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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/m^2) 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 ($Ps < 0.05$). Walkability was not associated with BMI, however, was associated with walking (but not MVPA) in both phenotypic and biometric analyses ($Ps < 0.05$), 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.

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