Neighborhood Characteristics and Body Mass Index: Selection or Causation? (R21 DK080406-01) National Institute for Health, The National Institute of Diabetes and Digestive and Kidney Diseases (NIDDK). Ken Smith and Lori Kowaleski-Jones, Co- Principal Investigators, Project Period 9/08-9/12.

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Final Report

A. Specific Aims

Obesity and overweight are major public health problems. An estimated 65% of US adults are overweight or obese (Hedley 2004)with up to 280,000 annual deaths attributable to obesity (Allison, Fontaine et al. 1999; Flegal, Graubard et al. 2005). In an effort to understand factors associated with adult obesity/overweight, attention has recently focused on the potential effects of environmental influences. Yet, studies linking the physical environment to the risk of being overweight or obese are limited by the fact that residents are not randomly distributed by neighborhood. If significant associations are found between neighborhood characteristics and individuals' body mass indices (BMI) in observational studies, one cannot confidently draw conclusions about causality. Neighborhood features may cause people to be more physically active, or physically active individuals with low BMI's may be more likely than overweight, sedentary individuals to choose neighborhoods that support their pre-existing healthy lifestyle, or both directions of influences may occur.

If non-random selection into neighborhoods exists, then the observed association between individual BMI and neighborhood features arises from two sources: (a) physical or socio-cultural features of the built environment give rise to variation in individual BMI (i.e., a causal mechanism), and (b) unobserved characteristics that affect both residential location and individual BMI (i.e., a non-random selection mechanism). If non-random selection occurs, estimates that do not correct for its effects will misstate the strength of the causal relationship.

In this study, our aim was to characterize the relative contributions of the causal and selection explanations with non-experimental data by testing three hypotheses:

- Walkable neighborhoods, as measured by population density, pedestrian-friendly design, and land-use diversity (e.g., mixed use, proximity to open space, access to grocery stores) are associated with lower levels of individual BMI, *ceteris paribus*.
- Individual characteristics (e.g., age, sex, race), familial characteristics (e.g., family history of obesity), and socio-cultural factors (e.g., neighborhood ethnic composition) influence individual BMI, *ceteris paribus*.
- The size of the causal effects identified in hypotheses 1 and 2 will be attenuated after adjusting for the effects of non-random selection into neighborhoods, *ceteris paribus*.

To test these hypotheses, we compared and contrasted three methods for assessing the influence of causal effects in the presence of non-random residential selection. These methods were (1) structural equations models with instrumental variables, (2) counterfactual approaches using propensity scores, and (3) longitudinal mover-stayer models. There is no definitive statistical test of the relative contributions of causation and selection that can be used when dealing with non-experimental data. Accordingly, we implemented these three statistical approaches – each with varying strengths and weaknesses – to assess the causal relationshipsbetween neighborhood characteristics and individual BMI in the presence of neighborhood selection effects. The collective results of these analyses contribute crucial information to understanding the relationship between neighborhoods and the individual risk of overweight or obesity.

This study relied on a world-class population-based data source, the Utah Population Database (UPDB). The vast genealogical records in the UPDB were linked to state-wide administrative and vital records (driver licenses, birth certificates) that contained longitudinal data on height and weight (used to construct BMI) and residential location for individuals and their kin. The UPDB was also linked to U.S. Census, state, and county information on neighborhood characteristics using Geographic Information Systems (GIS) databases. The UPDB represents a unique and comprehensive database with which to address neighborhood effects on BMI; it encompassesthe adult/adolescent population and represents the full range of neighborhood settings.

B. Results for Aims

Aim 1: Walkable neighborhoods, as measured by population density, pedestrian-friendly design, and land-use diversity (e.g., mixed use, proximity to open space, access to grocery stores) are associated with lower levels of individual BMI, ceteris paribus.

Most studies of walkable designrely on operationalizations from the 3Ds of walkability—density, diversity, and design(Brown et al, 2012. In short, this conceptualization of walkability makes the assumption that when large numbers of residents (density) live close to walkable destinations (land use diversity) and have good pathways to get there (pedestrian friendly design), then they may choose to active modes of transportation (i.e., walking, cycling).

