DO NEIGHBORHOOD CHARACTERISTICS MATTER FOR OLDER ADULTS LIVING IN PRIMARILY RURAL NEIGHBORHOODS, AND IF SO, HOW AND FOR WHOM?

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ABSTRACT

Sarah Dorothy Kowitt: Do Neighborhood Characteristics Matter for Older Adults Living in Primarily Rural Neighborhoods, and If So, How and for Whom?
(Under the direction of Edwin B. Fisher)

Background. More than half of all adults in the United States—117 million people—have a chronic condition. In addition to accounting for most health care expenditures (86%), chronic disease is often associated with considerable decline in quality of life, increased risk of mortality, and decreased psychosocial and psychological functioning. Individual risk factors have been extensively linked to chronic disease and growing evidence now suggests that aspects of the neighborhood are associated with health and wellbeing.

Methods. Accordingly, this dissertation includes two studies that examine the relationships among neighborhood characteristics and mental and physical functioning in older adults with knee osteoarthritis (Study 1) and the relationships with depression in a broader sample of older adults (Study 2). Specifically, Study 1 examined in multilevel, cross-sectional and longitudinal analyses if four neighborhood characteristics were a) associated with mental and physical functioning and b) interacted with key individual-level characteristics among older adults with knee osteoarthritis (n=656). Study 2 focused on older adults (91% of whom had at least one chronic condition, n=1558) and using structural equation modeling, examined if neighborhood characteristics were associated with depression, and if so, what factors (i.e., physical activity, social support, perceived individual control), selected from an a priori theoretical framework, mediated these relationships. For both studies, data came from a prospective cohort study in North Carolina designed to examine risk factors for osteoarthritis—the Johnston County Osteoarthritis Project.

Results. Although few longitudinal associations were found, cross-sectional results from Study 1 suggested that perceived neighborhood social cohesion and perceived neighborhood resources for physical activity and walking were associated with less depression and greater physical functioning among older adults with knee osteoarthritis. Additionally, several interactions were found among neighborhood characteristics and race, disease severity, and presence of comorbidities. Study 2 again found relationships between neighborhood characteristics and depression. Further, mediation analysis indicated that these associations were mediated by physical activity, social support, and perceived individual control.

Conclusions. Comprehensive approaches to chronic disease management should include attention to neighborhood context, in addition to targeting modifiable individual-level factors, such as physical activity, social support, and perceived individual control that mediate neighborhood influences.

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LIST OF ABBREVIATIONS

AIC	Akaike information criterion
BIC	Bayesian information criterion
BRFSS	Behavioral Risk Factor Surveillance System
BMI	Body mass index
CDC	Centers for Disease Control and Prevention
CES-D	Center for Epidemiologic Studies Depression
CFI	Comparative Fit Index
CFA	Confirmatory factor analysis
EMA	Ecological Momentary Assessment
FIML	Full information maximum likelihood
GIS	Geographic Information System
GPS	Global Positioning System
ICC	Intraclass correlation
JOCO OA	Johnston County osteoarthritis
KL	Kellgren and Lawrence
KOOS	Knee Injury and Osteoarthritis Outcome Score
NIH	National Institutes of Health
NC	North Carolina
OA	Osteoarthritis
PHQ-9	Patient Health Questionnaire
PROMIS-D	Patient-Reported Outcome Measurement Information System Depression
RMSEA	Root mean square error of approximation
SES	Socioeconomic
SEM	Structural equation model

SD	Standard Deviation
T2	Time 1 Wave
T3	Time 2 Wave
TLI	Tucker-Lewis Index
US	United States
WLSMV	Weighted Least Squares Means and Variance Adjusted

CHAPTER 1: INTRODUCTION

Overview

More than half of all adults in the United States (US)—117 million people—and more than 85% of older adults have a chronic condition.[1-3] In addition to accounting for most of the US' health care expenditures (86%),[4] chronic disease is often associated with considerable decline in quality of life, increased risk of mortality, and decreased psychosocial and psychological functioning.[5] The burden and patterning of chronic disease are clear—individuals marginalized by social, economic, and geographic structures are disproportionately burdened by chronic disease.[6] Indeed, there is growing evidence that aspects of the neighborhood are associated with health behaviors, health outcomes, and quality of life, especially as they relate to chronic disease prevention and management.[6] This dissertation research combines theories on neighborhoods and health with advanced statistical methods to identify and examine how neighborhood context is associated with mental and physical functioning among a unique population: older adults living in primarily rural neighborhoods with a specific chronic disease (knee osteoarthritis, OA, Study 1) and a general sample of older adults living in primarily rural neighborhoods—91% of whom have at least one chronic condition (Study 2). Extending previous empirical and conceptual research, two studies examine *if* neighborhoods matter (Study 1), *for whom* neighborhoods matter most (Study 1) and *how* neighborhoods affect health (Study 2).

Study Populations

Study 1 focuses on a specific chronic disease (knee OA) for four reasons. First, while research on neighborhoods and health has increased, few studies have focused specifically on OA, as will be demonstrated in the subsequent chapters. Second, this study examines how neighborhood characteristics interact with key individual-level characteristics to influence health and wellbeing to determine if neighborhoods matter more for certain sub-populations. In order to look at how biological and clinical

features (e.g., disease severity) influence health outcomes and interact with neighborhood level characteristics, a focus on a specific disease is needed (in this case, knee OA). Third, research suggests that adults with arthritis and other chronic conditions fare worse on several indicators than adults with multiple chronic conditions, not including arthritis, which makes research on arthritis important.[7] Finally, the dataset used in this dissertation was specifically designed to assess OA prevalence and functioning.

Study 2 focuses on older adults more generally, without inclusion or exclusion based on OA status, for two reasons. First, most studies on neighborhoods and health have focused on a single disease, which can be useful for understanding a specific disease pattern or examining disease-specific outcomes, but limits comparisons across studies. Second, more than 85% of older adults have at least one chronic disease, most of which share common underlying risk factors (e.g., unhealthy weight) or factors that complicate disease management (e.g., lack of social support).[3] Since this aim focuses on understanding how neighborhoods are associated with health and examines general mediators that public health interventions could target, a broader focus is relevant.

Study 1 Background

Arthritis is one of the most common chronic diseases in the US,[4] particularly among older adults, among whom half of those over the age of 65 report having arthritis.[8] Of the different types of arthritis, OA is the most common.[9] OA is a degenerative joint disease that often causes pain, stiffness, and limitations in movement.[9,10] An extensive body of literature has identified individual-risk factors for OA, including age,[11] gender,[11] race,[12-15] socioeconomic status (SES),[12-15] genetics,[16] bone density,[16] overuse of joints,[16,17] joint injury,[11,16] and obesity.[18] However, research has shown that even after controlling for individual risk factors, variation in arthritis prevalence and management is not fully explained.[19] There is now growing evidence that neighborhood aspects are associated with functioning and wellbeing among adults with arthritis.[19]

However, there are several notable limitations. First, the majority of previous studies have examined neighborhood characteristics among people with *self-report arthritis*, not radiographic OA, which is the focus of this study.[20-26] Second, relatively few studies have examined how neighborhoods

affect mental health among individuals with OA,[23,26] which is arguably an important dimension of OA functioning. Third, the majority of studies have examined a single neighborhood characteristic—neighborhood SES—which limits our understanding of how neighborhoods affect health and comparisons across studies.[12-14,20-24,26-31] While neighborhood SES is important, few studies have examined other determinants of neighborhood context that may be associated with OA-related outcomes. Fourth, the vast majority of studies examining neighborhood-level characteristics and OA outcomes have been cross-sectional,[12-14,20-29,32,33] with few notable exceptions. Finally, few of these previous studies have examined how neighborhood characteristics may interact with key individual-level characteristics to influence OA functioning.[24]

Addressing these limitations, Study 1 examines if neighborhood context is associated with mental and physical health outcomes among individuals with knee OA cross-sectionally and over time and assesses whether neighborhood characteristics interact with one another and key individual level characteristics to influence health outcomes. Using multilevel modeling and a cohort of older adults with radiographic knee OA, this study comprehensively examines the contributions of neighborhood context to health outcomes. Findings from this study can help public health policy makers and researchers understand the influence of differing neighborhood characteristics on important OA outcomes.

Study 2 Background

Many of the limitations on neighborhoods and OA extend to research on neighborhoods and health, more broadly. First, most neighborhood studies have only examined one health outcome or condition, namely obesity, chronic disease risk and management, morbidity, and mortality,[34] and the studies that have examined mental health[35-40] have often only looked at one neighborhood dimension (SES). More research on neighborhood social and physical structures and mental health is needed. Second, most of the research on neighborhoods and health was conducted in urban environments, with few studies examining how findings extend to rural and suburban areas.[41] The narrow focus of prior research (one neighborhood characteristic, one health outcome, mostly urban settings) has limited interpretability and comparison of results across studies.

Third, despite a number of theories and conceptual frameworks illustrating *how* neighborhoods affect health (see work on social determinants of health,[42] social disorganization theory[43] and conceptual models from Diez Roux & Mair,[34] Brown et al.,[44] Carpiano,[45] and Blair et al[46]), these conceptual models have rarely been empirically tested. Finally, most of these conceptual models were built for general use, without regard to specific populations. However, some research suggests that neighborhoods are particularly important for older adults due to their more limited mobility,[47] shrinking social networks,[48] and increased exposure to residential neighborhood effects over time.[41,49]

Study 2 examines *how* neighborhood characteristics are associated with depression among a unique population: older adults living in primarily rural neighborhoods—91% of whom have at least one chronic condition. Using prior theories and conceptual frameworks, neighborhood poverty is hypothesized to affect three neighborhood characteristics: perceived social cohesion, perceived safety, and perceived resources for physical activity and walking. These three neighborhood characteristics are then posited to affect depression through health behaviors (i.e., physical activity) and psychosocial processes (i.e., social support and perceived individual control).

Significance for Public Health

The contribution of the proposed research is to better understand, if, how, and for whom neighborhood and community factors affect health outcomes among older adults. These studies build on and contribute to research on neighborhoods and chronic disease management in important ways.

Neighborhoods Matter

An extensive litany of meta-analyses and reviews have documented the robust and consistent effects of neighborhood characteristics on mortality,[50] mental health,[35-40] chronic disease,[51-53] health behaviors, such as physical activity,[54-58] and other metrics of wellbeing, such as cortisol levels.[59] Because residential areas are also segregated, typically by income and/or race and ethnicity, and marked by unequal distribution of resources, neighborhoods not only affect health outcomes, but also contribute to health disparities.[34,60] Further research on neighborhoods and health is therefore important and timely.

Large Scale Guidelines and Initiatives Often Mention Neighborhoods but Are Limited

While researchers and policymakers emphasize the importance of neighborhoods and communities (see Healthy People 2020,[61] the Affordable Care Act,[62] and new models of health care delivery, such as the Chronic Care Model[63]), little research has attempted to intervene, change, or leverage neighborhood characteristics to improve health.[64] Without fully understanding if, how, and for whom neighborhood characteristics matter, research, guidelines, and interventions to improve chronic disease management and functioning will remain limited.

Neighborhood Research Can Be Directly Applied to Create Interventions

Neighborhoods naturally contain resources, such as social bonds, parks, reliable and safe public transportation, that can be used in interventions to protect against stressors and positively impact communities' and individuals' health.[65] Relatedly, because neighborhoods are geographically bound, research on how neighborhood context affects health can be directly applied to create public health interventions. In fact, a growing number of interventions have targeted neighborhood-level characteristics. Beyond the classic "Moving to Opportunities" study, in which individuals were given vouchers to move from high to low-poverty areas,[66] interventions have also manipulated other neighborhood features, including aesthetic improvements to strengthen social networks and social capital,[67] improvements to indoor and outdoor spaces to allow individuals to foster and maintain relationships[68], and improvements to lighting and sidewalks to increase physical activity.[69] Increasingly, researchers are also using tools, such as Geographic Information System (GIS), to comprehensively map out neighborhood features and advocate for population health approaches that address problematic areas.[70] For these reasons, research on neighborhoods can be directly applied to create interventions.

Contributions of This Dissertation

Studies 1 and 2 can make important contributions to public health research and practice. Findings from Study 1 could provide more specific recommendations to practitioners, interventionists, and providers focused on improving OA management and quality of life. National agencies, like the Centers for Disease Control and Prevention (CDC) and the Arthritis Foundation already recognize the importance

of neighborhoods for OA prevention and management.[71] Study 1 can move these recommendations forward by providing more concrete guidance on what neighborhood characteristics should be addressed, individuals who represent priority populations for interventions, and how neighborhood characteristics interact with key individual-level characteristics to influence health. Additionally, not only does the proposed study explore neighborhood effects on physical health outcomes, but it also examines effects on depression. This is important because depression has emerged as an important public health problem in its own right.[72] In addition, depression has been independently associated with OA management and outcomes and co-morbid depression and OA have been correlated with poorer functioning,[73,74] increased pain,[73,75,76] increased health care use,[76] and costs[76] than either condition alone. Thus, the proposed research broadens the current reach and impact of OA interventions, especially for those that may focus on different OA-related outcomes.

Study 2 could provide support to better tailor interventions and policies for older adults (the vast majority of which have at least one chronic disease), specifying *where* and *how* to intervene to more efficiently allocate resources. For instance, if the proposed research demonstrates a relationship between neighborhood poverty and depression that is mediated by physical activity, then interventions could target physical activity, while also recognizing the importance of neighborhood context (i.e., poverty) when designing intervention components. Overall, this study can be directly applied to create future public health interventions that seek to mitigate neighborhood-level risk factors or leverage neighborhood-level protective factors to improve chronic disease management and wellbeing among older adults.

