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Effects of Neighborhood Walkability on Healthy Weight: Assessing Selection and Causal Influences

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Abstract

Studies that examine the relationship between neighborhood characteristics and weight are limited because residents are not randomly distributed into neighborhoods. If associations are found between neighborhood characteristics and weight in observational studies, one cannot confidently draw conclusions about causality. We use data from the Utah Population Database (UPDB) that contain body mass index (BMI) information from all drivers holding a Utah driver license to undertake a cross-sectional analysis that compares the neighborhood determinants of BMI for youth and young adults. This analysis assumes that youth have little choice in their residential location while young adults have more choice. Our analysis makes use of data on 53,476 males and 47,069 females living in Salt Lake County in 2000. We find evidence of residential selection among both males and females when BMI is the outcome. The evidence is weaker when the outcomes are overweight or obesity. We conclude that studies that ignore the role of residential selection may be overstating the causal influence of neighborhood features in altering residents' BMI.

Obesity and overweight are growing public health problems. An estimated 66% of US adults are overweight or obese (National Institute of Diabetes Digestive and Kidney 2007) with up to 280,000 annual deaths attributable to obesity (Allison, Fontaine et al. 1999; Flegal, Graubard et al. 2005). In the past twenty years the obesity rate among adolescents aged 12 to 19 more than tripled, increasing from 5% to 17.6% (Ogden, Carroll et al. 2008). Obesity is related to other health problems, such as diabetes and cardiovascular disease, as well as social costs (Ogden, Yanovski et al. 2007) and economic costs (Finkelstein, Ruhm et al. 2005).

Researchers have accordingly begun to assess the role that obesogenic physical environments may play in affecting this upward trend in obesity/overweight (Jeffery and Utter 2003). Yet, observational studies that make causal statements linking the physical environment to the risk of overweight or obesity are limited by the fact that residents do not randomly select their neighborhoods. If significant associations are found between neighborhood characteristics and residents' overweight and obesity risks in observational studies, one cannot confidently draw conclusions about the causal effects of neighborhood characteristics. Neighborhood features may prevent or reduce overweight and obesity by

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encouraging people to be more physically active or choose healthier diets. Alternatively, individuals with healthy body mass indices (BMIs) may choose neighborhoods that support their pre-existing healthy lifestyle.

To assess whether residents select themselves into neighborhoods in a manner that may induce an association between individual-level BMI and neighborhood characteristics, we use cross-sectional analyses to compare associations between neighborhood characteristics and risks of overweight or obesity among youth and young adult, using driver license data from the Utah Population Database (UPDB). These data are invaluable because they contain population-level information on height, weight, and residential location. This analysis assumes that youth living at home with parents have far less control over their residential locations compared to young adults. As young adults, residential location choices reflect more of their own preferences for physical activity, as well as other factors such as proximity to kin, work, open space, and food-related businesses, and various social, economic, and cultural amenities of the neighborhood. Under these assumptions, neighborhood characteristics are viewed as an exogenous determinant of youth BMI (Ewing, Brownson et al. 2006). This suggests that comparisons of age-specific regressions (youth versus young adults) that relate neighborhood characteristics to individual BMI can shed light on the presence and strength of neighborhood selection bias in studies examining neighborhood effects of overweight and obesity.

Neighborhood Characteristics and BMI

Past research has found relationships among walkable neighborhood designs, support for physical activity and healthy eating, and the risk of being overweight and/or obese (see reviews by Papas, Alberg et al. 2007; Saelens and Handy 2008). Many studies use a range of walkability measures and find selected support for the association between BMI and the “3-Ds” of walkability: density, land use diversity, and pedestrian-friendly design. Specifically, some research has linked higher density neighborhoods to lower BMI (Lopez 2004; Vandegrift and Yoked 2004; Lopez-Zetina, Lee et al. 2006; Ross, Tremblay et al. 2007; Rundle, Roux et al. 2007; Stafford, Cummins et al. 2007; Smith, Brown et al. 2008). Indicators of diverse and walkable destinations in a neighborhood have been associated with lower weight (Frank, Andresen et al. 2004; Mobley, Root et al. 2006; Rundle, Roux et al. 2007; Stafford, Cummins et al. 2007; Tilt, Unfried et al. 2007; Smith, Brown et al. 2008; Brown, Yamada et al. 2009). More pedestrian friendly street connectivity or accessible/high quality sidewalks have also been associated with fewer weight problems (Giles-Corti, Macintyre et al. 2003; Doyle, Kelly-Schwartz et al. 2006; Boehmer, Hoehner et al. 2007; Smith, Brown et al. 2008; Zick, Smith et al. 2009).

Among youth, various elements of the built environment have been linked to increased physical activity and better nutrition. Children and adolescents with access to recreational facilities and programs, usually near their homes, are more active than those without such access (Sallis, Rochaska et al. 2000). Adolescent girls’ physical activity is related to the proximity of recreational facilities (Cohen, Ashwood et al. 2006; Norman, Nutter et al. 2006). Sallis and colleagues report that the more frequent use of recreational facilities by young adolescents, the greater their total physical activity, with parks in the neighborhood most important for boys and with commercial facilities in the neighborhood most important for girls (Sallis et al., 1993).

In all of these studies, neighborhood characteristics are treated as exogenous factors. That is, land use diversity, density, and design as well as the social and cultural aspects of a neighborhood are seen as predetermined factors that affect an individual’s risk of overweight or obesity.