We focused on measures of the 3Ds of walkability—density, diversity, and design—that are frequently used and available at the census block group level. Density was assessed as the total population density per area in the block group. Diversity was assessed by the proportion of the block group that can walk to work, taken as an indicator that residential and employment land uses were within walking distance and thus a proxy measure of neighborhood land use mix. Some of our studies also explored more fine-grained measures of diversity by relying on the land-use codes available at the parcel level in Salt Lake County or Dun and Bradstreet measures of food environments. The TIGER/line file from the U.S. Census provided data to calculate intersection densities. Greater intersection densities provide those using active modes of transportation multiple options and fairly direct routes to destinations; they also require cars to stop at intersections, which add to pedestrian-friendly design. Finally, housing age within the block group was intended to measure multiple aspects of walkability, given that older neighborhoods often provide mixed land uses, narrow tree-lined streets, and interconnected street forms.

We utilized traditional control variable approaches to controlling for selection in studies that were designed to assess the roles of socioeconomic differences and variations in measures and geographic units of analysis in the assessment of walkability. In a cross sectional study that focused on neighborhood socioeconomic effects, greater walkability was generally related to lower BMI/obesity risk among 453,927 Salt Lake County residents aged 25 to 64(Zick, Smith et al. 2009). Walkability was assessed with census measures of neighborhood housing age, proportion of residents who walk to work, intersection density in a 1 km buffer, and population density. The Utah Population Data Base (UPDB) driver license data provided BMI/obesity measures. The analysis compared the strength of walkability associations to weight in low income (bottom quartile) compared to non-low income (top three quartiles) census block group neighborhoods. Two walkability measures were related to fewer weight problems. Greater population density was associated with lower BMI and obesity risk in both low income and non-low income neighborhoods, with the magnitude effects greater in low income neighborhoods. As the percentage of workers who walked to work increases, the lower the BMI and obesity risk, especially for low income neighborhoods. Older neighborhood housing, which may indicate a more walkable neighborhood, was associated with lower BMI and obesity risk, especially in non-low income neighborhoods. Similarly, and counter to a walkability hypothesis, an increase in the number of intersections was associated with an increase in BMI and obesity risk, but the magnitude of this positive effect was significantly greater in non-low income neighborhoods than in low income neighborhoods.

Land use diversity is believed to support walking, but diversity has been measured in a wide variety of ways, with measures varying by availability, scale, and directness of measuring mixed use. To investigate the effects

of such variations in operationalizations, we compared common mixed use measures for a random sample of 5000 adults from Salt Lake County and found that several previously published measures and some novel measures were superior to other measures used in past research(Brown, Yamada et al. 2009). Specifically, the Census proxy measure of the proportion of residents in the area who walk to work consistently related to lower BMI, despite the fact that fewer than 3% of residents walk to work. This measure indicated that housing and employment land uses were within walking distances and the measure related to lower BMI in our prior research in Salt Lake County(Smith, Brown et al. 2008). However, more fine grained measurement was possible by relying on land-use codes, which can focus on particular types of land uses, such as housing, business, or educational land uses that might invite walking to destinations. These latter measures required more effort, as they involved summarizing across diverse land-use categories (Salt Lake County had 157 categories) and individualizing measures to individual residences by constructing spatial buffers around each residence or small area. However, these efforts provided useful correlates of weight outcomes. The presence of six categories of land uses—single family housing, multi-family housing, retail, office, education, and entertainment—revealed stronger relationships to weight outcomes than traditionally used entropy score that assesses the equal spread of the six land uses. This means that the presence of walkable land uses, not their equal spread, was more predictive of healthier weights. For males, more multifamily housing related to lower BMI and more office and educational land related to lower overweight risk. For females, more office and entertainment land related to lower BMI and higher risks of obesity related to less entertainment and more educational land. In addition, proximity to light rail stops related to lower female BMI.

A continuing question in the field of walkability and weight outcomes relates to the proper geographic unit of analysis, with researchers often assessing walkability features at census tract, block group, or individual buffer distances, but often without comparing the three. A follow-up study addressed this question and revealed that there was no one geographic level of aggregation that proved superior for all measures(Yamada, Brown et al. 2012). For example, the best fit models showed that, for males, lower BMIs were associated with lower intersection density at the census tract level ($p = 0.006$), older housing at the block group level ($p = 0.001$), and more multifamily residential use at the 1-km street network buffer level ($p = 0.027$). Lower BMIs of females were associated with closer light rail stations ($p = 0.009$) and more entertainment land use at the 1-km buffer level ($p = 0.021$), controlling for area sociodemographic characteristics and individual age.

