



Quasi-causal associations of physical activity and neighborhood walkability with body mass index: A twin study



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ABSTRACT

Objective. Physical activity, neighborhood walkability, and body mass index (BMI, kg/m²) associations were tested using quasi-experimental twin methods. We hypothesized that physical activity and walkability were independently associated with BMI within twin pairs, controlling for genetic and environmental background shared between them.

Methods. Data were from 6376 (64% female; 58% identical) same-sex pairs, University of Washington Twin Registry, 2008–2013. Neighborhood walking, moderate-to-vigorous physical activity (MVPA), and BMI were self-reported. Residential address was used to calculate walkability. Phenotypic (non-genetically informed) and biometric (genetically informed) regression was employed, controlling for age, sex, and race.

Results. Walking and MVPA were associated with BMI in phenotypic analyses; associations were attenuated but significant in biometric analyses ($P_s < 0.05$). Walkability was not associated with BMI, however, was associated with walking (but not MVPA) in both phenotypic and biometric analyses ($P_s < 0.05$), with no attenuation accounting for shared genetic and environmental background.

Conclusions. The association between activity and BMI is largely due to shared genetic and environmental factors, but a significant causal relationship remains accounting for shared background. Although walkability is not associated with BMI, it is associated with neighborhood walking (but not MVPA) accounting for shared background, suggesting a causal relationship between them.

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Introduction

Obesity is a major public health problem in the U.S.; prevalence rates have more than doubled over the past decades (Flegal et al., 2002, 2010; Hedley et al., 2004; Ogden et al., 2006, 2014). Obesity is associated with several adverse and costly health conditions (American Diabetes Association, 2008; Anderson et al., 2005; National Institutes of Health, 1998; Flegal et al., 2005; Pronk et al., 1999; Wang et al., 2011). Effects of lifestyle behaviors such as diet and physical activity on health outcomes such as body mass index (BMI) are of primary interest because they are modifiable factors amenable to intervention.

A narrow focus on the effects of a behavior such as physical activity on BMI is shortsighted, however, because obesity is multifactorial and influenced by many interacting variables spanning biology to policy (National Heart Lung and Blood Institute, 2004). For example, most

studies indicate moderate to strong genetic effects on BMI (Elks et al., 2012). The relative contributions of genetic and non-genetic influences on activity are controversial, however, with several European studies indicating moderate to strong genetic effects on physical activity participation (Carlsson et al., 2006; Eriksson et al., 2006; Joosen et al., 2005; Lauderdale et al., 1997; Maia et al., 2002; Perusse et al., 1989; Simonen et al., 2002; Stubbe et al., 2006). Environmental differences across the countries in which these studies were conducted could influence activity behaviors and limit the generalizability of findings, as demonstrated in a U.S. twin study in which unique environmental, and not genetic, factors primarily explained differences in physical activity participation (Duncan et al., 2008).

The role of the physical or built environment in supporting healthy lifestyles and subsequent effects on health outcomes has gained increased attention over the last decade. Consistent associations have been reported between built environmental features such as neighborhood “walkability” and activity outcomes, including more leisure-time and transportation-related walking (Ewing et al., 2003; Frank et al., 2004, 2005, 2006, 2007; Moudon et al., 2006, 2007; Saelens et al., 2003). Neighborhood walkability itself has been associated with better health outcomes, including lower BMIs among residents (Black and

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Macinko, 2008; Diez Roux et al., 2002; Ewing et al., 2003; Frank et al., 2004, 2006; Papas et al., 2007). Neighborhood walkability is thought to exert its effects on health primarily by facilitating or inhibiting behaviors, such as physical activity and diet, which in turn strongly influence BMI (Papas et al., 2007). Others have suggested a broader view in which the physical and social environment affect the overall health and well-being of residents (Black and Macinko, 2008; CDC, 2007). For example, physical and/or social factors in the environment that contribute to stress, malnutrition, and inactivity could influence the risk of adverse health in the next generation through factors that act in utero and early life (Novak et al., 2006; Reynolds et al., 2013). Thus, neighborhood walkability could also influence genetic tendencies toward higher BMI. Regardless of the pathway linking neighborhood walkability to health, this ever-growing body of literature is dominated by observational studies with inherent methodological problems, chiefly an inability to adequately account for nonrandom selection of residents into neighborhoods (Oakes, 2004, 2006). Twins are an optimal way to address this self-selection problem (Duncan et al., 2014; Turkheimer and Harden, 2014).