More recently, work by Plantinga and Bernell challenges the assumption that neighborhood characteristics are fixed (Plantinga and Bernell 2005; Plantinga and Bernell 2007a; Plantinga and Bernell 2007b). They build and test a model where choices about residential location are made simultaneously with choices about work, leisure, and consumption. Using longitudinal data from the National Longitudinal Survey of Youth, Plantinga and Bernell (2007a) estimate a cross-sectional model where BMI is estimated as a function of contemporaneously measured county-level sprawl, based upon Ewing's index that combines measures of density and pedestrian friendly design (Ewing, Schmid et al. 2003). The results of this model are then compared to the results of a longitudinal mover-stayer model where the change in residential location is modeled as a function of the pre-move BMI while the subsequent change in BMI is modeled as a function of the change in the county sprawl index. Although these later analyses are based on relatively small sample sizes (ranging from N=262 to 381), Plantinga and Bernell find evidence suggesting that BMI and residential location are likely simultaneously determined: individuals lose weight when they move to denser neighborhoods and lower BMI individuals choose denser neighborhoods.

The results of Plantinga and Bernell's work (Plantinga and Bernell 2007a; Plantinga and Bernell 2007b) lead them to question public policy initiatives aimed at reducing weight problems by modifying neighborhood environments to promote greater physical activity, a conclusion also supported by Eid and collaborators (Eid, Overman et al. 2008). Plantinga and Bernell argue that such initiatives may serve to attract residents who already have lower BMIs thus limiting the effectiveness of such policies in reversing recent trends in obesity.

Plantinga and Bernell's analyses raise interesting questions about the underlying relationship between residential location and BMI. In this paper, we build upon their work in several ways. First, we employ more finely-grained geographic measures of neighborhood characteristics that may be associated with BMI. Plantinga and Bernell are limited to a county-level measure of sprawl which they treat as a dichotomous variable. In contrast, our analyses are based on census block group measures of specific neighborhood characteristics that have been linked to BMI in past studies. (Approximately 1,500 individuals comprise a census block group whereas the average 2000 county population is approximately 135,000.) We therefore expand on their study by using multiple continuous measures of walkability at a geographic scale that may better represent typical walking distances from individual residences (Colabianchi, Dowda et al. 2007).

Second, rather than rely on a very small number of movers to assess the endogeneity of residential location and BMI, we compare the estimated relationships between neighborhood characteristics and overweight/obesity risk for two groups. The first group comprises 17 to 20 year olds whose preferences for physical activity and food environments are less likely to determine their parents' residential location choices. The second group comprises individuals aged 27 to 30 who will have largely established their residence independent of their families of origin and thus, can be viewed as making personal choices about residential location that are consistent with their BMI and related lifestyle preferences. By comparing and contrasting the results when estimation is done using both groups versus when the estimation is done separately by age group, we will draw insights about the relative roles of selection and causation as they relate to neighborhood 3-D's and BMI.

The strategy of exploiting natural experiments in observational data to evaluate selection bias in neighborhood research builds upon prior work. Lopez Turley (2003) examined whether the effects of neighborhood characteristics were stronger for children who lived in a neighborhood longer, suggesting that it is neighborhood factors, rather than family characteristics, that affect childhood outcomes. Kowaleski-Jones and colleagues (Kowaleski-Jones, Dunifon et al. 2006) used a similar strategy to examine selection bias in

studies of neighborhood characteristics and youth outcomes. We argue that the strategy of using cross-sectional comparisons by age is an effective tool that can enhance our understanding the nature of selection bias in non-experimental data.

Finally, our research extends earlier work by controlling for familial factors that may affect both BMI and residential location – and if these factors were left uncorrected they would cloud the selection versus causation issue. We accomplish this by including controls for parental BMI as a proxy for both the transmission of parents' residential and energy balance preferences and the possible transmission of biological factors affecting BMI.

In sum, we expect youth, compared to young adults, to be living in areas that are less likely to reflect their own preferences for physical activity and other lifestyle factors possibly affecting BMI. Observed relationships between the 3Ds and BMI among youth would capture the operation of the 3Ds with little regard to youth preferences. Associations between the 3Ds and BMI among young adults would likely express a mixture of both selection preferences and exposures to neighborhoods consistent with those preferences. For example, those who prefer physical activity will locate in areas with more 3Ds while those who prefer little physical activity will locate in less walkable areas. The net effect will be to strengthen the relationships between the 3Ds and BMI for the older age group relative to the younger age group.

Research Design

This study utilizes data from the Utah Population Database (UPDB). The UPDB is one of the world's richest sources of linked population-based information that focus on demographic, genetic, epidemiological, and public health outcomes. It includes information on over 7 million individuals spanning two centuries. Measures of height and weight with which to calculate BMI, overweight, and obesity, as well as spatial location are obtained from contemporary driver license data that have been included in the UPDB under an agreement with the Utah Department of Public Safety. As part of the University of Utah's Institutional Review Board approval process, the UPDB staff retains the driver license address information and provides researchers with driver license BMI information linked to census block groups via Universal Transverse Mercator (UTM) coordinates. Height and weight information are converted to BMI (weight in kg/height in m²) and then recoded to categorical measures of overweight ($25 \leq \text{BMI} < 30$) and obesity ($\text{BMI} \geq 30$) in relation to healthy weight ($18.5 \leq \text{BMI} < 25$). We exclude individuals who are underweight ($\text{BMI} < 18.5$) from our analysis because these individuals may have health conditions that limit their physical activity. We use the adult guidelines for overweight among youth age as previous research has established that youth aged 14 and over generally follow adult weight classifications (Dietz 1999; Dietz and Bellizzi 1999).

