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Genetic and environmental influences on residential location in the U.S

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Abstract

We used a classical twin design and measures of neighborhood walkability and social deprivation, using each twin's street address, to examine genetic and environmental influences on the residential location of 1,389 same-sex pairs from a U.S. community-based twin registry. Within-pair correlations and structural equation models estimated these influences on walkability among younger (ages 18–24.9) and older (ages 25+) twins. Adjusting for social deprivation, walkability of residential location was primarily influenced by common environment with lesser contributions of unique environment and genetic factors among younger twins, while unique environment most strongly influenced walkability, with small genetic and common environment effects, among older twins. Thus, minimal variance in walkability was explained by shared genetic effects in younger and older twins, and confirms the importance of environmental factors in walkability of residential locations.

Keywords

Environment; Genetics; Neighborhood; Twins; Walkability

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Introduction

The role of the physical or built environment in supporting healthy lifestyles has gained increased attention over the last decade. However, causal conclusions about the effects of the built environment on health are tenuous because the allocation of people into residential locations is neither random nor simply based on individual choices. People are born into certain environments with certain genetic predispositions that may be associated with important health outcomes. In other words, residential selection and health may exhibit some familial transmission. Moreover, irrespective of shared environment and genes, not everyone can live in the environment or “neighborhood” they prefer based on their own experiences and expectations. The differential allocation of people to locations due to social forces and other selection processes (i.e., social and economic stratification) is addressed in statistical models by adjusting for individual characteristics such as age, sex, race, income, education, and, more recently, housing and land use preferences (Frank et al., 2007; Handy et al., 2006). Even so, the problems of structural and possible familial confounding still exist (Messer, 2007; Oakes, 2004, 2006; Oakes and Church, 2007). Statistical models can adjust for known correlates, but omit important factors that are difficult or impossible to measure or unrecognized.

Twin studies provide one method to examine the host of factors that drive the selection of residential locations because the degree of similarity in the choices made within monozygotic (MZ) and dizygotic (DZ) pairs can be partitioned into genetic, as well as shared and non-shared environmental factors. For example, in one co-twin control study, MZ twins lived spatially closer to one another than DZ twins (Neyer, 2002) suggesting that choice of residential location may be partially heritable. Similarly, at least two classical twin studies have investigated genetic and environmental influences on residential location selection. This design typically requires the use of population-based twin registries that compare a phenotype of interest in MZ and DZ pairs. The Australian Twin Registry found strong effects for both genetic and shared environmental factors on residential location, measured as the distance from major urban centers, with heritability influenced by both the sex and age of the twins (Whitfield et al., 2005). As shared environmental effects decreased with age, additive genetic factors increased. In contrast, the Netherlands Twin Register observed both common and unique environmental factors determined residential location of Dutch twins, suggesting differences in choice of residential location by urbanization level were not genetic in origin (Willemsen et al., 2005). Despite their differences, age and geography appear to influence genetic and environmental factors on selection into residential locations.

Notably, the Australian and Dutch studies defined residential location using a categorical description of the urbanization level. One measure that may have implications for public health is an indicator of environmental walkability (Frank et al., 2005). Highly walkable environments can exist across the spectrum of urbanization. Walkability indices are continuous measures that capture how walkable a location is independent of urbanization, applicable in cities, suburbs, and even rural areas. We, therefore, conducted a classical twin study of the genetic and non-genetic environmental factors influencing residential location using a walkability index in a community-based U.S. twin registry. The aims of our study were to: 1) estimate the contribution of common and unique environmental factors to walkability; 2) determine if the common and unique environmental influences on walkability vary by age; and, 3) determine if common and unique environmental influences on walkability are independent of neighborhood socioeconomic status.

Methods

Participants and setting

The study sample consisted of 1,389 same-sex twin pairs from the University of Washington Twin Registry (UWTR). The UWTR is a community-based sample of adult twin pairs assembled from Washington State Department of Licensing records. Details of the construction and characteristics of the Registry are described elsewhere (Afari et al., 2006). Briefly, in Washington State, all new driver license applicants and identification card applicants are asked if they are a member of a twin. Since 1999, data on all twin applicants have been transmitted to the UWTR from the Department of Licensing. Twins were mailed a brief survey that included items on zygosity, socio-demographics, height and weight, general health and common medical conditions, and lifestyle behaviors. We only used data from twins who lived in Washington State and for whom had residential street addresses from surveys completed between 2006 the present. A waiver of written consent was approved for the initial survey by the university's institutional review board.

