Neighborhood characteristics, social capital, and depression: a twin study

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Abstract

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INTRODUCTION: Depression is one of the leading contributors to the global burden of disease, and can have a debilitating effect on quality of life. While it is already well-accepted that individual-level factors can influence depression, there is growing recognition of the important role the social and built environment plays in exacerbating or alleviating mental health problems. Depression risk varies across neighborhoods, and differences in neighborhood context may impact depression through diverse pathways, including reduced social services and lack of infrastructure, fear of crime and victimization, and a break down of social trust and community participation. Social capital, a measure of the social environment that encompasses the emotional, economic, and informational resources available to an individual or a group through their social networks, has been hypothesized as a protective factor against depression. It has further been hypothesized as a potential explanatory factor for the association between neighborhood context and depression. There is, however, little consensus about which domains of social capital are most relevant to depression, and while much of the previous literature has shown how social capital differs across neighborhoods, relatively less research is devoted to understanding what causes this variation. Understanding how the neighborhood social and built environment influences depression risk can inform decisions about investing scarce resources in community-based mental health promotion, and may ultimately contribute to a reduction in the burden depression places on individuals and the healthcare

system. The goal of this dissertation was to explore pathways linking neighborhood characteristics, social capital, and depression. Although previous literature has evaluated these potential associations, inferences are limited due to concerns about unmeasured genetic and childhood environment confounding and self-selection into neighborhoods. This dissertation contributes to the literature by partially addressing these methodological concerns through the use of a twin study.

METHODS: This study uses data from the community-based University of Washington Twin Registry (UWTR). The UWTR contains over 8,000 monozygotic (identical, MZ) and dizygotic (fraternal, DZ) adult twins. It contains extensive survey data on sociodemographics, health behaviors and outcomes, and built environment measures linked to geocoded residential addresses. All twins included in the study were from same-sex pairs. Chapter One assesses the association between five neighborhood environment factors (neighborhood socioeconomic depression, crime, residential instability, gentrification, and income inequality) and depression. Chapter Two examines the association between different domains of social capital (cognitive and structural) and depression, and investigates whether social capital serves as a moderator or a mediator in the neighborhood socioeconomic deprivation-depression pathway. Chapter Three explores possible reasons for the variation of social capital across neighborhoods by assessing the associations between three built environment domains (neighborhood composition, pedestrian-oriented design, and commercial diversity) and social capital in the Puget Sound region of Washington State. All analyses employed a random intercept “within-between” twin model with the outcome hypothesized to follow a Poisson distribution. In this model, the individual-level outcome is regressed on the twin-pair mean exposure and the individual twin’s deviation from their twin pair mean. The within-pair effect is the main parameter of interest because it inherently controls for potential confounding due to genetic and childhood environment factors shared between twins within a pair.

RESULTS: In Chapter One, only neighborhood socioeconomic deprivation showed an association with depression in the unadjusted and adjusted models; specifically, higher deprivation was linked to greater depressive symptoms, independent of individual-level sociodemographic characteristics and population density. In Chapter Two, greater cognitive social capital, which refers to how individuals perceive their

environment and was measured by sense of belonging, neighborhood social cohesion, workplace connections, and trust, was associated with fewer depressive symptoms. In contrast, structural social capital, which refers to social actions and behaviors and was measured by community participation, volunteerism, and social interactions, was not significantly associated with depression. Further, no social capital measure served as a mediator or a moderator in the neighborhood socioeconomic deprivation-depression association. Finally, in Chapter Three, only property values were linked to any of the neighborhood social capital variables, and these results were mixed. In the unadjusted models, property values were associated with greater sense of belonging, neighborhood social cohesion, and perceived safety; however, the associations were no longer significant in the models adjusted for sociodemographic characteristics. Further, no measure of pedestrian-oriented design or commercial diversity was associated with social capital.

CONCLUSION: Overall, these results indicate that both neighborhood socioeconomic deprivation and cognitive social capital are important risk factors for depression, independent of individual-level sociodemographics characteristics. These two factors do not, however, contribute to depression risk through the same pathway, nor does social capital influence the neighborhood socioeconomic deprivation-depression association. Additionally, the study does not provide evidence that differences in characteristics of the built environment can explain differences in the distribution of depression across neighborhoods. This suggests that there is not a strong association between these measures of social capital and built environment, and that specific interventions targeting the built environment may not improve social capital directly. The finding that social capital and neighborhood socioeconomic deprivation do influence depression risk is of great importance; however, other pathways to improving social capital, and therefore depression, will need to be explored.

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Chapter One: Socioeconomic characteristics of the neighborhood and depression

ABSTRACT

Introduction: Depression is a leading contributor to the global burden of disease. While it is well accepted that individual-level factors influence depression risk, there is growing recognition that neighborhood environment also profoundly affects mental health. The goal of this study is to assess the associations between five neighborhood constructs – socioeconomic deprivation, crime, residential instability, gentrification, and income inequality – and depression within twin pairs.

Methods: To analyze the associations between the neighborhood constructs and depression, we used multilevel random-intercept Poisson regression among monozygotic (identical, MZ) and same-sex dizygotic (fraternal, DZ) twin pairs from the University of Washington Twin Registry. The within-pair effect in a twin model inherently controls for confounding by genetic and environmental factors shared between twins within a pair, and thus is the main parameter of interest in our analysis. Models were adjusted for individual-level income, education, and marital status, and neighborhood-level population density.

Results: When twins were treated as individuals and not members of a pair, all neighborhood constructs except crime were significantly associated with depression. However, only neighborhood socioeconomic deprivation and gentrification showed significant within-pair associations. A ten-unit difference in neighborhood socioeconomic deprivation, measured by the Singh Index, was associated with 6 percent greater depressive symptoms (1.06, 95% CI: 1.01, 1.11) in the unadjusted model; the association did not substantially change in any of the adjusted models. For gentrification, measured as change in housing value over a ten-year period, the within-pair inverse association was only significant among DZ twins in the unadjusted model; the association was nonsignificant in all adjusted DZ models and among MZ twins.

Conclusion: This study provides evidence linking neighborhood socioeconomic deprivation with greater depression. It further suggests a potential inverse association between gentrification and depression; however, these results are mixed and the association may be influenced by genetic factors. Associations

between crime, residential instability, and income inequality with depression were not statistically significant. Additional research is needed to understand the mechanisms linking neighborhood context to depression. To further strengthen causal inference, future studies should combine twin models with longitudinal designs.

INTRODUCTION

Depression is a considerable health burden for individuals and the population. Among adults in the United States, the prevalence of diagnosed depression is approximately 8%.[1] Furthermore, among adults 18-44 years of age, antidepressants are the most frequently prescribed drug, and outpatient visits for depressive disorders increased by 48 percent between 1995 and 2005.[1-4] Healthcare utilization and loss of productivity due to depression cost society up to $97 billion annually.[5] Worldwide, major depression is predicted to be among the top three contributors to the global burden of disease by 2020.[6]

It is well accepted that individual-level factors such as socioeconomic status and social isolation influence depressive symptoms by affecting behaviors, moods, and neuroendocrine stress responses, and by modifying gene expression through epigenetic processes.[7,8] In addition, there is growing evidence that neighborhood-level factors also contribute to poor mental health risk, independent of individual-level characteristics.[9]

The importance of the neighborhood was shown in a notable early study by Faris and Dunham, which linked neighborhood disorganization with mental health outcomes.[10] Although the definition of what constitutes "neighborhood disorganization" has evolved over time, and currently varies across studies, it generally refers to a breakdown in social ties and norms among neighborhood residents. It can result in a lack of trust and community participation, and undermines residents' ability to jointly address neighborhood concerns, identify and work towards common goals, and exert informal social control to prevent crime and incivilities.[11-13] This leads to chronic life stress,[14] which in turn decreases resiliency to negative life experiences and increases risk of depression.[15-17] Five neighborhood-level constructs that contribute to neighborhood disorganization and will be considered in this paper are socioeconomic deprivation,[18] crime,[19] residential instability,[20] gentrification,[21] and income inequality[22] (Figure 1.1).

Neighborhood socioeconomic deprivation can lead to negative perceptions of neighborhood quality and fear of crime and victimization, which prevents the creation of social ties and a sense of community.[11,18] Neighborhood deprivation can also affect mental health through the quality of neighborhood infrastructure and access to local amenities including parks and recreation facilities and healthcare services.[23-27]

High levels of crime can lead to feelings of powerlessness, and negatively influence social cohesion

and connectedness.[19] In addition to actual levels of crime, perceptions of neighborhood crime are risk factors for poor mental health,[28] and both experiencing and witnessing violent crime are associated with depression.[29]

Residential instability, or the extent to which residents remain in the neighborhood over time, may impede the formation of social ties.[20] Previous studies have linked residential instability to mental health disorders.[11,30-32]

Gentrification, defined here as the increase of socioeconomic investments in a neighborhood often as a result of an influx of higher-income individuals, may break already existing social ties. Although this can have the benefit of helping urban revitalization and renewal, new residents often supplant old ones, causing further displacement of the urban poor and resulting in conflict between new and long-time residents.[21] Because economically disadvantaged people rely more on place-based and social goods, the dislocation of residents and breaking of the social fabric of the neighborhood can be especially detrimental.[33] Gentrification has been linked to a number of risk factors and health outcomes, such as air pollution and preterm birth;[21,33,34] however, little focus has been given to its potential association with depression.

Finally, income inequality, defined as an unequal distribution of income among a population, is hypothesized to increase stress by decreasing the public services and amenities offered if those with higher incomes withdraw from participation in such services. Additionally, income inequality may decrease the sense of civic fairness and justice, and increase perceived loss of autonomy and helplessness in the face of obstacles, discrimination, and victimization.[22,35,36] Exclusion and isolation may further exacerbate depressive symptoms.[37]

Despite positive findings in previous studies, support for the association between neighborhood factors and mental health outcomes is limited by concerns about bias due to individual self-selection into neighborhoods. Residential self-section will result in bias if the factors that drive self-selection are also associated with the health outcome of interest.[38-40] Traditional observational studies, such as cohort and case-control designs, attempt to address this by explicitly measuring and adjusting for variables that are thought to drive self-selection, such as socioeconomic status or neighborhood preferences. However, it is not possible to measure all variables associated with selection into neighborhoods, and so some

unmeasured factors will remain.[40]

Because residential self-selection can be driven by genetic and childhood upbringing factors,[41,42] the twin study design offers a means of partially addressing this bias.[43] Twins reared together share both their genes and their upbringing, and the co-twin control study inherently controls for these potential genetic and shared environmental confounds. Because twins are frequently discordant in behavior and location of residence in later life, it is possible to investigate associations between neighborhood characteristics and health outcomes while controlling for much of the confounding that would otherwise limit inference in an observational study among unrelated individuals.[43,44] This interpretation comes as close as possible to approximating a randomized experimental design from an observational study.[45]

The aim of this study is to examine the associations between depression and neighborhood deprivation, crime, residential instability, gentrification, and income inequality, controlling for confounding by genetic and childhood environment factors shared within twin pairs. We hypothesized that better neighborhood socioeconomic characteristics would be associated with less depressive symptoms.

METHODS

Study population

This study used a cross-sectional analysis of data from the University of Washington Twin Registry (UWTR), a community-based sample of adult twins raised together. Twins were initially identified by the Washington State Department of Motor Vehicle Licensing. Each twin completed a recruitment survey upon enrollment, and a follow-up survey providing information on sociodemographics, lifestyle behaviors, and health outcomes. Additionally, each twin's residential address was geocoded and linked to a variety of environmental factors. All procedures were reviewed and approved by the University of Washington's Institutional Review Board.

All twins in the study were from same-sex pairs. Using standard questions about childhood similarity, twins were categorized as either identical (monozygotic, MZ) or fraternal (dizygotic, DZ). Compared to DNA-based methods, these questions have been shown to have greater than 90% accuracy at identifying zygosity.[46,47]

A total of 7476 twins were included in the study. About 70% were MZ twins. Most lived in Washington State (74%); however, twins also lived in the District of Columbia and all 50 states except Delaware. Approximately 78 percent of twins lived in different census tracts from their cotwin; compared to MZ twins, DZ twins were less likely to live in the same census tract as their cotwin (82% vs. 76%).

Measures

Exposures

All neighborhood exposures were measured at the census tract level. Neighborhood socioeconomic deprivation was measured by the Singh Index, which used principal components analysis to determine factor loadings combining 2010 census data on education, employment, income and income disparity, poverty, characteristics of the home, and home, vehicle, and telephone ownership.[48,49] Greater deprivation is represented by higher index scores.

Crime was based on the Uniform Crime Report, which aggregates all reported crimes from seven main categories. Crime rates per 100,000 people are then calculated. However, only those living in cities of more than 10,000 had crime rates associated with their address.[50,51]

Residential instability was operationalized as the percentage of the population in a given census tract who had moved into owner-occupied units within the previous five years. This was derived from the 2010 American Community Survey (ACS) five-year estimates.

Gentrification was operationalized as the change in median home value of owner-occupied units in each census tract between 2000 and 2010. Median home value in 2000 came from the Census; in 2010, it was derived from the 5-year ACS estimates.

Income inequality was measured by the Gini index from the 2010 ACS five-year estimates. The Gini index ranges from 0 to 1; values close to 0 represent more equal distributions and values close to 1 represent unequal distributions where the majority of income is earned by a small proportion of the population. The Gini index is the most commonly used measure of income inequality in public health, and although several measures of income inequality are available,[52] previous research suggests that the choice of measure does not substantially change conclusions.[53]

Because of the considerable difference in scale between the outcome measure and the neighborhood exposures listed above, several of the exposures were rescaled for the analysis. Neighborhood deprivation and residential instability were each divided by 10, the crime rate was rescaled to total number of crimes per 100 people, and gentrification was rescaled to the change in median home value in 10,000 dollar increments.

Outcome

Our outcome was depression, measured by the 2-item Patient Health Questionnaire (PHQ-2). The PHQ-2 is a shorter version of the 9-item scale (PHQ-9), and measures self-reported depressive symptoms through questions about the two cardinal symptoms from the PHQ-9: depressed mood and anhedonia, or the inability to experience pleasure. Respondents were asked how often in the last 4 weeks they had been bothered by either symptom, and responses were given on a 4-point Likert scale (0 not at all; 1 several days; 2 more than half the days; 3 nearly every day). Responses can be summed to create a scale of symptom severity while a cut-off of 3 or greater is often used for classifying major depression. The measure has been validated in other populations using the DSM-IV as the gold standard, and has shown substantial rater agreement when compared to a mental health professional interview ($\kappa = 0.62$).[54] While the longer 9-item scale is more commonly used in research on neighborhood effects,[55,56] the PHQ-2 has shown acceptable validity compared to the PHQ-9 (sensitivity 91%, specificity 78%).[57]

Covariates

Traditional confounders of age, sex, and race/ethnicity are inherently controlled for in the twin model, and so not included as covariates in this analysis. At the individual-level, we decided *a priori* to include annual household income, education, and marital status. All three can drive self-selection into specific neighborhoods, and are associated with depression risk.[58-62] At the census tract level, we included population density (people/square mile) as a potential confounder because of its association with various neighborhood characteristics and mental health.[63,64]

Statistical analysis

We began the analysis with descriptive statistics of select sociodemographic characteristics of the sample. Next, to evaluate associations between the neighborhood exposures and depressive symptoms, we estimated beta coefficients and 95% confidence intervals using a multi-level random intercept model with the outcome modeled as a Poisson distribution. Random intercepts at the census tract and twin-pair level were included to account for the correlation between twins within a pair and between individuals within the same census tract.

We first estimated the phenotypic association by regressing depression on the neighborhood exposures for each individual. In this model, each individual is treated as a singleton instead of a member of a twin pair, and the model assumes that the average difference in outcome associated with a given difference in exposure is the same for twins within a pair as for unrelated individuals. Thus, although the model accounts for the correlation in the data, it does not provide the within-pair estimates that inherently adjust for shared genetic and environmental characteristics.