Organization of the Dissertation

This dissertation has six chapters. The first chapter contains an introduction to the dissertation, an overview of the two studies proposed, and the significance of research on neighborhoods and health. Chapter 2 synthesizes previous empirical research on neighborhoods and health, chronic disease management, and OA and highlights research gaps, which informed the current studies. Chapter 3 details how and why neighborhoods may be associated with health, drawing from a number of theories and conceptual frameworks. Chapters 4 and 5 detail results from Study 1 and Study 2, respectively. The final

chapter—Chapter 6—synthesizes results across the two studies and provides a summary of the dissertation's strengths, limitations, and implications for future research, practice, and policy.

CHAPTER 2: BACKGROUND AND RESEARCH GAPS

Neighborhoods and Health

Over the past few decades, a growing body of research has established that neighborhoods affect health. Specific neighborhood features have been associated with health behaviors, health outcomes, quality of life, psychological health, and mortality.[34,77] Indeed, neighborhoods are such an important predictor of health that many individuals have declared, "longevity may be more influenced by your zip code than by your genetic code."[78] Because neighborhoods encompass economic, physical, and social features, there are plausible links between neighborhoods and health, independent of individual-level risk factors, and increasing evidence demonstrates that neighborhood context is an important social determinant of health.

In this chapter, I briefly review the evidence linking neighborhoods to health, focusing on seven key dimensions: historical trends, health conditions, methods, mediators, interactions with key individual-level characteristics, populations, and settings. Then, I synthesize research gaps and discuss how these gaps informed Studies 1 and 2.

Historical Trends

Although there has been longstanding interest in how neighborhoods and communities affect health, studies examining the effects of neighborhood characteristics only began in earnest in the late 1980s / early 1990s.[34] Many of these early studies, e.g., Haan et al. in 1987,[79] examined whether neighborhood poverty, socioeconomic position, or disadvantage were associated with health outcomes and/or mortality. For instance, in one of the first studies, Hann et al. (1987), found that residents of federally-designated poverty areas experienced higher mortality over a nine year follow-up period compared with residents of non-poverty areas.[79] While subsequent neighborhood studies began to focus on additional neighborhood characteristics—e.g., social and physical features—economic conditions

remain some of the most studied structural factors relevant to health status.[80] Even today, few studies assess neighborhood characteristics using area-level indicators that are independent of residents' perceptions (such as neighborhood poverty measured through census indicators) and self-reported neighborhood characteristics (such as individuals' perceptions of neighborhood safety), which is important since many neighborhood characteristics cannot be measured without self-report (e.g., social cohesion[81]) and area-level measures and self-reported neighborhood measures are associated with health in different, but important ways.[82]

For research on neighborhoods and arthritis, this focus on neighborhood economic conditions, is especially pronounced. Indeed, most studies have examined neighborhood SES, using census-based measures to capture proportion of people living in poverty[12-14,21-24,26,27] or indices of relative disadvantage.[20,28-31] Some studies have looked at community barriers and facilitators,[32,33] perceived neighborhood social environment (e.g., cohesion, aesthetics, safety),[25] or the types of resources used by adults with OA.[83,84] However, only two studies have quantitatively investigated the role of physical or social neighborhood characteristics on OA outcomes and both studies focused on disability.[32,33]

Health Conditions

In addition to limiting their foci to one or two neighborhood characteristics, most neighborhood studies have only examined one health outcome or condition, namely those related to physical health, as indicated by the substantial number of studies linking neighborhoods to obesity, chronic disease risk and management, morbidity, and mortality.[34] While at least six systematic reviews in the past decade[35-40] have documented how neighborhood features may be associated with depression and mental health, most of these studies only focused on neighborhood SES. Indeed, one of the six reviews focused exclusively on neighborhood SES,[35] three of the reviews included a majority of articles that focused only on neighborhood SES,[36,37,39] and two of the reviews included characteristics of the built environment, but mostly assessed factors like housing quality, residential density, air quality, etc., without examining other features of the built environment, such as accessibility or availability of resources for physical activity or walking.[38,40]

Additionally, research on neighborhoods and certain health conditions (e.g., OA) or multiple health conditions (e.g., comorbidities) is lacking. Initially, most research examining neighborhoods and arthritis focused on self-report arthritis.[20-26] While these studies were useful in providing a foundation for how neighborhoods are associated with arthritis outcomes, few studies focused on OA, despite it being the most common type of arthritis. This is important, since OA differs from other types of arthritis, such as rheumatoid arthritis, with regard to risk factors (i.e., body mass index, BMI) and self-management guidelines (i.e., physical activity, weight management). Within the past five to ten years, more research has been devoted to neighborhoods and OA, which is likely a result of increased research from the Johnston County Osteoarthritis (JOCO OA) project. Specifically, researchers have found household poverty to be associated with greater odds of radiographic, bilateral radiographic, and symptomatic knee OA,[14] as well as increased pain among individuals with radiographic knee OA.[12] While evidence continues to grow (with at least six studies demonstrating that neighborhood factors are associated with OA prevalence,[13,14] pain,[12,27] or disability[31,33]), further research examining neighborhood characteristics and their association with OA-related outcomes, particularly mental health, is needed.

Methods, Measurement, and Study Design

Studies on neighborhood and health have evolved methodologically. Early studies often used ecological study designs to examine associations among neighborhood context and health outcomes aggregated to the group level.[34] This approach typically defined areas using administrative boundaries (e.g., census tracts in the US), focused on neighborhood socioeconomic status, disadvantage, or deprivation, typically relied on cross-sectional observational data, and established the importance of neighborhoods for health. However, by removing individual-level data, these studies were not able to disentangle temporal patterning of neighborhood predictors and health outcomes, ignored the contribution of individual risk and protective factors on health, did not examine how neighborhoods may influence health in a multilevel way, and did not investigate other neighborhood-level features relevant to health.

The second wave of studies on neighborhoods and health began using multilevel methods, which allow for: a) simultaneous examination of neighborhood and individual-level predictors, b) non-

independence of observations within neighborhoods, and c) examination of both within-neighborhood and between-neighborhood variation.[85] While most multilevel research still used administrative boundaries and relied on cross-sectional, observational data, these studies allowed researchers to ask more sophisticated questions regarding how neighborhoods affect health, such as: Do neighborhoods differ in average outcomes after controlling for individuals within them? Are neighborhood-level variables related to outcomes after controlling for individual-level variables? Do individual-level associations vary from neighborhood to neighborhood? Do neighborhood-level variables modify the effects of individual-level variables?[85]

More recently, researchers examining neighborhoods and health have started to use GIS and spatial analysis techniques. These approaches allow researchers to use "person-centered buffers" or buffers around household or work locations to understand how relevant neighborhood characteristics affect health.[86] A major application of GIS has been to characterize features of the built environment (e.g., land use, street connectivity, housing density, physical activity resources), typically by compiling observational data from different sources.[87] While GIS approaches allow for more precise measurement of certain neighborhood characteristics, particularly the built environment, they may not be amenable to all research questions or studies, particularly studies examining social environmental characteristics that are generally assessed using scales and not disaggregated using person-centered buffers.

Additionally, while methodological advancements have allowed research questions to evolve, more research is needed to disentangle the complex interactions among neighborhoods and health, for instance: How do neighborhoods affect health over time? How do neighborhoods modify the effects of individual-level characteristics to influence health? And in what ways or through what mediators do neighborhoods affect health? Some researchers have begun using advanced statistical techniques, such as structural equation modeling (SEM), to estimate complex models in which one or more variables are simultaneously predicted and predictor variables,[88] however, applications remain limited.[89] More research, particularly longitudinal research and research using more advanced statistical techniques, is needed.

Mediators

Since the 1980s, researchers have developed a number of theories and conceptual frameworks to illustrate how neighborhoods affect health (see work on social determinants of health,[42] social disorganization theory[43] and conceptual models from Diez Roux & Mair,[34] Brown et al.,[44] Carpiano,[45] Blair et al.,[46] and Kawachi & Berkman[81]), yet these models have rarely been empirically tested. In these models, characteristics of the neighborhood economic environment (e.g., that can refer to both neighborhood disadvantage and compositional features of neighborhoods, such as racial segregation, that have been used as proxies for economic disadvantage) are thought to influence characteristics of the neighborhood physical environment (e.g., environmental exposures, food, physical activity, and recreation resources, services), and neighborhood social environment (e.g., safety, norms, cohesion, capital).[34] In turn, characteristics of the neighborhood physical and social environments are then hypothesized to be associated with health outcomes both directly and indirectly through various mediators, including but not limited to:

1) Psychosocial processes (e.g., social support, stress, resiliency, sense of control, sense of fear and anxiety)[34,46]
2) Health behaviors, including physical activity[34,42-45,90,91]
3) Access to resources, medical care and quality[34,42,44,91]

More research empirically testing these hypotheses is needed.

Interactions with Key Individual-Level Characteristics

An attractive feature of multilevel models is their ability to examine interactions among neighborhood characteristics and individual-level characteristics (termed "cross-level interactions"). Despite hypotheses that neighborhood context may interact with individual-level characteristics, relatively few studies have examined interactions and findings have generally been inconsistent.[34] Indeed, within arthritis research, few studies have even attempted to examine cross-level interactions.[20,24,92] Summarizing this gap, one researcher in 2008 concluded, "few studies using both individual and community characteristics have used arthritis as an outcome; hardly any have examined how community

contexts interact with individual characteristics."[24] While research since then on cross-level interactions has increased, understanding how neighborhood characteristics interact with individual-level characteristics to influence OA-related outcomes would help researchers understand how neighborhoods affect health and for which sub-populations neighborhood characteristics are most important.

Populations

Research on neighborhoods and health has generally established that neighborhood context matters. With increasing research, more specificity and nuance for whom neighborhoods matter is important. Some research suggests that neighborhoods are particularly important for older adults for several reasons.[49] First, older adults typically have more limited mobility,[47] which makes residential neighborhood features important. Second, the frequency and number of social contacts decline with age,[48] which makes neighborhood social cohesion and connectedness important. Third, older adults may not leave their neighborhoods as much as younger adults who may be working or have other obligations.[41] Fourth, nearly 80% of older adults own their homes[93] and have lived in their neighborhoods for a number of years, thereby increasing exposure to residential neighborhood effects. Finally, more than 80% of older adults have chronic conditions,[3] which have been shown to be extensively associated with neighborhood characteristics.[34] The number and magnitude of these factors suggest that older adults may be more vulnerable to certain neighborhood features and make research on neighborhoods and older adults especially useful.[41,94]

Settings

Finally, most neighborhood research has been conducted in urban environments, with few studies examining whether associations between neighborhood context in health extend to rural and suburban areas.[41,95,96] This finding stands in stark contrast to the disproportionately greater rates of chronic disease, obesity, and physical inactivity experienced by residents in rural areas.[97] Only recently have researchers begun to define what constitutes a "rural neighborhood."[95] In one of the first studies of its kind, researchers conducted semi-structured interviews with 29 individuals from rural Georgia to examine how rural residents define and operationalize their neighborhoods.[95] When asked if they would consider the

area around their home to be a neighborhood and how they would draw this area, most participants agreed that the area around their home could be considered a neighborhood (26 out of 29 individuals) and drew neighborhood boundaries that were less than 0.5 square miles (22 out of 26 individuals).[95] When asked "what kinds of things make it a neighborhood?", participants described personal connections with neighbors, structural factors, and shared resources.[95] This study was important for two reasons. First, it confirmed that research on rural neighborhoods is applicable since individuals define the areas around their homes to be neighborhoods. Second, it illustrated that even in rural areas that are typically sparsely populated, neighborhoods are defined by small boundaries.

In the past decade, other researchers have begun creating measures to assess rural environments, however, these measures have focused more on town center characteristics, rather than neighborhood features.[98,99] While more research is beginning to focus on rural neighborhoods,[95,96] greater attention defining rural neighborhoods, measuring their characteristics, and evaluating their associations with health is needed.

Synthesis of Research Gaps

Despite the contributions of previous research on neighborhoods and health and the evolution of the field, a number of gaps remain, including:

1) Measures: Most studies have focused on neighborhood SES and have not included measures of physical or social environments.
2) Health outcomes: Relatively few studies have focused on mental health outcomes and OA, compared to physical health outcomes and other chronic diseases.
3) Methods: Most studies have been cross-sectional and few studies have used SEM.
4) Research questions: Few studies have examined mediation or moderation research questions.
5) Populations and settings: Few studies have focused on older adults and/or rural settings.

Indeed, previous researchers have called for further research to explore mechanisms through which neighborhoods affect health[100]—especially for individuals with OA,[12,14,22,30] examine how community context interacts with individual level characteristics,[24] determine if associations are causal

and/or longitudinal,[32,33,37,83,87] examine perceived neighborhood characteristics from the social and physical environment,[25] examine mental health outcomes,[34] and explore how neighborhoods affect health in rural settings.[95,96] Studies 1 and 2 begin to address these gaps.

In brief, Studies 1 and 2 rely on data from the JOCO OA project and examine how neighborhood characteristics are associated with health outcomes among older adults living in primarily rural areas of North Carolina (thereby addressing Gap 5 from the list above). Additionally, Study 1 examines if neighborhood context is associated with mental and physical health outcomes among individuals with knee OA cross-sectionally and over time and assesses whether neighborhood characteristics interact with one another and key individual level characteristics to influence health outcomes (addressing Gaps 1, 2, 3, 4). Study 2 extends these findings and examines *how* neighborhood characteristics are associated with depression by investigating the influence of three mediators selected from previous conceptual models and theoretical frameworks (addressing Gaps 1, 2, 3, and 4).

CHAPTER 3: THEORETICAL FRAMEWORKS AND CONCEPTUAL MODELS

There are different ways in which neighborhoods may affect health, as well as different ways of conceptualizing neighborhood characteristics. Based on definitions from the often-cited article by Diez Roux and Mair on neighborhoods and health,[34] neighborhood characteristics may be sorted into the following overarching domains:

- Economic environment, which includes neighborhood deprivation, neighborhood poverty, community disadvantage, social affluence, and other compositional features of neighborhoods e.g., immigrant population or ethnic heterogeneity, which have been used as proxies for economic disadvantage
- Physical environment, which includes neighborhood resources, community facilities, aesthetic quality, community characteristics, food availability / accessibility, walkability, barriers in the physical environment, rurality, and health services availability / problems
- Social environment, which includes social integration, religious support, social networks, social / civic engagement, social cohesion, social environment, neighborhood problems (e.g., safety, housing, crime), social capital, and belonging.