Although significant associations among activity level, neighborhood walkability, and BMI are common, in the absence of random assignment to environmental conditions such relationships do not imply causality. There are two major unmeasured confounds in the observed relationship between BMI and activity level. The first is broadly characterized as genetic: if persons with certain genetic characteristics are more likely to engage in regular exercise, and the same genes contributing to activity also contribute to BMI, a correlation will exist regardless of any causal relationship. A second confound is environmental. If people raised in affluent families living in supportive environments are more likely to be both active and have a lower BMI, then any correlation between activity and BMI could be mediated by family income or residential location rather than result from a direct causal relationship.

The co-twin control design helps address the aforementioned limitations by providing a quasi-experimental method of accounting for genetic and environmental selection processes that might otherwise confound purported causal relations among uncontrolled variables (Turkheimer and Harden, 2014). Thus, despite evidence that neighborhood walkability may protect against high BMI between families, no study to date has investigated whether this effect remains significant within families. Therefore, the purpose of the current study was to use quasi-experimental twin methods to test associations between physical activity level and neighborhood walkability (an index of activity-supportive environments) (Frank et al., 2005, 2006, 2007; Frumkin et al., 2004; Moudon et al., 2006) with BMI in twins. We hypothesized that activity levels and walkability would each be independently associated with BMI within twin pairs, controlling for common genetic and environmental background shared between predictors and outcome.

Materials and methods

Participants

The University of Washington Twin Registry (UWTR) is a community-based sample of twins reared together; construction methods appear elsewhere (Afari et al., 2006; Strachan et al., 2013). Briefly, twins completed a survey with items on socio-demographics, health, and lifestyle behaviors. Standard questions about childhood similarity that determine zygosity with greater than 90% accuracy when compared with DNA-based methods were used to classify twins as identical (monozygotic; MZ) or fraternal (dizygotic; DZ) (Eisen et al., 1989; Spitz et al., 1996; Torgersen, 1979). We used 2008–2013 survey data; residential addresses were not available prior to 2008. Written informed consent was obtained, approved by the University's institutional review board. The final sample included 4060 female (2802 MZ, 1258 DZ) and 2316 male (1585 MZ, 731 DZ) pairs. Overall, the sample was young (39.4 ± 17.6 years) and predominantly White (90.3%).

Measures

Outcome

The primary outcome was BMI (kg/m^2) from self-reported height and weight. In a separate study, self-reported BMI and directly measured BMI were highly correlated ($r = 0.98, p < 0.01$) among 200 UWTR twin pairs, indicating strong construct validity in our sample. There was a tendency for higher BMI individuals to under-report to a greater extent than lower BMI individuals ($r = -0.27, p < 0.01$), but this discrepancy was not correlated with activity level ($r = -0.01, p = 0.80$) or walkability ($r = -0.03, p = 0.59$).

Predictors

Twins reported the number of days per week they engaged in vigorous physical activity for at least 20 min and in a separate question moderate physical activity for at least 30 min. A continuous activity measure was constructed by summing moderate and vigorous days weighted by their respective durations (MVPA). This measure provides an estimate directly corresponding to activity levels recommended for health (Garber et al., 2011; U.S. Department of Health and Human Services, 1996). In a sub-sample of 104 twins who wore accelerometers and GPS devices over a 2-week period in an ongoing funded study, subjective MVPA correlated significantly with objectively measured MVPA ($r = 0.46, p < 0.01$). There was a tendency for more active individuals to under-report MVPA to a greater extent than less active individuals ($r = -0.71, p < 0.01$), but this discrepancy was not associated with BMI ($r = 0.13, p = 0.18$). Twins also reported how many days during a typical week they walked in their neighborhood and minutes per walking bout (Lee and Moudon, 2006; Moudon et al., 2006). Responses of less than 15 min were coded as 10 min, whereas responses of 90 or more were top coded as 90 min.