To estimate these within-pair associations, we used the following model[45]:

$$\log(\lambda_{ij}) = \beta_0 + \beta_B{*}x_i + \beta_W{*}(x_{ij} - x_i) + \beta_3{*}g_z + \beta_4{*}g_z{*}(x_{ij} - x_i) + \mu_{k[ij]} + \mu_i \quad (1)$$

where λ_{ij} represents the risk of depression for twin *j* in pair *i* as a function of the mean neighborhood exposure of twin-pair *i*, x_i, and each individual twin's deviation from their twin-pair mean, $(x_{ij} - x_i)$. Pair zygosity, g_z, is coded 0 for MZ twins and 1 for DZ twins, and $\mu_{k[ij]}$ and μ_i are random intercepts for census tract and twin pair, respectively.

Due to the nature of the twin model, the within-pair association for MZ twins (β_W) is not subject to confounding by genetic or shared childhood environment factors. When exponentiated, it can be interpreted as the ratio of depressive symptoms associated with a one-unit difference in neighborhood exposure within a MZ twin pair, conditional on the mean neighborhood exposure of the twin-pair. The between-pair coefficient, β_B, represents the extra variation in depression due to differences between twin pairs. The inclusion of β_B allows an individual twin's risk of depression to be influenced by the overall average exposure of the twin-pair.

Additionally, because β_W is subject only to confounding by factors that differ between twins within a pair while β_B is subject to confounding by all factors not included in the model, the relative contribution of the within- and between-pair effects to the variation in depression assessed by comparing the two

coefficients, can be interpreted to inform the degree of confounding. If they are similar, this indicates that the magnitude of the association between the neighborhood exposure and depression would be the same for twins within a pair as for unrelated individuals, suggesting that the observed association is not confounded by characteristics that differ between pairs (e.g. childhood environment and upbringing). By contrast, a significant difference between the coefficients would suggest the presence of confounders operating between pairs.[65]

Additionally, the inclusion of an interaction term for zygosity can assist in making inferences about genetic confounders. As mentioned above, the within-pair difference for MZ twins is β_W; for DZ twins it is $\beta_W + \beta_4$. Because MZ twins share all their genes and DZ twins share only half their genes, if the within-pair effect for MZ twins is significantly different from that for DZ twins ($\beta_4 \neq 0$), this is suggestive of genetic confounding in the observed association.

If the interaction term for zygosity was not significant, we removed zygosity from the model, simplifying the equation to[65]:

$$\log(\lambda_{ij}) = \beta_0 + \beta_B{*}x_i + \beta_W{*}(x_{ij} - x_i) + \mu_{k[ij]} + \mu_i \quad (2)$$

The first model we constructed (Model A) regressed depression only on the neighborhood exposure. Each subsequent model included the potential confounders; Model B had the individual-level covariates of income, education, and marital status, and Model C included these individual-level covariates as well as neighborhood-level population density.

We conducted two sensitivity analyses. First, each model that showed a significant association between the neighborhood exposure and depression was also run with the random intercept for census tract both removed and changed to the county level. This was done to determine if the size of the geography affected our results. Second, to explore the possible differential effects by income of the neighborhood exposures on depression, we included income as an effect modifier in each model. For these analyses, income was operationalized as a binary measure of below or above the approximate median income for Washington State.

All probability values were 2-sided, and the significance level was set at 0.05. Models were fit using the lme4 package in R.[66]

RESULTS

Table 1.1 gives select characteristics of the 7476 twins included in the study. The majority were female (66%), and the study sample was mostly non-Hispanic White. Most respondents had greater than a high school education (82%) and were married or living with a partner (56%). Eight percent of the sample scored a three or greater on the PHQ-2, indicating the presence of diagnosable depression. This is commensurate with the prevalence of depression in the general population.[1]

Within Washington State, twins lived in 1301 of 1318 census tracts. There were no substantial differences in neighborhood exposures between the 1301 census tracts with UWTR members and the remaining 17 census tracts (data not shown). The range of each neighborhood characteristics across census tracts and the individual deviation from the within-pair mean are given in the supplemental tables. Mean neighborhood poverty, measured as the percent of families in the census tract living in poverty, was 8.2% (standard deviation: 11.2%; interquartile range: 5.0%, 14.3%).

Phenotypic models

All neighborhood exposures except crime were significantly associated with depressive symptoms in the phenotypic models (data not shown). For neighborhood socioeconomic deprivation, residential instability, and income inequality, the interaction term with zygosity was not significant, and was thus removed from the model. A ten-unit difference in Singh Index was associated with approximately 6 percent greater depressive symptoms (1.06; 95% CI: 1.03, 1.13); a ten-unit difference in residential instability was associated with approximately 3 percent greater depressive symptoms (1.03; 95% CI: 1.00, 1.04); and a completely unequal income distribution (Gini index=1) was associated with approximately 78 percent greater depressive symptoms compared to complete income equality (Gini index=0) (1.78; 95% CI: 1.01, 3.13).

In the gentrification model, the interaction term with zygosity was significant. The association in twins overall (ignoring the interaction term) was significant as well (0.99; 95% CI: 0.98, 0.99); however, this main effect was driven entirely by the association among DZ twins (0.98; 95% CI: 0.97, 0.99). Among MZ twins, there was no association between gentrification and depression.

Within-Between twin models

Only neighborhood deprivation and gentrification showed significant within-pair associations in the within-between models. The interaction term with zygosity was not significant in the neighborhood deprivation model; thus we used equation 2 to assess the association with depression. In the unadjusted model, a ten-unit difference in neighborhood deprivation was associated with nearly 6 percent greater depressive symptoms (1.06, 95% CI: 1.01, 1.11), conditional on the mean deprivation score for the twin pair; this association did not substantially change when adjusting for individual and neighborhood-level covariates (Table 1.2). Individuals in the 25th percentile of neighborhood deprivation (Singh Index = 81.6) had on average 12 percent greater depressive symptoms (1.12, 95% CI: 1.02, 1.23) than those in the 75th percentile of neighborhood deprivation (Singh Index = 101.9).

A likelihood ratio test comparing the within- and between-pair effects found that the two coefficients were not significantly different ($p>0.05$); thus the association between neighborhood deprivation and depressive symptoms was not influenced by factors differing between pairs.

There were several differences between respondents residing in low and high deprivation neighborhoods that were taken into account in the adjusted models. Respondents living in less deprived areas were more likely to have higher incomes (65% vs. 42%) and have completed a Bachelors degree (59% vs. 37%) compared to those living in more deprived areas. Neighborhoods with less deprivation were also likely to have greater population density (4976.7 people/sq. mile vs. 3701.0 people/sq. mile).

For the model with gentrification, the interaction term for zygosity was significant ($p=0.035$); thus we used equation 1. However, for ease of interpretation, results are presented stratified by zygosity (Table 1.3). Within DZ twins in the unadjusted model, a $10,000 difference in gentrification was associated with a slightly lesser risk of depressive symptoms (0.99; 95% CI: 0.97, 0.99). This association became nonsignificant when adjusting for covariates. There were no associations in any of the models between gentrification and depression among MZ twins. Additionally, gentrification did not show a significant difference between the within- and between-pair effects among DZ twins in the unadjusted model, suggesting that the observed association was not confounded by factors differing between pairs.

As with neighborhood deprivation, there were several differences between respondents who lived in areas experiencing greater gentrification than those living in areas with less gentrification. Respondents

living in neighborhoods with greater gentrification had higher incomes (62% vs. 44%), and were more likely to have at least a Bachelors degree (59% vs. 38%) and live in an area with greater population density (5738.7 people/sq. mile vs. 3436.5 people/sq. mile).

There were no significant within-pair effects for the other three neighborhood characteristics; additionally, the between-pair effect was not significant in any of the adjusted models.

Sensitivity analyses

For the neighborhood deprivation and gentrification models, we explored the effect of the size of geographical unit on the observed association by removing the random intercept for census tract and by changing the random intercept for census tract to be at the county-level. Neither variation qualitatively changed our conclusions.

Income did not act as an effect modifier in any model.

DISCUSSION

The results of this study support the hypothesis that neighborhood socioeconomic deprivation is associated with greater depression. It further suggests that gentrification may be related to depression, although this association is influenced by genetic factors. It does not, however, provide evidence linking crime, residential instability, or income inequality to depression.

Results from previous studies of neighborhood deprivation and depression are mixed.[9,26,27,67,68] A 2008 review found that eleven of twenty-two community-based studies showed a significant association between neighborhood deprivation and depression among adults after controlling for individual-level characteristics.[26] A subsequent review of the literature published between January 2009 and January 2010 found that two of five studies showed significant associations between neighborhood deprivation and depression after adjusting for individual-level characteristics.[9]

Differences in results may be due to differences in operationalizing neighborhood deprivation. While measures of neighborhood deprivation are commonly derived from administrative data, variables may be single indicators (e.g. percent of families living below the Federal Poverty Level (FPL)) or a combination of multiple indicators (e.g. percent of families living below the FPL, percent female-headed households,

and percent of individuals with a high school diploma/GED).[26] The inclusion of these distinct aspects of neighborhood deprivation can affect results if they are linked to depression through different mechanisms. Neighborhood deprivation is a complex construct, and a more comprehensive measure such as the Singh Index may provide a better estimator of the underlying concept. However, without testing specific theories or causal pathways, it is unclear if contradictory conclusions are due to differences in study design and methodology or to the absence of important mechanisms from specific studies.[9]

Previous studies have shown associations between gentrification and health; however, the direction of the association is not consistent across studies. Higher levels of gentrification have been linked to lower air pollution, but also to higher preterm birth.[21,33,34] We observed an inverse association between gentrification and depression, but this association did not remain significant after adjusting for individual factors. Further, given the size of the effect, the width of the confidence interval, and the number of tests done in this analysis, it is possible that our observed association is due to chance.

Gentrification is a challenging concept to measure. Other studies have used methods such as principal components analysis to combine information on changes in residents' income, education, and race/ethnicity, as well as changes in housing characteristics.[21,34] In contrast, we used only the change in median home property value over a ten-year period, which may not be an adequate proxy for all the relevant facets of gentrification.

Additionally, we did not distinguish between residents who moved into the neighborhood while it was gentrifying and those who had been there at the beginning of the ten-year period that the measure encapsulates. Although gentrification often brings a decrease in crime and an increase in services and amenities, the experience of gentrification could be different for newer compared to long-term residents. As noted previously, gentrification may force less affluent residents out of a neighborhood, thereby breaking the social fabric. For families that remained within the gentrified neighborhood, the loss of social support, combined with an influx of new amenities that they may not be able to afford, could increase stress and feelings of isolation, which in turn lead to depression. Thus their experiences of gentrification may be radically different from the experience of someone who moved into the neighborhood because it was undergoing urban revitalization.[33,69] We attempted to investigate this possibility with a cross-level interaction with income, but found no significant effect.

Additionally, the experience of displacement is not adequately captured in our measure of gentrification. Residents forced out of a neighborhood will lose their neighborhood-based social, informational, and economic support, regardless of the affluence of their new neighborhood.

That the association between gentrification and depression was seen only among DZ twins suggests that there may be some uncontrolled genetic factors confounding the association. MZ twins share all of their genes; thus, genetic factors cancel out in a within-pair MZ association. By contrast, DZ twins share on average half their genes, so genetic factors may still influence the observed relationship between gentrification and depression. Future epigenetic research could be useful in teasing apart the relationship between these measures. Additionally, although the association was no longer significant after adjusting for individual-level covariates, this does not necessarily mean that neighborhood gentrification has no causal effect on depression. The individual-level measures included in this study and traditionally linked to depression (e.g. income, education) can be influenced by neighborhood characteristics because individual opportunities are, to some degree, a product of where people live.[11]

Finally, although the magnitude of the associations between depression and neighborhood deprivation and gentrification are small, because intervening at the neighborhood level has the potential to reach large segments of the population, even small changes can have large effects on public health.

Despite positive findings with neighborhood deprivation and gentrification, there was no association between depression and crime, residential instability, or income inequality. The lack of an association with crime may be due to several factors. First, crime data was only available for cities with over 10,000 residents; twins living in suburban and rural areas were excluded from the analysis. This limited the statistical power of the analysis, and reduced the variation in exposure because crime rates differ substantially between urban and non-urban areas.[70,71] Second, crimes rates were calculated as total reported crime, without distinguishing between types of crime that may have different impacts on depression.[51] Further, the rates in each area are driven primarily by the more prevalent but typically less serious crimes, such as larceny-theft. The Crime index therefore indicates that jurisdictions with higher numbers of larceny-thefts have higher crime rates, downplaying the importance of less frequent violent crime. Third, crime was measured as objective rates, whereas previous studies have suggested that individual experiences of crime and perceived risk of crime, but not actual neighborhood crime rates,

have a greater effect on depression risk.[19]

There has not been much previous research on mental health and residential instability; however, our results are inconsistent with other published studies.[11,30,32] This contrast could be due to the fact that we looked only at residential instability of the current neighborhood, whereas residential instability may be more etiologically relevant during childhood.[30] A further issue is our use of a single indicator as a measure of instability. While most previous studies have used the percent of movers within the last five years, these studies have created more comprehensive measures by including factors such percent of residents with home ownership, percent living in apartment buildings, and percent vacant households.[11,30,32]

As with residential instability, the absence of an association between income inequality and depression in our study was inconsistent with previous positive findings.[37,72,73] However, there are a number of differences between our study and previous research. First, we conceptualized income inequality at the neighborhood level, while other studies have used state-[37] or country-level measures.[72] Aggregating individual responses in a specific area can lead to statistical bias resulting in different inferences being observed depending on the boundaries used.[74] Aggregating to a larger scale (e.g. counties instead of census tracts) can obscure heterogeneity in the neighborhood. Aggregating to a different set of boundaries (e.g. zip codes instead of census tracts) can produce different observed associations because of the differences in the way individuals are grouped.[74,75] Thus the most appropriate level of aggregation depends on the proposed mechanism. If income inequality affects health primarily through decreased government services, such inequality could be more relevant at the city, county, or state level. Alternatively, if income inequality erodes social cohesion and contributes to social disorder, the neighborhood (census tract) may be a more appropriate level.[76]

Although the Gini index is the most commonly used measure of income inequality, and previous research suggests that the choice of measure will not substantially change the results,[53] it is possible that a different measure would capture an aspect of income inequality not included in our study.[77] Finally, our negative results may be explained by the threshold effect where adverse health effects only appear after reaching a certain threshold in income inequality.[73]

The results of our sensitivity analysis suggest that individual-level income does not modify the association between neighborhood contextual factors and depression. Although there is recognition of the

importance of understanding how neighborhood- and individual-level characteristics interact, there has been less investigation of these mechanisms, and results are mixed.[11,26,78] More research on this topic is needed.

Strengths and limitations

An important strength of this study design is the use of a large community-based sample of adult twins, which controls for confounding due to shared genetic and childhood environment factors. Early-life socioeconomic status predicts socioeconomic status in adulthood, and the socioeconomic characteristics of the neighborhood in which a child is born and raised are strongly correlated with those of the neighborhood in which they will live as adults. A twin design effectively controls for this source of confounding because twins raised together share the same childhood environment. By additionally adjusting for select individual-level sociodemographic characteristics, this study can overcome some of the concerns regarding residential self-selection. Because it is neither practical nor ethical to randomize individuals to different neighborhood environments, a genetically-informed twin model is the best approximation to an experimental design because twins can be considered "randomized" to some degree since they would be balanced on some early-life predictors.

