical activity, controlling for demographic factors and public transit use.

Methods: Data were obtained from 2,244 same-sex twin pairs from the community-based University of Washington Twin Registry. Green space around each twin's home was measured using the Normalized Difference Vegetation Index (NDVI), which ranges from -1 (barren areas of rock, sand, or snow) to +1 (temperate and tropical rainforests). Unadjusted and adjusted GEE and twin-difference regression models were constructed to determine the association between NDVI and physical activity levels.

Results: There was a significant association between NDVI and both total walking levels in the neighborhood and total MVPA in unadjusted models (all $p < 0.001$). The associations were attenuated, but still significant (all $p < 0.001$), when controlling for age, income, education and ethnicity/race with no further changes when additionally controlling for transit use. However, there were no significant associations between NDVI and each of the activity outcomes in the twin-difference models (all $p > 0.05$). The results were unchanged when stratified by zygosity.

Conclusion: The findings of this study demonstrate that higher levels of objectively measured green space are associated with more walking and MVPA overall. However, this relationship is confounded by genetic and shared environmental factors, suggesting that physical activity levels and access to green space are not causally related.

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Introduction

The health benefits of regular physical activity are well established, including a reduced risk for several chronic diseases such as cardiovascular disease, diabetes, certain cancers, osteoporosis, and depression (1-5). The US Department of Health and Human Services recommends that adults engage in 150 minutes per week of moderate-intensity, or 75 minutes per week of vigorous-intensity, aerobic physical activity in order to maintain good health (6). The amount of physical activity people actually engage in, however, is quite variable and dependent on behavioral, social, environmental and genetic factors (7). Over the past several years, the literature has increasingly focused on the relations between the physical or "built" environment and physical activity, especially walking because it is the major source of daily physical activity for most Americans (8).

The built environment has primarily focused on the environment immediately surrounding the home location, or residential "neighborhood"(9, 10). Aspects of the home built environment that have been investigated in connection with walking include neighborhood walkability, crime rates, transportation infrastructure, and, more recently, access to green space (11-13). Green space may be an important correlate of physical activity because greater access to green space provides an attractive and serene area to walk (14), reflecting elements both of natural and man-made (built) environments.

Studies that have explored the relation between physical activity and green space have produced mixed findings; some studies have found that physical activity levels increase with increased access to green space (11, 14-16) while others have found no such association (17, 18). There are many potential reasons for the discrepancies in findings reported among studies investigating physical activity and green space. One issue is that most studies have not distinguished between purpose of the physical activity.For example, it is unknown whether the physical activity subjects engaged in was actually due to access to green space (i.e., recreational or utilitarian-related activity), or whether the purported association was confounded by the necessity to walk to and from sources of public transportation (i.e., transportation-related activity) (14). Another potential reason lies in genetic and shared (familial) factors that may pre-dispose people to be either physically active and/or self-select into areas that provide greater access to physical activity and/or green space. For example, multiple studies have shown various levels of influence of genetic and shared/ non-shared environmental factors on participation in physical activity (19-22) and residential selection (23-25).

This study examined the physical activity-green space relationship by investigating the association between different types of physical activity and access to green space in the proximal home neighborhood among a large community-based sample of adult twins. Using twins allowed us to effectively eliminate the confounding effects of genetics and shared familial factors when considering exposures such as the environment and health outcomes such as physical activity level, thus permitting us to focus on environmental effects. We measured the total levels of walking in the home neighborhood, total levels of moderate-to-vigorous physical activity, and use of transit services from self-report, and have calculated the Normalized Difference Vegetation Index (NDVI) to estimate the “greenness” of the area around the twins’ homes, as described in the literature (26, 27). We hypothesized that access to green space within a one mile radius of the home was associated with increased levels of both total walking within the home neighborhood and moderate-to-vigorous physical activity levels among adult twins, controlling for demographic factors and use of transit services.