Measures

Demographic information used in the analysis consisted of age, sex, zygosity, race (dichotomized as white/non-white), education (categorized into less than high school, high school graduate, or at least some college), and marital status (categorized into single, married, widowed/divorced/separated, or living with someone). Zygosity was determined using standard questions on childhood similarity that are highly accurate (Eisen et al., 1989; Torgersen, 1979). We constructed a neighborhood walkability index that is commonly cited in the physical activity and built environment literature (Frank et al., 2005). The index combines measures of land use mix, residential density, and street connectivity taken within a 1-km distance from a location of interest—in this case, the participants' home. Participants' home addresses were geocoded with a minimum match score of 100%. Addresses that failed automatic geocoding were reviewed individually and matched manually. A 1-km buffer was delineated along the street network around each twin's residential location using ESRI StreetMap Premium (North America NAVTEQ 2009 Release 1, 2009). The neighborhood walkability index was calculated for each network buffer, and included measures of land use mix, as areas occupied by residential, commercial, or office land uses, obtained from the Washington State parcel database (the University of Washington Geographic Information Service, Parcels Working Group, 2009); residential density from the 2000 U.S. Census block groups; and intersection density. All spatial analyses were performed within ArcGIS 9.3.1 (ESRI, Redlands 2008). The final walkability index was derived from the z-score of each measure, and entered into the following equation: $(6 * \text{z-score of land use mix}) + (\text{z-score of net residential density}) + (\text{z-score of intersection density})$. The final output is a single continuous value representing the walkability for each participant, with higher values representing more walkable environments.

We also constructed a composite measure of the neighborhood socioeconomic status as described by Singh (Singh, 2003). This composite area-based deprivation index consists of 17 socioeconomic indicators that are related to the material and social conditions, and relative socioeconomic disadvantage, in a given community. The indicators comprising the index for our twins were calculated at the census tract level, using data from the 2000 Washington State Census and standardized to the means and standard deviations of all of the twins in the state. The range of the Singh index for Washington state is -2.9 to $+4.6$, representing the least to the most deprived areas.

Analyses

Descriptive statistics were calculated as means and standard deviations for continuous variables and percentages for categorical variables. Descriptive statistics were also calculated after stratifying the twins into a younger (ages 18–24) and older (ages 25+) group. Because the UWTR has a lower age limit of 18 and is relatively young, these categories were designed to separate twins who may still be living at their parental home or in transient housing such as a college dormitory or apartment, from twins who have left the household of origin. Independent samples *t*-tests and χ^2 tests assessed differences on continuous and categorical demographic characteristics, respectively.

We estimated the genetic and environmental influences on walkability in two ways. First, we calculated twin correlations with 95% confidence intervals for the walkability score stratified by zygosity. Comparing the within-pair twin correlations provides an initial indication of the genetic and environmental influence on walkability. An MZ correlation that is larger than the DZ correlation suggests a genetic influence on walkability, and a correlation that is similar in MZ and DZ pairs indicates a role for common family environment. The absence of correlations in either MZ or DZ pairs suggests that the variation in walkability is due primarily to unique environmental influences.

To help put the within-pair correlations into perspective, we constructed a separate sample of “faux pairs” to estimate the correlation of walkability scores for two unrelated individuals to serve as a comparison. To construct this group, we randomly selected 400 individual twins from our sample. Then, we randomly selected another unrelated twin for each of the 400 twins originally selected matched to the reference twin on age within five years and sex. Thus, the faux pairs measured the correlation in walkability for two unrelated individuals of the same age and sex living in Washington state. For the descriptive and correlation analyses, $p < 0.05$ defined statistical significance.

To formally estimate genetic and environmental effects on walkability we used structural equation modeling (SEM). A model, fit to the raw data and stratified by age group, estimated the percentage of phenotypic variance due to additive genetic (A), common environmental (C), and unique environmental (E) components. The full ACE model, as well as reduced models (i.e., AE, CE, E), were fit to the data. The best-fitting model was determined by a likelihood ratio χ^2 test comparing the full ACE model to reduced models that did not include all A, C, and E effects (e.g., CE). A non-statistically significant χ^2 test between the full and reduced models indicates that the reduced model is a better, more parsimonious fit to the data. Akaike’s information criterion was used as a global measure of goodness of model fit, with lower values being an indication of a better-fitting model (Akaike, 1987). To determine if genetic and environmental influences on walkability were independent of neighborhood socioeconomic status, we refit our models after adjusting for Singh Index scores. All SEM analyses were conducted using the program MPlus.