The twin design, however, does not account for other factors that can affect self-selection into neighborhoods. For example, we were unable to adjust for aspects such as general neighborhood preference, wanting to live close to work or within a certain school's catchment area, or the desire for nearby amenities or public transit. A further limitation is the cross-sectional study design, which does not address the problem of reverse causation. This is particularly important in the investigation of neighborhood effects on health because of self-selection concerns. While the underlying hypothesis in our study is that neighborhood characteristics affect health (social causation), previous studies have shown that individual health can affect neighborhood choice (social selection).[79,80] However, other research suggests that, while social selection may be an important factor for explaining the association between socioeconomic factors and some mental disorders like schizophrenia, social causation is the more relevant mechanism to depression.[81,82]

The use of census tracts presents another limitation as they are imperfect representations of the neighborhood.[83] Neighborhood is a complex concept, and selecting the boundaries of a neighborhood would ideally be driven by theoretical considerations instead of methodological ones. However, the availability and consistency of boundaries over time make census tracts a widely used operationalization of neighborhood in the United States. Additionally, census tracts are designed to be economically homogenous, decreasing concerns that individual heterogeneity may obscure results.[84] Further, state and local governments may allocate resources based on these administrative areas, and this can impact the experience of the individuals residing in them.[85]

Finally, the lack of racial diversity in the sample limits generalizability to other populations. Despite this, there was substantial diversity of income, and while the twins in the UWTR may not be representative of the U.S. population as a whole, they are generally representative of residents of Washington State. Further, we must make the assumption that twin studies are generalizable to the non-twin population. This assumption has only been infrequently addressed in previous research; however, some studies suggest that the results from twin studies are generalizable across a variety of outcomes.[86,87]

Conclusion

The results of this study suggest that neighborhood socioeconomic deprivation is associated with worse depressive symptoms. It further provides some evidence for an inverse association between gentrification and depression. Future research evaluating neighborhood effects could be improved by the use of more consistent definitions and measures for the concepts of interest. This would facilitate comparisons across studies that can inform causal inferences. Additionally, such studies should employ longitudinal designs to better address the social causation versus social selection issue. Longitudinal designs would also allow for testing the trajectory of depression as deprived neighborhoods may worsen already existing symptoms by impeding access to amenities, healthcare services, and treatment. Finally, future studies should use causal mediation methods to empirically test proposed pathways and theories.

Figure 1.1. Conceptual model linking the five characteristics of neighborhood context to depression.

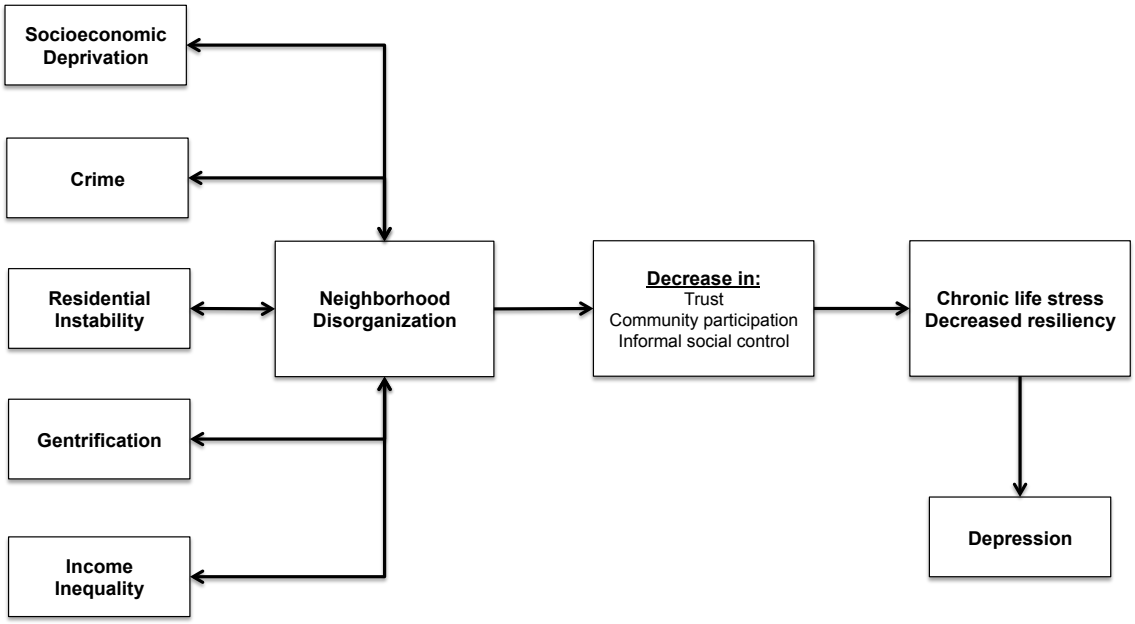

Table 1.1. Select characteristics of adult twins in the University of Washington Twin Registry, 2009-2013

	N	%
Age[a]	41.0	17.1
Male	2,582	34.5
White	6,910	92.4
Hispanic	303	4.1
Income		
<$60,000	3,528	47.2
≥$60,000	3,944	52.8
Education		
Less than HS	195	2.6
HS grad	1,169	15.6
Some college	2,663	35.6
Bachelors or more	3,449	46.1
Marital status		
Single	2,395	32.0
Living as married	4,169	55.8
Previously married	912	12.2
Population density[a]	4,243.7	7,772.9
Singh Index[a]	89.1	20.6
Crime Index[a]	4,854.3	2,016.6
Percent moved within 5 years[a]	38.9	14.1
Change in median home value[a]	137,572.9	92,804.7
Gini index[a]	0.40	0.07
PHQ-2[a]	0.81	1.24
PHQ-2 ≥ 3	601	8.0

[a]Mean ± standard deviation.

Table 1.2. Associations between neighborhood deprivation and depressive symptoms[a] among adult twins in the University of Washington Twin Registry, 2008-2012.

	Model A[b]			Model B[c]			Model C[d]		
	exp(β)	**95% CI**	**P-value**	**exp(β)**	**95% CI**	**P-value**	**exp(β)**	**95% CI**	**P-value**
Singh Index									
Between-pair	1.06	1.03, 1.20	<0.001	1.02	0.99, 1.06	0.251	1.02	0.987, 1.06	0.219
Within-pair	1.05	1.01, 1.11	0.009	1.05	1.01, 1.09	0.028	1.05	1.01, 1.10	0.027
Income				0.92	0.90, 0.94	<0.001	0.93	0.91, 0.94	<0.001
Education				0.91	0.86, 0.97	0.004	0.91	0.86, 0.97	0.003
Marital status									
Single				1.00	ref	ref	1.00	ref	ref
Living as married				0.78	0.70, 0.88	<0.001	0.78	0.69, 0.87	<0.001
Previously married				1.05	0.91, 1.21	0.537	1.05	0.91, 1.21	0.526
Population density[e]							1.01	0.94, 1.10	0.718
Random Effects Variance									
Census tract	0.12			0.09			0.09		
MZ twins	0.74			0.66			0.67		
DZ twins	0.74			0.63			0.65		

CI confidence interval.
[a]Measured by the 2-item Patient Health Questionnaire.
[b]Model unadjusted for other covariates.
[c]Model adjusted for individual-level income, education, and marital status.
[d]Model adjusted for individual-level income, education, and marital status, and area-level population density.
[e]Scaled to 10,000 people per square mile.

Table 1.3. Associations between gentrification and depressive symptoms[a] among adult twins in the University of Washington Twin Registry, 2008-2012, stratified by zygosity.

	Model A[b]			Model B[c]			Model C[d]		
	exp(β)	**95% CI**	**P-value**	**exp(β)**	**95% CI**	**P-value**	**exp(β)**	**95% CI**	**P-value**
MZ Twins									
Between-pair	0.99	0.98, 1.00	0.090	1.00	0.99, 1.01	0.835	1.00	0.99, 1.01	0.914
Within-pair	1.00	0.99, 1.01	0.745	1.00	0.99, 1.01	0.405	1.00	0.99, 1.01	0.638
Random Effects Variance									
Census tract	0.14			0.10			0.10		
Twin pair	0.77			0.69			0.70		
DZ Twins									
Between-pair	0.98	0.97, 0.99	0.006	0.99	0.98, 1.01	0.409	0.99	0.98, 1.01	0.377
Within-pair	0.99	0.97, 0.99	0.035	0.99	0.98, 1.00	0.127	0.99	0.98, 1.00	0.107
Random Effects Variance									
Census tract	0.28			0.22			0.22		
Twin pair	0.62			0.57			0.57		

CI confidence interval; MZ monozygotic; DZ dizygotic.
[a]Measured by the 2-item Patient Health Questionnaire.
[b]Model unadjusted for other covariates.
[c]Model adjusted for individual-level income, education, and marital status.
[d]Model adjusted for individual-level income, education, and marital status, and area-level population density (10,000 people per square mile).

Chapter Two: Social capital, neighborhood socioeconomic deprivation, and depression

ABSTRACT

Introduction: Depression is predicted to be a top contributor to the global burden of disease by 2020; thus identifying risk factors for depression is vital to public health. There is growing recognition of the importance of the social determinants of depression. Social capital, defined as the emotional, economic, and informational resources available to individuals and groups through their social networks, has become increasingly prevalent in public health research. However, social capital as a construct is not well defined, and there is little consensus on which domains are most essential for mental health. The goals of this study are to examine the association between different domains of social capital and depression within twin pairs, and to examine whether social capital influences the association between neighborhood socioeconomic deprivation and depression.

Methods: We conducted a multilevel random-intercept Poisson regression among same-sex twin pairs from the University of Washington Twin Registry, a community-based registry of adult twins raised together, to analyze the association between social capital and depression. We included nine self-reported measures of individual-level social capital: sense of belonging, neighborhood social cohesion, workplace connections, trust, community participation, volunteerism, social interaction, informal social control, and perceptions of safety. The main parameter of interest was the within-pair association between social capital and depression because it was not subject to confounding by genetic or environmental factors shared between twins within a pair. We further investigated if social capital influences the association between neighborhood socioeconomic deprivation and depression through the inclusion of an interaction term and a mediation analysis.

Results: The measures of cognitive social capital, sense of belonging, neighborhood social cohesion, workplace connections, and trust, all showed significant within-pair associations in the unadjusted and adjusted models. For each measure, greater social capital was associated with less depressive symptoms. The measure of informal social control gave mixed results, while the remaining measures had

null results in all models. There was no evidence that social capital influenced the neighborhood socioeconomic deprivation-depression association.

Conclusion: These results suggest that cognitive social capital is associated with depression; however, they do not provide evidence for an association between depression and other forms of social capital. The results additionally do not demonstrate that social capital moderates or mediates the neighborhood socioeconomic deprivation-depression association. Further research is needed to elucidate which domains of social capital are most relevant to depression, and to understand the mechanisms that link neighborhood environment to mental health.

INTRODUCTION

Depression is predicted to be among the top three contributors to the global burden of disease by 2020.[6] The prevalence of major depression among U.S. adults is 8%, and anti-depressants are the most frequently prescribed drug among U.S. adults ages 18-44 years.[1,3] Between 1995 and 2005, outpatient visits for depression increased by 48 percent.[4] Identifying risk factors for depression has become increasingly important in public health. While it is well accepted that individual-level sociodemographic factors can influence depression[7,8], there is growing recognition that the health of a population is determined by more than the individual characteristics of the group members; the collective characteristics of social groups matter as well.[88] Understanding how the social environment impacts depression can inform decisions about investing resources in community-based mental health promotion efforts.

One measure of the social environment that has increasingly been used in the public health literature over the past fifteen years is social capital.[89] It is broadly defined as the emotional, economic, and informational resources available to individuals and groups through their social networks. It has been conceptualized and operationalized in diverse ways, with individual studies emphasizing different domains of the construct. Thus, the use of social capital in research poses methodological challenges: it is broad, not concretely defined, and composed of several domains which can be measured at either the individual- or group-level. Although it has been linked to health outcomes including mortality,[90] general health,[91] HIV prevalence,[92] heart disease,[93] and even depression,[94] there is little consensus on which domains are most essential for mental health, and differences in instruments used limit comparisons of results across studies.[95]

Social capital is often divided into cognitive and structural domains. Cognitive social capital refers to perceptions, such as the sense of belonging to a community, while structural social capital refers to behaviors and activities, such as participation in organizations and volunteerism.[12,96] Social capital can additionally be divided into bonding, bridging, and linking capital.[36] Bonding social capital connects people of similar attributes or social identities, bridging social capital connects groups that differ in their characteristics, and linking social capital connects groups along an explicitly vertical power structure.[13,36,97]

Little previous research has been devoted to exploring which social capital domains are most relevant for depression risk. While findings are mixed, there is greater evidence of an association between depression and cognitive, as compared to structural, social capital. A 2005 literature review found that seven of eleven studies investigating associations between individual-level cognitive social capital and common mental disorders (depression and anxiety) found significant inverse associations, while the remaining four had null results.[98] The same review found more varied results among individual-level structural social capital; of the eleven studies included, three showed significant inverse associations, seven showed null associations, and one showed a positive association. Further, none of the studies included measures of bridging or linking social capital, and less research has been devoted to understanding the differences in bonding, bridging, and linking domains.[98]

Results are mixed for neighborhood-level social capital as well. In a 2008 review, three of the five studies included had null results, while one showed a significant inverse association with depression and one had inconclusive results.[26] A 2010 review indicated that both studies of social capital published in the previous year found an inverse association between cognitive social capital and depression while no studies investigated measures of structural social capital.[9] More research is needed to elucidate how the different domains of social capital relate to depression.

In addition to being a potential explanatory factor for differences in depression risk, social capital has also been suggested as a moderator or a mediator in the association between neighborhood characteristics, such as neighborhood socioeconomic deprivation, and depression. Moderation refers to the process by which the association between two variables is dependent upon a third variable; in mediation, one variable affects another through the third variable (Figure 2.1).

Several potential mechanisms have been hypothesized to link neighborhood deprivation, social capital, and depression. As a moderator, social capital may buffer the effects of neighborhood disadvantage on depression while having no affect in advantaged neighborhoods; or it may disproportionately benefit advantaged communities if both neighborhood advantage and high social capital reinforce their respective contributions to mental health.[99] In a mediation model, neighborhood deprivation may prevent the creation of social capital, which in turn influences depression by determining the economic resources available to the neighborhood;[100,101] or deprivation can determine accepted

norms of action and diminish individuals' ability to intervene for the common good of the neighborhood, and this informal social control affects mental health.[20]

Although previous research has linked social capital and neighborhood deprivation to depression, genetic confounding and bias due to self-selection into neighborhoods and communities limit the ability to make causal inferences from study results. Twin designs address these limitations by inherently controlling for confounding due to shared genetic and childhood environment factors.[43] However, only one previous study has used a twin design to overcome the above limitations in exploring the association between social capital and depression, and its findings were mixed.[91] To address these gaps in the literature, the aims of this study are:

1. To examine the association between different domains of social capital and depression, controlling for confounding due to shared genetic and childhood environment factors within twin pairs.
2. To examine whether social capital influences the association between neighborhood socioeconomic deprivation and depression.

We hypothesized that higher levels of social capital would be associated with fewer depressive symptoms, and that social capital would serve as a mediator in the neighborhood deprivation-depression association.

METHODS

Study population

We conducted a cross-sectional analysis using data from the University of Washington Twin Registry (UWTR), a community-based registry of adult twins raised together. The UWTR is described in more depth in Chapter One; briefly, twins completed surveys on health behaviors and outcomes, and each twin's residential address was geocoded and linked to a variety of environmental factors. All procedures were reviewed and approved by the university's institutional review board.