Methods

Sample and study design

This study was a secondary data analysis of the University of Washington Twin Registry (UWTR). Data was obtained from surveys completed since 2008 from approximately 2,244 same-sex twin pairs including data on physical activity levels, eating habits, sleep, health conditions, and mental health. Details of the construction of the UWTR have been published elsewhere (28, 29). Briefly, twin pairs in the state of Washington are identified by the Department of Licensing (DOL). The DOL uses a formula to create license numbers using a person’s last name, first and middle initials, and date of birth. This means that twins could get the same license number, and thus everyone who applies for a new or renewed license is asked if he or she is a member of a twin pair. The Washington DOL then relays the twin’s contact info to the UWTR, and an invitation to participate in the survey is mailed. If the individual is interested and completes the survey, an invitation is extended to the other twin. Both monozygotic (MZ, identical) and dizygotic (DZ, fraternal) twin pairs were included in the data, and all participants are age 18 or older. Informed consent was obtained on the survey instrument as approved by the UW Institutional Review Board.

Measures

Zygosity was determined using standard questions on childhood similarity that correctly assign zygosity about 95% of the time (30, 31). Twins of indeterminate zygosity were excluded from analysis (2%).

Height and weight were converted to body mass index (BMI, kg/m^2). The survey asks respondents how many times per week they exercise moderately for at least 30 minutes and vigorously for at least 20 minutes. We constructed a total physical activity measure by multiplying the reported number of moderate days by 30 and vigorous days by 20 and summing them together to estimate the total minutes per week of moderate-to-vigorous physical activity (MVPA). The survey also asks for information on the number of days per week the respondent walked for recreational or other purposes in the home neighborhood, and how many minutes they spent walking each time they walked for recreational or other purposes in the home neighborhood. Finally, data on the number of days per week subjects used transit services was also collected.

Participants' addresses were geocoded and matched to that area's measured NDVI, a measure of the density of live green vegetation in a pre-defined area, used as a measure of "green space" access in the neighborhood (32). NDVI is measured via satellite and ranges from -1.0 to +1.0. Very low values of NDVI (0.1 and below) correspond to barren areas of rock, sand, or snow. Moderate values represent shrub and grassland (0.2 to 0.3), while high values indicate temperate and tropical rainforests (0.6 to 0.8) (33). Demographic information collected in the survey and used in this analysis includes age, income, education, and race.

Data Analysis

Descriptive statistics were provided in terms of means and standard deviations (s.d.) or percentages where appropriate. Regression analyses followed the methods described by Carlin et al. (34) using both twin pairs overall and twin-pair difference values on the relationships between NDVI and the two activity related outcomes. Data was first analyzed in long format to determine the association between NDVI and physical activity outcomes by treating twins as unrelated individuals and ignoring the paired nature of the data. The data were then converted to wide format and twin-pair difference values computed for NDVI, physical activity outcomes, and demographic variables. Twin-pair difference values were calculated as twin 1 value-twin 2 value, so some difference values are negative and some are positive. We first examined regression coefficients from unadjusted models. Next, we calculated two adjusted models, testing for the association between NDVI and physical activity outcomes (total walking and total MVPA) adjusting for demographic factors and then additionally for transit use. Associations were established using the Wald test to determine whether the regression coefficient is equal to zero at the 0.05 alpha level. All analyses were conducted using Stata12.

Results

Select sociodemographic and activity data of the study sample is shown in Table 1, stratified by green space density. The mean NDVI level was 0.568, indicating a moderate to high vegetation density. There were no significant differences between the high (N = 2,455) and low (N = 2,033) NDVI groups in any of the measured characteristics.

Results of the GEE regression models are shown in Table 2. There was a significant association between NDVI and both total walking levels in the neighborhood and total MVPA in all unadjusted and adjusted models (all $p < 0.001$). The magnitude of the association between NDVI and each physical activity outcome was attenuated, but still significant, in the models adjusted for income, age, and education with no further change when additionally adjusting for transit use (all $p < 0.001$).

Results of the twin-pair difference models are shown in Table 3. There were no significant associations between NDVI and each of the activity outcomes in these models (all $p > 0.05$). The results were unchanged when stratified by zygosity (Table 4). Although the overall twin difference effect was not significant (see Table 3), results stratified by zygosity are still presented for context.