Results

Complete physical street addresses were available and geocoded for 1,317 of 1,389 twin pairs. As shown in Table 1, the two groups differed significantly on all demographic characteristics examined (all $p < 0.05$). The older age group had a higher mean walkability index than their younger counterparts (0.44 versus -0.76 , $p < 0.05$). Mean walkability for all twins was -0.36 (range, -8.47 to 26.68), and the corresponding quartiles of walkability were -6.76 (25th percentile), -1.88 (50th percentile), and 4.00 (75th percentile), respectively. Thus, the mean walkability index of the older twins’ residences was in the third and younger twins in the first quartile of the walkability distribution.

Among all twins, strong correlations were found for walkability ($p < 0.05$), while within-pair correlations were stronger for MZs than DZs (Table 2). Within-pair correlations for older twins were attenuated substantially compared with younger twins, although all associations remained significant ($p < 0.05$). As expected the within-pair correlations for faux pairs were small and non-significant ($r = 0.03$, 95% CI = $-0.07 - 0.16$; $p = 0.57$).

In younger twins, the best-fitting, most parsimonious model for residential walkability index was the reduced CE model. In the older twins the model-fit differences between the reduced AE and CE models were trivial (i.e., did not provide a reliable means of choosing between them) as were the differences between those models and the full ACE model. Given that situation, the full ACE model likely provides the best description of the data (Table 3). In the younger age group (top panel), 65% of the phenotypic variance in walkability was accounted for by the common environment (C) and 35% by the unique environment (E) components, respectively. In contrast, among older pairs (bottom panel), the unique environment (E) component was dominant, explaining 62% of the total variance in walkability with smaller and equal (19%) contributions of additive genetic (A) and common environment (C) factors.

Table 4 displays the genetic analyses controlling for the Singh Index. In both age groups, the Singh Index was significantly associated with walkability, but it only accounted for a small portion (~10%) of the total variance. In both younger and older twins, the full ACE model was the best fit (for the older twins, we observed the same trivial differences between the reduced AE and CE models as were observed in the unadjusted models). In the adjusted models, the greatest proportion of variance was explained by the C component in the younger cohort (48%), and the E component in the older cohort (51%), with a relatively small additive genetic component in both age groups (13% and 20% in younger and older twins, respectively).

Discussion

In unadjusted models, our results demonstrate that common environment explains the greatest proportion of phenotypic variation in neighborhood walkability among younger twins, with no additive genetic and a small unique environmental influence. In contrast, among older twins, unique environmental influences dominate with smaller and equal contributions of additive genetic and common environmental factors. Our results also suggest that environmental factors are still strongly related to neighborhood walkability even after controlling for the level of neighborhood social deprivation, with a small contribution from additive genetics. In fact, among younger twins, the effect of additive genetics on residential selection appears non-significant until social deprivation is accounted for in the model. However, although the additive genetic effect is small and largely stable over time, the relative contribution of unique environmental experience to variability in residential selection increases dramatically over time compared to the common environment. Specifically, among younger twins, common environment is most important with a lesser contribution of unique environmental factors and a small contribution of additive genetics. Among older twins, walkability is more strongly influenced by environmental factors that are unique to individuals with a smaller effect of common environment and additive genetics.

The differential patterns of effects according to age are not entirely surprising. The younger cohort (18–24 years) represents the traditional college-age student in the U.S. Individuals in this age group usually gain greater independence from their parents upon graduation from high school, but have limited financial resources and are much less likely to have started a family. Thus, younger individuals still depend to some extent on the shared financial and

housing security provided by their parents. Twins at this age are also more likely to live together (compared to older twins) which could contribute to a greater shared environment component in residential selection models. However, we repeated our analyses excluding twins that shared the same address and obtained results consistent with those presented in Tables 3 and 4. This suggests that the stronger common environmental influence on neighborhood walkability among younger twins is not due merely to an abundance of twins living together. In contrast, individuals in the older group (over 25 years) have typically graduated from college and are beginning their careers and family. In this presumably more settled, older group, unique environment is more powerful, with only modest genetic and common environmental effect. Differences between age groups in key demographic variables support this notion; younger twins were much less likely to have graduated from college and much more likely to be single compared to older twins who were more likely to be married. In addition, younger twins more often lived together than their older counterparts, possibly explaining why the relative contribution of genetic and environmental factors was so highly dependent on age.

Although the higher within-pair correlations in MZ than DZ twins in both younger and older age groups suggest a genetic influence, the magnitude of this difference was not significant. The substantial attenuation of the correlations with age further supports a diminishing genetic influence. Interestingly, the within-pair correlations for walkability among faux pairs, who by definition were unrelated and thus shared no genetic and common environmental influence, was essentially zero and non-significant—even though the faux pairs could be living in different neighborhoods with the same environmental characteristics (i.e., unique environment). In other words, we tested these age and sex-matched faux pairs based on the possibility that age and sex-matched people, at least in Washington State, might systematically end up in similar neighborhoods for reasons entirely outside of familial confounding. However, because there was no correlation among the faux pairs we can assume that similarities in age and sex alone cannot explain the pattern of phenotypic variation in neighborhood walkability we found among younger and older twin pairs in the present study.