The UPDB has the advantage of extensive coverage but the potential limitation of reliance on self-reported weight and a time lag between the measurement of physical environment and weight measures. The weight data likely share the limitations of self-reported weight in other studies. Specifically, individuals often underestimate their weight (Nawaz, Chan et al. 2001; Gorber, Tremblay et al. 2007). Nevertheless, self-reported weights, such as those in the CDC Behavioral Risk Factor Surveillance System (BRFSS), have proved valuable for monitoring obesity trends in the United States (Mokdad, Ford et al. 2003; Centers for Disease Control and Prevention 2007). Given self-reported weight underestimation, the time lag between census and driver license data, and the fact that individuals typically gain weight over time, the estimates in this study are likely underestimates of current weight. We have no evidence, however, that reporting errors for weight are associated with geography. Moreover, the effects of weight misreporting on our estimates are mitigated when self-

reported values are used to derive BMI *categories* (i.e., there are fewer individuals who are *misclassified* because of the reliance on self-reported weight).

For this study, we select individuals in the UPDB between the ages of 17 to 20 and 27 to 30 in 2000, who had valid driver licenses, and who lived in Salt Lake County. These age and geographic restrictions result in samples of 23,334 males and 21,021 females who were between the ages of 17 and 20, and 30,142 males and 26,078 females between the ages of 27 and 30. The age category 27 to 30 is used as the comparison because the majority of these individuals have established their own residences (White 1994), completed schooling, and have exercised choice in their residential location. We focus on residents of Salt Lake County because of its considerable variation in neighborhood diversity, density, and design as measured for 564 census block groups in the county (Smith, Brown et al. 2008; Zick, Smith et al. 2009).

The Federal Highway Administration (2006) estimates that, nationally, 57% of 17 year-olds had a driver license in 2000. By age 20, the percentage was 77%. By age 27–30, the percentage of individuals with driver licenses was over 90%. Unfortunately, we do not have percentages for Salt Lake County but we assume the fraction holding driver licenses in the county mirrors these national numbers. Utah requires that drivers provide height and weight information at the time they get their license and that it be updated after a change of residence, name changes, loss of license, or at the time of renewal which is required every ten years. Assuming that most of the 27–30 year olds recently renewed their driver licenses, both age groups should have relatively current height and weight reports. We choose to focus on age in 2000 because it represents the year with the most census data.

Neighborhood characteristics taken from the 2000 Census and measured at the block group and census tract level are linked to individuals in the UPDB based on the UTM for their residences. Measures of density, housing age, and percentage of residents who walk to work are assessed at the block group level. Pedestrian-friendly design is measured by street connectivity and our proxy for this is the number of intersections within one kilometer of the resident's home. Street connectivity is derived from street data in the U.S. Census TIGER/Line file (U. S. Bureau of the Census 2008).

At the individual level, all analyses control for gender as recorded on the driver license. Additional socio-demographic census variables taken from the 2000 census include neighborhood racial/ethnic composition (the proportion of the block group that is Hispanic, African-American, Hawaiian/Pacific Islander, and Asian), median family income, and median age of individuals in the block group.

The UPDB is a relational database where parents and siblings' information are linked to each other. We capitalize on these linked records to capture the effects of the parental environment (e.g., parental preferences for foods, exercise, and residential location) by including the mother's and fathers' BMI calculated from their driver license data that is closest to the year 2000. These parental BMI measures are adjusted for age of the parents and the year of the driver license. For those individuals where the parents' BMI data are missing, we use the mean value (26.07 for mothers and 28.04 for fathers) and include a dummy variable that equals to "1" if parental BMI information is missing, "0" otherwise.

Regressions are estimated to assess if the "three D's" relate to BMI and the risk of overweight or obesity when controlling for individual, familial and neighborhood socio-demographic characteristics. The regressions are estimated separately for males and females. To test explicitly for neighborhood selection effects, we include both the 17–20 year olds and the 27–30 year olds together in the same regression. We also include a dummy variable set equal to one if the respondent is age 27–30, and set equal to zero otherwise, that is

interacted with all of the independent variables in the regression. We then repeat the estimation separately for each age group.

We view the coefficients for the 17–20 year olds as valid estimates of the structural relationships between neighborhood design and individual BMI *under the assumption that adolescents have little or no voice in residential choice*. That is, adolescents have most likely not chosen where they live and consequently, their neighborhood characteristics may be viewed as predetermined factors that influence BMI and overweight/obesity risk.

We compare the estimates obtained with the 17–20 year olds to: (1) estimates obtained when the two age groups are combined, and (2) estimates obtained using only the 27–30 year olds. Both comparisons provide insights about the relative roles of causation and selection. Differences in the results across either alternative specification relative to the model estimated with the 17–20 year olds is an indication of selection. Unfortunately, we cannot formally test for differences when we compare the estimates based on the 17–20 year olds to those obtained when we combine the two age groups. But, we can formally test for differences when comparing the models estimated with the 17–20 year olds to models estimated with 27–30 year olds by including interaction terms between an age dummy and all of the other independent variables in a pooled sample. The tests of statistical significant for these interactions provide further confirmation of any selection effects we observe when contrasting the combined age estimates with the estimates based on the 17–20 year olds.

All estimation uses SAS software (Cary, NC, 2002 Version 9.1.3 using PROC MIXED). Analyses adjust for statistical dependence among observations induced by clustering of cases within block groups (Binder 1983; Särndal, Swenson et al. 1992). The significance level adopted is $p \leq .05$.