In this chapter, I focus on theoretical and conceptual research examining *how* neighborhood social, economic, and physical characteristics are associated with health. I first focus on each of these neighborhood influences separately and then discuss literature linking all three influences.

The Social Environment and Health

While there are many different dimensions of the neighborhood social environment, I focus primarily on perceived neighborhood social cohesion (often conceptualized as the extent to which individuals trust their neighbors, the extent to which neighbors feel connected to one another, the presence or absence of social bonds, etc.) and perceived neighborhood safety. I focus on these two

dimensions of the neighborhood social environment given their inclusion in the dataset that I will be using and their importance for health behaviors and outcomes. While some researchers hypothesize that neighborhood social cohesion affects neighborhood safety (i.e., cohesive neighborhoods are more able to exert social control and increase safety and/or perceptions of safety),[81] other researchers argue that neighborhood safety influences neighborhood social cohesion (i.e., safer neighborhoods facilitate more bonds and connectedness among residents).[101] In this dissertation, I define social cohesion and safety as two separate, but interrelated, domains of the neighborhood social environment.

Mechanisms Through Which the Social Environment Influences Health

A growing number of studies have examined neighborhood social cohesion and safety as predictors of individual-level health behaviors and outcomes. Kawachi & Berkman (2014) hypothesized that the levels of social cohesion in neighborhoods impact health outcomes through three pathways: 1) health-related behaviors, 2) access to services and amenities, and 3) psychosocial processes.[81]

Regarding the first pathway, it is likely that neighborhood social cohesion would affect health behaviors by a) promoting more rapid diffusion of health information and b) exerting social control over deviant health-related behaviors.[81] Supporting these pathways, the theory of diffusion of innovations posits that cohesive communities (in which more residents know and trust one another) are more likely to diffuse information.[102] Research from social disorganization theory (discussed more in-depth later) also suggests that socially cohesive neighborhoods are more able to exert social control over deviant behaviors. While social disorganization theory has mostly been applied to substance use (e.g., smoking, drinking, drug use), Kawachi & Berkman hypothesize that through this same pathway, social cohesion would influence social control (also referred to as "collective efficacy") and thereby health behaviors.[81]

Regarding the second pathway, social cohesion has also been hypothesized to affect access to services and amenities.[81] Specifically, individuals in socially cohesive neighborhoods may be better positioned to lobby for provision of services and use services, which are directly related to health. As articulated by Chuang et al., "A more cohesive society may invest more in public infrastructure such as education, social welfare, and health services, which narrow down health inequality and reduce unequal

access to health services."[103 p., 3] Clearly, access to health-related resources and services, would then be associated with health outcomes.

Last, regarding the third pathway, social cohesion likely influences psychosocial processes by directly affecting levels of affective support, empowerment, self-esteem, and mutual respect—all of which have been found to be associated with overall health. For instance, with regard to social support, relationships are fundamental among primates[104] and directly influence biological processes undermining health outcomes.[105] Indeed, in a meta-analysis of 148 longitudinal studies, Holt-Lundstad et al. found that there was a 50% reduction in mortality for individuals with strong social relationships which was comparable with reductions in mortality attributable to smoking.[106]

Given the strong theoretical and empirical body of research connecting social cohesion to health outcomes, I rely on Kawachi & Berkman's framework and analyze how perceived neighborhood social cohesion influences health through health behaviors (i.e., physical activity) and psychosocial processes (i.e., social support and perceived individual control). Furthermore, given strong links between social cohesion and safety,[101] I hypothesize perceived neighborhood safety to influence health through similar pathways.

In the paragraphs that follow, I turn to literature discussing the links between the neighborhood economic environment and health.

The Neighborhood Economic Environment and Health

Early research on neighborhoods and health focused on the neighborhood economic environment, typically defined through poverty, socioeconomic position, or other measures of deprivation or disadvantage.[34] While subsequent neighborhood studies began to focus on additional neighborhood characteristics, e.g., social and physical features, economic conditions remain some of the most studied structural factors relevant to health status.[80]

Mechanisms Through Which the Economic Environment Influences Health

A number of theories and conceptual frameworks have proposed mechanisms through which the neighborhood economic environment affects health; however, no unifying theory exists. I therefore

present six theoretical / conceptual frameworks that discuss how and why neighborhood economic conditions are important to health. Synthesizing results, I then describe how I will use these frameworks to create the conceptual model that guides this proposal.

Social disorganization theory, which was first introduced by Shaw and McKay (1969), was one the earliest theories linking neighborhood disadvantage to crime and health behaviors.[43] Specifically, this theory posits that disadvantaged neighborhoods are characterized by high economic disadvantage, residential instability, and ethnic heterogeneity.[107] These risk factors disrupt social control and collective efficacy by diminishing communities' resources to sustain institutions, like churches, schools, and voluntary organizations and reducing communities' ability to sustain connections, implement shared goals, and encourage social relationships.[90] While this theory focuses less on neighborhood poverty and more on the disorganization that is thought to result from neighborhood poverty and similar processes, it remains one of the earliest theories on neighborhood poverty and health and its findings have influenced later theories.

Over the past 20-25 years, a growing body of research on **social determinants of health** has emerged.[42] Though this theory does not explicitly emphasize the mechanisms through which neighborhood poverty affects health, it does highlight the importance of neighborhood economic conditions and resources on health. The mechanisms through which these effects occur include but are not limited to: living and working conditions in homes and communities; medical care; and personal behaviors.

In a seminal paper on neighborhoods and health, **Diez-Roux and Mair (2010)** conceptualized how neighborhood economic characteristics influence health.[34] Specifically, their framework suggests that neighborhood economic context (which produces inequalities in resource distribution and residential segregation) influences neighborhood physical environments (e.g., food and recreational resources, built environment) and neighborhood social environments (e.g., safety, social cohesion, norms). In turn, both the physical and social environments influence behavioral mediators and stress—which influences health outcomes. They also point out that many of these pathways are bi-directional, so for instance, residential

segregation can result in spatial inequalities in resources, which in turn can reinforce residential segregation. Also, of importance, these processes may operate over the life course and can be modified by individual-level characteristics.

Mentioning similar pathways as Diez-Roux and Mair, **Carpiano (2006)** proposed that neighborhood socioeconomic factors (e.g., income, home ownership, poverty, income inequality) influences health outcomes through two main pathways.[45] The first pathway includes social processes (namely social cohesion and social capital), which then influence health. The second pathway emphasizes that neighborhood socioeconomic factors affect health directly through risk factors, health behaviors, and health status.

Authors have also proposed how neighborhood economic context influences specific disease outcomes. For instance, focusing specifically on individuals with chronic diseases, **Brown et al. (2004)** proposed that neighborhood SES influences health outcomes through three mechanisms: 1) health behaviors, 2) access to care, and 3) processes of care (i.e., the quality of care offered to individuals).[44] Because their framework was specifically created for individuals with chronic diseases, specifically diabetes, more emphasis was placed on health care processes (e.g., quality of care) than has been proposed in other theoretical frameworks.

Finally, in a review of studies examining neighborhood characteristics and depression outcomes, **Blair et al. (2014)**, identified 14 longitudinal studies published between 2003 and 2011.[46] From these studies, they created a conceptual model to explain how neighborhood exposures, including social disadvantage, affect depression. The proposed pathways through which these health effects occurred included: exposure to stress; formation of supportive and/or mobilized social networks; resiliency to negative affectivity; perceptions of aesthetics; sense of control or powerlessness; and sense of fear and anxiety.

Synthesis

In summary, numerous theories and conceptual frameworks have highlighted the importance of neighborhood economic conditions for health, including social disorganization theory, social determinants

of health theory, and conceptual models from Diez Roux & Mair,[34] Brown et al,[44] Carpiano,[45] and Blair et al.[46] In total, these frameworks have proposed a number of mediating mechanisms through which the neighborhood economic environment influences health.[34,42-46,90,91] These pathways include:

1) The social environment (i.e., social control, collective efficacy, social cohesion, violence, safety)[34,42-46,90]
2) Access to resources, medical care and quality[34,42,44,91]
3) Health behaviors[34,42-45,90,91]
4) Psychosocial processes (e.g., stress, resiliency, sense of control, sense of fear and anxiety)[34,46]

Pulling from these previous theories and conceptual models, I therefore hypothesize that neighborhood poverty directly and indirectly affects health outcomes through influences on: 1) perceptions of the social and physical neighborhood environment, 2) health-related behaviors, and 3) psychosocial processes. Though there are likely other mechanisms at play, e.g., stress, gene-environment interactions, medical care (access and quality), etc. I selected these three mechanisms because of their preponderance in theoretical and empirical research and their inclusion in the dataset that I will be using.

The Neighborhood Physical Environment and Health

Last, a growing body of research has examined how and why the neighborhood physical environment (or "built environment") is associated with health. Typically, research on the built environment has examined homes, buildings, streets, open spaces, parks, resources for physical activity, and infrastructure and their association with physical activity, diet, and obesity.[34]

Mechanisms Through Which the Physical Environment Influences Health

Prior research has demonstrated strong links between aspects of the physical environment (e.g., neighborhood walkability, land use policies, access to walking resources) and physical activity;[34,49] the neighborhood food environment and eating behaviors;[34,108] and resources from the built environment and obesity.[109-112] In a review of 20 studies investigating how the built environment is associated with BMI, Papas and colleagues found that 17 of the 20 studies found a significant association between some aspect of the built environment and BMI.[49] Other reviews have found similar findings (with perhaps strongest

associations between the built environment and health behaviors and weaker, but still consistent associations between the built environment and BMI), therefore suggesting strong and stable relationships between the built environment and health, especially through health behaviors.[34] I therefore hypothesize that perceptions of the physical envionment influence health outcomes directly and indirectly through health behaviors.

Synergistic Effects of Neighborhood Social, Economic, and Physical Environments on Health

Most neighborhood research has examined different types of neighborhood characteristics (e.g., social environment, economic environment, physical environment) separately. However, theory, and specifically those theories presented by Diez Roux and Mair,[34] Carpiano,[45] and Blair et al.[46] posit that neighborhood domains interact to affect health. In these conceptual models, neighborhood SES is considered a structural antecedent to neighborhood social and physical features. More specifically, neighborhood SES influences resources available to residents, affects isolation or integration of residents, influences perceptions of safety, and changes the quality of residents' engagement with one another and neighborhood cohesion. In other words, neighborhood SES likely influences and interacts with social cohesion, safety, and features of the built environment.[34,44]

Despite hypotheses that neighborhood characteristics may interact with one another, relatively little research has empirically examined how different neighborhood factors may interact to influence health. In fact, according to Diez-Roux and Mair "a relatively unexplored area is the synergistic effect of neighborhood physical and social environments. Most research has tended to treat both domains as independent although they are clearly closely related and may have synergistic effects on health."[34 p. 136] This makes empirical research on interactions between neighborhood characteristics especially fruitful, which I investigate in my dissertation.

Conceptual Model and Research Questions

This dissertation examines how neighborhood factors affect physical and mental health outcomes among individuals with a specific chronic disease (knee OA, Study 1) and a general sample of older adults—91% of whom have at least one chronic disease (Study 2). Specifically, Study 1 examines if

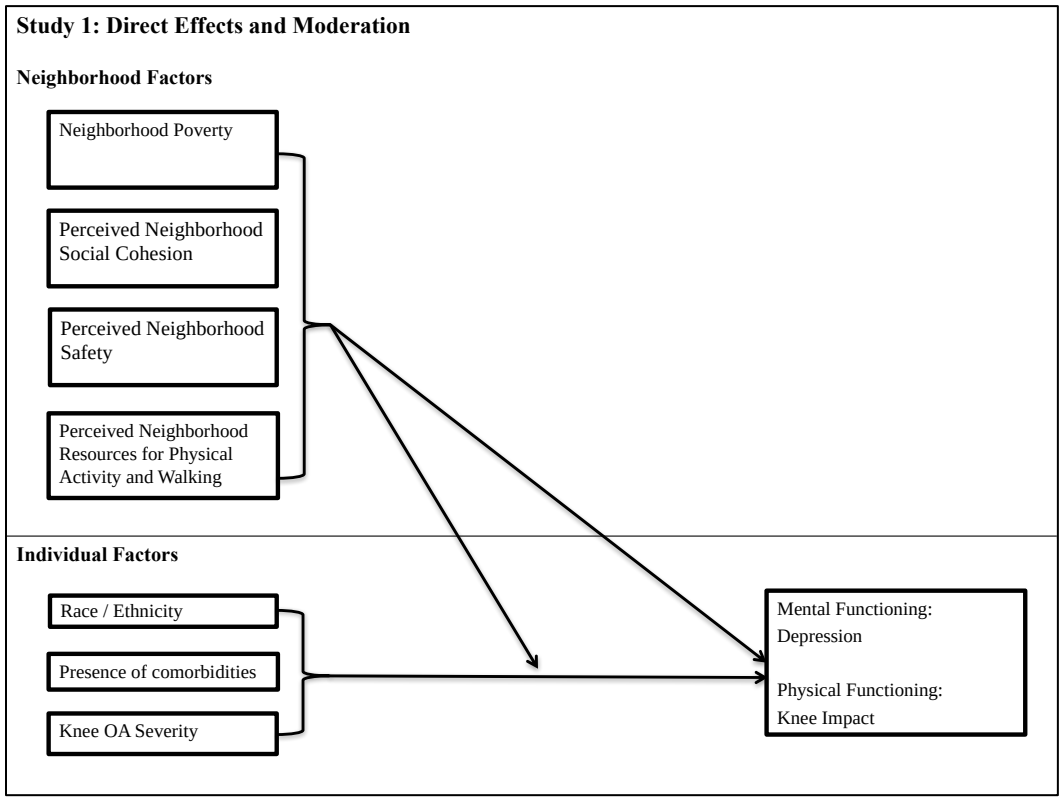
neighborhood context is associated with mental and physical functioning among individuals with knee OA and explores for whom neighborhood characteristics matter most by examining interactions among neighborhood characteristics and key individual-level characteristics. Study 2 examines what factors mediate the relationship between neighborhood context and depression among older adults, most of whom have at least one chronic disease. Broadly, this dissertation examines:

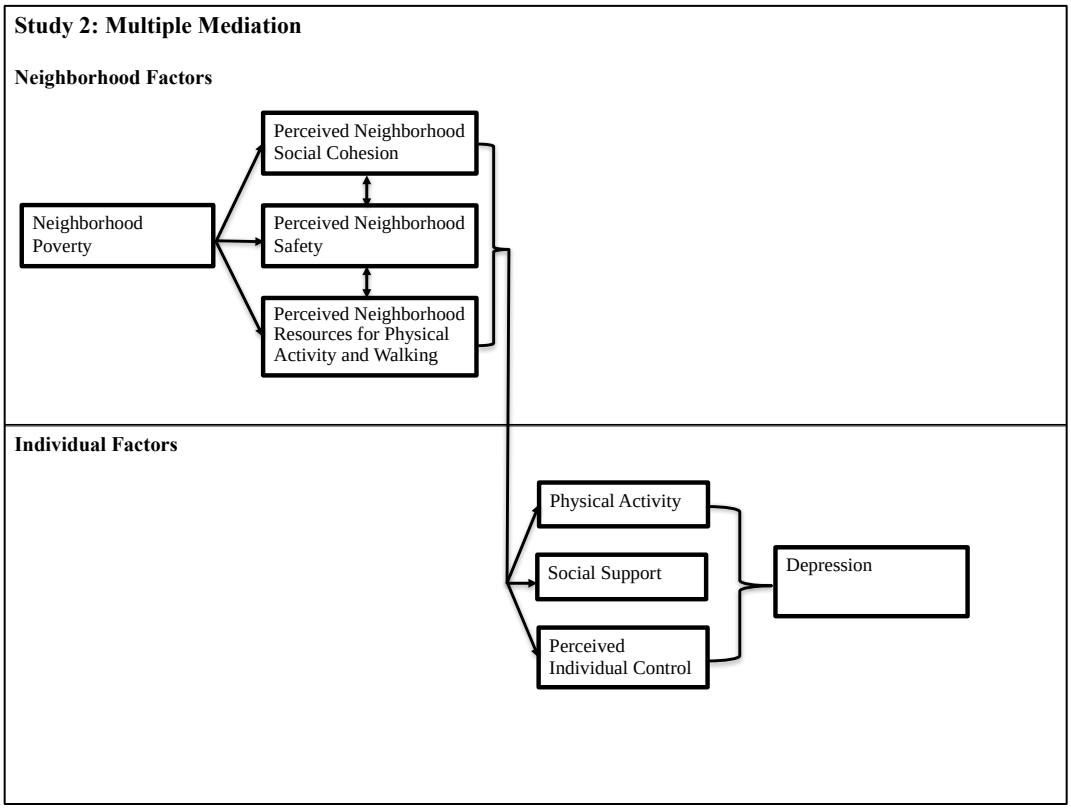
1. Do neighborhoods matter?
2. For whom do they matter most?
3. How do they matter?

Figure 1 illustrates key relationships proposed for my dissertation. In Study 1, neighborhood poverty, perceived neighborhood social cohesion, perceived neighborhood safety, and perceived neighborhood resources for walking and physical activity are hypothesized to affect health outcomes among individuals with knee OA and interact with one another and with key individual-level characteristics to influence health. The bidirectional arrows connecting the neighborhood characteristics illustrate the hypothesis that neighborhood characteristics may interact to influence health outcomes.

In Study 2, using prior theory and conceptual frameworks, neighborhood poverty is hypothesized to affect perceptions of three neighborhood characteristics: social cohesion, safety, and resources for physical activity and walking. Perceptions of these three neighborhood characteristics are then posited to affect health outcomes (namely depression) through health behaviors (i.e., physical activity) and psychosocial processes (i.e., social support and perceived individual control).

Figure 1. Conceptual models for Studies 1 and 2





Hypotheses and Aims

The following aims and hypotheses are proposed

Study 1: Aim

Examine how neighborhood context (i.e., neighborhood poverty, perceived neighborhood social cohesion, perceived neighborhood safety, perceived neighborhood resources for physical activity and walking, interactions among them and with key individual-level characteristics) is associated with mental and physical functioning cross-sectionally and longitudinally among older adults with knee OA.

Study 1 hypothesis 1

In a 2009 review of different neighborhood factors and their influence on older adults' health, Yen et al. found that neighborhood-level SES was the strongest and most consistent predictor of a variety of health outcomes, compared to other neighborhood-level characteristics.[49] I therefore hypothesize that neighborhood poverty will be the strongest and most consistent neighborhood-level predictor of health outcomes among individuals with knee OA. In the absence of data suggesting neighborhood poverty to be more strongly associated with mental or physical health outcomes, I propose that neighborhood poverty will be equally associated with mental and physical functioning.

Study 1 hypothesis 2

In the same 2009 review by Yen et al. mentioned above, researchers also found a fairly consistent relationship between the neighborhood physical environment and physical activity.[49] Since physical activity is linked to disability, pain, morbidity and mortality, I hypothesize that perceived neighborhood resources for physical activity and walking will be significantly associated with mental and physical functioning among older adults with knee OA, but more strongly associated with physical health outcomes than mental health outcomes.

Study 1 hypothesis 3

Previous reviews[34] and studies (including a study with adults with arthritis)[25] have demonstrated a fairly consistent relationship among neighborhood social environment characteristics and mental health outcomes, particularly depression. Few studies have investigated features of neighborhood social environments and physical health outcomes.[34] As a result, I hypothesize that perceived neighborhood social cohesion and safety will be most consistently associated with mental health outcomes (compared to physical health outcomes) among older adults with knee OA.

Study 1 hypothesis 4

In a 2009 study by Mair et al. examining cross-sectional and longitudinal associations of neighborhood cohesion and stressors with depressive symptoms, researchers found that neighborhood social cohesion, aesthetics, and violence were associated with depressive symptoms cross-sectionally but not longitudinally. In my study, I will likely have reduced power (smaller sample size) to observe significant associations longitudinally. As a result, I hypothesize that relationships among neighborhood characteristics and outcomes will emerge more consistently in cross-sectional analyses than in longitudinal analyses.

Study 1 hypothesis 5

Previous empirical research suggests that there are clear racial and ethnic disparities in OA prevalence, function, and pain[113-115] and theory suggests that neighborhood context contributes to racial health disparities.[34] For instance, in a study examining neighborhood context and self-rated health using NHIS data, Do et al. found that adding residential context to models resulted in a 15-76% reduction of Black / white disparities in self-rated health that were previously unaccounted for by individual-level controls.[116] I therefore hypothesize that neighborhood context will interact with race / ethnicity to influence mental and physical health outcomes and that the interaction will be the strongest for physical health outcomes.

Study 1 hypothesis 6

Given previous research suggesting that additional comorbidities (e.g., diabetes, heart disease) affect the health and wellbeing of individuals with OA,[117,118] and some research suggesting that specific neighborhood contexts are associated with development of comorbidities,[119] I hypothesize that neighborhood context will interact with presence of comorbidities to influence mental and physical health outcomes among individuals with OA.

Study 1 hypothesis 7

Previous research has found differences in OA function, pain, and treatment options based on level of OA severity.[115] In addition, several studies have shown that OA severity is a result of several modifiable risk factors, including BMI[120] and physical activity at work.[121] As a result, I hypothesize that neighborhood context will interact with knee OA severity to influence both mental and physical health outcomes among individuals with OA.

Study 2: Aim

Determine what factors (i.e., physical activity, social support, perceived individual control), as specified in prior theories and conceptual frameworks mediate the relationships between neighborhood characteristics and depression among older adults—91% of whom have at least one chronic condition.

Study 2 hypothesis 1

Based on previous theories and conceptual frameworks,[34,42,44-46,81,107] I hypothesize that neighborhood poverty will be associated with depression through perceived neighborhood social cohesion, perceived neighborhood resources for physical activity and walking, and perceived neighborhood safety. I also hypothesize that this mediation will be partial, not complete; in other words, there will still be a direct effect from neighborhood poverty to depression.

Study 2 hypothesis 2

Given the strong relationships between a) neighborhood characteristics and physical activity,[34] and b) physical activity and depression,[122,123] I expect that physical activity will be the strongest

mediator in the pathway from neighborhood characteristics to depression. I also hypothesize that social support and perceived individual control will be significant, but weaker, mediators. For all three mediators, I hypothesize that this mediation will be partial, not complete; in other words, there will still be a direct effect from neighborhood characteristics to depression.

CHAPTER 4: STUDY 1

Introduction

Arthritis is one of the most common chronic diseases in the US,[4] particularly among older adults, where half of all adults 65+ report having arthritis.[8] An extensive body of literature has identified individual-risk factors for arthritis, including age,[11] gender,[11] race,[12-15] SES,[12-15] genetics,[16] bone density,[16] overuse of joints,[16,17] joint injury,[11,16] and obesity.[18] However, research has shown that even after controlling for individual risk factors, variation in arthritis prevalence and management is not fully explained.[19] There is now growing evidence that aspects of the neighborhood are associated with arthritis related outcomes.[12-14,20,22-24,27,32,33]

Indeed, neighborhood SES has been found to be associated with: increased prevalence of self-reported arthritis[20,22,24] and radiographic hip and knee OA;[13,14] reduced quality of life[23] and increased depression[26] among individuals with self-report arthritis; and increased pain[12] and disability[27,32,33] among individuals with or at risk for developing OA. Important among these previous studies is their illustration that neighborhood conditions matter for individuals with arthritis. However, despite the growing body of evidence that neighborhoods influence the health and well-being of individuals with arthritis, several notable gaps in the literature remain. First, the majority of previous studies have not focused on OA, despite it being the most common type of arthritis.[20-26] This is important, since OA differs from other types of arthritis, such as rheumatoid arthritis, with regards to risk factors (i.e., BMI) and self-management guidelines (i.e., physical activity, weight management).[9]

Second, while studies have found associations among neighborhood context and several OA outcomes (i.e., prevalence of self-reported arthritis,[20,22,24] prevalence of radiographic hip and knee OA,[13,14] joint replacement,[28,29] pain,[12] and disability[27,32,33]) relatively few studies have examined how neighborhoods affect mental health of individuals with OA. Previous research has found neighborhood

SES to be associated with reduced quality of life,[23] and depression[26] among individuals with self-report arthritis. However, there is limited research examining neighborhood context and psychological well-being among individuals with OA, despite the relatively high prevalence of depression and anxiety among individuals with OA[73,124,125] and research suggesting co-morbid depression and OA are associated with poorer functioning,[73,74] increased pain,[73,75,76] increased health care use,[76] and costs,[76] than either condition alone.[76]

Third, the majority of studies have examined neighborhood SES either by using census-based measures to capture proportion of people living in disadvantaged areas[12-14,21-24,26,27] or creating indices of relative disadvantage.[20,28-31] While these types of analyses are important, few studies have examined other determinants of neighborhood context that may be associated with OA-related outcomes. For instance, researchers examining the association between perceived neighborhood social environment and OA functioning found that individuals with self-report arthritis had increased odds of depressive symptoms if they perceived lower neighborhood safety and lower neighborhood social cohesion.[25] The authors therefore concluded that, "findings from this research suggest that future researchers consider the importance of the *perceived neighborhood environment* (aesthetics, safety, and social cohesion) when examining the influence of place on health, particularly mental health, in individuals with arthritis."[25]

Fourth, few previous studies have examined how neighborhood characteristics may interact with key individual-level characteristics to influence OA functioning. OA prevalence, pain, and functioning differ by race / ethnicity, knee OA severity, and presence of comorbidities. For instance, research has found that African Americans have more than double the prevalence of severe knee OA than Caucasians;[115] they are more likely to have significantly worse pain, stiffness, and function;[113,114] and they are less likely to seek and receive joint replacement therapy or pain medication.[126-128] In addition to race, individuals with severe OA (compared to non-severe OA) are more likely to experience pain and disability and need total joint replacement.[115] Finally, individuals with OA and another chronic condition may experience increased physical limitations, find it harder to manage OA (e.g., being physically active), and have worse OA outcomes.[5] Yet no studies to my knowledge have analyzed how

neighborhood characteristics interact with individual-level characteristics among individuals with OA. Summarizing this important gap, Canizares et al. concluded, "few studies using both individual and community characteristics have used arthritis as an outcome; hardly any have examined how community contexts interact with individual characteristics."[24]

Finally, as is common with research on neighborhoods and health more generally,[34] few studies have examined longitudinal associations among neighborhood-level characteristics and OA outcomes.[12-14,20-29,32,33]

The present study examines if neighborhood context is associated with mental and physical functioning and begins to address limitations of previous research by answering the following research questions among individuals with knee OA:

1. Is neighborhood context associated with mental and physical health outcomes?
2. Do neighborhood characteristics interact to influence health outcomes?
3. Do key individual characteristics interact with neighborhood context to influence health outcomes?
4. Is neighborhood context associated with health outcomes over time?

Methods

Participants and Procedures

Data for this study come from a population-based prospective cohort of knee and hip OA among African American and Caucasian individuals (the JOCO OA project).[129] Recruitment occurred in Johnston County, North Carolina (NC), which at the time of this study, was classified as a mostly rural county.[130] Details on the study design, data collection procedures, and study population are detailed in previous publications.[129] In brief, the study was designed to be representative of civilian, non-institutionalized African Americans and Caucasians over the age of 45 who resided in one of six towns or townships in Johnston County, NC for at least one year, were living in the county at the time of study enrollment, and physically and mentally capable of completing the study protocol. All participants completed an initial home interview, a limited clinical and functional examination, which included an

assessment of weight and height and radiographic examination of the knees, and an additional home interview approximately 2 weeks after the clinic visit. At baseline, all participants provided informed written consent at the time of recruitment. The study was approved by the Institutional Review Boards of the University of North Carolina Schools of Medicine and Public Health and the CDC.