Our findings can be compared with those reported in the Netherlands Twin Study (Willemsen et al., 2005). The Netherlands study, which used an urbanization phenotype, found that a CE model fit their data best in both younger and older age groups. However, our results differ with respect to the magnitude of the shift in C and E components with age; C was twice as strong as E among younger twins, and E was twice as strong among older twins. In contrast, the shifts were much more subtle among both men and women over the three birth cohorts in the Netherlands sample. Interestingly, the full ACE model instead of the reduced CE model was the best fit among younger twins when we controlled for the Singh index, providing evidence for a small genetic component. This finding is similar to that observed in the youngest cohort of Australian twins (Whitfield et al., 2005) which characterized residential location using a measure of urbanization. The ACE model was still the best fit among older twins even after controlling for the Singh index, resulting in identical and equal contributions of additive genetic and common environmental influences on neighborhood walkability between the unadjusted and adjusted models. This highlights that walkability is not simply a surrogate for neighborhood material and social conditions and relative socioeconomic disadvantage but rather a unique phenotype.

This study adds to the existing literature in many respects. Similar to the Australian study, our twins resided across a large geographic area. Washington State covers over 71,000 square miles, and has a total population over 6.7 million concentrated in a few large and many small cities. Residential location categories used in previous studies defined locations as urban, suburban, and nonurban. We used an alternative measure of residential location

defined as neighborhood walkability, which characterizes the proximal environment, including its residential density and ease of access to local retail and businesses. Low walkability scores indicate that the person lives away from neighbors and from commercial activity, in an area that could be suburban, exurban or even rural, while high walkability scores apply to urban or suburban neighborhoods, or even small towns. In contrast, the Netherlands twin study drew from a sample of comparatively highly urbanized twins. Even the lowest of the five urbanization levels, which ranged from “very heavy” to “none”, likely would correspond to a suburban, but not exurban, location in Washington state or Australia.

Understanding the factors influencing why people live in different neighborhoods is a challenging task and, like others, our study has limitations. For example, our SEM models estimated genetic and environmental sources of variation in walkability but cannot elucidate mechanisms. Thus, determining the exact nature of the common and unique environmental contributions to walkability and evaluating how these factors may be amenable to intervention is difficult. Nonetheless, our results suggest that environmental factors underlie the walkability of residential location among twins living in the U.S. The relative contribution of common or familial and unique environmental factors to walkability depends on age, while shared genetic factors account for minimal variance in walkability regardless of age.

Implications of these findings extend beyond merely explaining proportions of variation in neighborhood walkability. For example, multiple surveys and market research reports indicate that many U.S. households want housing with improved accessibility, land-use mix, and diverse transportation options (Carnoske et al., 2010; Communications, 2004; Levine and Frank, 2007; Litman, 2009), all of which contribute to greater neighborhood walkability. In fact, the stock of such housing may be far short of demand (Communications, 2004; Levine and Frank, 2007; Litman, 2009), suggesting that governmental and political barriers to building such communities need to be overcome (Carnoske et al., 2010; Communications, 2004).

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Highlights

- Genetic and environmental influences on residential walkability of twins were examined.
- In twins 18–24.9 years, residential walkability was influenced by common environment factors.
- In twins 25+ years, residential walkability was influenced by unique environment factors.
- There was a small genetic effect on residential walkability in both age groups.
- These findings confirm the importance of environmental factors in residential walkability.

Table 1

Demographic characteristics of individual twins by younger (18 – 24 years) and older (25+ years) age groups.

Characteristic	All Twins (<i>n</i> = 2,634)	Younger Twins (<i>n</i> = 1,763)	Older Twins* (<i>n</i> = 871)
Age (years)	27.5 (14.3)	19.4 (1.3)	43.9 (14.5)
Sex (% Male)	39%	42%	34%
Zygosity (% Monozygotic)	56%	56%	57%
Race (% White)	85%	82%	92%
Education (%)			
Less than high school	10%	13%	6%
High school graduate	34%	44%	18%
Some college/college graduate	55%	43%	76%
Marital Status (%)			
Single	69%	93%	21%
Married	18%	2%	51%
Widowed/Divorced/Separated	7%	0.2%	20%
Living with someone	6%	5%	8%

* Twins less than 25 years of age differed significantly from twins 25 years of age and older with respect to all demographic characteristics examined ($p < 0.05$). Age presented as the mean (standard deviation) while all other variables presented as percentages.