Discussion

The results of the present study indicate that increasing NDVI is associated with both greater total walking levels in the home neighborhood and total levels of MVPA across the twin population examined without specifically using information on twin's shared characteristics (i.e., in the GEE models in which twins were treated as individuals). As shown in Table 2, in the unadjusted GEE models, a 0.1 unit increase in NDVI was associated with an increase of about 14 minutes of walking and 19 minutes of MVPA per week. A 0.1 unit increase in NDVI would translate to a slightly greener area, either in terms of grass, trees, shrubs, etc. This suggests that across twins and without consideration for age, income, education, or public transit use, there is a large increase in overall physical activity levels as green space around the home is increased. However, when idemographic factors are taken into consideration, the average relationship changes considerably. Inclusion of these variables resulted in a decrease of the coefficient from 14 to 6 minutes of walking and 19 to 9 minutes of MVPA per week for each 0.1 unit increase in NDVI. Thus, although the average relationship across twins between activity and NDVI remained significant, the magnitude of the association decreased considerably, suggesting that demographic factors play an important role in the activity-NDVI relationship. Similar findings have been reported in other studies examining factors, including NDVI, that influence physical activity levels (6, 35, 36). Additional adjustment for transit use as a control variable did not change the association between walking or MVPA and NDVI in any meaningful way. This suggests that public transit use does not have an effect on overall activity levels as a function of NDVI over and above demographic factors, although several studies have reported that it does have a significant impact on activity levels on their own (37-39).

The results from the GEE models are similar to those found in other studies in the literature that have found an association between green space and physical activity (11, 14-16). For example, Mytton and colleagues reported that individuals living in the greenest quintile of the whole of England were 1.27 times more likely to achieve the recommended amount of physical activity than those living in the least green quintile (14). Similarly, Coutts et al. suggested that the gross amount of green space within a county and the amount of green space within a certain distance of the home was positively associated with increased

MVPA (15). However, these studies examined the activity-NDVI relationship in unrelated individuals and thus did not consider the impact of genetic and shared environmental factors on this relationship. As discussed next, the use of twin-pairs in our study controls for these potential confounders, and the inclusion of these factors resulted in the elimination of the associations observed across twins.

The association of total walking within the home neighborhood and total MVPA with NDVI after removing shared factors that are constant between twins in the within-pair effects analyses was not significant (see Table 3). In addition, there was no change in the regression coefficients when adjusted for income, and education, and further for transit use, in the various models, which suggests that these factors were not confounding the activity-NDVI relationship in the twin-difference model beyond genetic and shared environmental factors, although they did confound this relationship in the GEE models. This can be explained by the fact that both income and education are highly heritable traits and were probably already well accounted for in the twin-difference model (40). We stratified the results by twin zygosity to determine whether there were any trends present by twin type, but found no substantial changes in the magnitude or direction of the association between NDVI and physical activity levels in either MZ or DZ pairs.

A study by de Vilhena e Santos et al. demonstrated that physical activity levels were more highly correlated within MZ twin pairs than DZ twin pairs, suggesting that physical activity is a highly heritable trait and thus important to consider (41). Residential selection may be a partly heritable trait as well (23-25), thus having implications for NDVI levels in the neighborhood around the twins' home. Because both physical activity level and residential selection have a heritable component, it is possible that the results of the studies noted previously that found an association between physical activity and green space were merely confounded by genetic and shared environmental factors. Indeed, results from our within-pair effects models support this suggestion.

Strengths and limitations. An important strength of this study was the use of adult twin pairs, which allowed us to control for important genetic and shared environmental factors such as shared childhood experiences and familial influences that contribute to both physical activity level and residential selection. Another strength of the study was the inclusion of transit use as an additional control in the analysis, which allowed us to eliminate walking to and from public transit as a significant source of non-leisure time physical activity, which is a voluntary form of activity whereas walking to transit use may be activity out of necessity to get to and from work or other important destinations. There are also several limitations to this study worth noting. Physical activity was self-reported and thus subject to recall and measurement bias. In addition, the use of NDVI as a measure of green space is purely objective, and does not take into account how subjects perceive the space around their residential neighborhood. For example, a study by Tilt et al found different levels of association between physical activity and objective versus subjective greenness, which implies that subjective views on the accessibility of the neighborhood space may be an important determinate of whether that space is used for physical activity (43). Another limitation of the present study is that measures of greenness were only taken around the home and not in other areas where the subject may spend time being physically active, such as work or school. Finally, the UW Twin Registry is not representative of the population as a whole, and is largely made up of white people with higher education and income levels than average, although it is largely reflective of the demographic characteristics of Washington State residents.