All twins in the study were from same-sex pairs. Twins were categorized as either identical (monozygotic, MZ) or fraternal (dizygotic, DZ) using standard questions about childhood similarity that have been shown to have greater than 90% accuracy at identifying zygosity when compared to DNA-based methods.[46,47]

All same-sex pairs with geocoded addresses received electronic or paper surveys asking about their social capital and the presence of depressive symptoms. Twins contacted electronically received three email reminders about the study; twins contacted by mail received one follow-up mailing. Because respondents were included in the analysis only if both twins in the pair completed the survey, non-responders whose cotwin had completed the survey may have also received a follow-up phone call. Of the 8130 individuals contacted, 2561 (31.5%) completed and returned the survey; however, only 1586 (19.5%) were members of a complete pair.

Monozygotic twins comprised approximately 76% of the analytic sample. Most twins lived in Washington State (68%); however, twins lived in the District of Columbia and 44 states, excluding Iowa, Kentucky, Mississippi, North Dakota, Rhode Island, and South Dakota.

Measures

Exposures

We measured several domains of social capital in this study: sense of belonging, neighborhood social cohesion, workplace connections, community participation, volunteerism, social interaction, trust, informal social control, and perceptions of safety. Each domain was derived from self-report and conceptualized at the individual-level.

Cognitive Social Capital. We included four domains of cognitive social capital: sense of belonging, neighborhood social cohesion, workplace connections, and trust. For sense of belonging, neighborhood social cohesion, and vertical workplace connections, respondents were asked to rate their agreement (1 Strongly disagree; 2 Disagree; 3 Neutral; 4 Agree; 5 Strongly agree) with several statements. For each domain, responses to the statements were averaged to create an overall score.

Sense of belonging was assessed through three statements: I don't feel I belong to anything I'd call a community; I feel close to other people in my community; My community is a source of comfort. The response to the first statement was reverse-coded before averaging. This measure has been previously used in studies linking sense of belonging to depression.[91,102,103] The internal consistency (Cronbach's α)[104,105] of the scale in the sample was 0.84.

Neighborhood social cohesion used the following five statements:[106] People in this neighborhood can be trusted; This is a close-knit neighborhood; People around here are willing to help their neighbors; People in this neighborhood generally don't get along with each other; People in this neighborhood do not share the same values. The last two statements were reverse-coded before being included in the average. This scale is one of the most commonly used measures of social cohesion in public health research.[96] The internal consistency (Cronbach's α)[104,105] of the scale in the sample was 0.83.

Vertical workplace connections was assessed by the following three statements: We can trust our supervisor; Our supervisor treats us with kindness and consideration; Our supervisor shows concern for our rights as employees. These questions have been linked to depression and antidepressant use in previous research.[94,107] The internal consistency (Cronbach's α)[104,105] of the scale in the sample was 0.93.

We used two measures of trust; a question about general trust (What percentage of people can be trusted?) and a question about political or governmental trust[108] (To what degree do you trust the local/city government?). For governmental trust, respondents could indicate five options: very high, high, not particularly high, and not at all. While both measures capture the cognitive aspects of social capital, the question about general trust is not easily placed into a bonding or bridging category. By contrast, governmental trust captures linking social capital by asking about the respondent's perception of a political hierarchy.

Because communities and neighborhoods are often homogenous in terms of residents' characteristics, sense of belonging and neighborhood social cohesion are thought to capture measures of bonding social capital.[36] In contrast, the domain vertical workplace connections explicitly asks about relations in a hierarchical power structure, making it a measure of linking social capital.[94,107]

Structural Social Capital. Structural social capital was measured through questions about community participation, volunteerism, and social interaction.[91,102,109] Respondents were asked to indicate the number of hours per month they volunteered in a healthcare setting, at a youth-related activity, for a political organization or cause, or in any other local organization. Responses were summed to create the measure of total hours spent volunteering per month. For community participation, respondents were

asked to indicate the number of hours per month they spent at religious services or meetings of religious groups, union or professional meetings, sports or social gatherings, and other groups. Again, responses were summed to create a measure of total hours per month. These questions capture a mix of bonding and bridging social capital, depending on the membership of the organizations.[36]

Social interaction was assessed through two questions:[18] respondents were asked to indicate how often (1 Never; 2 Rarely; 3 Sometimes; 4 Often) people in their neighborhood had parties or get-togethers; and how often people in the neighborhood ask each other advice about personal things such as child-rearing or job openings. Each question was included separately in the analysis. As mentioned above, neighborhoods are frequently homogenous in terms of residents' characteristics; thus social interaction is considered a measure of bonding social capital.[36]

Neighborhood Characteristics

We also measured informal social control and perceptions of safety. To assess informal social control, respondents were asked to rate their agreement with the statement: Neighbors could be counted on to intervene if children were spray-painting graffiti on a local building.[106] To assess perceptions of neighborhood safety, respondents were asked to rate their agreement with the statement: My neighborhood is safe from the threat of crime. Both questions used the same 5-point Likert scale described above.

Finally, neighborhood socioeconomic deprivation was measured by the Singh Index. Principle components analysis determined factor loadings from 2010 census data on education, employment, income and income disparity, poverty, characteristics of the home, and home, vehicle, and telephone ownership.[48,49]

Outcome

Depression was measured by the 2-item Patient Health Questionnaire (PHQ-2), a subset of the longer 9-item scale (PHQ-9). The PHQ-2 measures self-reported depression through questions about the cardinal symptoms from the PHQ-9: depressed mood and anhedonia, or the inability to experience pleasure. Respondents were asked how often in the last 4 weeks they had been bothered by either

symptom, and responses were given on a 4-point Likert scale (0 Not at all; 1 Several days; 2 More than half the days; 3 Nearly every day). Answers to the two questions were then summed to create a scale ranging from 0 to 6. A cut-off of 3 or greater is often used for assigning major depression; however, responses can also be used as a measure of symptom severity. The measure has been validated in other populations using the DSM-IV as the gold standard; predictive validity was measured as rater agreement with a mental health professional interview ($\kappa = 0.62$).[54] The PHQ-9 is more commonly used in research on neighborhood effects;[55,56] however, the PHQ-2 has shown acceptable validity compared to the longer scale (sensitivity 91%, specificity 78%).[57]

Covariates

Traditional confounders of age, sex, and race/ethnicity were not included in the analysis because they are inherently controlled for in the twin model. At the individual-level, we decided *a priori* to include income, education, and marital status. At the census tract level, we included population density (people/square mile) and neighborhood socioeconomic deprivation, measured by the Singh Index described above, as covariates.[48,49]

Statistical analysis

The analysis employed a multi-level random intercept model, with the outcome assumed to follow a Poisson distribution. The random intercepts account for the correlation between twins within a pair, and between individuals within the same census tract. To estimate the within-pair effects that inherently adjust for shared genetic and childhood environmental characteristics, we used the following Poisson model:[65]

$$\log(\lambda_{ij}) = \beta_0 + \beta_B{*}x_i + \beta_W{*}(x_{ij} - x_i) + \mu_{k[ij]} + \mu_i \quad (1)$$

where λ_{ij} represents the risk of depression for twin *j* in pair *i* as a function of the mean social capital of twin-pair *i*, x_i, and each individual twin's deviation from their twin-pair mean, $(x_{ij} - x_i)$. Random intercepts $\mu_{k[ij]}$ and μ_i are for census tract and twin pair, respectively.

Due to the nature of the twin model, the within-pair effect (β_W) is not subject to confounding by shared genetic or childhood environment factors. When exponentiated, it can be interpreted as the ratio of depressive symptoms associated with a one-unit difference in social capital within a twin pair, conditional

on the mean social capital of the twin-pair. The between-pair effect, β_B, while not intuitively interpretable, represents the extra variation in depression due to differences between twin pairs.[65]

Because β_W is only subject to confounding due to factors that differ between twins within a pair, and β_B is subject to confounding due to all factors not included as covariates in the model, a comparison of the two coefficients can give a suggestion of the relative contribution of the within- and between-pair effects to the variation in depression. If the two coefficients are similar, the difference in depression associated with a one-unit difference in social capital would be the same for twins within a pair as for unrelated individuals, indicating that the observed association is not confounded by characteristics that differ between pairs (e.g. childhood environment and upbringing). By contrast, a significant difference between the coefficients would suggest the presence of confounders operating between pairs.[65]

We first regressed depression on each social capital variable (unadjusted, Model A). We next added the individual-level covariates of income, education, and marital status into the model (Model B). Our final model (Model C) included the individual-level covariates, population density, and neighborhood socioeconomic deprivation.

Finally, to assess whether social capital influences the association between neighborhood deprivation and depression, we first used equation 1 above to estimate the within- and between-pair effects of neighborhood deprivation on depression. We then added each individual measure of social capital into the equation as moderators using equation 2 below:

$$\log(\lambda_{ij}) = \beta_0 + \beta_B{*}x_i + \beta_W{*}(x_{ij} - x_i) + \beta_3{*}sc_{ij} + \beta_4{*}sc_{ij}{*}(x_{ij} - x_i) + \mu_{k[ij]} + \mu_j \quad (2)$$

where λ_{ij} once again represents the risk of depression for twin *j* in pair *i*; x_i is the mean neighborhood deprivation for twin pair *i*; and x_{ij} and sc_{ij} are the neighborhood deprivation and social capital scores, respectively, for twin *j* in pair *i*. In this equation, β_4 is the coefficient for the interaction term between neighborhood deprivation and social capital, and the presence of moderation can be evaluated by its magnitude and statistical significance.

In the absence of moderation, we tested for mediation[110,111] by including each social capital variable individually in the model with depression and neighborhood deprivation, using equation 3 below:

$$\log(\lambda_{ij}) = \beta_0 + \beta_B{*}x_i + \beta_W{*}(x_{ij} - x_i) + \beta_3{*}sc_{ij} + \mu_{k[ij]} + \mu_j \quad (3)$$

Only those social capital variables that were associated with depression in equation 1 were included in equation 3. We assess the influence of social capital on the deprivation-depression association by determining if the within-pair coefficient for neighborhood deprivation (β_W) changes substantially with each social capital variable in the model.

All probability values were 2-sided, and the significance level was set at 0.05. The analysis was done in STATA Release 13 (StataCorp, College Station, TX).

RESULTS

Table 2.1 gives select characteristics of twins who received the social capital survey, stratified by pair completeness. If both twins within a pair completed the survey, they are included in the first columns (complete pairs); individuals who completed the survey while their cotwins did not are in the second columns (incomplete pairs). Individuals who did not return the survey are in the last set of columns (non-responders). There are a few differences between the groups. Of note, complete pairs were more likely to be female, monozygotic, and living as married, and to have higher incomes and educational attainment than incomplete pairs and non-responders.

Cognitive social capital

Sense of belonging, neighborhood social cohesion, and workplace connections all showed significant within-pair associations with depressive symptoms in the unadjusted models (Table 2.2). The associations remained significant in both adjusted models; further, the inclusion of other covariates did not substantially change the magnitude of the within-pair coefficient. Adjusted for individual-level sociodemographics, population density, and neighborhood socioeconomic deprivation, a one-unit difference in sense of belonging was associated with 27 percent less depressive symptoms (0.73, 95% CI: 0.62, 0.94); a one-unit difference in neighborhood social cohesion was also associated with 27 percent less depressive symptoms (0.73, 95% CI: 0.57, 0.94); and a one-unit difference in vertical workplace connections was associated with 24 percent less depressive symptoms (0.76, 95% CI: 0.65, 0.88).

A likelihood ratio test comparing the fully adjusted within- and between-pair coefficients found a borderline nonsignificant difference for sense of belonging (p=0.074) and a significant difference for neighborhood social cohesion (p=0.050), suggesting the presence of confounds operating between pairs (e.g. differences in childhood environment). In contrast, the fully-adjusted within- and between-pair associations were not significantly different (p=0.780) for vertical workplace connections, suggesting that the association between workplace connections and depressive symptoms was not influenced by factors differing between pairs.

General trust and governmental trust showed significant within-pair associations in the unadjusted model (Table 2.2). General trust became borderline nonsignificant in the fully adjusted model (0.94, 95% CI: 0.87, 1.01). However, after adjusting for individual-level sociodemographic factors, neighborhood deprivation, and population density, higher governmental trust is associated with fewer depressive symptoms (0.70, 95% CI: 0.56, 0.87). Governmental trust did not show significant differences in the magnitudes of the fully-adjusted within- and between-pair effects (p=0.238), suggesting the observed association was not confounded by factors operating between pairs. Random intercept variances are given in the supplemental tables.

Structural social capital

There were no significant within-pair associations for community participation, volunteerism, or social interaction and depression (Table 2.3).

Informal social control and perceptions of safety

Neighbors' willingness to intervene if children were spray-painting graffiti showed a significant within-pair association with depressive symptoms in the unadjusted model; this association was borderline nonsignificant in the model adjusted for individual-level factors and then significant in the fully adjusted model (Table 2.4). Adjusted for individual-level sociodemographics, population density, and neighborhood socioeconomic deprivation, a one-unit difference in this measure of informal social control is associated with 17 percent less depressive symptoms (0.83, 95% CI: 0.70, 0.99).

The within- and between-pair effects were similar for informal social control (p=0.790), suggesting that the association was not influenced by factors differing between pairs. Random intercept variances are given in the supplemental tables.

There were no significant within-pair effects for perceptions of safety and depressive symptoms.

Neighborhood socioeconomic deprivation, social capital, and depression

The unadjusted within-pair association between neighborhood deprivation and depressive symptoms was borderline nonsignifciant, and became completely nonsignificant in the unadjusted models (Table 2.5). After adjusting for individual-level and neighborhood-level covariates, none of the social capital measures moderated the deprivation-depression association (data not shown).

Sense of belonging, neighborhood social cohesion, vertical workplace connections, general trust, governmental trust, and informal social control had all shown significant or borderline nonsignificant within-pair associations with depression in the fully adjusted models; therefore, these six domains were individually added into the fully adjusted neighborhood deprivation model for the mediation analysis. The inclusion of these domains did not substantially change the within-pair effect for neighborhood deprivation (Table 2.5).

DISCUSSION

Social capital and depression

The results of this study suggest that lower cognitive social capital is independently associated with greater risk of depression. Sense of belonging, neighborhood social cohesion, workplace connections, and both general and government trust were associated with decreased depressive symptoms. By contrast, the study does not provide evidence of an association between structural social capital, operationalized as community participation, volunteerism, and social interaction, and depression.

Cognitive and structural social capital are hypothesized to affect mental health through different pathways. Cognitive social capital lends itself more readily to the social support and inequality mechanisms, both of which focus on psychosocial factors. The social support mechanism builds on theories of social isolation and depression,[88] and defines social capital as the extent of social networks

and the norms of support and reciprocity within those networks. The inequality mechanism posits that widening economic inequalities lead to decreased social capital in the form of decreased sense of civic fairness and justice.[12,96] This leads to increased depression due to stress and anxiety resulting from a perceived loss of autonomy and helplessness in the face of obstacles, as well as discrimination and victimization.[35,36]

In contrast to the above mechanisms, linking structural social capital to health often relies on the political economy approach, which argues that social capital can affect access to resources. Groups or individuals with higher social capital can intervene to protect themselves from budget cuts, address governmental or workplace policies, acquire resources from those in positions of power, or offset other financial concerns.[100,101]

Our finding that cognitive social capital was more strongly associated with depression is in agreement with much of the previous literature,[98] and provides support for the hypothesized social support and inequality mechanisms. A related possible explanation suggests that cognitive social capital and depression are more strongly related because they both involve psychosocial processes.[13] It could be that the perceptions of relationships, and not the objective interactions, matter most for depression risk.[112] For example, while the quantitative amount of social interactions within a community may reflect an individual's actual experience, it is the psychological sense of belonging to that community that would most affect depression risk. This hypothesis has some support in the literature; indicators such as perceived social isolation and perceived sense of belonging have been consistently more strongly linked to depression than social interaction.[112]

Although studies of social capital and health have become increasingly prevalent over the past fifteen years, methodological limitations, including confounding and selection bias, remain.[26] Only one previous study has used a twin design to investigate the association between social capital and depression.[91] Fujiwara and Kawachi used a twin-differences model among 944 twin pairs. This model regresses the within-pair difference in outcome on the within-pair difference in exposure, and estimates a within-pair, but not a between-pair, association. The authors reported an inverse association between measures of depressive symptoms and sense of belonging, social trust, and community participation among DZ twins.