Study Analytic Sample

The analytical sample for this study uses two time points: Time 1 (T2 wave), which was collected between 2006-2011 (for cross-sectional analyses) and Time 2 (T3 wave), which was collected between 2013-2015 (for longitudinal analyses). Individuals' temporal positions within waves were generally held constant. For instance, if someone were interviewed early in the T2 wave (e.g., 2006, 2007), they would likely be interviewed early in the T3 wave (e.g., 2013). As a result, between 4 and 7 years generally elapsed between the T2 and T3 waves. For the purposes of this study, I restricted analyses to individuals with knee OA. Researchers assessed presence or absence of OA using radiography and the Kellgren and Lawrence (KL) grade, which scores OA severity on a scale of 0-4.[16] I classified individuals with scores of 2-4 as having knee OA. The reliability and validity of using the KL scale to determine OA has already been established; in previous studies, both inter-rater reliability and intra-rater reliability have been high (weighted inter-rater reliability = 0.86; Kappa for intra-rater reliability = 0.89).[12]

Among adults with knee OA at T2 (n=729), cases in which individuals were missing on any control variables (n=73) were dropped from the sample, yielding a sample size of 656. Among adults with knee OA at T3 (n=485), cases in which individuals were missing on any control variables (n=51) were dropped from the sample, yielding a sample size of 434.

Measures

A comprehensive list of all measures and how they were coded can be seen in Appendix A.

Outcomes. I measured two outcomes, depression and knee impact scores.

Depression. For cross-sectional analyses, I used the Center for Epidemiologic Studies (CES-D) to assess depression. The CES-D is one of the most widely used self-report scales to assess current levels of depressive symptomology.[131] Developed in 1977, the CES-D was intended to assess epidemiology of

depression in the *general population*, rather than diagnosis at clinical intake.[131] While items were chosen from previously validated depression scales and based on symptoms of depression in clinical cases, the CES-D was not designed to reflect diagnostic criteria of depression at the time of its development.[131] Indeed, some diagnostic criteria are not reflected (e.g., suicidality) and many "healthy" or "normal" people could experience some of the symptoms reflected in CES-D items. In contrast to other widely used measures, such as the Beck Depression Inventory, the CES-D focuses more on affective aspects of depression, rather than depression cognitions.[132]

The CES-D contains 20 items that assess the frequency of depressive symptoms in the week prior to the interview. Response options range from 0 to 3, which refer to frequency of the symptoms (i.e., "rarely of none of the time" to "all of the time"). The CES-D was originally posited to have a four-factor structure model composed of depressed affect, positive affect, somatic activity, and interpersonal issues.[131] For instance, the item "I felt depressed" would belong to the depressed affect factor, "I felt hopeful about the future" would belong to the positive affect factor, "my sleep was restless" would belong to the somatic activity factor, and "people were unfriendly" would belong to the interpersonal issues factor. However, more than 20 alternative factor structures—including a unidimensional factor structure,[133]—have been reported.[134] In practice, many researchers (including Radloff, the original developer of the CES-D) report a total score.[133] I therefore summed item responses to create a total score that ranged from 0 (best possible) to 60 (worst) (Cronbach's alpha in this study = 0.86), where higher scores reflect more symptoms of depression, weighted by frequency of occurrence in the previous week.[131] Given this complexity in interpreting scores, I report results using the terminology "CES-D scores." Although a cut-off point of 16 has been used in previous research to indicate risk for moderate or severe depression,[135] I conceptualized and analyzed CES-D scores as a continuum (not merely in dichotomous terms).

Between T2 and T3, the parent study switched depression measures from the CES-D to the Patient-Reported Outcome Measurement Information System Depression (PROMIS-D) scale. Thus, for longitudinal analyses, I used the PROMIS-D scale as a measure of depression with the CES-D entered

into models as the corresponding measure at T2. PROMIS measures were developed by the National Institutes of Health (NIH) to more precisely and efficiently measure patient-reported symptoms, functioning, and health-related quality of life.[136] In contrast to the CES-D, PROMIS-D items excluded somatic symptoms, such as appetite and sleep to prevent confounding when assessing individuals with physical health conditions.[137,138] Instead, PROMIS-D items focus on negative affect (e.g., sadness), views of self (e.g., worthlessness), social cognition (e.g., loneliness), and decreased positive affect (e.g., loss of interest).[138] Indeed, while some items from the CES-D and PROMIS-D are the same (e.g., "I felt depressed") or have conceptual overlap (e.g., in the CES-D "I felt hopeful about the future" vs. in the PROMIS-D "I felt hopeless"), many of the items in the CES-D are distinct from those in the PROMIS-D (e.g., "I could not get going," "My sleep was restless," "I felt that people dislike me" all appear in the CES-D but are absent in the PROMIS-D). Also, in contrast to the CES-D, an Item Response Theory approach was used to develop item banks for the PROMIS-D (rather than a Classical Test Theory approach, which was used to develop the CES-D). Regardless of differences, the PROMIS depression scale has shown strong correlations with the CES-D (>0.80) and the Patient Health Questionnaire (PHQ-9) (>0.70) among individuals with major depressive disorder seeking outpatient treatment,[139] as well as the general population.[137]

I used an 8-item short form of the PROMIS-D. These 8 items were rated on a 5-point scale (1=never; 2=rarely; 3=sometimes; 4=often; and 5=always) with higher scores indicating greater severity of depression.[138] I summed responses and then converted the raw scores to standardized scores, in line with scoring guidelines[138] (Cronbach's alpha in this study = 0.94).

Reported knee impact scores. I used three sub-scales (Knee-Related Quality of Life, Function in Daily Living, and Pain) from the Knee Injury and Osteoarthritis Outcome Score (KOOS) to assess the impact of knee OA.[140] Because of high observed correlations in these separate sub-scales (>0.85 in this study), I calculated a composite score from the items comprising the sub-scales and named it "knee impact." Example items from the three sub-scales include: "how often are you aware of your knee problems?" (Knee-Related Quality of Life), "what degree of difficulty do you have descending stairs due

to your knee?" (Function in Daily Living), and "how much pain do you have in your knee while twisting / pivoting?" (Pain). Response options determine the frequency of problems in the past week and each item is scored 0 to 4. I calculated the mean of the 30 items and transformed scores to a 0-100 scale, with zero representing extreme problems and 100 representing no problems (Cronbach's alpha in this study = 0.98). The KOOS has been extensively validated among individuals with OA,[140] shown to have adequate reliability,[141] and used in a number of OA studies.[142,143]

At T2, items from the KOOS sub-scales were asked without regard to specific knee, whereas at T3, items from the KOOS sub-scales were asked of each knee. For example, at T2, I asked individuals: "How often are you aware of your knee problems?" and at T3, I asked individuals: "How often are you aware of your knee problem? (left)" and "How often are you aware of your knee problem? (right)". To make scores comparable in longitudinal analyses, I took the highest score for each set of knees at T3, rather than each knee. Using the same example from above, if an individual scored their left knee to be a 4 and their right knee to be a 0, I calculated the score for that set of items to be a 4. I analyzed scores this way on the intuitive assumption that individuals think of their most painful knee when asked to evaluate overall knee functioning. I calculated the mean of the 8 items and transformed scores to a 0-100 scale, with 0 representing extreme problems and 100 representing no problems (Cronbach's alpha in this study for knee impact scores at T3 = 0.99).

Neighborhood characteristics. I measured four neighborhood characteristics.

Neighborhood poverty. I defined neighborhood poverty as the percentage of households with income below the poverty line within a census block group. These data were compiled from the 2010 U.S. Census. I used census block groups as the unit of analysis, since they are the smallest administrative boundary from the census that includes economic data. Census block groups generally contain between 600 and 3,000 people.[144]

Perceived neighborhood social cohesion. I measured perceived neighborhood social cohesion using Sampson et al.'s 5 item measure of Social Cohesion and Trust.[145] An example item is: "people around here are willing to help their neighbors." I assessed all items on a 5-point likert response scale

(1=strongly agree to 5=strongly disagree). I then summed responses, which ranged from 5-25, with higher scores indicating more social cohesion (Cronbach's alpha in this study = 0.85). Previous studies have found high reliability for this scale (Cronbach's alpha over 0.80) and consistency over time (test-retest ICC: 0.90; 95% CI: 0.84, 0.94).[146] Supporting validity, this scale has also been used in a variety of research studies assessing social cohesion / social capital.[25,37,147]

Perceived neighborhood resources for physical activity and walking. I measured perceived neighborhood resources for physical activity and walking using 11 items from the Walking and Exercise Environment scale. This scale assesses opportunities for exercise in individuals' neighborhoods. An example item is: "my neighborhood offers many opportunities to be physically active." I assessed all items on a 5-point likert response scale (1=strongly agree to 5=strongly disagree) and summed responses, where higher scores indicate more resources (Cronbach's alpha in this study = 0.71). Previous studies have shown this scale to have high reliability and consistency over time (test-retest ICC: 0.88; 95% CI: 0.79, 0.93).[146]

Perceived neighborhood safety. I measured perceived neighborhood safety with three items. An example item is: "I feel safe walking in my neighborhood during the evening." All items were assessed on a 5-point likert response scale (1=strongly agree to 5=strongly disagree) and summed, where higher scores indicate more safety (Cronbach's alpha in this study = 0.67). Previous studies have demonstrated these items to be reliable and consistent over time (test-retest ICC: 0.80; 95% CI: 0.67, 0.88).[146]

Moderators. I assessed three cross-level interactions involving 1) race/ethnicity, 2) knee OA severity, and 3) presence of comorbidities. First, I examined race / ethnicity as a moderator, given previous research suggesting racial and ethnic disparities in OA prevalence, function, and pain,[113-115] and research suggesting that neighborhood characteristics may contribute to racial disparities in health.[34] Second, I examined knee OA severity as a moderator given previous research linking knee OA severity with functioning and pain,[8] and hypotheses that neighborhood context may interact with knee OA severity to influence health outcomes. I defined non-severe knee OA as presence of a KL score of 2 and severe knee OA as presence of a KL score of 3 or 4. Finally, I examined presence of comorbidities as a

moderator and defined this variable at two levels: individuals with knee OA only or individuals with knee OA plus heart disease or diabetes. I selected heart disease and diabetes rather than other comorbidities given research suggesting that 1) heart disease and diabetes are common comorbidities of OA,[8] 2) they may interfere with OA management guidelines, such as physical activity,[148,149] which could interact with neighborhood characteristics, and 3) they are associated with poor functioning and well-being among individuals with OA.[150,151]

Control variables. In all main effect models (i.e., models without interaction terms), control variables assessed were race / ethnicity (White or Black / African American), education (categorized as less than high school or high school or greater), body mass index (BMI), gender (male or female), age, health insurance status (categorized as health insurance or no health insurance), number of comorbidities (defined using the Disease Inventory at T2 and the Charlson Comorbidity Index at T3), and physical activity (categorized as inactive, insufficiently active, or sufficiently active using questions from the Behavioral Risk Factor Surveillance System, BRFSS[152]).

In models involving interactions with race / ethnicity, I included all control variables except race / ethnicity, which I conceptualized as part of our interaction term; in models involving interactions with knee OA severity, I included all control variables; and in models involving interactions with presence of comorbidities, I included all control variables except number of comorbidities, since number of comorbidities and presence of heart disease or diabetes would be collinear.

Data Analysis

Descriptive statistics. I first examined distributions of the data, checked for multicollinearity (all Variance Inflation Factor scores were less than 3), and looked at bivariate associations among neighborhood characteristics, physical activity, and health outcomes.

Centering. Before modeling the data in multilevel models, I created group means for three neighborhood variables (i.e., perceived neighborhood social cohesion, perceived neighborhood resources for physical activity and walking, and perceived neighborhood safety) based on average scores within census block groups. I then a) grand mean centered these variables at the neighborhood level, which

means I calculated the deviation of each neighborhood's score from the overall mean of each neighborhood variable and b) group mean centered these variables at the individual level, which means I calculated the deviation of each individual's score from the mean for the individual's cluster (neighborhood census block group in this case). I used these centered variables to partition the variance as between-neighborhood variance and within-neighborhood variance.[89,153] This approach is known as an unconflated multilevel model and reduces bias due to conflation.[89] Finally, I grand mean centered the remaining control variables to make the intercept for each of the multilevel models more interpretable.[89] For clarity, I labeled all individual-level variables as "Level 1" variables or "within-neighborhood" variables and labeled all neighborhood-level variables as "Level 2" variables or "between-neighborhood" variables.

Multilevel models. After centering, I conducted a series of multilevel models, which is appropriate when data are nested (i.e., individuals are nested in larger organizational clusters, in this case census block groups).[154] I used multilevel models to examine the associations among neighborhood characteristics and outcomes, adjusting for control variables. In addition, I allowed Level 1 variables to be modeled as random effects, which allows parameter estimates to vary across Level 2 units. For example, modeling education as a random effect implies that the effect of education on depression may vary based on the neighborhood. Although it may be beneficial to assess random effects, depending on the research question and theory, random effects can also be computationally demanding to calculate. Therefore, if models failed to converge, I removed random effects and modeled Level 1 units as fixed effects with random intercepts.

Poisson regression. I observed that scores for depression were highly positively skewed, in that more individuals had lower CES-D and PROMIS-D scores. Accordingly, I used a multilevel poisson regression to model results, as has been done in previous research.[155]

Longitudinal analyses. In longitudinal analyses, I used residualized change scores to model change in outcomes, controlling for prior levels of the measured outcome. For instance, when I modeled PROMIS-D scores as the outcome at T3, I controlled for CES-D scores measured at T2. For time-varying

variables, which included BMI, age, and physical activity, I calculated average scores across the two time points. For health insurance status, which also varied across time points, I calculated this variable as proportion of individuals who had any health insurance at either time point and used this as a control. For all other time non-varying variables, I included scores from T2 as control variables.