Table 2

Correlations for neighborhood walkability among twin pairs by younger (18 – 24 years) and older (25+ years) age groups and zygosity.

Zygosity	Younger Twins (<i>n</i> = 878 pairs)	Older Twins (<i>n</i> = 432 pairs)
All	0.65 (0.61 – 0.69) *	0.34 (0.04 – 0.42) *
Monozygotic	0.68 (0.63 – 0.73) *	0.39 (0.28 – 0.49) *
Dizygotic	0.62 (0.55 – 0.68) *	0.28 (0.14 – 0.40) *

* Indicates significant Pearson's correlation ($p < .05$); coefficients presented with 95% confidence interval in parentheses.

Table 3
Estimated genetic and environmental parameters for neighborhood walkability by age group.

Model [‡]	Estimates of variance components [‡]			Test of model fit		
	Additive Genetics (A)	Common Environment (C)	Unique Environment (E)	ΔX^2	df	Δp
<i>Younger Twins (18 – 24 years)</i>						
ACE	0.12 (0.04, 0.26)	0.56 (0.47, 0.66)	0.32 (0.28, 0.36)	--	--	--
AE	0.70 (0.67, 0.73)	--	0.30 (0.27, 0.33)	53.23	1	< .001
CE		0.65 (0.62, 0.68)	0.35 (0.31, 0.38)	3.56	1	= .06
E	--	--	1.00	492.81	2	< .001
<i>Older Twins (25 – 87 years)</i>						
ACE	0.19 (0.01, 0.56)	0.19 (0.03, 0.50)	0.62 (0.54, 0.71)	--	--	--
AE	0.40 (0.33, 0.48)	--	0.60 (0.52, 0.68)	1.68	1	0.60
CE	--	0.34 (0.28, 0.42)	0.66 (0.59, 0.73)	1.32	1	0.25
E	--	--	1.00	55.38	2	< .001

[‡] Proportion of variance explained by additive genetics, common environment, and unique environment according to each model.

[‡] ACE refers to the model including additive genetics (A), common environment (C), and unique environment (E). AE includes only additive genetics and unique environment. CE common and unique environment, and E unique environment; reduced models are compared to ACE.

[§] Akaike's information criterion (AIC) is a global measure of goodness of model fit; best-fitting and most parsimonious models are shown in bold.

Estimated genetic and environmental parameters for neighborhood walkability by age group, controlling for social deprivation score.

Table 4

Model [‡]	Estimates of variance components [‡]			Test of model fit			
	Additive Genetics (A)	Common Environment (C)	Unique Environment (E)	b_{Singh}	ΔX^2	df	Δp $\Delta AIC^{\S}$
<i>Younger Twins (18 – 24 years)</i>							
ACE	0.13 (0.04, 0.26)	0.48 (0.39, 0.58)	0.31 (0.27, 0.35)	0.08 (0.10, 0.27)	--	--	--
AE	0.63 (0.59, 0.66)	--	0.29 (0.26, 0.32)	0.08 (0.10, 0.27)	44.19	1	<.001 42.19
CE	--	0.58 (0.55, 0.62)	0.34 (0.30, 0.37)	0.08 (0.10, 0.27)	4.15	1	= .04 2.15
E	--	--	0.90 (0.88, 0.93)	0.10 (0.07, 0.12)	451.05	2	<.001 447.05
<i>Older Twins (25 – 87 years)</i>							
ACE	0.20 (0.03, 0.50)	0.19 (0.04, 0.44)	0.51 (0.44, 0.59)	0.10 (0.08, 0.13)	--	--	--
AE	0.40 (0.34, 0.47)	--	0.50 (0.43, 0.57)	0.10 (0.08, 0.13)	2.07	1	0.15 0.07
CE	--	0.35 (0.28, 0.41)	0.55 (0.49, 0.59)	0.10 (0.08, 0.13)	2.00	1	0.16 0.001
E	--	--	0.91 (0.88, 0.94)	0.09 (0.06, 0.12)	69.21	2	<.001 65.21

[‡] Proportion of variance explained by additive genetics, common environment, and unique environment according to each model.

[‡] ACE refers to the model including additive genetics (A), common environment (C), and unique environment (E). AE includes only additive genetics and unique environment, CE common and unique environment, and E unique environment; reduced models are compared to ACE.

[§] Akaike's information criterion (AIC) is a global measure of goodness of model fit; best-fitting and most parsimonious models are shown in bold.