These associations were not seen among MZ twins, and the authors further did not find any association between volunteerism and depressive symptoms.

Our results differ somewhat from Fujiwara and Kawachi's; this may be explained in part by differences in the measures used. They measured depressive symptoms by the Composite International Diagnostic Interview Short Form (CIDI-SF). The CIDI-SF is a more comprehensive measure than the PHQ-2; in addition to depressed mood and anhedonia, the CIDI-SF assesses feeling tired, loss of appetite, trouble sleeping, trouble concentrating, and suicidal ideation. Further, although we used identical measures of sense of belonging, volunteerism, and community participation, this study employed a different measure of trust, and included other aspects of social capital as well.

Differences in the results may also have been due to differences in the study population. Although both studies had similar distributions of age and race, participants in our study were more likely to be female and to have a Bachelors degree or higher, and less likely to be married. Our sample also had a greater number and percentage of MZ twins; it is therefore possible that Fujiwara and Kawachi did not find any associations among MZ twins because of power issues.

The twin-differences model used by Fujiwara and Kawachi does not include the twin-pair mean in the equation. Inclusion of the twin-pair mean in the within-between model makes the interpretation of the within-pair effect conditional on the average social capital of the twin pair, and allows us to make inferences about the relative contributions of the within- and between-pair differences.[113] The present study therefore builds on the groundwork laid by Fujiwara and Kawachi to further investigate the associations between social capital and mental health, and extends their study by employing enhanced twin analyses.

Neighborhood socioeconomic deprivation, social capital, and depression

In this study, the association between depression and neighborhood deprivation is borderline nonsignificant. This is likely due to a lack of statistical power; in Chapter One, which has a sample size over three times larger than the subsample used here, the association is significant. However, because this analysis only used twins who had completed the social capital questionnaire, the sample size was substantially reduced.

Despite the lack of a statistically significant association between neighborhood deprivation and depression, we continued with the moderation and mediation analyses because these methods are still valid in the absence of an overall association between exposure and outcome.[110] However, we found no evidence that social capital acted as a mediator or moderator in the neighborhood deprivation-depression association. This contrasts with previous literature. Among studies investigating social capital as a moderator, social capital has been shown to buffer the effect of neighborhood deprivation on health. For example, several studies in the United States and United Kingdom have found that high social capital attenuates the effect of neighborhood deprivation on mental health among disadvantaged neighborhoods, but has little or no effect on the association in more advantaged neighborhoods.[114-117] Our study included both advantaged and disadvantaged neighborhoods in the analysis, which may have obscured an overall finding. To address this concern, we performed a subgroup analysis among deprived neighborhoods; however, we did not find any evidence of moderation by social capital.

Unlike moderation, which is primarily assessed by testing the statistical significance of the interaction terms, mediation has been explored through various methods that span a range of complexity and sophistication. In a cross-sectional study of block-groups in a city in Louisiana, mediation was informally assessed by including bridging social capital measures in a model that regressed depression on neighborhood deprivation. Social capital was significantly associated with depression and changed the magnitude of the regression coefficient for neighborhood deprivation; from this, the authors concluded that bridging social capital served as a mediator in the neighborhood deprivation-depression association.[118]

Some studies have employed more formal methods for testing mediation. A longitudinal study in enumeration districts in Canada used structural equation modeling to show that neighborhood deprivation decreased social cohesion, and this in turn negatively affected maternal depression.[119] A study among census tracts in Montreal, Canada, used a formal method proposed by Krull and MacKinnon for assessing mediation in multilevel models, by which the mediated effect is estimated by multiplying the coefficient of regressing neighborhood deprivation on social capital with the coefficient of regressing social capital on depression.[111].[120] The authors found no association between neighborhood deprivation

and depression for men, but among women, the association existed and was mediated by neighborhood cohesion.

Like the studies in Louisiana and Chicago, we used informal methods for testing mediation. It is possible that the more formal methods, particularly structural equation modeling which is frequently used with twin designs,[45] might give different results. Additionally, as mentioned previously, because of the lack of consensus on the relevant domains of social capital and the best instruments to measure the construct, comparisons of studies are limited.[95] Therefore, differences in the measurement of social capital may explain inconsistent results across studies.

Strengths and Limitations

A strength of this study is the use of a large sample of adult twins, which controls for confounding by genetic and environmental factors shared between twins within a pair. Given that it is not feasible or ethical to randomize individuals to different social environments, a genetically-informed twin model best approximates an experimental design. Further, the use of a community-based registry improves our ability to generalize to other populations. Although there was little racial or ethnic diversity in the sample, there was diversity of income, and twins in the UWTR are generally representative of the Washington State population.

However, a limitation of the study is the use of a cross-sectional design, which raises concerns about reverse causation. This is particularly important because of the inclusion of the informal mediation analysis. The cross-sectional design cannot ensure the necessary temporal order of events; specifically, that the mediator (i.e. social capital) precedes the outcome (i.e. depression), but follows the exposure (i.e. neighborhood deprivation). This calls into question any conclusion about the presence of mediation; at most, we can only evaluate social capital as having some influence on the deprivation-depression association.[121] The temporal sequence of exposure and mediator is of particular concern with neighborhood deprivation and social capital because the two variables may also influence each other, creating a feedback loop that cannot be accurately modeled in a cross-sectional design.

There are additional limitations related to the choice of social capital variables. Because there is no agreed upon definition of social capital, there is disagreement in the literature about whether the domains

frequently measured are in fact part of the construct. This is particularly relevant when considering the role of trust, which has been regarded not only as a domain of the construct, but as both an antecedent to, and a result of, social capital.[122-124] A further critique of questions about trust is that it is unclear if they measure perceptions of trustworthiness or trustfulness, personality, past experience, or the predominant culture. Likewise, trustful attitudes do not necessarily coincide with trusting behavior.[125]

In contrast to some previous studies, we have conceptualized social capital as an individual-level resource in this study. Measures are frequently aggregated (e.g. to the census tract level) to create group-level characteristics for use in multi-level models. Given the relatively low number of individuals living in the same census tract, this method was not feasible. Further, although social capital exists in the social structure and relationships between people and therefore requires a group in which to occur, it is a resource that can be drawn upon by an individual, and therefore can also be conceptualized at the individual level.[36,89] It has further been argued that, conceptually, the greatest value of social capital is at the individual level because it is at this level that it influences health outcomes.[124]

Finally, some theorists criticize commonly used measures of social capital for not including the role of power dynamics, and for ignoring the propagation of social inequity through differential access to social capital within a group and exclusion of those outside a group.[12,122] The inclusion of linking social capital addresses the first concern. That trust in government showed an inverse association with depressive symptoms suggests the importance of explicitly addressing political context when exploring associations between social environment and mental health. However, a single question still may not effectively enumerate the ways in which power differentials affect social capital.[126] Future research should attempt to replicate our governmental trust findings, and to expand the construct of linking social capital to encompass other ways in which individuals interact within a hierarchy.

To address the second critique, there is a growing consensus in public health research that social capital is not inherently beneficial: it can lead to coercion, inhibit individuality, and encourage norms of unhealthy behavior;[127] strong social capital within one group can exclude members of other groups, such as enforcing de facto residential racial segregation or preventing women from accessing resources necessary for employment advancement;[128,129] and it can lead to obligations that place stressful burdens on individuals through norms of behavior and reciprocity.[89]

Additionally, it has been argued that emphasis on social capital might lead to poor public policy by allowing governments to under-invest in economic safety nets in favor of encouraging citizens to become more socially cohesive.[127] It will be important that future research respond to these concerns, and use social capital theory to advocate for addressing inequities in power and wealth.[130]

Conclusion

This study provides evidence of an association between cognitive social capital and depression; however, it does not demonstrate that social capital moderates or mediates the neighborhood socioeconomic deprivation – depression association. Future studies should use more formal mediation models to assess the mechanisms that link neighborhood deprivation, social capital, and depression, and longitudinal designs to address concerns about reverse causation. Further research is needed to elucidate the domains of social capital relevant to mental health, explore whether social capital should be conceptualized as a group- or individual-level resource, and understand how to better include power differentials into analyses.

Figure 2.1 Potential Roles of social capital in the relationship between neighborhood socioeconomic deprivation and depression.

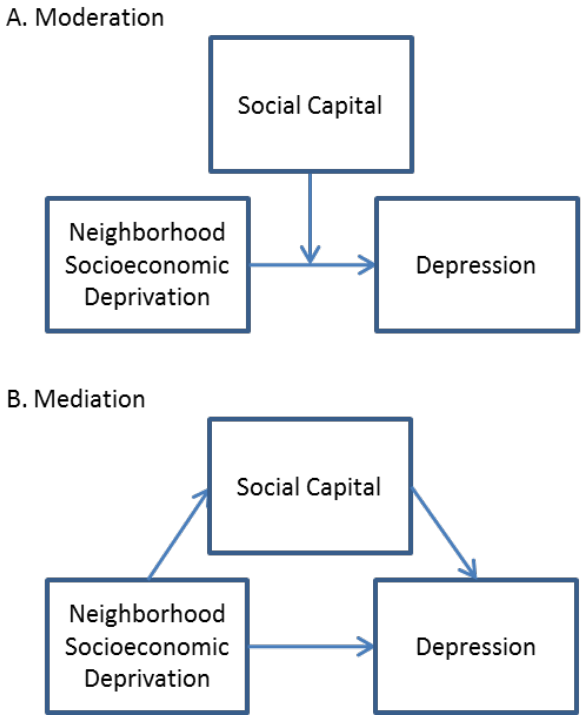

Table 2.1. Select characteristics of adult twins from the University of Washington Twin Registry, stratified by pair completeness.

	Complete Pairs N=1586		Incomplete Pairs N=975		Non-responders N=5569	
	N	**%**[a]	**N**	**%**[a]	**N**	**%**[a]
Age[b]	48.9	16.8	45.8	16.8	39.6	17.3
Male	428	27.0	332	34.1	2047	36.8
White	1503	94.8	914	93.7	5071	91.1
Hispanic	42	2.7	41	4.2	233	4.2
MZ twins	1200	75.7	653	67.0	3894	69.9
Income						
<$60,000	603	38.0	420	43.1	2619	47.0
≥$60,000	983	62.0	555	56.9	2950	53.0
Education						
Less than HS	20	1.3	16	1.6	187	3.4
HS grad	163	10.3	125	12.8	1002	18.0
Some college	466	29.4	324	33.2	2065	37.1
Bachelors or more	933	58.8	507	52.0	2281	41.0
Marital status						
Single	302	19.0	259	26.6	2001	35.9
Living as married	1,051	66.3	602	61.7	2840	51.0
Previously married	196	12.4	106	10.9	660	11.9
PHQ-2[b]	0.68	1.20	0.79	1.32	0.84	1.26
PHQ-2 ≥ 3	108	6.8	83	8.5	470	8.4

[a]Percentages include missing.

[b]Mean ± standard deviation.

Table 2.2. Associations between depression and cognitive social capital among adult twins at the University of Washington Twin Registry, 2015.

	Unadjusted Model			Adjusted Model[a]			Fully Adjusted Model[b]		
	exp(β)	**95% CI**	**P-value**	**exp(β)**	**95% CI**	**P-value**	**exp(β)**	**95% CI**	**P-value**
Sense of belonging									
Between-pair	0.56	0.49, 0.65	<0.001	0.57	0.50, 0.66	<0.001	0.59	0.51, 0.70	<0.001
Within-pair	0.79	0.69, 0.91	0.001	0.80	0.69, 0.92	0.002	0.73	0.62, 0.87	<0.001
Neighborhood cohesion									
Between-pair	0.43	0.36, 0.53	<0.001	0.48	0.39, 0.57	<0.001	0.52	0.42, 0.66	<0.001
Within-pair	0.76	0.63, 0.92	0.004	0.82	0.67, 0.99	0.047	0.73	0.57, 0.94	0.014
Workplace connections									
Between-pair	0.70	0.61, 0.79	<0.001	0.69	0.60, 0.78	<0.001	0.74	0.64, 0.86	<0.001
Within-pair	0.74	0.65, 0.84	<0.001	0.76	0.67, 0.86	<0.001	0.76	0.65, 0.88	<0.001
General trust									
Between-pair	0.84	0.79, 0.89	<0.001	0.85	0.81, 0.90	<0.001	0.87	0.82, 0.93	<0.001
Within-pair	0.90	0.85, 0.96	0.001	0.92	0.87, 0.98	0.007	0.94	0.87, 1.01	0.067
Government trust									
Between-pair	0.69	0.57, 0.84	<0.001	0.76	0.62, 0.93	0.006	0.80	0.65, 1.00	0.050
Within-pair	0.64	0.54, 0.78	<0.001	0.70	0.58, 0.85	<0.001	0.70	0.56, 0.87	0.002

CI confidence interval.
[a]Adjusted for individual-level income, education, and marital status.
[b]Adjusted for individual-level income, education, and marital status, and area-level Singh Index and population density (10,000 people/mile^2).

Table 2.3. Associations between depression and structural social capital among adult twins at the University of Washington Twin Registry, 2015.

	Unadjusted Model			Adjusted Model[a]			Fully Adjusted Model[b]		
	exp(β)	**95% CI**	**P-value**	**exp(β)**	**95% CI**	**P-value**	**exp(β)**	**95% CI**	**P-value**
Volunteering									
Between-pair	1.00	0.99, 1.00	0.401	1.00	0.99, 1.00	0.294	1.00	0.99, 1.01	0.545
Within-pair	0.99	0.99, 1.00	0.177	0.99	0.98, 1.00	0.087	0.99	0.98, 1.01	0.221
Community participation									
Between-pair	0.98	0.97, 0.99	0.001	0.98	0.97, 0.99	0.001	0.98	0.97, 0.99	0.004
Within-pair	0.99	0.98, 1.00	0.108	0.99	0.98, 1.00	0.074	0.99	0.98, 1.01	0.211
Advice									
Between-pair	0.77	0.67, 0.90	0.001	0.84	0.72, 0.98	0.028	0.87	0.73, 1.03	0.108
Within-pair	0.98	0.85, 1.12	0.770	1.00	0.87, 1.15	0.995	0.97	0.82, 1.15	0.752
Social gatherings									
Between-pair	0.84	0.72, 0.99	0.036	1.04	0.98, 1.10	0.171	0.88	0.74, 1.06	0.170
Within-pair	1.08	0.94, 1.24	0.300	1.06	0.99, 1.12	0.078	1.10	0.93, 1.30	0.269

CI confidence interval.
[a]Adjusted for individual-level income, education, and marital status.
[b]Adjusted for individual-level income, education, and marital status, and area-level Singh Index and population density (10,000 people/mile^2).

Table 2.4. Associations between depression and informal social control and perceptions of safety among adult twins at the University of Washington Twin Registry, 2015.

	Unadjusted Model			Adjusted Model[a]			Fully Adjusted Model[b]		
	exp(β)	**95% CI**	**P-value**	**exp(β)**	**95% CI**	**P-value**	**exp(β)**	**95% CI**	**P-value**
Graffiti									
Between-pair	0.72	0.61, 0.84	<0.001	0.79	0.68, 0.94	0.006	0.80	0.67, 0.96	0.019
Within-pair	0.84	0.74, 0.96	0.011	0.88	0.76, 1.02	0.084	0.83	0.70, 0.99	0.033
Safety from crime									
Between-pair	0.74	0.65, 0.85	<0.001	0.79	0.69, 0.90	<0.001	0.85	0.73, 0.99	0.035
Within-pair	0.89	0.79, 1.01	0.063	0.91	0.80, 1.04	0.159	0.88	0.76, 1.03	0.117

CI confidence interval.
[a]Adjusted for individual-level income, education, and marital status.
[b]Adjusted for individual-level income, education, and marital status, and area-level Singh Index and population density (10,000 people/mile^2).