Results

Definitions of our 3D measures and their mean values by BMI status (i.e., healthy weight, overweight, obese) are presented in Table 1 for men and women. Several elements of this table are noteworthy. First, we find that males in either age group have higher rates of overweight and obesity than their similarly aged female counterparts, and the risk of overweight or obesity increases with age for both genders. For females, 82% of the 17–20 year olds are in the healthy weight group but that falls to 69% for 27–30 year old women. Correspondingly, for males the figures are 69% in the healthy weight group for 17–20 year olds and 47% for their older counterparts.

Second, young adults differ somewhat from 17–20 year olds in terms of their neighborhood characteristics, and these differences are consistent with what is known about residential preferences. Young adults live in neighborhoods that could be characterized as more walkable than the neighborhoods of teens where their parents more often chose places with larger homes and parcels (to accommodate larger families). Both males and females age 27–30 (who likely have no or fewer children than older adults) tend to live in older and more densely populated neighborhoods relative to their younger counterparts. They also tend to live in neighborhoods where higher proportions of workers walk to work and pedestrian friendly design (i.e., intersection density) is marginally greater. But, no clear pattern emerges between these physical features of a neighborhood and BMI within age/gender groups.

Table 2 shows the gender-specific parameter estimates for the 3D variables as they relate to BMI. Three different models are estimated. In the first individuals from both age groups are pooled and we include a main effect age dummy to capture the differences between these two groups. In the second and third columns we present the coefficients when the equations

are estimated separately for each age group. The complete set of parameter estimates for the age-interaction models appear in Appendix Table A.1.

If individuals age 17–20 have little control over their neighborhood of residence, then we should view the coefficients in the middle column to represent estimates of the causal link between neighborhood design, density, diversity and BMI. The estimates in this column indicate that higher population density relates to lower BMI for young men age 17–20, consistent with the idea that density supports walking. For young women age 17–20 the greater the proportion of workers who walk to work in the neighborhood, the lower the BMI, again consistent with the idea that more individuals walk to work in areas where homes and workplaces are within walking distance, a measure of mixed land use. This effect does not rest on the assumption that the person in question walks to work but only that the neighborhood has features that promote walking which should benefit all those in that neighborhood.

The estimated coefficients associated with the combined model (coefficients column 1) are often different from those estimated for the 17–20 year-olds, both in terms of their magnitudes and their statistical significance. These differences suggest that residential selection may be playing a role in the cross-sectional parameter estimates of the relationship between neighborhood characteristics and BMI. These differences are also reflected by the significant interactions between age group membership and the 3D's as they relate to BMI. Contrasting the second and third columns of coefficients, we see that for men, there are statistically significant age group interactions for the variables “median housing age” and the “proportion of workers who walk to work.” In the case of women, there are significant age group interactions for median housing age, population density, and number of intersections. These significant interactions suggest that cross-sectional estimates of the relationships between the 3D's and BMI are a mixture of both causation and residential selection; among the older age group, where selection and environmental causation are allowed to work in concert, effects are stronger.

Table 3 shows the relationship between neighborhood 3D characteristics and the odds of being overweight (obese) for males relative to being normal weight.¹ In the case of the 17–20 year old males, none of the 3D measures are linked to the risk of being overweight or the risk of being obese. Yet, the combined-age model estimates suggest that increases in the median housing age, population density, and proportion of workers who walk to work are all associated with a reduction in the odds of being overweight. In addition, increases in median housing age and the proportion of workers who walk to work are associated with significantly lower odds of being obese for men. Comparisons of the combined-age odds ratio estimates with the estimates for males age 17–20 suggest that much of the association observed in the combined-age model may be attributable to residential self-selection on the part of the 27–30 year old males although not all age interactions are significant. (See Appendix Table A.2 for the complete set of age-interaction estimates.)

A parallel story can be told for the women whose odds ratios are reported in Table 4. One specific 3D walkability factor is significant for the 17–20 year old group; the higher the proportion of residents who walk to work, the lower the overweight/obesity risk for women age 17–20. Yet, the combined-age estimates depict statistically significant relationships between all four measures and the risk of overweight/obesity relative to being normal weight. These contrasts again suggest that much of what we observe in more conventional cross-sectional estimates of the relationship between neighborhood features and the odds of

¹Note that respondents who are obese are excluded from the overweight versus normal weight comparisons and respondents who are overweight are excluded from the obese versus normal weight comparisons.

overweight/obesity may be attributable to self-selection in combination with the effects of walkability. However, as is the case with the males, although the estimated age interactions are also suggestion of residential selection effects, they generally are statistically significant (See Appendix Table A.3 for the complete set of age-interaction estimates).

It is noteworthy that higher parental BMI is associated with a higher youth and young adult BMI. Parents are likely influencing their offspring's BMI through learned eating and exercise habits, genetics, and perhaps, via residential preferences. As a check of this latter possibility, we re-estimated the models presented in Tables 2–4 excluding the parental BMI variables. We compared the resulting 3D parameter estimates to those presented in the tables. None of the estimated coefficients or odds ratios changed signs and only two of the parameter estimates changed from being statistically insignificant to statistically significant ($p=.05$).² This suggests that much of the impact of parental influence may be occurring through the intergenerational transmission of eating/exercise preferences and/or genetics rather than through residential preferences.