In sum, across variations in walkability measures, geographic units of analysis, and data sources for BMI, the research identified significant relationships between walkability and weight. These results suggest that policy and design efforts to enhance walkability may have public health benefits for BMI and overweight/obesity risks.

Aim 2: Individual characteristics (e.g., age sex, race), familial characteristics (e.g., family history of obesity), and socio-cultural factors (e.g., neighborhood ethnic composition) influence individual BMI, ceteris paribus.

All analyses done as part of our research project were stratified by gender to test for gender and residential selection interaction effects. We consistently found important gender differences both in terms of the effects of neighborhood walkability measures (discussed elsewhere) and in terms of individual characteristics and socio-cultural factors highlighted here. Within our analyses, individual characteristics were captured by age, education, race, and/or marital status when birth certificate records were the source of information (women only). Age was the only individual-level characteristic that could be included when driver license data were used (women and men). All analyses included socio-cultural controls as measured by the neighborhood's racial/ethnic composition, median household income, and median age. One analysis also included measures of the local food environment. Finally, four of our analyses included measures of familial BMI as captured by either parental BMI or sibling BMI.

Not surprisingly, we found that BMI and overweight/obesity risk is positively linked to age and marital status and inversely related to education level. These estimated relationships were always statistically significant. We also consistently observed that increases in the proportion of the neighborhood that was Hispanic or Hawaiian/Pacific Islander was linked to higher women's BMI and overweight/obesity risk. In contrast, as the proportion of the neighborhood that was Asian increased, both male and female BMI and overweight/obesity risk declined. The coefficient associated with median household income was always inversely related to BMI

and overweight/obesity risk for both men and women. As these socio-demographic findings were typically not the centerpiece of our manuscripts, sometimes the coefficients and standard errors associated with these control variables were included in tables (Smith, Zick et al. 2011; Yamada, Brown et al. 2012; Zick, Hanson et al. in review) and other times they were simply noted in table footnotes (Brown, Yamada et al. 2009; Zick, Smith et al. 2009; Kowaleski-Jones, Brown et al. 2010).

We believe that further research needs to be undertaken to gain a clear understanding of how socio-cultural factors measured at the neighborhood level relate to residents' BMI and overweight/obesity risk. We do not yet know what it is about the ethnic and economic mix of neighborhoods that facilitate or inhibit overweight/obesity risk, *ceteris paribus*. Expanding knowledge in this domain could help to identify and tailor important public health interventions to specific neighborhood characteristics.

In one of our analyses, we examined how individual BMI relates to the socio-cultural norms as captured by detailed aspects of the neighborhood food environment (Zick, Smith et al. 2009). A key finding of that study was that healthy food options (e.g., full-service restaurants, grocery stores) and a mixture of food options were inversely related to BMI and overweight/obesity risk. Importantly, these relationships were stronger in low-income neighborhoods than in non-low-income neighborhoods. Our findings suggest that public policies designed to increase healthy food options within neighborhoods (e.g., policies that encourage grocers to expand their fresh produce offerings) may be effective in reducing individuals' obesity risks, especially if these efforts are focused on low-income neighborhoods.

Finally, four analyses controlled for the potential familial component in BMI while also looking at residential selection issues (Kowaleski-Jones, Brown et al. 2010; Smith, Zick et al. 2011; Smith, Hanson et al. 2012; Zick, Hanson et al. in review). In analyses where the focus was on understanding the correlates of young adults' BMI, we included covariates for parental BMI (Kowaleski-Jones, Brown et al. 2010; Smith, Zick et al. 2011). In analyses where the focus was on mothers, familial effects were approximated by age-adjusted sibling average BMI (Smith, Hanson et al. 2012; Zick, Hanson et al. in review). Both of these variables potentially capture genetic effects *and* family environment effects. We find that familial BMI effects are always positive, sizable, and statistically significant.