Table 2.5. Associations between depressive symptoms, neighborhood socioeconomic deprivation, and social environment among adult twins at the University of Washington Twin Registry, 2015.

	Unadjusted Model			Adjusted Model[a]			Fully Adjusted Model[b]		
	exp(β)	**95% CI**	**P-value**	**exp(β)**	**95% CI**	**P-value**	**exp(β)**	**95% CI**	**P-value**
Singh Index									
Between-pair	1.04	0.98, 1.10	0.171	1.00	0.95, 1.07	0.872	1.01	0.95, 1.07	0.770
Within-pair	1.06	0.99, 1.12	0.078	1.04	0.98, 1.11	0.194	1.04	0.98, 1.11	0.170
Sense of Belonging									
Singh Index between-pair				1.00	0.94, 1.06	0.987	1.00	0.95, 1.06	0.901
Singh Index within-pair				1.04	0.98, 1.11	0.186	1.04	0.98, 1.11	0.159
Neighborhood Cohesion									
Singh Index between-pair				0.99	0.94, 1.05	0.774	1.00	0.94, 1.05	0.871
Singh Index within-pair				1.02	0.96, 1.08	0.623	1.02	0.96, 1.08	0.568
Workplace Connections									
Singh Index between-pair				1.03	0.97, 1.10	0.296	1.04	0.97, 1.10	0.280
Singh Index within-pair				1.06	0.99, 1.13	0.080	1.06	0.99, 1.13	0.080
General Trust									
Singh Index between-pair				0.99	0.93, 1.05	0.668	0.99	0.93, 1.05	0.763
Singh Index within-pair				1.03	0.96, 1.09	0.445	1.03	0.97, 1.10	0.396
Governmental Trust									
Singh Index between-pair				1.00	0.94, 1.06	0.923	1.00	0.94, 1.07	0.982
Singh Index within-pair				1.03	0.97, 1.10	0.311	1.04	0.97, 1.11	0.278
Graffiti									
Singh Index between-pair				1.00	0.94, 1.06	0.991	1.00	0.95, 1.07	0.900
Singh Index within-pair				1.03	0.97, 1.10	0.303	1.03	0.97, 1.10	0.272

CI confidence interval.
[a]Adjusted for individual-level income, education, and marital status.
[b]Adjusted for individual-level income, education, and marital status, and area-level Singh Index and population density (10,000 people/mile^2).

Chapter Three: Built environment and social capital: an evaluation of New Urbanism principles

ABSTRACT

Introduction: Social capital has become an increasingly important concept in public health, and has been shown to vary across physical space. Despite recognition of the role variations in social capital play in health risk, relatively little attention has been given to understanding the causes of this variation across neighborhoods. Understanding whether the structural features of neighborhood impact social capital may provide additional avenues for intervention such as urban design initiatives.

Methods: We conducted a multilevel Poisson regression analysis of the associations between neighborhood social capital and attributes of the built environment among same-sex twin pairs residing in the Puget Sound region (King, Kitsap, Pierce, and Snohomish counties). Data came from the community-based University of Washington Twin Registry. Built environment variables were measured within a 1666m radius buffer zone around the respondent's geocoded address. The built environment domains included as exposures in the study were neighborhood composition, pedestrian-oriented design, and commercial diversity. Neighborhood social capital was assessed as sense of belonging, neighborhood social cohesion, informal social control, perceived safety, and social interaction. The main coefficient of interest from the twin analysis was the within-pair effect, which inherently controls for shared genetic and childhood environment confounding. Models were adjusted for individual-level income, education, and marital status.

Results: Only property values showed a significant association with any of the neighborhood social capital domains. A $10,000 increase in property value was associated with 4 percent greater sense of belonging (95% CI: 1.01, 1.08), 3 percent greater neighborhood social cohesion (95% CI: 1.01, 1.06), and 8 percent greater sense of perceived safety (95% CI: 1.01, 1.15). However, this association was no longer significant in the adjusted models. No associations were seen between any of the other measures

of neighborhood composition, pedestrian-oriented design, and commercial diversity, and neighborhood social capital.

Conclusion: These results do not support the hypothesis that neighborhood composition, pedestrian-oriented design, and commercial diversity are associated with neighborhood social capital independent of individual-level sociodemographics. There is some evidence to suggest that greater property values may be linked to greater neighborhood social capital; however, results are mixed. Future research should investigate how different built environment variables may interact with each other to influence the creation and maintenance of social capital.

INTRODUCTION

Social capital, here defined as the emotional, economic, and informational resources available through social networks, has been investigated as a risk factor for health outcomes ranging from HIV[92] to heart disease[93] and depression.[94] Increasingly, studies have investigated how social capital varies across physical space; yet they have given relatively little attention to why this variation exists.[131-133] Understanding the underlying reasons for the unequal distribution of social capital is critical for designing interventions such as policy decisions regarding urban design.[134]

Theories about the reason for the unequal distribution of social capital in neighborhoods often build on ideas of New Urbanism,[135] an urban design strategy that promotes dense, pedestrian-oriented neighborhoods with diverse land-use and housing options.[136] These features encourage neighborhood residents to form social ties and engage in neighboring behaviors. In contrast, the traditional suburban subdivision, which contains only houses, requires the use of automobiles to reach commercial and recreational destinations, and often doesn't have sidewalks, discourages residents from spending time in their neighborhood, and eliminates opportunities for informal social interaction.[137] Thus the way in which the neighborhood physical space divides or connects neighbors influences their ability to create and maintain social capital.[138,139]

The residential built environment can be divided into three interrelated domains: neighborhood composition, pedestrian-oriented (i.e. "walkable") design, and commercial diversity. Neighborhood composition encompasses characteristics of the type and number of people who live in a given neighborhood. Examples of these characteristics include residential density and property values. Studies investigating residential density posit that density can create diversity by combining single-family homes and apartments within the same neighborhood, thus facilitating shared space between renters and home owners. Density further provides the critical mass necessary for sustaining public transit options and commercial and retail space.[136] Higher density can facilitate social capital by providing more opportunities for neighborhood residents to interact. Property values measure both an individual or family's wealth and the desirability of a neighborhood. Higher property values are associated with safer and more attractive

neighborhoods, while lower property values are associated with neighborhood stressors such as greater crime and heavy traffic.[140]

In addition to neighborhood composition, much of the previous research has focused on pedestrian-oriented design as an explanatory factor for differences in social capital.[131,133,135,138,141,142] Pedestrian-oriented neighborhoods are characterized by the presence of sidewalks, short blocks with safe street-crossings, and destinations such as shops and parks within easy walking distance.[135,137] Pedestrian-oriented neighborhoods encourage residents to use public space, allowing them to meet casually and spontaneously, and to develop informal relationships with other residents.[134,137,142]

Finally, commercial diversity, or the presence of several different types of amenities, allows neighborhood residents to meet most of their daily needs within the neighborhood, and, in the process, encourages them to interact with other residents.[143] Further, as neighborhood residents access the same amenities, commercial diversity may overcome limitations of spatial distance by connecting people who live in different parts of a neighborhood and would not otherwise interact.[142] This domain often also includes non-commercial locations, such as parks and community centers, which can encourage informal gathering and the creation and maintenance of social ties.[133] However, objective and perceived commercial diversity may differ, and each may uniquely impact the use of amenities, and therefore the creation of social capital.[141]

Despite these theoretical links, evidence for the association between social capital and neighborhood composition, pedestrian-oriented design, and commercial diversity is mixed.[134,144] Additionally, these three constructs are broad and encompass many different features of the built environment, and less is known about which specific features best promote social interaction, and under what circumstances.[138]

Finally, while empirical evidence provides some examples of associations between neighborhood built environment and social capital, there continues to be debate over the composition and context theories raised above.[134,144] Twin designs can help address this concern by inherently controlling for confounding due to shared genetic and childhood environment factors that may be associated with self-selection into neighborhoods and communities.[43] Thus the goal of this study is to examine the associations between specific features of the built environment and several domains of neighborhood social capital to better elucidate the mechanisms by which social capital is unevenly distributed

throughout space. We hypothesized that features of the built environment that followed New Urbanist designs would be associated with higher levels of social capital.

METHODS

Study population

We conducted cross-sectional analyses of the associations between specific constructs of neighborhood social capital and attributes of the built environment. Data came from the University of Washington Twin Registry (UWTR). More in depth details of the UWTR are given in Chapter One; briefly, the UWTR is a community-based registry of adult twins raised together, and contains information on health behaviors and outcomes and environmental exposures.

The study used only same-sex twin pairs. Using standard questions about childhood similarity that have greater than 90% accuracy when compared to DNA-based methods, twins were categorized as either identical (monozygotic, MZ) or fraternal (dizygotic, DZ).[46,47]

In order to link the built environment measures (described below) to individual twins, respondents' home addresses were geocoded using ESRI StreetMapUSA Premium North America NAVETQ 2012 Release 1 (ESRI, Redlands, CA). Approximately 60% of addresses were automatically matched via a software algorithm to a building or parcel centroid, and 20% were matched to a street address using a 100% match score. The remaining 20% were matched manually.

Social capital variables came from the social capital survey described in Chapter Two. Over a ten-week period (February through mid-April, 2015), twins were contacted by paper and electronic surveys asking about their perceived social environment. Only pairs where both members completed the survey were included in the analysis. The survey was sent to all twins with geocoded addresses; however, because the built environment data was only available for twins in the four counties that make up the Puget Sound region (King, Kitsap, Pierce, and Snohomish), this analysis was limited to the 318 individuals residing in that area.

All procedures were reviewed and approved by the university's institutional review board.

Measures

Exposures

The residential neighborhood was defined as a buffer zone with a 1666m radius around the geocoded address, corresponding to a distance walkable in approximately 20 minutes. Buffer zones were captured by "sausage network buffers." The use of sausage network buffers has been described elsewhere.[145] The buffer is created by selecting the street network within 1666m of an individual respondent's home parcel and buffering the road centerline by 100m. This definition of neighborhood corresponds to an individual's access to activities along streets, and can be replicated across different software platforms.

Neighborhood composition. Neighborhood composition was measured by 3 built environment attributes: residential density (residential units / km^2), employment density (total number of employees from major employers / km^2), and average residential property value of the buffer area (total property value within buffer / total number of residential units within the buffer area). Residential density and property values data came from each county's assessor's tax parcel data, and employment data was developed by the Urban Form Lab (UFL) at the University of Washington, as described elsewhere.[146]

Pedestrian-oriented design. Pedestrian-oriented design was measured by two built environment variables: street connectivity (total number of 3- or 4-way intersections within the buffer area) and traffic volume (millions/m). ESRI StreetMapUSA Premium was used to get intersection data while traffic volume came from the Puget Sound Regional Council.

Commercial diversity. Commercial diversity was defined by two variables: perceived and objectively measured access to amenities. Perceived access to amenities was measured as part of the social capital survey. Respondents were asked to select if they had any of the following in their neighborhood: convenience store, grocery store or supermarket, fast food restaurant, other restaurant, park, gym, recreation or community center, doctor or dentist, and a bus stop; responses were summed to create a score ranging from 0 (no amenities) to 9 (all listed amenities). Objectively measured access to amenities used the same above 9 destinations, and measured their presence in the buffer area around a respondent's house. This data was derived from InfoUSA and classified by the UFL.[147]

Outcomes

A full description of all social capital variables, including details of their measurement, is given in Chapter Two. For this study, we selected only variables that assessed neighborhood social capital: sense of belonging, neighborhood social cohesion, neighborhood informal social control, perceived safety of the neighborhood, and neighborhood social interaction.

For sense of belonging and neighborhood social cohesion, respondents rated their agreement (1 Strongly disagree; 2 Disagree; 3 Neutral; 4 Agree; 5 Strongly agree) with several statements. Sense of belonging used the following three statements:[91,102,103] I don't feel I belong to anything I'd call a community; I feel close to other people in my community; My community is a source of comfort. Negative statements were recoded so that greater scores indicated higher social capital, and then responses were summed to create an overall score. The internal consistency (Cronbach's α)[104,105] of the scale in the sample was 0.83.

Neighborhood social cohesion was assessed by five statements:[96,106] People in this neighborhood can be trusted; This is a close-knit neighborhood; People around here are willing to help their neighbors; People in this neighborhood generally don't get along with each other; People in this neighborhood do not share the same values. As with sense of belonging, negative statements were reverse-coded and responses were summed to create an overall score. The internal consistency (Cronbach's α)[104,105] of the scale in the sample was 0.78.

Informal social control was measured by agreement with the statement: Neighbors could be counted on to intervene if children were spray-painting graffiti on a local building.[106] Perceived neighborhood safety was measured by agreement with the statement: My neighborhood is safe from the threat of crime. Responses to both statements followed the same 5-point Likert scale described above.

To measure social interaction, respondents indicated how often (1 Never; 2 Rarely; 3 Sometimes; 4 Often) neighborhood residents held parties or other get-togethers; and how often they asked for advice about personal things such as child-rearing or job openings.[18] The two questions were included separately in the analysis.

Covariates

Confounders including age, sex, and race/ethnicity are inherently controlled for in the twin model and thus not included as covariates in the analysis. Characteristics that can differ between twins within a pair, however, are not inherently controlled for in twin models and thus need to be included as covariates. We decided *a priori* to include current household income, education, and marital status as potential confounders.

Statistical analysis

We employed a multi-level random intercept model for this analysis. The outcome was assumed to follow a Poisson distribution, and the random intercepts accounted for the correlation existing between twins within a pair and individuals within a census tract. The within-pair effects in this model inherently control for genetic and childhood environmental characteristics shared between twins within a pair. To estimate these effects, we used the following equation:[65]

$$\log(\lambda_{ij}) = \beta_0 + \beta_B{*}x_i + \beta_W{*}(x_{ij} - x_i) + \mu_{k[ij]} + \mu_i$$

where λ_{ij} denotes the social capital domain for twin *j* in pair *i.* The features of the built environment are given in x_i ,the mean built environment of twin-pair *i*, and $(x_{ij} - x_i)$, the individual twin's deviation from their twin-pair mean. Random intercepts $\mu_{k[ij]}$ and μ_i represent census tract and twin pair, respectively.

As mentioned above, the model's within-pair effect (β_W) is not subject to confounding by genetic or childhood environmental factors shared between twins within a pair. When exponentiated, it can be interpreted as the ratio of an individual's social capital score associated with a one-unit difference in built environment, conditional on the mean built environment of the twin-pair. The between-pair effect, β_B, represents the extra variation in social capital due to differences between twin pairs.[65]

We began by regressing each social capital variable on each built environment variable (unadjusted, Model A). We then added our hypothesized confounders of household income, education, and marital status to the model (Model B).

All probability values were 2-sided, and the significance level was set at 0.05. The analysis was done in STATA Release 13 (StataCorp, College Station, TX).

RESULTS

Sociodemographics characteristics of the sample are given in Table 3.1. The majority of twins were female (67%), non-Hispanic White (96%), and members of a monozygotic pair (77%). Compared to the overall sample of complete pairs used in Chapter Two (N=1586), the twins in this sample were more likely to have higher incomes (72% vs. 62%), to have earned a Bachelors degree or higher (63% vs. 59%), and to be single (24% vs. 19%).

Table 3.2 presents means and standard deviations for the selected built environment characteristics. There were similar mean levels of residential and employment density in the sample, but employment density had far greater variation, as measured by the standard deviation. The correlation between the two measures of density was 0.73, (95% CI: 0.68, 0.78). Subjective and objective access to amenities also had similar means (6.3 vs. 6.7, respectively); however, the correlation between the two measures was only 0.22, (95% CI: 0.12 to 0.32).