Discussion and Conclusions

Our analyses of causal and selection mechanisms linking neighborhood characteristics to an individual's risk of having an unhealthy weight are estimated with the assumption that 17–20 year-olds have limited choice over their neighborhoods, especially with respect to their preferences for the food and physical activity features that might alter BMI and the odds of overweight or obesity. Consequently, we view neighborhood characteristics to be exogenous factors affecting the BMI of youth. We further assume that 27–30 year olds have considerably more choice over their residential location. These assumptions allow us to compare coefficients estimated for the 27–30 year-olds to those estimated for the 17–20 year-olds as an indirect test of neighborhood selection effects.

Like other studies, we find inconsistent evidence of a causal link between neighborhood 3D's and BMI or overweight/obesity risk for youth and young adults when the 3Ds are tested separately (Frank, Andresen et al. 2004; Rutt and Coleman 2005; Eid, Overman et al. 2008; Smith, Brown et al. 2008) or when tests are done across neighborhoods differing in SES (Lovasi, Hutson et al. 2009). In our study, among males, it appears that a higher neighborhood population density is linked to lower BMI but this relationship disappears when examining overweight or obesity risk. Among females, the proportion of workers who walk to work is inversely related to BMI, overweight risk, and obesity risk. These results suggest that physical features associated with neighborhood walkability show inconsistent relationships with BMI, indicating that we have not yet fully discovered under what circumstances walkability features relate to BMI. The most consistent effect in this study involves a variable rarely used in other studies; the proportion of people who walk to work in a neighborhood is consistently related to lower BMI among females.

The percentage of workers in a neighborhood who walk to work is typically low, averaging less than 3% in the U.S and less than 2% in Salt Lake County. Thus, walking to work by that small fraction of individuals is unlikely to be directly responsible for the lower BMI of a particular person in the neighborhood. Rather, higher proportions of individuals who walk to work likely indicate a neighborhood with other walkability features that may encourage

²In one instance the odds ratio associated with population density for men age 27–30 became statistically significant when the parental BMI controls were removed. In the second instance, the odds ratio associated with the proportion of residents who walk to work became statistically significant in the estimating equation for males age 17–20 when the parental BMI controls were removed. The complete estimates are available from the authors upon request.

residents to walk more generally. Future research should seek to identify what the key walkability features are in these neighborhoods.

Residential selection appears to operate somewhat differently across genders with women exhibiting greater selection effects than men. Our findings suggest that women with healthier weights are more likely to choose to live in neighborhoods with older housing, greater population density, and fewer intersections. In the case of men, we find that men with healthier weights are more likely to choose to live in neighborhoods with older housing and a larger fraction of residents who walk to work. To the extent that young adults' residential choice is guided by economics, our findings may reflect the fact that older housing in more densely populated, mixed land use neighborhoods is more affordable rather than a preference for walkable neighborhoods.

Our analysis builds on the work of Plantinga and Bernell (2007a, 2007b, 2005) in several ways. First, we use more geographic proximal measures of the neighborhood environment. Second, we control for the role of parental preferences/biology by including parents' BMI variables among the covariates. Third, we have the statistical advantage of much larger sample sizes. Yet, when focusing on BMI, we reach similar conclusions to their studies. As such, this study contributes to the small, but growing body of evidence that suggests it is important to control for residential selection effects when estimating the relationship between neighborhood characteristics and BMI. Without doing so, investigations may be overstating the potential BMI reductions associated with policies and design mechanisms that create more walkable environments.

It is important to note that while we find strong residential selection effects when our dependent variable is BMI, the evidence is somewhat less compelling when we examine the risk of overweight or obesity versus normal weight. Contrasts between the combined-age estimates and the estimates based on 17–20 year olds are consistent with residential selection effects, but the estimated interactions between the 17–20 year olds and the 27–30 year olds, are typically weaker. This finding suggests that residential selection may be less of an issue when the researcher is focused on these discrete public health outcomes.

While our findings add to the nascent literature on residential selection and BMI, it is also important to recognize the limitations of our analysis. Specifically, the current empirical work assumes that the effect of neighborhood environments on weight does not change with age. In addition, we must exclude all individuals in our two age groups who do not have a valid driver license in 2000. This selection effect is likely greater among 17–20 year olds than those age 27–30 though the proportion of 17–20 year olds with licenses is comparable or superior to response rates found in even well-designed social surveys. The impact of excluding non-drivers is unclear but, if non-drivers are more physically active, it could mean that our results regarding residential selection effects are conservative. Finally, we acknowledge that the choice of residential location is the outcome of a complex decision process where physical features of the neighborhood are only one dimension. Income constraints, proximity to kin and work, and many other factors enter into the decision. Consequently, we view our results as suggestive.

Definitive evidence of the presence or absence of residential selection bias awaits replication of the approach used here in other geographic locations and that examines a more diverse set of local land use measures (e.g., measures of the food environment). In addition, insights could be gained by applying Plantinga and Bernell's instrumental variables approach and their mover-stayer model to longitudinal data sets that contain measures of the residents' immediate neighborhood characteristics.

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- This analysis assumes that youth have little choice in residential location while young adults have more choice. Our analysis makes use of data on 53,476 males and 47,069 females living in Salt Lake County in 2000.
- We find evidence of residential selection when BMI is the outcome. The evidence is weaker when the outcomes are overweight or obesity.
- We conclude that studies that ignore the role of residential selection may be overstating the causal influence of neighborhood features in altering residents' BMI.

Table 1

Mean Values of Neighborhood 3D Characteristics by Weight Status, Age Group and Gender.