Very few studies have investigated the role of familial BMI. Our consistently significant finding is both intuitive and novel. Yet, it does not parse out the relative effects of genes versus the family environment. Future research in this area, perhaps focusing on the relationship between familial eating and exercise norms acquired in childhood and adult BMI, could provide important insights regarding overweight/obesity risk.

Aim3: The size of the causal effects identified in hypotheses 1 and 2 will be attenuated after adjusting for the effects of non-random selection into neighborhoods, ceteris paribus.

Our third aim was designed to determine whether the size of the causal effects identified in aims 1 and 2 (degree of walkability in neighborhoods [aim1] as well as individual, family, and socio-cultural factors [aim2]) will be attenuated after adjusting for the effects of non-random selection into neighborhoods, *ceteris paribus*.

As noted above, we implemented three distinct analytic strategies to explore how non-random selection into neighborhoods may affect the association between BMI and neighborhood characteristics. The three analytic approaches used were (1) instrumental variables (2) propensity scores and (3) mover-stayer models.

In the instrumental variables analysis(Zick, Hanson et al. in review), we address how cross-sectional studies face the problem of non-random residential selection which complicates the interpretation of neighborhood effects on BMI and limits researchers' ability to assess whether neighborhood environments have causal effects on the risk of unhealthy levels of BMI. Using cross-sectional data on 14,689 non-Hispanic white women living in Salt Lake County, Utah, instrumental variables techniques were used to adjust for the possibility that neighborhoods may affect weight but heavier or lighter women may also choose to live in certain neighborhoods. These analyses included statistical controls for familial predisposition for overweight/obesity, a nearly universally omitted variable in the literature.

Through the use of instrumental variables, cross-sectional analyses relating neighborhood characteristics to BMI were found to understate the strength of the relationship statistical adjustments for the decision to live in a walkable neighborhood are neglected. Standard cross-sectional estimation reveals no significant relationship between neighborhood walkability and BMI. However, the instrumental variables estimates reveal statistically significant effects.

This analysis provides evidence that residential selection leads to an understatement of the causal effects of neighborhood walkability features on BMI. Although caution should be used in generalizing from research done with one demographic group in a single locale, our findings support the contention that public policies designed to alter neighborhood walkability may moderately affect the BMI of large numbers of individuals.

Using a propensity score analysis(Kowaleski-Jones, Zick et al. in review), we addressed the issue that statistical analyses using cross-sectional, non-experimental data that seek to establish an association between neighborhood characteristicsand individual-level BMI often ignore the fact that individuals living in a given type of neighborhood may not have otherwise-similar counterparts living in other types of neighborhoods (i.e., there may be a lack of shared representativeness of similar individuals living in different neighborhoods to support an analysis on which to compare the effects of these neighborhoods). A useful solution is to use the propensity score method to address these shortcomings. This study tested whether the relationship between neighborhood characteristics and BMI remains significant after imposing propensity score constraints so that comparisons between similar persons but living in different neighborhoods could be analyzed. This technique explicitly adjusts for residential self-selection within the context of a cross-sectional, non-experimental study design. The study relies on data from 160,688 men and 190,779 women who were between the ages of 16 and 64 living in Salt Lake County, Utah.

The findings confirm previous work that identifies an association between an older housing stock, a measure of neighborhood walkability, and lower adult BMI. These results demonstrate that residential selection bias inherent in cross-sectional analysis is modest for this study. Results lend support to the growing body of research that concludes that neighborhoods that are more walkable are also less obesogenic. Absent propensity score controls, the causal relationship between environment and obesity would be overestimated by 20% for males and 6% for females. The remainder of the relationship suggests an obesogenic environment is association with walkability.

In the final selection analysis(Smith, Hanson et al. 2012), we introduced a novel approach --a variant of a mover-stayer model--that exploits longitudinal information on both individual BMI status and neighborhood BMI status to assess the degree to which differential neighborhood selection by BMI occurs. Mover-stayer models compare individuals and places between three groups: those who remain in the place of origin, those already living in the place of destination, and migrants moving between the two places. This permits an assessment of differential selection into and out of specific types of neighborhoods. We assess the relative contributions of the causal and selection explanations with non-experimental data by testing whether individuals moving from lower to higher BMI neighborhoods will be a non-random subset of those living in the lower BMI neighborhoods. We hypothesized that these movers will already have a higher BMI before they move relative to those who stay. Conversely, those moving from higher to lower BMI neighborhoods will have a lower BMI again, before the move, in relation to stayers.