Among the built environment measures, only average property value showed a within-pair association with any of the social capital variables (Table 3.3). In the unadjusted models, a $10,000 increase in property value was associated with 4 percent greater sense of belonging (95% CI: 1.01, 1.08), 3 percent greater neighborhood social cohesion (95% CI: 1.01, 1.06), and 8 percent greater sense of perceived safety (95% CI: 1.01, 1.15). When the covariates were added into the model, the association became nonsignificant for sense of belonging and social cohesion, and borderline nonsignficant for perceived safety. Further, the association between property values and seeking advice from neighbors was borderline nonsignficant in the unadjusted model (1.07, 95% CI: 1.00, 1.08, p=0.061).

The between-pair associations were significant in both the adjusted and unadjusted models for sense of belonging, frequency of neighborhood gatherings, and seeking advice from neighbors, providing evidence that some extra variation in these three social capital variables was due to differences operating between twin pairs (Table 3.3).

The variances of the twin pair and census tract intercepts were 0 to five decimal places in all models (data not shown).

DISCUSSION

The results of this study do not provide evidence supporting the principles of New Urbanism that neighborhood composition, pedestrian-oriented design, and commercial diversity are associated with neighborhood social capital. Of the neighborhood composition variables, only property values was significantly associated with any measure of social capital. It may be that property values and density should not be included in the same domain as they measure distinctly different characteristics of the neighborhood. Property values explicitly include a measure of socioeconomic status, while the associations between density and socioeconomic status are less clear. Further, New Urbanism does not make specific claims about property values as a measure of neighborhood composition, and research exploring associations between property value and residential density have inconclusive findings.[148-151] It is therefore possible that wealth matters more than other neighborhood composition factors.

The associations between property values and neighborhood social capital became nonsignificant when adjusting for income, education, and marital status, providing further evidence of the importance of wealth. These findings suggest that the sociodemographic covariates may measure a similar construct to property values; however, it does not necessarily mean that property values have no causal effect on social capital. As a proxy for neighborhood quality, property value can influence the opportunities available to neighborhood residents, and facilitate or impede their ability to attain higher socioeconomic position.

Although previous public health studies have shown associations between measures of socioeconomic status and health, property values have only recently been adopted as a wealth metric. Property value can represent a substantial percentage of an individual or family's wealth, and may be a more accurate measure of economic security than income or employment.[140] Among low-income families, home equity can represent half of a family's total net wealth.[152] Property values also correlate highly with measures of neighborhood socioeconomic status, and have the added benefit of not being subject to administrative boundaries, but can be calculated for an individual's home, or as an average over a certain buffer zone.[153] They have been linked to health behaviors and outcomes in other studies, including cardiometabloic risk score[152], body mass index and obesity[140,154] diet,[155] general health,[153] and

mortality.[156] Compared to other measures of neighborhood socioeconomic status, property values have been shown to better predict self-rated general health.[153]

Although property values may serve as a useful wealth metric, they are affected by more than just the value of the home. They can be sensitive to the presence or absence of specific neighborhood attributes; a study conducted in Seattle found that areas with lower property values were more likely to have greater crime and heavy traffic, and to be closer to bars and liquor stores, fast-food restaurants, convenience stores, and supermarkets, while neighborhoods with higher property values were more likely to be perceived as safe and attractive and close to parks, trails, and other recreational areas.[140] Further, the measure of property value used in this study was the average value of the 1666m buffer zone. Instead of providing the individual value for a given residence, this measure represents the average value of the neighborhood, and may therefore serve as a better proxy for the neighborhood built environment.

Social capital was not associated with any of the other measures of neighborhood composition; nor was it associated with any of the measures in the pedestrian-oriented design or commercial diversity domains. Findings from previous studies have been mixed. For neighborhood composition, results regarding residential density are particularly inconclusive. Density has been linked to both an increased and decreased sense of community,[138,144] and has shown no association with other social capital measures including trust, norms of reciprocity, and organizational membership.[131,134]

Some studies have linked pedestrian-oriented design and perceived walkability to greater social capital variables such political participation, trust, and social engagement[137] and sense of community.[138,144] Social capital has also been positively linked to higher commercial floor area ratio, sometimes used as a measure of walkability because it represents places with shops closer to the sidewalk and less land devoted to parking lots.[134] Despite these positive findings, other studies have found no association between street-connectivity and social capital.[131,134]

Finally, studies have shown positive associations between sense of community and net retail in a neighborhood,[144] and between trust, norms of reciprocity, and attachment to place and land use mix and number of neighborhood parks.[131] Yet studies have also found no association between access to parks and social cohesion and informal social control.[157]

A final concern when interpreting the results of such studies is that the neighboring behaviors often measured do not necessarily translate into increased social capital. For example, one found that while residents of neighborhoods that followed New Urbanist designs experienced greater social interaction and engagement in outside activity than those living in more traditional suburbs, both groups had an equal sense of community. [136]

Differences in study results may also be due to differences in how the built environment variables are measured. For example, commercial diversity can be operationalized in different ways. This construct can be measured as self-reported use of, and not only access to, different destinations.[142,158] Commercial diversity may be modeled separately or combined with other characteristics into a single walkability score.[131] It can further be measured objectively through GIS techniques or subjectively by self-report.[141] Finally, the choice of amenities included in the measure can vary across studies, ranging from just commercial and retail places to including parks and public transit.[137,159]

Studies further differ in whether the quality of amenities is taken into consideration in the measures used. For example, most studies, ours included, do not consider the different ways in which parks are used, or the characteristics such as maintenance and aesthetics that may encourage or deter residents from visiting neighborhood parks.[139,160] Additionally, while neighborhood destinations allow people to meet and form social ties, if people come from outside the neighborhood to use these destinations, the social capital they form may not be an aspect of the neighborhood, but rather of the amenity itself.[134,160]

Finally, differences in the studies' conceptual models may impact observed associations. In this study, perceived safety was conceptualized as a social capital outcome variable. However, perceived safety can influence how a person uses and responds to their neighborhood; residents must believe their neighborhood is safe before they are willing to use it.[141,143,159] Thus associations between built environment and neighborhood social resources may rely on levels of perceived safety.[159] This potential for interaction extends beyond perceived safety; attitudes about, and perceptions of, the neighborhood can also moderator associations.[135,159]

In addition to the above explanations, it may be possible that the specific measures of the built environment included in this study were not linked to social capital because the associations between built and social environment are complex, and cannot be adequately captured in a single variable.

Further, these complex associations may be influenced by an individual's resources, including economic and material capital. Because average neighborhood property values are dependent not only on characteristics of the home, but also on the neighborhood in which the home resides, the variable encompasses both family socioeconomic status and characteristics of the residential environment, creating a more comprehensive measure.

Strengths and Limitations

A strength of this study is the use a genetically-informed twin model, which inherently controls for genetic and childhood environmental confounding due to factors shared between twins within a pair. Given the observational nature of the data, this type of twin study best approximates an experimental design.

Another strength is the use of geographic buffers around residential addresses to approximate neighborhoods. In the literature, neighborhood is primarily operationalized by administrative boundaries such as census tracts, with all residents of a census treat treated as though they are equally exposed to the built environment. Geographic buffers based on street networks more accurately represent a respondent's neighborhood.[131]

The main limitation of this study is its cross-sectional design, which prevents us from ruling out the possibility of reverse causation, or the outcome causing the exposure. A related limitation of neighborhood studies is residential self-selection, whereby people with certain characteristics select into specific neighborhoods. In such a scenario, people with higher social capital would choose to live in neighborhoods with higher property values. Although controlling for shared genetic and childhood environment factors and adult income, education, and marital status allows us to partially addresses these concerns, future research should use longitudinal designs to strengthen causal inference.

Additionally, the inclusion of income in the adjusted property value models poses some concerns. Given the correlation between property values and individual-level income, the inclusion of income may have decreased statistical power due to over-adjustment of the model. We addressed this possibility by removing income from the model; however, this did not substantially change our results. It is further possible that our hypothesized relationship between income, property values, and social capital does not

accurately reflect the mechanisms at play. Rather than income confounding the property value-social capital association, property values may mediate the income-social capital association. Future research should focus on disentangling the relationships between these different measures of wealth.

Conclusion

This study does not provide evidence supporting the principles of New Urbanism that neighborhood composition, pedestrian-oriented design, and commercial diversity of the neighborhood are associated with social capital; however, it suggests that property values may be associated with some measures of social capital, independent of shared genetic and childhood environment factors. Future research should consider how each built environment variable may interact with other environment and family characteristics to influence social capital. Studies should also consider how built environment variables are measured. Some characteristics may be more important to the formation of social capital than others.

Table 3.1. Select characteristics of adult twins residing in the Puget Sound region[a], University of Washington Twin Registry, 2009-2013.

	Twins in Sample N=318		All Twins N=2392	
	N	**%[b]**	**N**	**%[b]**
Age[c]	45.7	15.4	42.1	15.6
Male	73	23.0	866	36.2
White	297	96.2	2135	89.3
Hispanic	10	3.1	84	3.5
Monozygotic	244	76.7	1360	56.4
Income				
<$60,000	85	26.7	1108	46.3
≥$60,000	228	71.7	1284	53.7
Education				
Less than HS	1	0.3	41	1.7
HS grad	26	8.2	297	12.4
Some college	91	28.6	866	36.2
Bachelors or more	200	62.9	1188	49.7
Marital status			NA[d]	NA[d]
Single	75	23.6		
Living as married	203	62.8		
Previously married	32	10.1		

[a]King, Kitsap, Peirce, and Snohomish counties.
[b]Percentages include missing.
[c]Mean ± standard deviation.
[d]Data not available for individuals who did not complete the social capital survey.

Table 3.2. Select characteristics of the built environment linked geocoded addresses of adult twins residing in the Puget Sound region[a] , University of Washington Twin Registry, 2009-2013.

	Twins in Sample N=318		All Twins N=2392	
	Mean	**St. Dev**	**Mean**	**St. Dev**
Residential density (count/km^2)	1056.4	752.6	1103.2	849.2
Employment density (count/ km^2)	1065.9	2579.6	1299.3	3648.0
Property value (in thousands)[b]	292.5	125.6	281.6	133.7
3- and 4-way intersections (in ten thousands)	278.4	237.9	293.2	266.6
Traffic volume (millions/m)	186.8	224.8	218.3	282.8
Subjective access to amenities	6.3	2.7	NA[c]	NA[c]
Objective access to amenities	6.7	3.1	6.7	3.0

[a]King, Kitsap, Peirce, and Snohomish counties.
[b]Mean property value per buffer area
[c]Data not available for individuals who did not complete the social capital survey.

Table 3.3. Associations between property values and social capital domains among adult twins residing in the Puget Sound region[a], University of Washington Twin Registry, 2009-2013.

	Unadjusted Model			Adjusted Model[b]		
	exp(β)	**95% CI**	**P-value**	**exp(β)**	**95% CI**	**P-value**
Sense of belonging						
Property value between-pair	1.05	1.02, 1.09	0.002	1.06	1.03, 1.10	0.001
Property value within-pair	1.04	1.01, 1.08	0.016	1.02	0.99, 1.06	0.177
Neighborhood social cohesion						
Property value between-pair	1.02	1.00, 1.05	0.077	1.03	1.00, 1.06	0.077
Property value within-pair	1.03	1.00, 1.06	0.035	1.01	0.98, 1.04	0.358
Informal control[c]						
Property value between-pair	1.02	0.96, 1.08	0.541	1.04	0.97, 1.11	0.268
Property value within-pair	1.05	0.99, 1.11	0.121	1.03	0.96, 1.09	0.407
Neighborhood safety						
Property value between-pair	1.02	0.96, 1.09	0.474	1.02	0.95, 1.10	0.576
Property value within-pair	1.08	1.00, 1.15	0.024	1.07	1.00, 1.14	0.064
Social gatherings						
Property value between-pair	1.09	1.01, 1.17	0.019	1.10	1.01, 1.19	0.024
Property value within-pair	1.02	0.95, 1.10	0.516	1.01	0.93, 1.09	0.898
Advice						
Property value between-pair	1.10	1.02, 1.09	0.011	1.12	1.03, 1.10	0.008
Property value within-pair	1.07	1.01, 1.08	0.061	1.03	0.99, 1.06	0.496

CI confidence interval.
[a]King, Kitsap, Peirce, and Snohomish counties
[b]Adjusted for individual-level income, education, and marital status.
[c]Measured by agreement the statement "Neighbors could be counted on to intervene if children were spray-painting graffiti on a local building."

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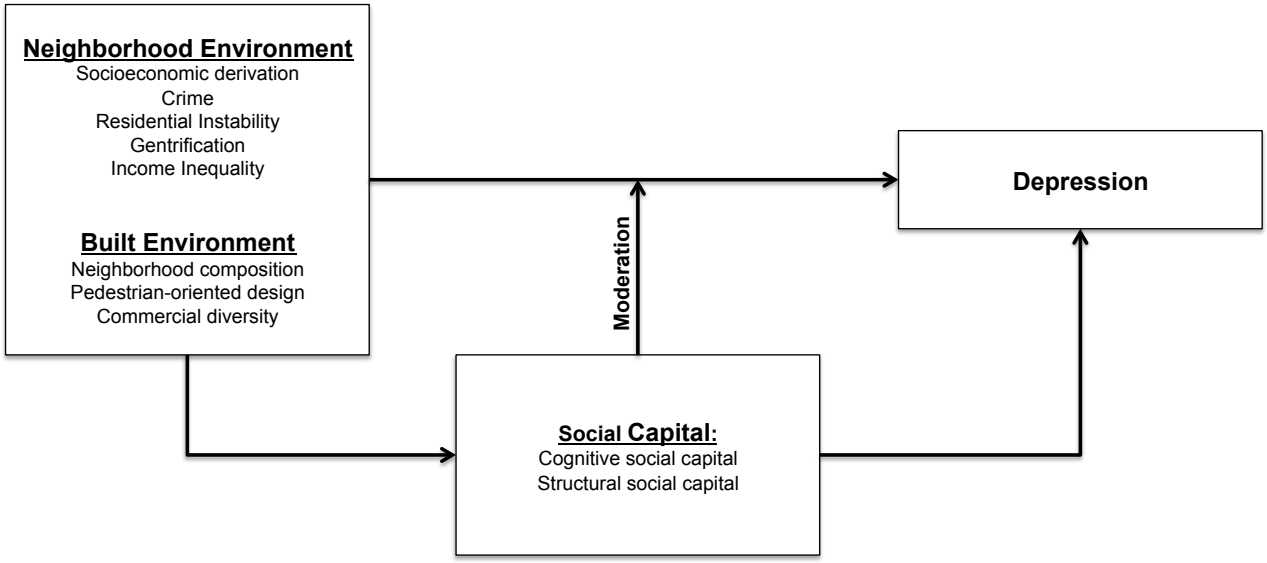
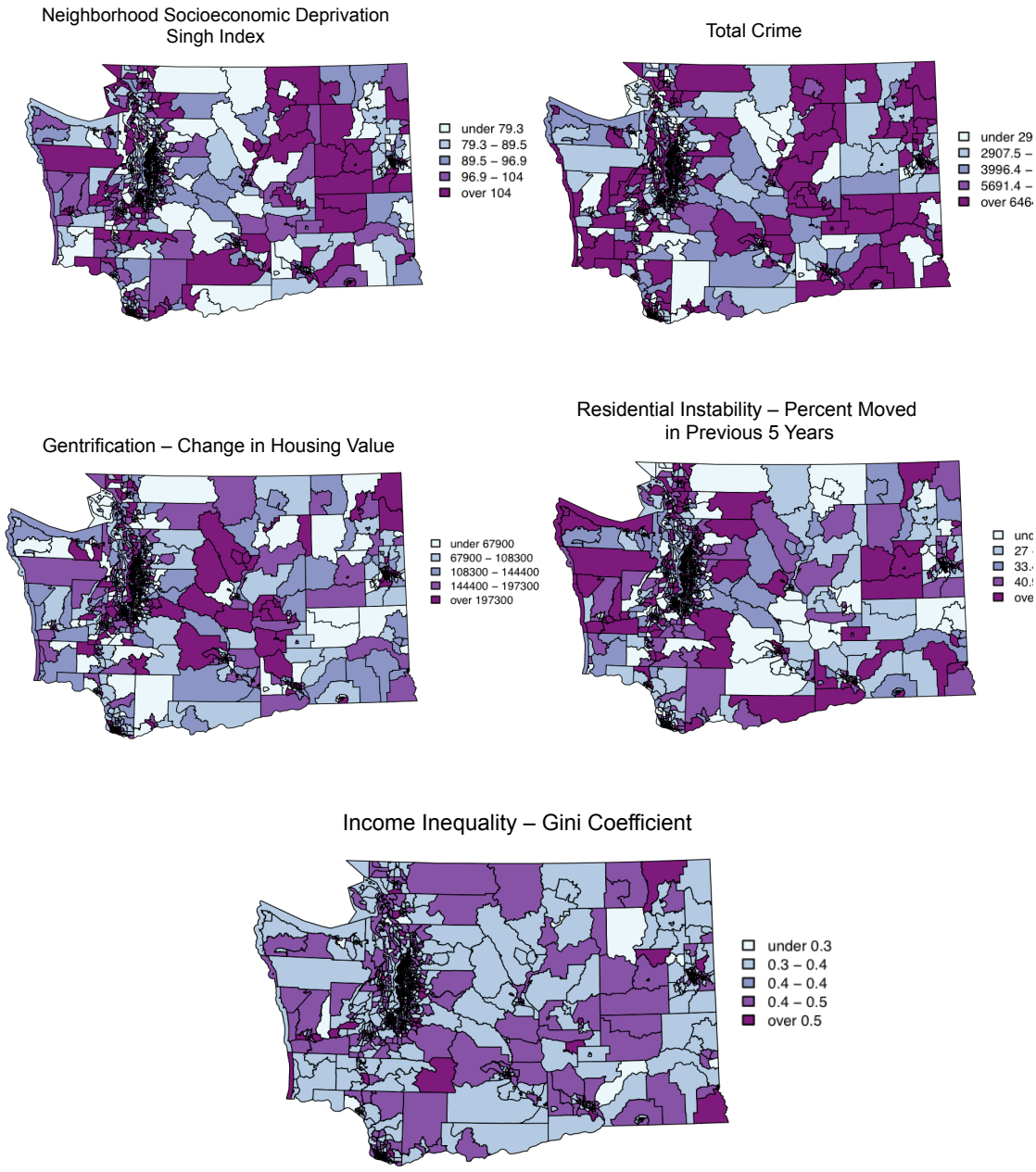
Appendix A: Conceptual model linking neighborhood characteristics, features of the built environment, social capital, and depression.