Interactions. After conducting separate multilevel models for each outcome cross-sectionally and longitudinally, I added interaction terms to four separate models for: 1) each neighborhood characteristic with the other neighborhood characteristics, 2) each neighborhood characteristic with race / ethnicity, 3) each neighborhood characteristic with knee OA severity, and 4) each neighborhood characteristic with presence of comorbidities. Given the number of potential interactions, I only probed and graphed interactions that were significant at $p<.01$. Otherwise, I set critical $\alpha = .05$ and used 2-tailed statistical tests. For all analyses, I used SAS version 9.4 survey procedures (SAS Inc., Cary, NC, USA).

Sensitivity Analyses

I conducted three sensitivity analyses for the cross-sectional analyses. First, I used multiple imputation to impute missing data (all missing data were measured at Level 1).[156] Using SAS Proc MI, I created twenty multiply-imputed complete data sets.[157] I then used the multilevel modeling approach described above to separately assess each of the 20 imputed data sets and obtained results via the SAS Proc MIANALYZE procedure. Finally, I determined whether use of multiple imputation produced different results than listwise deletion by comparing the parameter estimates and p-values.

Second, I excluded individuals who resided in a census block group with less than 5 other individuals (n=37), since small neighborhood size might bias within- and between-neighborhood estimates for these individuals.

Finally, I analyzed somatic and non-somatic depressive symptoms separately, since it is possible that they would be differentially associated with neighborhood characteristics. Somatic symptoms included items 1, 2, 5, 7, 11, and 20 from the CES-D and referred to whether individuals were bothered by things, had a poor appetite, had trouble keeping their mind on what they were doing, felt that everything was an effort, had restless sleep, and could not get going.[134]

Results

Participant Characteristics

Table 1 provides details on the demographic characteristics of participants. At T2, our sample included adults who were on average 70.0 years old (standard deviation (SD): 9.0). Participants were diverse, with a substantial number of African Americans (34.0%) and individuals without a high school degree (25.5%). On average, participants had 1.9 comorbidities in addition to knee OA, and 39.8% had either heart disease or diabetes. Additionally, participants had low CES-D scores (mean: 6.6, SD: 7.4, possible range: 0-60), although 11.7% had scores at or above 16 indicative of being at risk for moderate or severe depression, and reported high knee impact scores (mean: 77.5, SD: 23.3, possible range: 0-100). At T3, PROMIS-D scores were still low (mean: 10.7, SD: 3.4, possible range: 8-40) and reported knee impact scores were still high (mean: 70.0, SD: 25.9, possible range: 0-100).

Correlations

Table 2 provides details on observed correlations among key neighborhood characteristics, physical activity, and health outcomes. At T2, CES-D scores were associated with all neighborhood variables, except poverty, with correlations ranging from -0.19 to -0.25, all p-values <0.001. Reported knee impact scores were associated with all neighborhood variables, including poverty, and in the expected direction, with correlations ranging from -0.10 (for neighborhood poverty) to 0.21, all p-values <0.01. Also, at T2, all neighborhood variables were significantly associated with physical activity, with correlations ranging from -0.15 (for neighborhood poverty) to 0.09, all p-values <.05.

At T3, no neighborhood variables were significantly associated with PROMIS-D or reported knee impact scores with the exception of perceived neighborhood safety, which was positively associated with reported knee impact scores at T3 (r=0.11, p=0.02). Also at T3, physical activity was significantly associated with neighborhood poverty (r=-0.10, p=0.03) and perceived neighborhood social cohesion (r=0.14, p=0.005), but not other neighborhood variables. CES-D scores at T2 and PROMIS-D scores at T3 were significantly, moderately correlated (r=0.40, p<0.001), while reported knee impact scores at T2 and T3 were significantly, moderately correlated (r=0.66, p<0.001).

Is Neighborhood Context Associated with CES-D Scores and Knee Impact?

Our models with random effects for Level 1 variables failed to converge. I therefore modeled all Level 1 variables as fixed effects. A summary table with results from all main effects can be seen in Table 3. Tables 4 and 5 include results from multilevel models for CES-D scores and reported knee impact scores, respectively. For both Tables 4 and 5, two models are presented. Model 1 includes all Level 1 correlates (i.e., all individual-level characteristics, including Level 1 neighborhood variables) and Model 2 includes all Level 1 correlates, plus Level 2 correlates (i.e., Level 2 neighborhood variables). Results presented below are from Model 2.

Adjusting for control variables, I found that Level 1 perceived neighborhood social cohesion (B= -0.04, p< 0.001) and Level 1 perceived neighborhood resources for physical activity and walking (B= -0.03, p< 0.001) were associated with lower CES-D scores (Table 4). I found no significant effect of Level 1 perceived neighborhood safety on CES-D scores. Level 2 perceived neighborhood social cohesion (B= -0.07, p=0.02) was associated with lower CES-D scores, while Level 2 neighborhood poverty, perceived neighborhood resources for physical activity and walking, and perceived neighborhood safety were not.

Turning to knee impact, after adjusting for control variables, I found no significant effects of Level 1 perceived neighborhood social cohesion or safety on reported knee impact scores, but Level 1 perceived neighborhood resources for physical activity and walking were associated with higher reported knee impact scores (B=0.48, p=0.008). I observed no significant Level 2 neighborhood effects on knee impact scores (Table 5).

Do Neighborhood Characteristics Interact with One Another to Influence Health?

A summary table with results from all interactions can be seen in Table 6. I observed no significant interactions among neighborhood variables and CES-D scores. However, for reported knee impact scores, I observed a significant interaction among Level 2 neighborhood poverty, Level 2 perceived neighborhood safety, and reported knee impact scores (p=0.009) (Figure 2a). Specifically, I found that among neighborhoods with high poverty levels (defined as one SD above the mean), Level 2 perceived neighborhood safety was associated with lower reported knee impact scores (B= -8.05,

p=0.003). In addition, among neighborhoods with medium poverty levels (defined as within one SD of the mean), Level 2 perceived neighborhood safety was associated with lower reported knee impact scores (B= -3.36, p=0.03). However, for neighborhoods with low poverty levels (defined as one SD below the mean) Level 2 perceived neighborhood safety was not associated with reported knee impact scores (B= 1.32, p=0.48). In other words, safety was only associated with reported knee impact scores for neighborhoods with high or medium poverty levels.

Do Key Individual Characteristics Interact with Neighborhood context?

I observed several significant interactions among neighborhood characteristics and key individual characteristics (Figure 2b-d). These interactions are also presented below, organized by each of the three moderators explored: race / ethnicity, presence of comorbidities, knee OA severity, and by outcome, starting with depression and then turning to knee impact scores. A summary table with results from all interactions can also be seen in Table 6.

Race / ethnicity. First, I found a significant interaction among race, Level 1 perceived neighborhood resources for physical activity and walking, and CES-D scores (p=0.004). Specifically, I found that for both Black (B= -0.03, p<.001) and white adults (B= -0.01, p=0.001), Level 1 perceived neighborhood resources for physical activity and walking was associated with lower CES-D scores, however, the effect was stronger for African American vs. white adults.

Second, I observed an interaction among race, Level 1 perceived neighborhood safety, and CES-D scores (p=0.009). For white adults, Level 1 perceived neighborhood safety was associated with lower CES-D scores (B= -0.04, p=0.003), whereas no association was found for Black adults (B= 0.02, p=0.33).

In other words, Level 1 perceived neighborhood resources for physical activity and walking were more strongly associated with CES-D scores for Black adults, but Level 1 perceived neighborhood safety was more strongly associated with CES-D scores for white adults.

Presence of comorbidities. Turning to comorbidities, I found four significant interactions.

First, I observed a significant association among Level 1 perceived neighborhood social cohesion, presence of comorbidities, and CES-D scores (p<0.001). Specifically, Level 1 perceived neighborhood

social cohesion was associated with lower CES-D scores for individuals with knee OA only (B= -0.07, p<0.001); there was no observed effect for individuals with knee OA plus heart disease or diabetes.

Similarly, I also observed a significant interaction among Level 2 perceived neighborhood social cohesion, comorbidities, and CES-D scores (p=0.001), where Level 2 perceived neighborhood social cohesion was associated with lower CES-D scores for individuals with knee OA only (B= -0.12, p<0.001), but there was no effect for individuals with knee OA plus heart disease or diabetes (B= 0.002, p=0.86).

Additionally, I observed a significant interaction among Level 2 perceived neighborhood safety, presence of comorbidities, and CES-D scores (p<0.001). Specifically, Level 2 perceived neighborhood safety was associated with lower CES-D scores among individuals with knee OA plus heart disease or diabetes (B= -0.15, p=0.02), but surprisingly associated with *higher* CES-D scores among individuals with knee OA only (B= 0.13, p=0.02). Appendix B includes a scatterplot of the data comprising this interaction, side by side the unexpected interaction.

Finally, turning to knee impact, I observed a significant association among Level 2 perceived neighborhood social cohesion, presence of comorbidities, and reported knee impact scores (p=0.004). Specifically, for individuals with knee OA plus heart disease or diabetes, Level 2 perceived neighborhood social cohesion was associated with higher reported knee impact scores (slope: 3.99, p=0.002), whereas there was no association for individuals with knee OA only (B= -0.48, p=0.62).

Together, these results suggested there were a number of interactions among perceived neighborhood social cohesion and presence of comorbidities. Interestingly, I found that for adults with knee OA only, Level 1 and Level 2 perceived neighborhood social cohesion was associated with lower CES-D scores, but for adults with knee OA plus heart disease or diabetes, Level 2 perceived neighborhood social cohesion was associated with higher reported knee impact scores. I also observed a surprising interaction for CES-D scores and perceived neighborhood safety, where Level 2 perceived neighborhood safety was associated with lower CES-D scores for adults with knee OA plus heart disease or diabetes, but associated with higher CES-D scores for adults with knee OA only.

Knee OA severity. Turning to knee OA severity, I found significant associations among Level 1 perceived neighborhood resources for physical activity and walking, knee OA severity, and CES-D scores ($p<0.001$) and Level 2 neighborhood poverty, knee OA severity, and CES-D scores ($p<0.001$).

For individuals with severe knee OA (B= -0.01, $p<0.001$) and individuals with non-severe knee OA (B= -0.04, $p<0.001$), Level 1 perceived neighborhood resources for physical activity and walking were associated with lower CES-D scores, however, the effect was stronger for individuals with non-severe knee OA.

For individuals with non-severe knee OA, contrary to expectations, Level 2 neighborhood poverty was associated with *lower* CES-D scores (B= -0.02, p=0.004), whereas there was no effect for individuals with severe knee OA (B= 0.001, p=0.85). Appendix B includes a scatterplot of the data comprising this interaction, side by side the unexpected interaction.

Overall, these results suggest that perceived neighborhood resources for physical activity and walking were more important for adults with non-severe OA and that poverty was unexpectedly associated with lower CES-D scores for adults with severe knee OA.

Is Neighborhood Context Associated with Depressive Symptoms and Knee Impact Over Time?

In longitudinal analyses (Tables 7 and 8), I found few significant relationships remained. For PROMIS-D scores, I found no significant main effects for Level 1 or Level 2 neighborhood variables (Table 7). For reported knee impact scores, I found Level 2 perceived neighborhood social cohesion was associated with lower reported knee impact scores (B= -1.65, p=0.04), while Level 2 perceived neighborhood safety was associated with higher reported knee impact scores (B=2.59, p=0.03) (Table 8).

Sensitivity Analyses

Additional tables with results from all sensitivity analyses are included in Appendix C and summarized below.

Analyzing the data with multiple imputation did not change any conclusions; all significant parameters remained significant and the magnitude of estimates was similar.

Analyzing the data excluding individuals living in census block groups with less than 5 individuals (n=37) also did not change any conclusions. All main effects remained significant with two exceptions. First, Level 2 perceived neighborhood social cohesion was no longer associated with CES-D scores (B=-0.07, p=0.10) and second, Level 1 perceived neighborhood safety became associated with higher reported knee impact scores (B=1.05, p=0.04). In addition, all interactions also remained significant.

Finally, analyzing the data by somatic vs. non-somatic reported depressive symptoms (which were moderately correlated with one another, r=0.64, p<.001) did not change our conclusions. All main effects were similar across these models, both in magnitude and significance.

Discussion

In a sample of older adults with at least one chronic disease (knee OA), I found that neighborhood context matters and interacts with key individual characteristics in nuanced ways. While relationships remained significant in cross-sectional analyses after controlling for a number of variables, I found few significant effects over time. Also of note, partitioning variance of the neighborhood effects into Level 1 (i.e., within-neighborhood) and Level 2 (i.e., between-neighborhood) components illustrated that Level 1 neighborhood effects were more consistently associated with our outcomes than Level 2 neighborhood effects. These findings have implications for research, practice, and policy, as discussed below.

In contrast to a previous systematic review that found neighborhood SES to be the strongest and most consistent predictor of health outcomes among older adults compared to other neighborhood characteristics,[49] I found no effect of neighborhood poverty on depression or knee impact scores. There are four possible reasons why this occurred. First, in multilevel modeling, most variables have between-group variation and within-group variation. In the present study, there was minimal clustering of health outcomes (i.e., CES-D scores and knee impact scores) by census block groups, which means that most of the variation in these outcomes was due to within-neighborhood variation, rather than between-neighborhood variation. As a result, it may have been difficult to detect associations among Level 2 variables (i.e., neighborhood poverty) and health outcomes. Second, although a number of previous

studies have found neighborhood SES to be significantly associated with health outcomes, this is likely an artifact of the increased number of studies on neighborhood SES compared to other neighborhood characteristics.[34] Third, using administrative boundaries to capture neighborhood characteristics (census block groups in this case) may not have accurately reflected what individuals think of as their neighborhoods (known as "spatial misclassification"). Finally, I found neighborhood poverty to be significantly correlated with other neighborhood characteristics in bivariate associations, namely social cohesion and perceived safety. Although poverty may have not had a direct effect on depression or knee impact, an indirect effect through other neighborhood characteristics could have been likely.