Our analysis focuses on 34,010 new mothers in Salt Lake County between 1989 and 2010 based on pre-pregnancy weights for the first and second births. Women with two children provide essential longitudinal data and those living in Salt Lake County, the most urban location in the state, are well characterized in terms of spatial attributes of neighborhoods. The mover stayer model showed that women in low BMI neighborhoods who are about to leave for high BMI neighborhoods, but have not yet made the move, are already heavier in the low BMI neighborhoods. A similar pattern was observed for women moving (or about to) in the opposite direction. This study demonstrated that both systematic selection into neighborhoods and direct effects of neighborhood design on BMI were present.

ARRA Administrative Supplement

In conjunction with the parent grant, we additionally received an ARRA administrative supplement. In this subproject, we pursued two aims focused on data base creation and one aim focused on whether physical activity mediates the relationship between walkability and weight outcomes.

ARRA administrative supplement aim #1. To geocode 239,869 Utah birth certificates that have not been geocoded because of incomplete/internally inconsistent addresses and the addition of new addresses in Utah.

The proposed geocoding has been done and these data were incorporated into the analyses done as part of the main grant. For study results please refer to the main grant final report.

ARRA administrative supplement aim #2. To purchase and categorize Utah-specific data from Dun & Bradstreet for 1995, 2000, and 2005 in order to describe, in greater detail than is presently possible, the food environment in Utah (e.g., access to grocery stores) at the neighborhood level (e.g., census block group).

Dun & Bradstreet historical data have been purchased; and relevant geocoding on food environments have been done. For study results please refer to the main grant final report.

ARRA administrative supplement aim #3.To use NHANES 2003-2004 data linked to Census measures in order to re-examine aims in the parent grant but at the national level. Specifically, we addressed the following questions based on the NHANES data:

- *Do our measures of neighborhood walkability relate to moderate physical activity levels and healthy weight outcomes (lower BMI, overweight, and obesity), net of individual and other neighborhood characteristics?*
- *Does physical activity mediate the relationship between neighborhood walkability and weight outcomes?*
- *Are the neighborhood walkability correlates of weight different for youth, who did not select their neighborhoods, compared to adults, who did select their neighborhoods?*

Using 2003-2006 NHANES data at the national level, we found that greater population density and older housing were associated with lower male BMI in bivariate analyses, but density and housing age effects were insignificant in multivariate models. For women, greater proportions of neighborhood workers who walk to work (block group mean=.02) and more Moderate to Vigorous Physical Activity (MVPA) is associated with lower BMI and lower obesity risk. For men, greater proportions of workers who bike to work (block group means=.004) and more MVPA is associated with lower BMI and obesity risk. For both effects, MVPA partially mediated the relationships between walkability/bikeability and BMI. If such associations are causal, doubling walk and bike-to-work proportions (to .04 and .008) would have -.3 and -.33 effects on the average BMIs of adult women and men living in the neighborhood. This equates to 1.5 lbs. for a 64" woman and 2.3 lbs. for a 69" male. Bikeability merits greater attention as a modifiable activity-friendliness factor, particularly for males (Brown, Smith et al. 2013).

We also used 2003-2006 NHANES data at the national level to study the relationship between physical activity bouts length, activity intensity, and weight outcomes. Clinically measured BMI and overweight/obese status were regressed on accelerometer measures of minutes/day in higher-intensity long bouts (≥10 minutes, ≥2020 accelerometer counts per minute (cpm), higher-intensity short bouts (<10 minutes, ≥2020 cpm), lower-intensity long bouts (≥10 minutes, between 760-2019 cpm) and lower-intensity short bouts (<10 minutes, between 760-2019 cpm). Socioeconomic and demographic characteristics were controlled. Our results show that both higher-intensity short bouts and long bouts of physical activity related to lower BMI and risk of overweight/obesity. Neither lower-intensity short bouts nor long bouts related to BMI or risk of overweight/obesity. We concluded that for weight gain prevention, bouts of less than 10 minutes are just as beneficial as the longer bouts, supporting the public health promotion message that “every ‘brisk’ minute counts.” (Fan, Brown et al. forthcoming). The policy implications are that public health will be supported when

communities design in opportunities for even short bouts of activity, such as the walk to a transit stop or corner store.