	Age 17–20			Age 27–30		
	Healthy Weight	Overweight	Obese	Healthy Weight	Overweight	Obese
Men (N=53,476)						
N	16,062	5,531	1,741	14,096	11,790	4,256
Median age of housing in the census block group	23.31	23.46	24.39	29.36	27.60	26.43
Population density per sq. mile in block group	5277.54	5396.58	5585.46	6197.15	6037.19	6101.60
Number of intersections within 1 sq. km. of the individual's address	41.80	42.33	43.00	43.48	42.75	43.01
Proportion of workers who walk to work in Block Group	0.01	0.01	0.01	0.03	0.02	0.02
Women (N=47,069)						
N	17,173	2,784	1,064	18,041	5,053	2,984
Median age of housing in the census block group	23.42	23.60	24.58	27.60	26.36	27.20
Population density per sq. mile in Block Group	5266.81	5574.93	5904.32	6010.43	6024.30	6099.41
Number of intersections within 1 sq. km. of the individual's address	41.72	42.08	43.50	43.03	43.38	43.43
Proportion of workers who walk to work in Block Group	0.01	0.01	0.01	0.02	0.02	0.02

Table 2

BMI Regression Parameter Estimates for the Effects of Neighborhood 3D Characteristics, by Age Group and Gender.

	Combined - Age Model		Age 17-20		Age 27-30	
	coefficient	t-ratio	coefficient	t-ratio	coefficient	t-ratio
Men						
Median age of housing in the census block group	-0.008	-5.20 *	0.001	0.72	-0.014	-6.82 *
Population density per sq. mile in Block Group (in 1,000s)	-0.017	-1.53	-0.035	-2.03 *	-0.011	-0.85
Number of intersections within 1 sq. km. of the individual's address	0.001	0.83	0.003	1.28	0.000	0.41
Proportion of workers who walk to work in Block Group	-4.19	-7.31 *	-1.23	-1.00	-4.50	-7.10 *
Adjusted R ²	.10		.07		.04	
Women						
Median age of housing in the census block group	-0.006	-2.49 *	-0.000	-0.02	-0.009	-2.90 *
Population density per sq. mile in Block Group (in 1,000s)	-0.045	-3.54 *	-0.0092	-0.50	-0.060	-3.58 *
Number of intersections within 1 sq. km. of the individual's address	0.006	2.81 *	-0.001	-0.61	0.010	3.45 *
Proportion of workers who walk to work in Block Group	-3.90	-4.08 *	-2.64	-2.24 *	-4.26	-3.50 *
Adjusted R ²	.10		.11		.06	

* p<.05

Bolded and italicized numbers indicate statistically significant age interactions.

All regressions control for the following block group characteristics: median family income, median age of the residents, the proportion of residents who are Black, the proportion of residents who are Hispanic, the proportion of residents who are Asian, and the proportion of residents who are Hawaiian or Pacific Islander. In addition, all regressions control for the following characteristics of the individual: mother's BMI and father's BMI. The combined-age model also includes a dummy variable that takes on a value of "1" when the individual is age 27-30 and "0" if the individual is age 17-20. All logistic regressions were estimated using PROC SURVEYREG in SAS to allow for the correlation across observations in the same block group. The complete set of regression coefficients is available from the authors upon request.

Table 3
Logistic Regression Odds Ratios for the Effects of Neighborhood 3D Characteristics by Age Group: Males

	Unit Change	Combined-Age Model		Age 17–20		Age 27–30	
		Odds Ratio	95% CI	Odds Ratio	95% CI	Odds Ratio	95% CI
Normal Weight vs. Overweight (excludes obese)							
Median age of housing in the census block group	10	0.958 *	0.941 0.975	0.982	0.947 1.017	0.949 *	0.930 0.969
Population density per sq. mile (BG)	1,000	0.989 *	0.979 0.999	0.988	0.969 1.008	0.989	0.978 1.000
Number intersections w/in 1 sq. km of the individual's address	10	1.005	0.988 1.023	1.015	0.985 1.047	0.998	0.980 1.017
Proportion of workers who walk to work (BG)	0.025	0.959 *	0.945 0.973	0.977	0.941 1.015	0.959 *	0.944 0.974
Model Chi-Square		2,907 *		575 *		371 *	
Normal Weight vs. Obese (excludes overweight)							
Median age of housing in the census block group	10	0.934 *	0.909 0.960	1.039	0.993 1.088	0.904 *	0.877 0.932
Population density per sq. mile (BG)	1,000	0.987	0.971 1.004	0.973	0.944 1.004	0.991	0.973 1.009
Number intersections w/in 1 sq. km of the individual's address	10	1.025	1.000 1.050	1.038	0.990 1.089	1.020	0.993 1.048
Proportion of workers who walk to work (BG)	0.025	0.923 *	0.899 0.949	0.945	0.884 1.009	0.927 *	0.902 0.953
Model Chi-Square		2,932 *		949 *		865 *	

* p<.05

Bolded and italicized numbers indicate statistically significant age interactions.

All logistic regressions control for the following block group characteristics: median family income, median age of the residents, the proportion of residents who are Black, the proportion of residents who are Hispanic, the proportion of residents who are Asian, and the proportion of residents who are Hawaiian or Pacific Islander. In addition, all regressions control for the following characteristics of the individual: mother's BMI and father's BMI. The combined-age model also includes a dummy variable that takes on a value of "1" when the individual is age 27-30 and "0" if the individual is age 17-20. All logistic regressions were estimated using PROC SURVEYLOGISTIC in SAS to allow for the correlation across observations in the same block group. The complete set of regression coefficients is available from the authors upon request.