Relatedly, I found more consistent significant effects for Level 1 perceived neighborhood social cohesion and Level 1 perceived neighborhood resources for physical activity and walking than the Level 2 correlates of these variables. In other words, individuals who perceived their neighborhoods to be more cohesive (Level 1 neighborhood social cohesion) or to have more built environment resources (Level 1 neighborhood resources for physical activity or walking)—relative to their neighbors' average scores—had better CES-D scores and/or knee impact scores. It is important to note that Level 1 neighborhood variables are not true measures of the "neighborhood" or "contextual neighborhood effects." Instead, they refer to individual-level perceptions of neighborhood conditions. Similar to our findings, some research has also found stronger effects for Level 1 neighborhood social cohesion (also called "individual level social cohesion") on walking,[158] psychological distress,[159] and smoking[160] than Level 2 neighborhood social cohesion.

Neighborhoods are not necessarily internally homogeneous. It is possible that self-reported assessments of neighborhoods more closely represent individuals' own neighborhoods, how they interact with them, and how they are exposed to different neighborhood characteristics than area-level aggregated indicators of neighborhood conditions.[82] It is also likely that our findings resulted from some of the reasons described above (i.e., minimal clustering of health outcomes, poor ability of census boundaries to represent neighborhoods) so that true neighborhood-level effects of social cohesion and resources for physical activity and walking are important may still be determinants of health. Finally, it is also plausible

that individuals with a particular disposition (i.e., individuals with depressed moods) may have rated their environments as less satisfactory than individuals with a different disposition (i.e., individuals without depressed moods) (termed "same source bias").[82] This explanation would explain why Level 1 neighborhood measures were significantly associated with CES-D scores, but Level 2 measures were generally not.

I also observed a number of significant interactions. In general, these interactions suggest that neighborhood context is associated with outcomes in different ways for subgroups of older adults with knee OA. Of the nine significant interactions, two were contrary to expectations: Level 2 perceived neighborhood safety was associated with *higher* CES-D scores among individuals with knee OA only and Level 2 neighborhood poverty was associated with *lower* CES-D scores among individuals with non-severe knee OA. Including only individuals living in neighborhoods with more than 5 individuals did not change this pattern of results, nor did analyzing the data using multiple imputation. Qualitative research teasing out why these interactions occurred might be useful. For instance, I used a standard measure of perceived neighborhood safety, which assessed how safe participants felt their neighborhood was during the evening; the extent to which they felt their neighborhood was safe from crime; and the extent to which they felt violence was a problem in their neighborhood.[146] However, research suggests that other dimensions of perceived neighborhood safety are important for older adults in rural neighborhoods.[161] For instance, when asked about neighborhood characteristics that affect physical activity, older adults from rural Georgia mentioned loose dogs and heavy or speeding traffic. Are these characteristics also important for depression? And if so, what are the implications of using measures that do not capture these dimensions? Qualitative research could also tease out what makes a neighborhood "healthy" or "unhealthy"? Despite recognizing that a number of neighborhood variables are important for health (e.g., economic welfare, built environment, environmental exposures, safety, parks, green spaces, etc.), understanding how these neighborhood characteristics affect one another; how they interact with other characteristics, such as genetic predispositions, individual-level characteristics, work and school

environments; and examining how these neighborhood characteristics change over time to affect health is needed.

The remaining seven interactions mostly concerned depression scores and generally suggested that better neighborhood characteristics were associated with lower CES-D scores for *less* vulnerable older adults (i.e., adults with non-severe knee OA, adults without diabetes or heart disease, and White adults). The exception being that Level 1 perceived neighborhood resources for physical activity and walking were more strongly associated with CES-D scores for African Americans and Level 2 perceived neighborhood safety was associated with lower CES-D scores for adults with knee OA plus heart disease or diabetes. Empirical and theoretical research on aging suggest that residential neighborhood context is particularly important for older adults due to a number of reasons, including limited mobility, shrinking social networks, and longer exposure to neighborhood conditions.[41,49] It is possible that more vulnerable older adults, i.e., those with increased presence of chronic disease comorbidities or complications, may not be able to take advantage of various neighborhood resources, such as parks or social network resources, thereby making these characteristics less important or meaningful in everyday life. Why I observed these associations for CES-D scores, but not knee impact scores is an interesting question for future research. Given the number of interactions I observed, their sometimes surprising directions, and inconsistent effects for CES-D and reported knee impact scores, our results should be interpreted with caution.

It is not surprising that I observed Level 1 and Level 2 perceived neighborhood social cohesion to be associated with CES-D scores, nor that I found a significant association for Level 1 perceived neighborhood resources for physical activity and walking and reported knee impact scores. These findings align with previous research in which extensive relationships have been documented between the physical environment and physical activity,[49] and among the social environment and mental health outcomes.[25,34] Interestingly, I did observe a significant association between perceived neighborhood resources for physical activity and walking and CES-D scores. Future research exploring associations among physical environment structures and mental health outcomes, particularly among older adults, is warranted.

In longitudinal analyses, I observed no consistent relationships among neighborhood characteristics and outcomes. In a prior study that also examined cross-sectional and longitudinal associations of neighborhood cohesion and stressors with depressive symptoms, researchers found that neighborhood social cohesion, aesthetics, and violence were associated with depressive symptoms cross-sectionally but not longitudinally.[147] Reduced power to observe significant associations longitudinally may explain these findings. Indeed, in longitudinal analyses, our sample size dropped by almost 35% due to participants' deaths. It is also possible that neighborhood characteristics *changed* between T2 and T3. Since I did not re-assess these characteristics, our measures of neighborhood environment (i.e., the exposures) would have been insensitive to the effects of such changes. It is likely that a combination of these reasons explained our findings of stronger associations in cross-sectional vs. longitudinal analyses.

Although the conventional longitudinal analyses did not show effects of neighborhood characteristics over time, consideration of the length of time individuals lived in their neighborhoods suggests another interpretation of the cross sectional analyses of T2 data. As other researchers have suggested, if neighborhood characteristics remain relatively stable over time, and if individuals have lived extended periods in those neighborhoods, then cross-sectional analyses reflect cumulative long-term exposure to those neighborhood features.[147] Supporting this interpretation of the current findings, 59.6% of participants reported being born in Johnston County and participants reported living at their current address and average of 45 years (SD: 21.34) in measures taken at the beginning of the parent study.

Strengths and Limitations

This study had a number of strengths, including our examination of four different neighborhood characteristics (neighborhood poverty, perceived neighborhood social cohesion, perceived neighborhood resources for physical activity and walking, perceived neighborhood safety) and two different metrics of health outcomes—depression and knee impact scores. Additionally, I assessed relationships cross-sectionally and longitudinally and explored whether key individual characteristics interacted with neighborhood characteristics to influence health. Finally, I conducted a number of sensitivity analyses to

see if results changed under different assumptions. The robustness of our findings strengthens our conclusions.

There are also a number of important limitations to this study. First, I did not control for individual-level income data, which may have accounted for the observed effects. While I included a measure of education and health insurance status, which have been used as proxies of income in previous studies, further research controlling for income *and* examining interactions between neighborhood income and individual income will be important. Second, this study relied on a specific population—older adults in Johnston County, NC. The use of this specific population limits generalizability to other settings, such as other counties in NC, states in the US, or other populations. Although in 2010, Johnston County was relatively similar to other counties in NC by racial / ethnic makeup (15.1% of Johnston County was African American vs. 21.5% of NC), age (10.3% of Johnston County was over the age of 65 vs. 13.0% of NC), density of population per square mile (213.4 in Johnston County vs. 196.1 in NC) and percent of households in poverty (16.1% in Johnston County vs. 17.5% in NC), other unmeasured differences may have made the sample of participants used for this study unique.[162] Relatedly, only White and Black or African American individuals were included in the T2 and T3 waves of the JOCO OA project. At the time of T2 (using American Community Survey 2010 estimates), 12.0% of Johnston County residents identified as Hispanic and at the time of T3 (using American Community Survey 2015 estimates, 13.2% of Johnston County identified as Hispanic.

Finally, it is also important to note that participants included these analyses were selected from a prospective cohort study and originally invited to participate between 1991-1997 (baseline) or 2003-2004 (for cohort enrichment). By the T2 wave of data collection (2006-2011), many individuals had died. Therefore, individuals sampled at the T2 wave of data collection may have been healthier at baseline than those not sampled at T2; in other words, individuals sampled at T2 could represent the "survivors" or the "heartiest" participants. Accordingly, results may not generalize to community samples of older adults. Indeed, at baseline, compared to participants *not included* in the T2 wave, participants included in the T2 wave were significantly more likely to:

- Be younger
- Be female
- Be White
- Have a high school degree or higher
- Have a BMI of 30 or greater
- Have fewer comorbidities
- Have a high SES job
- Have lower CES-D scores, and
- Live in a neighborhood with fewer households below the poverty line at baseline

However, compared to participants *not included* in the T2 analyses (i.e., the analytic sample used for cross-sectional analyses), participants included in the T2 analyses were significantly more likely to:

- Be older
- Be Black or African American
- Have less than a high school degree
- Have a BMI of 30 or greater
- Have more comorbidities, and
- Have a low SES job

Thus, participants included in T2 analyses were generally more disadvantaged at baseline than those not included in analyses. This finding is likely a result of the inclusion criteria for the T2 analyses (i.e., analyses were only conducted on participants with knee OA). A similar trend was found when I compared participants included in the T3 wave of data collection and the T3 analyses. All additional analyses can be found in Appendix D.

Conclusions

In this sample of older adults with radiographic knee OA, I found that neighborhood context affected health outcomes in nuanced, yet important ways. First, I found effects of perceived neighborhood

social cohesion on CES-D scores and effects of perceived neighborhood resources for physical activity and walking on CES-D and knee impact scores. Second, I found these effects to be more pronounced at the individual-level (or Level 1). Finally, while I did not observe many consistent relationships over time, I did observe a number of interactions, suggesting that less vulnerable older adults may benefit more from neighborhood resources. Interventions aiming to improve mental and physical functioning of older adults with knee OA can look to this study as evidence on the importance of neighborhood characteristics.

Tables for Study 1

Table 1. Participant characteristics of adults with knee OA from the T2 wave (n=656) and T3 wave (n=434) of the Johnston County Osteoarthritis Project, Johnston County, North Carolina, 2006-2011 and 2013-2015

	T2, 2006-2011	**T3, 2013-2015**
Characteristic	**N (%) or mean (SD)**	**N (%) or mean (SD)**
Age, years	70.0 (9.0)	72.5 (7.8)
Gender		
Male	215 (32.8)	148 (34.1)
Female	441 (67.2)	286 (65.9)
Race		
White	433 (66.0)	288 (66.4)
Black or African American	223 (34.0)	146 (33.6)
Education		
High school or greater	489 (74.5)	367 (84.6)
Less than high school	167 (25.5)	67 (15.4)
Health insurance		
No	27 (4.1)	27 (6.2)
Yes	629 (95.9)	407 (93.8)
BMI	33.1 (7.9)	32.0 (6.9)
Number of comorbidities [a]	1.9 (1.3)	4.0 (1.8)
Diabetes and/or heart disease		
No	395 (60.2)	256 (59.4) [b]
Yes	261 (39.8)	175 (40.6) [b]
Severe knee OA [b]		
No	229 (34.9)	183 (42.2)
Yes	427 (65.1)	251 (57.8)
Neighborhood poverty (range 0-44)	17.2 (10.7)	17.2 (11.2)
Perceived neighborhood social cohesion (range 5-25)	18.9 (3.6)	19.1 (3.5)
Perceived neighborhood resources for physical activity and walking (range 11-55),	35.5 (6.1)	36.2 (6.0)
Perceived neighborhood safety (range 3-15)	11.1 (2.2)	11.1 (2.2)
Physical activity		
Inactive	225 (34.3)	356 (59.0)
Insufficiently active	234 (35.7)	125 (28.8)
Sufficiently active	197 (30.0)	53 (12.2)
Depression scores (range 0-60)	6.5 (7.4)	10.7 (4.5)
Reported knee impact scores (range 0-100)	75.6 (23.3)	70.0 (25.9)

[a] Range for number of comorbidities at T2 was 0-11 (from the Disease Inventory) and range for number of comorbidities at T3 was 1-13 (from the Charlson Comorbidity Index)
[b] Totals do not add up to 434, since 3 participants were missing data on this variable. However, individuals were not excluded since they were not part of the analyses in the multilevel models.
[c] At T2, depression was assessed using the CES-D (range 0-60) and at T3, depression was assessed using the PROMIS-D (range 8-40).