Conclusions and Implications. The findings of this study demonstrate that exposure to higher levels of objectively measured green space does have a significant impact on walking and MVPA levels, but that this relationship is confounded by genetic and shared environmental factors that influence tendencies to be active or to select into environments that have greater green space. Alternatively, it is possible that subjective green space availability is a stronger influence on activity levels than is objectively measured green space. Future research should aim to elucidate if subjective measures of green space are associated with physical activity levels, and to measure green space not only in the home neighborhood, but around other areas subjects frequent, such as work and school. One caveat of any potential research is that it must include some level of control over genetic and shared environmental factors, as the results from the present study clearly show that these are major confounds in the green space-activity relationship.

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Table 1. Select sociodemographic characteristics and activity levels of twins, University of Washington Twin Registry, 2008-pres, according to level of green space* of current residence.		
	NDVI < .568	**NDVI > .568**
Age (yrs)	38.5 +/-16.4	38.6 +/-16.9
Physical Activity (min/week)		
Total MVPA	115.2 +/- 90.8	115.6 +/- 90.1
Total Walking**	91.6 +/-105.4	85.1 +/- 100.6
Zygosity (%)		
Monozygotic	28.2	27.4
Dizygotic	71.8	69.3
Transit Commuters (%)		
Yes	17.1	12.0
No	82.9	88.0
Income (%)		
< $50,000	38.5	48.1
≥ $50,000	61.5	51.9
Race (%)		
Non-White	10.9	8.2
White	89.1	91.6
Education (%)		
Less than High School	15.0	20.3
High School grad/GED	26.0	29.5
At Least Some college	59.0	50.2

Abbreviation is: MVPA, Moderate-vigorous physical activity

*Green space was measured using the normalized difference vegetation index (NDVI), a method of measurement via satellite that can assess the density of live green vegetation in the target area. Groups were defined using the mean value for the entire sample.

**Walking frequency and duration was measured as within the home neighborhood.

Table 2. Associations between physical activity levels and access to green space in the home environment among all twins, University of Washington Twin Registry, 2008-pres.						
	Model 1: Unadjusted		Model 2: Adjusted for income, age and education		Model 3: Adjusted for income, age, education, and transit use	
	Coefficient	95% Confidence Interval	Coefficient	95% Confidence Interval	Coefficient	95% Confidence Interval
Walking**	142.1*	136.7 - 147.5	34.7*	19.9 – 49.7	31.3*	16.6 – 46.0
MVPA	189.7*	184.8 - 194.6	101.0*	87.8 – 114.3	99.2*	85.9 – 112.5

Abbreviation: MVPA, moderate-vigorous physical activity

*Indicates a p-value < 0.001.

**Walking frequency and duration was measured as within the home neighborhood.

Table 3. Associations between physical activity levels and access to green space in the home environment among twin-pairs, University of Washington Twin Registry, 2008-pres.

	Model 1: Unadjusted		Model 2: Adjusted for income and education		Model 3: Adjusted for income, education, and transit use	
	Coefficient	95% Confidence Interval	Coefficient	95% Confidence Interval	Coefficient	95% Confidence Interval
Walking*	-15.5	-47.9 - 16.9	-13.0	-46.4 - 20.4	-14.3	-47.7 - 19.1
MVPA	12.7	-14.2 - 39.6	18.0	-9.79 - 45.8	17.8	-10.3 - 45.9

Abbreviation: MVPA, moderate-vigorous physical activity

*Walking frequency and duration was measured as within the home neighborhood.

Table 4. Associations between physical activity levels and access to green space in the home environment between twin-pairs, stratified by zygosity, University of Washington Twin Registry, 2008-pres.

		Model 1: Unadjusted		Model 2: Adjusted for income and education		Model 3: Adjusted for income, education, and transit use	
		Coefficient	95% Confidence Interval	Coefficient	95% Confidence Interval	Coefficient	95% Confidence Interval
MZ	Walking*	-28.0	-93.9 – 37.9	-31.3	-100.3 - 37.6	-27.0	-95.8 - 41.8
	MVPA	16.3	-37.5 – 70.1	17.2	-38.3 - 72.8	16.1	-39.7 - 72.0
DZ	Walking*	-24.1	-62.0 – 13.8	-15.9	-54.6 - 22.8	-19.1	-57.8 - 19.7
	MVPA	13.1	-18.8 – 45.0	19.9	-13.1 - 52.9	18.2	-15.1 - 51.6

Abbreviations are: DZ, dizygotic twin pairs; MZ, monozygotic twin pairs; MVPA, moderate-vigorous physical activity

*Walking frequency and duration was measured as within the home neighborhood.