Neighborhood walkability was estimated using two methods: the commercially available Walk Score® (Walk Score, 2012) and an index commonly cited in the urban planning and health literature created using measures of urban form (Frank et al., 2005). Addresses were entered into the Walk Score® website, which uses data from business listings, road networks, schools, and public transit to map walking distance to amenities in nine different categories (e.g., schools, parks, restaurants) (Walk Score, 2011). The algorithm then uses distances, counts, and weights to create a continuous score normalized on a scale of 0–100, with 0 representing the least and 100 the most “walkable” neighborhoods (Walk Score, 2011). The utility of Walk Score® as a walkability index has been published (Carr et al., 2010, 2011). The “planner’s” walkability index uses measures of land-use mix, intersection density, and residential density within a 1-km network buffer around the residence. The z-score for each of these variables is calculated and entered into an equation (Frank et al., 2005), providing a continuous score ranging between -8.98 and 27.34 (higher is more walkable). In a sub-sample of 3162 UWTR twins, the two indices correlated strongly with each other ($r = 0.78, p = 0.01$).

Statistical analysis

All analyses were conducted using latent variable path analysis in Mplus (v. 7.0, Los Angeles, CA) (Muthen and Muthen, 2012) and maximum likelihood estimation. Analyses were conducted for same-sex pairs only and controlled for linear effects of age, sex, and race.

Univariate biometric decomposition

We used the classical twin model (ACE) to decompose variation in measures into three components: additive genetic (A), variance attributable to the additive effect of individual genes; shared environmental (C), variance attributable to environmental influences shared by twins raised in the same family; and non-shared environmental (E), variance attributable to environmental influences unique to the individual. This analysis lays the foundation for the more elaborate analyses that follow.

Biometric regression

The use of MZ and DZ twins in the regressions of BMI on walkability and activity level allows the separation of the phenotypic effect of the predictors from the genetic and shared environmental background that they may share. The regression of BMI on activity level, for example, has three components: the phenotypic regression of the outcome on the predictor, plus A and C regressions that provide alternative explanations of the predictor–outcome association. The A regression represents the tendency for pairs with high genetic loadings for activity to also have genetic loadings for BMI. Descriptively, an A regression of BMI on activity induces a covariance between the activity level of one member of a pair and the BMI of the other, more so for the MZ twins who share 100% of

their genetic material than DZ twins who on average share half. The C regression represents the tendency for pairs to share a family environment conducive to both high activity and lower BMI. Descriptively, a C regression induces a covariance between the activity level of one twin and the BMI of the other, equally so for both MZ and DZ twins. With these pathways accounted for, the phenotypic regression represents the non-shared environmental effect of activity within pairs of twins. Descriptively, this means that a member of an identical twin pair with a higher activity level than the co-twin is also the twin with the lower BMI within the pair. The genetically informed phenotypic regression is the effect of the predictor on the outcome controlling for any common genetic or environmental background they share, and is therefore the best available approximation of any causal effect of the predictor (“quasi-causal” effect) (Turkheimer and Harden, 2014).

Results

Descriptive information for BMI and the predictors are shown in Table 1. Results were similar regardless of walkability index used; we present results using the Walk Score® derived index for simplicity. Walkability contained modest genetic and shared environmental variation, however, non-shared environment dominated (57%). Both MVPA and walking showed moderate heritability, almost no shared environmental variation, and large non-shared environmental variation (67% and 72%, respectively). In contrast, BMI consisted largely of additive genetic variation (76%), with no evidence of variation from the shared environment and modest contribution from the non-shared environment.

Next, we fit multivariate models in which activity level was regressed on walkability, and BMI was simultaneously regressed on walkability and activity. Unstandardized regression coefficients and standard errors for these non-genetically informed analyses are presented in the *phenotypic regression* columns of Table 2.