C. Significance

The significance of this project centers around the contributions made to the literature on the associations between the built environment and body mass index. Past research on walkability and weight often assesses the relationship between walkable neighborhood design and weight with minimal efforts to control for the residential selection threats. We addressed the problem of residential selection as a threat to internal validity in several ways across the studies reported here. We used instrumental variables and propensity score approaches to control selection in cross sectional data. We examined longitudinal data that allows individuals to serve as their own controls in a final mover stayer model. Finally, we used sociodemographic variables as controls in other models. Across these studies we find evidence for selection bias but also evidence for causation. The built environment is arguably more amenable to interventions than the socio-demographic contexts. Thus, our findings that the built environment has significant and independent impacts on individual physical activity and weight status even when addressing the potential for selection bias has important public health implications. New neighborhood designs should include more activity-inviting features and old neighborhood design may be modified to incorporate these features.

D. Enrollment data, protection of children, and sharable research materials

This project did not actively enroll subjects and relied on existing data. Children were not involved in this study. There were not any sharable research materials that resulted from this study.

E. Publications

Publications

Brown BB, Yamada I, Smith KR, Zick CD, Kowaleski-Jones L, Fan JX. Mixed land use and walkability: Variations in land use measures and relationships with BMI, overweight, and obesity. Health & Place 2009;15(4):1130-1141.PMCID: 19632875

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Papers under review

Fan, Jessie, Zick, Cathleen, Smith, Ken., Brown, Barbara., Hanson, Heidi.& Kowaleski-Jones, Lori. Neighborhood Food Environment and Individual BMI: Measurements and Associations.

Kowaleski-Jones L, Zick CD, Brown BB, Fan JX, Hanson, H., Smith KR. Older walkable neighborhoods and obesity: Evaluating effects with a propensity score approach.

Zick CD, Hanson H, Fan JX, Smith KR, Kowaleski-Jones L, Brown BB, et al. Re-Visiting the relationship between neighbourhood environment and BMI: An instrumental variables approach to correcting for residential selection bias.

Papers in progress

Kowaleski-Jones L, Zick CD, Brown BB, Fan JX, Hanson, H., Smith KR. Exploring gene-environment interactions in the association between walkability and BMI.

Conference Presentations

Fan, Jessie. Zick, Cathleen, Kowaleski-Jones, Lori. Smith, Ken., Brown, Barbara, Hanson, Heidi. 2012. Moderate to Vigorous Physical Activity and Weight Outcomes: Does Every Minute Count? Paper to be presented at the Annual Meetings of the Population Association of America in San Francisco, California.

Ken R. Smith,Ikuho Yamada, Kowaleski-Jones, L. Barbara Brown, Heidi Hanson, Cathleen Zick, Jessie Fan. 2010. Body Mass Index and Neighborhood Characteristics: Assessing Selection and Causation Mechanisms Using Mover-Stayer Models •, Poster presented at the 2010 annual meetings of the Population Association of America. Dallas TX.

Kowaleski-Jones, L. Ken R. Smith, Ikuho Yamada, Barbara Brown, Heidi Hanson, Cathleen Zick, Jessie Fan. 2010. Effects of Built Environment on Obesity: Using a Propensity Score Approach to Assess Selection and Causal Influences. , Poster presented at the 2010 annual meetings of the Population Association of America. Dallas TX.

Cathleen Zick,; Ken R. Smith,; Jessie Fan, Barbara Brown, Ikuho Yamada,Lori Kowaleski-Jones, 2009. Running to the Store? The Relationship between Neighborhood Environments and the Risk of Obesity Paper presented at the 2009 annual meetings of the Population Association of America. Detroit MI.

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Kowaleski-Jones, L., C. D. Zick, et al. (in review). "Older Walkable Neighborhoods and Obesity: Evaluating Effects with a Propensity Score Approach." Health and Place.

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