Appendix B: Supplemental Figures and Tables

Figure S.1. Washington State spatial distribution of the five neighborhood exposures from Chapter One: neighborhood socioeconomic deprivation, crime, gentrification, residential instability, and income inequality.



Supplemental Tables for Aim 1.

Table S.1. Range of the neighborhood characteristics among adult twins in the University of Washington Twin Registry, 2009-2013.

	Mean	St. Dev	Min	Max
Singh Index	89.1	20.6	-52.8	128.8
Crime Index	4854.3	2016.6	756.8	20089.0
Percent moved within 5 years	38.9	14.1	0.0	100.0
Change in median home value	137572.9	92804.7	-392900.0	912400.0
Gini index	0.4	0.1	0.2	0.8

Table S.2. Individual deviation from the within-pair mean of neighborhood characteristics among adult twins in the University of Washington Twin Registry, 2009-2013.

	Mean	St. Dev	Min	Max
Singh Index	11.1	21.6	-61.8	63.4
Crime Index	885.2	1512.6	-9378.7	9378.7
Percent moved within 5 years	0.0	8.4	-37.7	38.8
Change in median home value	12787.0	57720.0	-401850.0	448850.0
Gini index	0.0	0.0	-0.2	0.3

Supplemental Table for Aim 2.

Table S.3. Variances of the census tract and twin-pair random intercepts for the social capital variables significantly associated with depression among adult twins at the University of Washington Twin Registry, 2015.

	Unadjusted Model		Adjusted Model[a]		Fully Adjusted Model[b]	
	Census tract	Twin-pair	Census tract	Twin-pair	Census tract	Twin-pair
Sense of belonging	0.85	0.53	0.79	0.49	0.74	0.45
Neighborhood social cohesion	0.83	0.52	0.77	0.53	0.81	0.41
Vertical workplace connections	0.94	0.45	0.88	0.38	0.82	0.37
Governmental trust	0.72	0.79	0.67	0.69	0.64	0.69
Informal social control	0.85	0.69	0.77	0.55	0.77	0.55

[a]Adjusted for individual-level income, education, and marital status.

[b]Adjusted for individual-level income, education, and marital status, and area-level Singh Index and population density (10,000 people/mile^2).

Supplemental Table for Aim 3.

Table S.4. Associations between sense of belonging and characteristics of the built environment among adult twins residing in the Puget Sound region[a] University of Washington Twin Registry, 2009-2013.

	Unadjusted Model			Adjusted Model[b]		
	exp(β)	**95% CI**	**P-value**	**exp(β)**	**95% CI**	**P-value**
Population density						
Between-pair	1.01	0.95, 1.07	0.835	1.01	0.94, 1.08	0.864
Within-pair	1.00	0.93, 1.07	0.994	0.98	0.91, 1.05	0.510
Employment density						
Between-pair	1.00	0.98, 1.02	0.685	0.99	0.98, 1.01	0.606
Within-pair	0.99	0.97, 1.01	0.399	0.99	0.97, 1.01	0.303
Intersections						
Between-pair	1.01	0.98, 1.03	0.572	1.01	0.98, 1.03	0.594
Within-pair	1.00	0.973, 1.02	0.835	0.99	.96, 1.02	0.444
Traffic volume						
Between-pair	1.00	0.99, 1.00	0.527	1.00	1.00, 1.00	0.441
Within-pair	1.00	0.99, 1.00	0.889	1.00	1.00, 1.00	0.612
Subjective access to amenities						
Between-pair	1.01	0.99, 1.02	0.250	1.01	1.00, 1.03	0.141
Within-pair	1.00	0.99, 1.02	0.587	1.00	0.98, 1.02	0.945
Objective access to amenities						
Between-pair	1.00	0.99, 1.01	0.817	1.00	0.99, 1.01	0.978
Within-pair	1.00	0.99, 1.02	0.586	1.00	0.98, 1.01	0.744

CI confidence interval.
[a]King, Kitsap, Peirce, and Snohomish counties
[b]Adjusted for individual-level income, education, and marital status.

Table S.5. Associations between neighborhood social cohesion and characteristics of the built environment among adult twins residing in the Puget Sound region[a], University of Washington Twin Registry, 2009-2013.

	Unadjusted Model			Adjusted Model[b]		
	exp(β)	**95% CI**	**P-value**	**exp(β)**	**95% CI**	**P-value**
Population density						
Between-pair	1.00	0.95, 1.05	0.963	1.00	0.95, 1.06	0.911
Within-pair	1.00	0.95, 1.06	0.910	0.99	0.93, 1.05	0.644
Employment density						
Between-pair	1.00	0.99, 1.02	0.992	1.00	0.98, 1.02	0.964
Within-pair	1.00	0.98, 1.01	0.729	1.00	0.98, 1.01	0.602
Intersections						
Between-pair	1.00	0.98, 1.02	0.895	1.00	0.99, 1.02	0.680
Within-pair	1.00	0.98, 1.02	0.776	0.99	0.97, 1.01	0.399
Traffic volume						
Between-pair	1.00	1.00, 1.00	0.369	1.00	1.00, 1.00	0.437
Within-pair	1.00	1.00, 1.00	0.447	1.00	1.00, 1.00	0.240
Subjective access to amenities						
Between-pair	1.00	0.99, 1.01	0.822	1.00	0.99, 1.01	0.898
Within-pair	1.00	0.99, 1.01	0.887	0.99	0.98, 1.01	0.413
Objective access to amenities						
Between-pair	1.00	0.98, 1.01	0.603	1.00	0.99, 1.01	0.904
Within-pair	1.00	0.99, 1.01	0.652	0.99	0.98, 1.00	0.214

CI confidence interval.
[a]King, Kitsap, Peirce, and Snohomish counties
[b]Adjusted for individual-level income, education, and marital status.

Table S.6. Associations between informal control[a] and characteristics of the built environment among adult twins residing in the Puget Sound region[b], University of Washington Twin Registry, 2009-2013.

	Unadjusted Model			Adjusted Model[c]		
	exp(β)	**95% CI**	**P-value**	**exp(β)**	**95% CI**	**P-value**
Population density						
Between-pair	0.92	0.83, 1.03	0.141	0.95	0.84, 1.07	0.393
Within-pair	1.00	0.88, 1.14	0.982	0.98	0.86, 1.11	0.748
Employment density						
Between-pair	0.98	0.94, 1.01	0.242	0.98	0.95, 1.02	0.361
Within-pair	1.00	0.96, 1.04	0.890	0.99	0.95, 1.04	0.779
Intersections						
Between-pair	0.97	0.93, 1.01	0.099	0.98	0.94, 1.02	0.338
Within-pair	1.00	0.95, 1.04	0.864	0.99	0.94, 1.03	0.547
Traffic volume						
Between-pair	1.00	1.00, 1.00	0.148	1.00	1.00, 1.00	0.357
Within-pair	1.00	1.00, 1.00	0.971	1.00	1.00, 1.00	0.699
Subjective access to amenities						
Between-pair	0.99	0.97, 1.02	0.518	0.99	0.97, 1.02	0.683
Within-pair	1.00	0.98 1.03	0.799	1.00	0.97, 1.02	0.732
Objective access to amenities						
Between-pair	0.98	0.96, 1.00	0.091	0.99	0.97, 1.01	0.427
Within-pair	0.99	0.97, 1.02	0.701	0.99	0.96, 1.02	0.426

CI confidence interval.
[a]Measured by agreement the statement "Neighbors could be counted on to intervene if children were spray-painting graffiti on a local building."
[b]King, Kitsap, Peirce, and Snohomish counties
[c]Adjusted for income, education, and marital status.

Table S.7. Associations between perceived neighborhood safety and characteristics of the built environment among adult twins residing in the Puget Sound region[a], University of Washington Twin Registry, 2009-2013.

	Unadjusted Model			Adjusted Model[b]		
	exp(β)	**95% CI**	**P-value**	**exp(β)**	**95% CI**	**P-value**
Population density						
Between-pair	0.96	0.85, 1.08	0.470	0.94	0.82, 1.07	0.359
Within-pair	1.00	0.87, 1.16	0.952	0.98	0.85, 1.14	0.798
Employment density						
Between-pair	1.00	0.97, 1.04	0.823	1.00	0.97, 1.04	0.913
Within-pair	0.99	0.95, 1.03	0.496	0.98	0.95, 1.02	0.442
Intersections						
Between-pair	0.98	0.94, 1.03	0.473	0.98	0.94, 1.03	0.392
Within-pair	1.00	0.95, 1.05	0.959	0.99	0.94, 1.05	0.795
Traffic volume						
Between-pair	1.00	1.00, 1.00	0.544	1.00	1.00, 1.00	0.478
Within-pair	1.00	1.00, 1.00	0.703	1.00	1.00, 1.00	0.594
Subjective access to amenities						
Between-pair	0.98	0.95, 1.01	0.227	0.98	0.95, 1.01	0.194
Within-pair	1.00	0.97, 1.03	0.969	0.99	0.96, 1.03	0.737
Objective access to amenities						
Between-pair	0.99	0.96, 1.01	0.233	0.98	0.96, 1.01	0.250
Within-pair	1.00	0.97, 1.03	0.887	0.99	0.96, 1.02	0.634

CI confidence interval.
[a]King, Kitsap, Peirce, and Snohomish counties
[b]Adjusted for income, education, and marital status.

Table S.8. Associations between frequency of neighborhood gatherings and characteristics of the built environment among adult twins residing in the Puget Sound region[a], University of Washington Twin Registry, 2009-2013.

	Unadjusted Model			Adjusted Model[b]		
	exp(β)	**95% CI**	**P-value**	**exp(β)**	**95% CI**	**P-value**
Population density						
Between-pair	0.99	0.86, 1.13	0.835	1.00	0.86, 1.17	0.953
Within-pair	0.94	0.80, 1.11	0.456	0.93	0.79, 1.10	0.385
Employment density						
Between-pair	0.99	0.95, 1.03	0.629	0.99	0.95, 1.04	0.701
Within-pair	1.00	0.95, 1.05	0.936	1.00	0.95, 1.05	0.866
Intersections						
Between-pair	1.00	0.95, 1.05	0.938	1.01	0.96, 1.06	0.762
Within-pair	0.98	0.92, 1.03	0.412	0.97	0.91, 1.03	0.326
Traffic volume						
Between-pair	1.00	1.00, 1.00	0.631	1.00	1.00, 1.00	0.784
Within-pair	1.00	1.00, 1.00	0.641	1.00	1.00, 1.00	0.566
Subjective access to amenities						
Between-pair	1.02	0.98, 1.05	0.315	1.02	0.99, 1.06	0.221
Within-pair	1.00	0.96, 1.04	0.973	0.99	0.96, 1.03	0.724
Objective access to amenities						
Between-pair	1.00	0.97, 1.03	0.998	1.01	0.97, 1.04	0.744
Within-pair	0.99	0.95, 1.02	0.435	0.98	0.95, 1.02	0.318

CI confidence interval.
[a]King, Kitsap, Peirce, and Snohomish counties
[b]Adjusted for income, education, and marital status.

Table S.9 Associations between frequency of seeking advice and characteristics of the built environment among adult twins residing in the Puget Sound region[a], University of Washington Twin Registry, 2009-2013.

	Unadjusted Model			Adjusted Model[b]		
	exp(β)	**95% CI**	**P-value**	**exp(β)**	**95% CI**	**P-value**
Population density						
Between-pair	1.02	0.89, 1.16	0.825	1.02	0.87, 1.18	0.844
Within-pair	0.99	0.85, 1.17	0.941	0.94	0.80, 1.11	0.475
Employment density						
Between-pair	1.00	0.96, 1.04	0.901	0.99	0.95, 1.04	0.760
Within-pair	0.98	0.94, 1.03	0.496	0.98	0.93, 1.03	0.424
Intersections						
Between-pair	1.01	0.96, 1.06	0.765	1.01	0.96, 1.06	0.685
Within-pair	1.00	0.94, 1.05	0.915	0.98	0.92, 1.04	0.472
Traffic volume						
Between-pair	1.00	1.00, 1.00	0.455	1.00	1.00, 1.00	0.399
Within-pair	1.00	1.00, 1.00	0.671	1.00	1.00, 1.00	0.396
Subjective access to amenities						
Between-pair	1.01	0.97, 1.04	0.770	1.01	0.98, 1.05	0.535
Within-pair	1.01	0.98, 1.05	0.425	1.00	0.96, 1.04	0.946
Objective access to amenities						
Between-pair	1.00	0.97, 1.03	0.950	1.00	0.97, 1.03	0.979
Within-pair	1.01	0.97, 1.04	0.759	0.99	0.96, 1.03	0.589

CI confidence interval.
[a]King, Kitsap, Peirce, and Snohomish counties
[b]Adjusted for income, education, and marital status.