Table 4
Logistic Regression Odds Ratios for the Effects of Neighborhood 3D Characteristics by Age Group: Females

	Unit Change	Combined-Age Model		Age 17–20		Age 27–30	
		Odds Ratio	95% CI	Odds Ratio	95% CI	Odds Ratio	95% CI
Normal Weight vs. Overweight (excludes obese)							
Median age of housing in the census block group	10	0.961 *	0.936	0.991	0.948	0.949 *	0.922
Population density per sq. mile (BG)	1,000	0.979 *	0.965	0.993	0.963	0.976 *	0.961
Number intersections w/in 1 sq. km of the individual's address	10	1.030 *	1.007	0.987	0.947	1.048 *	1.021
Proportion of workers who walk to work (BG)	0.025	0.937 *	0.911	0.963	0.884	0.942 *	0.913
Model Chi-Square			2.038 *		967 *		658 *
Normal Weight vs. Obese (excludes overweight)							
Median age of housing in the census block group	10	0.963 *	0.927	0.999	0.885	0.967	0.925
Population density per sq. mile (BG)	1,000	0.973 *	0.955	0.991	0.956	0.970 *	0.951
Number intersections w/in 1 sq. km of the individual's address	10	1.046 *	1.015	1.078	0.976	1.048 *	1.012
Proportion of workers who walk to work (BG)	0.025	0.940 *	0.906	0.976	0.923 *	0.948 *	0.908
Model Chi-Square			2,545 *		905 *		931 *

* p<.05

Bolded and italicized numbers indicate statistically significant age interactions.

All logistic regressions control for the following block group characteristics: median family income, median age of the residents, the proportion of residents who are Black, the proportion of residents who are Hispanic, the proportion of residents who are Asian, and the proportion of residents who are Hawaiian or Pacific Islander. In addition, all regressions control for the following characteristics of the individual: mother's BMI and father's BMI. The combined-age model also includes a dummy variable that takes on a value of "1" when the individual is age 27–30 and "0" if the individual is age 17–20. All logistic regressions were estimated using PROC SURVEYLOGISTIC in SAS to allow for the correlation across observations in the same block group. The complete set of regression coefficients is available from the authors upon request.

Table A.1

BMI Regression Parameter Estimates for the Interaction Model, by Gender

Independent Variables	Males		Females	
	Estimate	t ratio	Estimate	t ratio
Intercept	14.94	38.50 [*]	15.28	43.72 [*]
Median Family Income (BG)	-0.01	-3.57 ^{**}	-0.01	-7.44 [*]
Proportion Black (BG)	-0.58	-0.23	2.35	0.78
Proportion Hawaiian/Pacific Islander (BG)	1.61	1.03	6.14	3.03 [*]
Proportion Hispanic (BG)	1.80	4.48 [*]	3.03	6.52 [*]
Proportion Asian (BG)	0.91	0.94	-1.59	-1.55
Median Age (BG)	0.01	1.52	-0.01	-2.13 [*]
Median Age of Housing (BG)	0.00	0.72	0.00	-0.02
Population Density per Sq. Mile (BG)	0.00	-2.03 [*]	0.00	-0.50
Number Intersections w/in 1 Sq. Km of the Individual's Address	0.00	1.28	0.00	-0.61
Proportion of Workers Who Walk to Work (BG)	-1.23	-1.00	-2.65	-2.24 [*]
Mother's BMI	0.15	19.74 [*]	0.18	23.12 [*]
Father's BMI	0.18	20.07 [*]	0.13	16.16 [*]
Father's BMI Missing (1=yes)	0.30	4.68 [*]	0.28	4.64 [*]
Mother's BMI Missing (1=yes)	-0.18	-2.73 [*]	-0.07	-1.01
Age Dummy (1=Age 27-30, 0=Age 17-20)	2.29	3.69 [*]	-2.29	-3.26 [*]
Median Family Income (BG) * Age Dummy	0.00	-1.87	-0.01	-1.97 [*]
Proportion Black (BG) * Age Dummy	-1.08	-0.35	-0.38	-0.09
Proportion Pacific Islander (BG) * Age Dummy	1.53	0.88	-0.95	-0.34
Proportion Hispanic (BG) * Age Dummy	-1.16	-2.46 [*]	1.15	1.95
Proportion Asian (BG) * Age Dummy	-4.56	-3.92 [*]	-0.13	-0.08
Median Age (BG) * Age Dummy	-0.02	-2.43 [*]	0.01	0.64
Median Age of Housing (BG) * Age Dummy	-0.02	-5.35 [*]	-0.01	-2.34 [*]
Population Density per Sq. Mile (BG) * Age Dummy	0.00	1.10	0.00	-2.09 [*]
Number Intersections w/in 1 Sq. Km of the Individual's Address * Age Dummy	0.00	-0.75	0.01	2.96 [*]
Proportion of Workers Who Walk to Work (BG) * Age Dummy	-3.27	-2.29 [*]	-1.62	-0.97
Mother's BMI * Age Dummy	0.02	1.22	0.03	2.06 [*]
Father's BMI * Age Dummy	0.03	1.89	0.11	6.23 [*]
Father's BMI Missing * Age Dummy	0.01	0.15	-0.06	-0.63
Mother's BMI Missing * Age Dummy	-0.27	-2.84 [*]	-0.38	-3.49 [*]
Adjusted-R ²	0.10		0.10	

*
 $p < .05$

Table A.2
Estimated Odds Ratios of being Overweight Versus Normal Weight for the Interaction Model, by Gender