Walkability was not associated with MVPA ($b_{phen} = 0.01, p = 0.12$) or BMI ($b_{phen} = -0.02, p = 0.32$). Higher MVPA, however, predicted lower BMI such that each additional hour per week was associated with a 0.39 kg/m² decrease in BMI. Walkability and MVPA jointly predicted 1.2% of the variance in BMI. Walkability and walking were positively associated; each additional unit in walkability was associated with a 2.4-minute increase in walking. As we observed in models using MVPA as the indicator for physical activity, walkability did not predict BMI ($b_{phen} = -0.01, p = 0.55$). More walking predicted lower BMI; each additional hour of walking was associated with a 0.22 kg/m² decrease in BMI. Walkability and walking jointly predicted 0.5% of the variance in BMI.

We then decomposed nonzero phenotypic regression coefficients into their ACE components. The model is illustrated in Fig. 1; unstandardized regression coefficients and standard errors for these genetically informed analyses are presented in the *quasi-causal regression* columns in Table 2. Controlling for genetic-based selection, the inverse association between MVPA on BMI remained statistically significant, although the

association was reduced in magnitude (-0.26 vs. -0.39 for quasi-causal and phenotypic regressions, respectively). The A regression of BMI on MVPA was significant and substantially larger than the genetically informed b_{phen} ($b_A = -0.92$ vs. -0.26).

The regression of walking on walkability remained significant after accounting for genetic and shared environment and was not attenuated compared with the phenotypic regression. The walking–BMI association also remained significant while controlling for common genetic background and showed evidence of genetic-based selection ($b_A = -0.91, p < 0.01$). The quasi-causal effect was substantially attenuated ($b_{phen} = -0.22$ and -0.12 in phenotypic and quasi-causal analyses, respectively).

Discussion

As expected, consistent with the literature, activity levels and BMI were significantly associated in the non-genetically informed analyses; each additional hour of MVPA was associated with a 0.39 unit reduction while each additional hour of neighborhood walking was associated with a 0.22 unit reduction in BMI. However, a novel finding from this study relates to the genetically informed twin analysis, which suggests that much of these phenotypic relationships were the result of a common genetic background, as evidenced by reductions in the magnitude of the phenotypic relationship after controlling for A confounds. Nonetheless, a significant and potentially causal relationship of both MVPA and neighborhood walking with BMI remained after the common background was accounted for.

Neighborhood walkability was not associated with BMI in phenotypic analysis. Although neighborhood walkability had little effect on mean level of MVPA, it was associated with more neighborhood walking. Extending the literature, we found that this association remained significant even after accounting for genetic and shared environmental confounds, suggesting that neighborhood walkability is in fact causally related to more neighborhood walking. Together, our findings provide evidence supporting the ecological framework whereby a measure of the built environment – neighborhood walkability – is *causally* associated with physical activity behavior, which is subsequently *causally* associated with BMI.

Twin models not only account for genetic effects, twins reared together are also matched for shared environmental background, including numerous childhood and adolescent exposures. The ability to control for these confounds is another strength of the twin model, and has implications for overcoming the bias resulting from neighborhood self-selection. Studies using a categorical description of urbanization in non-U.S. samples have documented the influence of shared environmental factors on residence (Whitfield et al., 2005; Willemssen et al., 2005), while other studies have revealed subtleties in the data. For example, a more recent report (Duncan et al., 2012) using a

Table 1
Descriptive statistics, twin intra-class correlations, and standardized variance components for walkability, physical activity, and body mass index, University of Washington Twin Registry, 2008–2013.

	Walkability	Moderate-to-vigorous physical activity (min/week)	Walking (min/week)	Body mass index (kg/m ²)
Descriptive statistics				
Mean (SD)	40.6 (28.1)	119.9 (92.2)	88.4 (101.1)	25.8 (5.5)
Sibling correlations				
MZ	0.43 (0.02)	0.34 (0.01)	0.29 (0.02)	0.76 (0.01)
DZ	0.34 (0.03)	0.17 (0.02)	0.13 (0.02)	0.38 (0.02)
ACE estimates				
h^2	0.18 (0.06)	0.31 (0.06)	0.28 (0.02)	0.76 (0.01)
c^2	0.25 (0.06)	0.02 (0.05)	0.00 (0.01)	0.00 (0.00)
e^2	0.57 (0.02)	0.67 (0.02)	0.72 (0.02)	0.24 (0.01)

Abbreviations: dizygotic, DZ; monozygotic, MZ.

ACE estimates: additive genetic (h), variance attributable to the additive effect of individual genes; shared environmental (c), variance attributable to environmental influences shared by twins raised in the same family; and non-shared environmental (e), variance attributable to environmental influences unique to the individual.

Data presented as means and standard deviations in parentheses.

Table 2

Trivariate models, body mass index predicted from environmental walkability and physical activity, University of Washington Twin Registry, 2008–2013.

Regression	Moderate-to-vigorous physical activity (min/week)		Walking (min/week)	
	Phenotypic regression (not genetically informed)	Quasi-causal regression (genetically informed)	Phenotypic regression (not genetically informed)	Quasi-causal regression (genetically informed)
Walkability → Activity				
b_A	–	–	–	0.09 (0.16)
b_C	–	–	–	–0.06 (0.09)
b_{phen}	0.01 (0.01)	0.01 (0.01)	0.04 (0.01)*	0.04 (0.01)*
Walkability → BMI				
b_A	–	–	–	–
b_{phen}	–0.02 (0.02)	–0.02 (0.02)	–0.01 (0.02)	–0.02 (0.02)
Activity → BMI				
b_A	–	–0.92 (0.20)*	–	–0.91 (0.17)*
b_{phen}	–0.39 (0.03)*	–0.26 (0.03)*	–0.22 (0.03)*	–0.12 (0.03)*

Abbreviation: body mass index, BMI (kg/m²).

The models represent the phenotypic regression of the outcome on the predictor (b_{phen}), plus A (b_A) and C (b_C) regressions that provide alternative explanations of the association between the predictor and the outcome.

Data presented as regression coefficients with standard errors in parentheses.

* Statistically significant ($p < 0.05$) regression coefficient.

continuous walkability index employing specific information about neighborhood urban form (Frank et al., 2005) observed that shared environmental factors were the largest contributor to residential selection among younger twins (ages 18–24.9) whereas unique environment was largest in older twins (ages 25+). Although differences among these studies underline the complexity of residential selection, it is clear that choice of residence should not be considered a random environmental exposure. Both genetic and shared environmental selection processes are determinants of residential selection and must be taken into account in any non-experimental study of environmental risk factors. Although some artifacts of self-selection will exist in any study of the relationship between environment and behavior, using twins in this type of investigation controls for as many potential confounds as possible.

Strengths and limitations

The sample, although representative of Washington State, was largely White and middle class; thus, results are not necessarily generalizable to other geographic or socio-demographic groups. Both activity and BMI were self-reported and may suffer from measurement bias. Additionally, the physical activity measure did not capture details on activity type (e.g., running, swimming, etc.) or domains of activity (e.g., household, occupational, transportation, etc.), or durations greater than 20 min for vigorous and 30 min for moderate activity. However, any potential underestimation of activity would lead to an underestimation of the “true” association between physical activity and BMI; thus, the magnitude of association found between MVPA/walking and BMI in the present study is a conservative estimate. In addition, the