Variable	Males		Females	
	Odds Ratios	95% CI	Odds Ratios	95% CI
Median Family Income (BG)	1.00	0.99	0.99*	0.98
Proportion Black (BG)	0.25	0.01	1.57	0.03
Proportion Hawaiian/Pacific Islander (BG)	4.88*	1.25	18.33*	3.16
Proportion Hispanic (BG)	1.80*	1.12	2.96*	1.80
Proportion Asian (BG)	2.04	0.75	0.48	0.10
Median Age (BG)	1.01	1.00	0.99	0.98
Median Age of Housing (BG)	1.00	1.00	1.00	1.00
Population Density per Sq. Mile (BG)	1.00	1.00	1.00	1.00
Number Intersections w/in 1 Sq. Km of the Individual's Address	1.00	1.00	1.00	1.00
Proportion of Workers Who Walk to Work (BG)	0.40	0.09	0.06*	0.01
Mother's BMI	1.05*	1.04	1.09*	1.08
Father's BMI	1.08*	1.07	1.07*	1.06
Father's BMI Missing (1=yes)	1.15*	1.06	1.13*	1.01
Mother's BMI Missing (1=yes)	0.95	0.88	1.13*	1.02
Age Dummy (1=Age 27-30, 0=Age 17-20)	10.98*	5.78	1.50	0.68
Median Family Income (BG) * Age Dummy	1.00	1.00	1.00	1.00
Proportion Black (BG) * Age Dummy	16.76	0.48	580.78	0.02
Proportion Hawaiian/Pacific Islander (BG) * Age Dummy	0.16*	0.03	0.54	0.06
Proportion Hispanic (BG) * Age Dummy	0.53*	0.29	1.26	0.72
Proportion Asian (BG) * Age Dummy	0.07	0.02	1.30	0.22
Median Age (BG) * Age Dummy	0.99	0.98	1.01	0.99
Median Age of Housing (BG) * Age Dummy	1.00	0.99	1.00	0.99
Population Density per Sq. Mile (BG) * Age Dummy	1.00	1.00	1.00	1.00

Variable	Males		Females	
	Odds Ratios	95% CI	Odds Ratios	95% CI
No. Intersections w/in 1 Sq. Km of the Person's Address * Age Dummy	1.00	1.00	1.01 *	1.01
Proportion of Workers Who Walk to Work (BG) * Age Dummy	0.46	2.56	1.60	17.46
Mother's BMI * Age Dummy	0.99	1.00	0.98 *	0.99
Father's BMI * Age Dummy	0.99	1.01	1.01	1.03
Father's BMI Missing * Age Dummy	0.99	1.09	0.80 *	0.93
Mother's BMI Missing * Age Dummy	0.81 *	0.91	0.95	1.09
Model Chi-Square	2999		2084	

* p<.05

Table A.3

Estimated Odds Ratios of being Obese Versus Normal Weight for the Interaction Model: Males and Females

Variables	Males		Females	
	Odds Ratios	95% CI	Odds Ratios	95% CI
Median Family Income (BG)	0.99	1.00	0.98*	0.97
Proportion Black (BG)	0.46	25.31	3.64	0.01
Proportion Hawaiian/Pacific Islander (BG)	3.29	34.02	17.51	1.05
Proportion Hispanic (BG)	3.40*	6.27	6.43*	2.92
Proportion Asian (BG)	1.08	6.35	0.38	0.04
Median Age (BG)	0.99	1.01	1.00	0.98
Median Age of Housing (BG)	1.00	1.01	1.00	0.99
Population Density per Sq. Mile (BG)	1.00	1.00	1.00	1.00
Number Intersections w/in 1 Sq. Km of the Individual's Address	1.00	1.01	1.00	1.00
Proportion of Workers Who Walk to Work (BG)	0.10	1.46	0.04*	0.00
Mother's BMI	1.11*	1.09	1.13*	1.11
Father's BMI	1.13*	1.12	1.09*	1.07
Father's BMI Missing (1=yes)	1.40*	1.60	1.46*	1.25
Mother's BMI Missing (1=yes)	1.00	1.15	1.10	0.94
Age Dummy (1=Age 27-30, 0=Age 17-20)	7.45*	20.17	1.22	0.38
Median Family Income (BG)* Age Dummy	1.00	1.00	1.01	1.00
Proportion Black (BG)* Age Dummy	2.29	268.13	0.58	<0.001
Proportion Hawaiian/Pacific Islander (BG)* Age Dummy	1.70	25.04	0.59	0.02
Proportion Hispanic (BG)* Age Dummy	0.43*	0.86	1.08	0.45
Proportion Asian (BG)* Age Dummy	0.11*	0.81	0.96	0.06
Median Age (BG)* Age Dummy	1.00	0.98	1.00	0.97
Median Age of Housing (BG)* Age Dummy	0.99*	0.99	1.00	0.99
Population Density per Sq. Mile (BG)* Age Dummy	1.00	1.00	1.00	1.00

Variables	Males		Females	
	Odds Ratios	95% CI	Odds Ratios	95% CI
Number Intersections w/in 1 Sq. Km of the Person's Address * Age Dummy	1.00	0.99	1.00	1.00
Proportion of Workers Who Walk to Work (BG) * Age Dummy	0.46	0.03	2.91	0.13
Mother's BMI * Age Dummy	0.99	0.97	0.99	0.97
Father's BMI * Age Dummy	1.01	0.99	1.04 *	1.01
Father's BMI Missing * Age Dummy	0.97	0.82	0.97	0.80
Mother's BMI Missing * Age Dummy	0.72 *	0.61	0.65 *	0.53
Model Chi-Square	3022		2608	

* p<.05