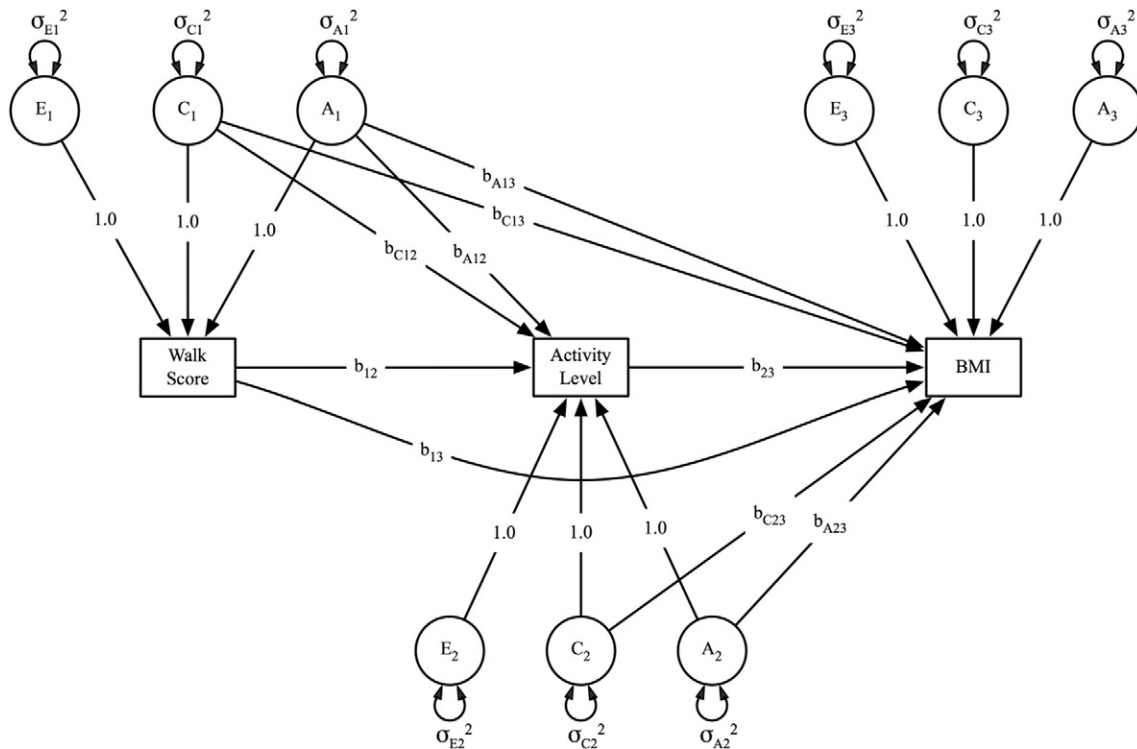


Fig. 1. Path diagram of the multivariate twin model. Activity level is regressed on walkability (Walk Score®) via a phenotypic pathway (b_{12}) in addition to genetic and shared environmental pathways (b_{A12} and b_{C12}). Body mass index (BMI) is regressed on Walk Score and activity level via phenotypic pathways (b_{13} and b_{23} , respectively), in addition to genetic (b_{A13} and b_{A23}) and shared environmental (b_{C13} and b_{C23}).

survey did not assess usual dietary intake, an unaddressed potential confounder. The use of the commercially available Walk Score® algorithm for estimating walkability is also a limitation because the measure is primarily an index of utilitarian destinations accessible by walking, and to a lesser extent neighborhood density, and not other specific measures of urban form that have been correlated with physical activity in the literature. Given this potential limitation, we conducted analyses using two measures of walkability and results were consistent regardless of exposure used.

Finally, although we have used the twin method to control for genetic and environmental confounds of possible causal predictors of BMI, even these methods have residual confounding and are not as robust as random assignment in establishing causal relations. Because the data utilized here were strictly cross-sectional, we are unable to rule out the possibility of reverse causality – i.e., that differences in BMI cause differences in activity or residential selection. Data collection in the UWTR is ongoing, and longitudinal designs are planned.

Conclusions

Using a multivariate twin model, we demonstrated how twins can be used to compute quasi-experimental estimates of causal relations between uncontrolled factors, such as neighborhood walkability and physical activity, and health outcomes, such as BMI. The results suggest that much of the phenotypic relationship between physical activity (both MVPA and neighborhood walking) and BMI is the result of a common genetic background, but a significant and potentially causal relationship remains after this common background is accounted for. We also observed a tendency for walkability to promote walking (but not MVPA) above and beyond any genetic or shared environmental confounds.

Conflict of interest

The authors declare that there are no conflicts of interests.

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