Table 2. Correlations among neighborhood characteristics, physical activity, and health outcomes, among adults with knee OA, from the T2 wave (n=656) and T3 wave (n=434) of the Johnston County Osteoarthritis Project, Johnston County, North Carolina, 2006-2011 and 2013-2015

	1.Neighborhood poverty	2.Perceived neighborhood social cohesion	3.Perceived neighborhood resources for physical activity and walking	4.Perceived neighborhood safety	5.Physical activity (T2)	6.Physical activity (T3)	7.CES-D scores (T2)	8.PROMIS-D scores (T3)	9.Reported knee impact scores (T2)	10.Reported knee impact scores (T3)
1	--	**-0.21*** **	0.03	**-0.23*** **	**-0.15*** **	**-0.10***	0.05	-0.06	**-0.10****	-0.08
2		--	**0.27*** **	**0.53*** **	**0.09***	**0.14****	**-0.23*** **	-0.08	**0.15*** **	0.01
3			--	**0.36*** **	**0.08***	0.04	**-0.19*** **	0.00	**0.18*** **	0.08
4				--	**0.08***	0.06	**-0.25*** **	-0.06	**0.21*** **	**0.11***
5					--	**0.24*** **	**-0.25*** **	-0.09	**0.21*** **	**0.19*** **
6						--	-0.02	-0.05	0.08	0.05
7							--	**0.40*** **	**-0.40*** **	**-0.34*** **
8								--	**-0.25*** **	**-0.35*** **
9									--	**0.66*** **
10										--

Boldface denotes significance at $p < 0.05$
* $p < .05$, ** $p < .01$, *** $p < .001$

Table 3. Summary of main effects from Study 1, using data from the T2 and T3 wave of the Johnston County Osteoarthritis Project, Johnston County, North Carolina, 2006-2011 and 2013-2015

Level 1 and Level 2 neighborhood characteristics	Cross-sectional results		Longitudinal results	
	CES-D scores	Knee impact scores	CES-D scores	Knee impact scores
Level 1 perceived neighborhood social cohesion	↓			
Level 1 perceived neighborhood resources for physical activity and walking	↓	↑		
Level 1 perceived neighborhood safety				
Level 2 neighborhood poverty				
Level 2 perceived neighborhood social cohesion	↓			↓
Level 2 perceived neighborhood resources for physical activity and walking				
Level 2 perceived neighborhood safety				↑

Note: Arrows indicate how to interpret effects. For instance, an arrow facing downwards indicates that there was a negative association between the independent variable and outcome for the specified cell. For instance, the arrow in the upper left quadrant indicates that there was a significant negative association between Level 1 perceived neighborhood social cohesion and CES-D scores. In other words, Level 1 perceived neighborhood social cohesion was associated with lower CES-D scores, or less depressive symptoms.
Note: Red arrows indicate findings contrary to expectations.

Table 4. Individual and neighborhood-level correlates of CES-D scores among individuals with knee OA, n=656, from the T2 wave of the Johnston County Osteoarthritis Project, Johnston County, North Carolina, 2006-2011

	Model 1 individual-level correlates		Model 2 (Model 1 + Neighborhood-level)	
Variable	Regression Coefficient (SE)	p-value	Regression Coefficient (SE)	p-value
Intercept	**1.78 (0.05)**	**p<0.001**	**1.76 (0.05)**	**p<.001**
Level 1 Fixed Effects				
African American (ref. White)	0.02 (0.04)	p=0.68	0.02 (0.04)	p=0.66
Female (ref. Male)	**0.24 (0.04)**	**p<0.001**	**0.24 (0.04)**	**p<0.001**
Age	**-0.005 (0.002)**	**p=0.02**	**-0.01 (0)**	**p=0.02**
BMI	**0.001 (0.04)**	**p=0.65**	**-0.001 (0.002)**	**p=0.62**
Less than high school (ref. ≥high school)	**0.09 (0.04)**	**p=0.02**	**0.09 (0.04)**	**p=0.02**
Health insurance (ref. no insurance)	**-0.17 (0.08)**	**p=0.04**	**-0.17 (0.08)**	**p=0.04**
Number of comorbidities	**0.11 (0.01)**	**p<0.001**	**0.11 (0.01)**	**p<0.001**
Insufficiently active (ref. inactive)	**-0.27 (0.04)**	**p<0.001**	**-0.27 (0.04)**	**p<0.001**
Sufficiently active (ref. inactive)	**-0.59 (0.05)**	**p<0.001**	**-0.59 (0.05)**	**p<0.001**
Perceived neighborhood social cohesion, [a]	**-0.04 (0.01)**	**p<0.001**	**-0.04 (0.01)**	**p<0.001**
Perceived neighborhood resources for physical activity and walking,[a]	**-0.02 (0)**	**p<0.001**	**-0.03 (0)**	**p<0.001**
Perceived neighborhood safety,[a]	-0.02 (0.01)	p=0.10	-0.02 (0.01)	p=0.10
Level 2 Fixed Effects				
Neighborhood poverty,[b]			-0.01 (0.01)	p=0.34
Perceived neighborhood social cohesion,[b]			**-0.07 (0.03)**	**p=0.02**
Perceived neighborhood access to physical activity and walking resources,[b]			0 (0.01)	p=0.99
Perceived neighborhood safety,[b]			0.04 (0.05)	p=0.46
Model Fit				
Akaike information criterion (AIC)	5640.80		5642.52	
Bayesian information criterion (BIC)	5674.83		5686.28	

Notes
Boldface denotes a significant effect at p<0.05
In the null model, the ICC was 0.02
[a] variables were group mean centered to estimate pure within effects
[b] variables were grand mean centered to estimate pure between effects
Results were estimated using a poisson multilevel model. To interpret results, regression coefficients can be added or subtracted from the intercept and exponentiated.

Table 5. Individual and neighborhood-level correlates of reported knee impact scores among individuals with knee OA, n=656, from the T2 wave of the Johnston County Osteoarthritis Project, Johnston County, North Carolina, 2006-2011

	Model 1 individual-level correlates		Model 2 (Model 1 + Neighborhood-level)	
Variable	Regression Coefficient (SE)	p-value	Regression Coefficient (SE)	p-value
Intercept	**75.63 (0.81)**	**p<0.01**	**75.63 (0.8)**	**p<.001**
Level 1 Fixed Effects				
African American (ref. White)	2.75 (1.81)	p=0.13	**3.97 (1.95)**	**p=0.04**
Female (ref. Male)	**-3.72 (1.79)**	**p=0.04**	**-3.95 (1.8)**	**p=0.03**
Age	0.04 (0.1)	p=0.69	0.03 (0.1)	p=0.80
BMI	**-0.83 (0.12)**	**p<0.001**	**-0.8 (0.12)**	**p<0.001**
Less than high school (ref. ≥high school)	**-5.4 (2)**	**p=0.007**	**-5.62 (2.02)**	**p=0.006**
Health insurance (ref. no insurance)	7.11 (4.22)	p=0.09	7.35 (4.22)	p=0.08
Number of comorbidities	**-2.7 (0.65)**	**p<0.001**	**-2.68 (0.65)**	**p<0.001**
Insufficiently active (ref. inactive)	**6.15 (2.01)**	**p=0.002**	**5.59 (2.02)**	**p=0.006**
Sufficiently active (ref. inactive)	**6.84 (2.11)**	**p=0.001**	**6.63 (2.12)**	**p=0.002**
Perceived neighborhood social cohesion, [a]	-0.11 (0.29)	p=0.71	-0.1 (0.29)	p=0.74
Perceived neighborhood resources for physical activity and walking,[a]	**0.47 (0.18)**	**p=0.008**	**0.48 (0.18)**	**p=0.008**
Perceived neighborhood perceived safety,[a]	0.94 (0.51)	p=0.07	0.91 (0.51)	p=0.07
Level 2 Fixed Effects				
Neighborhood poverty,[b]			-0.11 (0.1)	p=0.27
Perceived neighborhood social cohesion,[b]			1.26 (0.77)	p=0.10
Perceived neighborhood resources for physical activity and walking,[b]			0.41 (0.25)	p=0.11
Perceived neighborhood perceived safety,[b]			-1.9 (1.3)	p=0.15
Model Fit				
Akaike information criterion (AIC)	5808.7		5801.2	
Bayesian information criterion (BIC)	5811.1		5805.6	

Notes
Boldface denotes a significant effect at p<0.05
In the null model, the ICC was 0.01
[a] variables were group mean centered to estimate pure within effects
[b] variables were grand mean centered to estimate pure between effects

Table 6. Summary of interactions from Study 1, using data from the T2 wave of the Johnston County Osteoarthritis Project, Johnston County, North Carolina, 2006-2011

	Neighborhood variables		Race / Ethnicity		Presence of comorbidities		Knee severity	
	CES-D scores	Knee impact scores	CES-D scores	Knee impact scores	CES-D scores	Knee impact scores	CES-D scores	Knee impact scores
Level 1 perceived neighborhood social cohesion					↓ For adults with knee OA only			
Level 1 perceived neighborhood resources for physical activity and walking			↓ For Black adults (stronger) ↓ For White adults				↓ For adults with severe knee OA ↓ For adults with non-severe knee OA (stronger)	
Level 1 perceived neighborhood safety			↓ For White participants					
Level 2 neighborhood poverty							↓ For adults with severe knee OA	
Level 2 perceived neighborhood social cohesion					↓ For adults with knee OA only	↑ For adults with knee OA+		
Level 2 perceived neighborhood resources for physical activity and walking								
Level 2 perceived neighborhood safety		↓ For neighborhoods with medium and high poverty			↓ For adults with knee OA + ↑ For adults with knee OA only			

Note: Arrows indicate how to interpret effects. For instance, an arrow facing downwards indicates that there was a negative association between the independent variable and outcome for the specified cell. For instance, the arrow in the first row indicates that there was a significant interaction among Level 1 perceived neighborhood social cohesion, CES-D scores, and presence of comorbidities. Specifically, Level 1 perceived neighborhood social cohesion was associated with lower CES-D scores (less depressive symptoms) for adults with knee OA only (not individuals with OA plus heart disease or diabetes).
Note: Red arrows indicate findings contrary to expectations.
Note: OA+ indicates OA plus heart disease or diabetes.

Table 7. Individual and neighborhood-level correlates of PROMIS-D scores at T3 among individuals with knee OA, longitudinal results n=434, using data from the T2 wave and T3 wave of the Johnston County Osteoarthritis Project, Johnston County, North Carolina, 2006-2011 and 2013-2015

	Model 1 individual-level correlates		Model 2 (Model 1 + Neighborhood-level)	
Variable	Regression Coefficient (SE)	p-value	Regression Coefficient (SE)	p-value
Intercept	**2.35 (0.02)**	**p<0.001**	**2.35 (0.02)**	**p<.001**
Level 1 Fixed Effects				
CES-D scores at T2	**0.02 (0.002)**	**p<0.001**	**0.02 (0.002)**	**p<0.001**
African American (ref. White)	**-0.15 (0.04)**	**p<0.001**	**-0.14 (0.04)**	**p<0.001**
Female (ref. Male)	**0.09 (0.03)**	**p=0.01**	**0.09 (0.03)**	**p=0.01**
Age	-0.003 (0.002)	p=0.20	-0.003 (0.002)	p=0.27
BMI	0.00 (0.002)	p=0.92	0.00 (0.002)	p=0.98
Less than high school (ref. ≥high school)	0.00 (0.04)	p=0.99	0.00 (0.04)	p=0.99
Health insurance (ref. no insurance)	-0.12 (0.14)	p=0.40	-0.13 (0.14)	p=0.36
Number of comorbidities	**0.03 (0.01)**	**p=0.01**	**0.03 (0.01)**	**p=0.01**
Physical activity	-0.03 (0.03)	p=0.33	-0.03 (0.03)	p=0.32
Perceived neighborhood social cohesion, [a]	-0.004 (0.01)	p=0.38	-0.005 (0.01)	p=0.38
Perceived neighborhood resources for physical activity and walking,[a]	0.001 (0.003)	p=0.68	0.002 (0.003)	p=0.65
Perceived neighborhood safety,[a]	-0.005 (0.01)	p=0.61	-0.005 (0.01)	p=0.62
Level 2 Fixed Effects				
Neighborhood poverty,[b]			-0.002 (0.002)	p=0.39
Perceived neighborhood social cohesion,[b]			-0.01 (0.01)	p=0.53
Perceived neighborhood resources for physical activity and walking,[b]			0.01 (0.005)	p=0.07
Perceived neighborhood safety,[b]			0.01 (0.02)	p=0.49
Model Fit				
Akaike information criterion (AIC)	2329.20		2360.04	
Bayesian information criterion (BIC)	2388.07		2399.73	

Notes
Boldface denotes a significant effect at p<0.05
[a] variables were group mean centered to estimate pure within effects
[b] variables were grand mean centered to estimate pure between effects
Results were estimated using a poisson multilevel model. To interpret results, regression coefficients can be added or subtracted from the intercept and exponentiated.

Table 8. Individual and neighborhood-level correlates of reported knee impact scores at T3 among individuals with knee OA, longitudinal results n=434, using data from the T2 wave and T3 wave of the Johnston County Osteoarthritis Project, Johnston County, North Carolina, 2006-2011 and 2013-2015

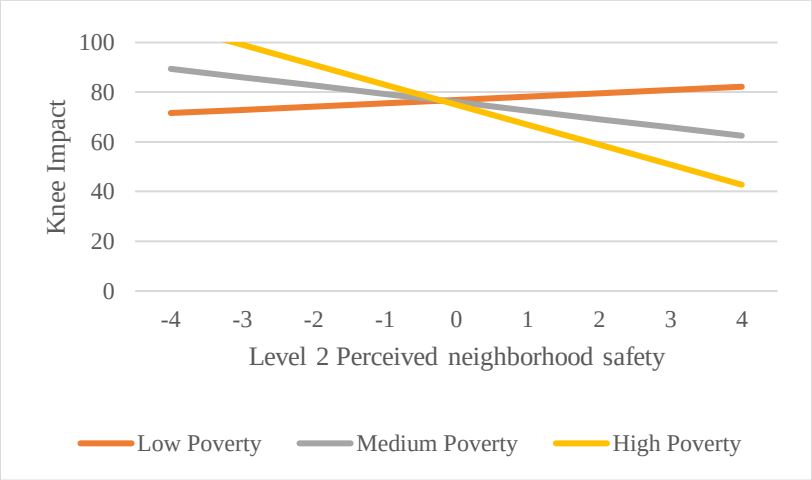
	Model 1 individual-level correlates		Model 2 (Model 1 + Neighborhood-level)	
Variable	Regression Coefficient (SE)	p-value	Regression Coefficient (SE)	p-value
Intercept	**69.94 (0.97)**	**p<0.001**	**69.95 (0.95)**	**p<.001**
Level 1 Fixed Effects				
Knee impact scores at T2	**0.7 (0.05)**	**p<0.001**	**0.71 (0.05)**	**p<0.001**
African American (ref. White)	3.09 (2.14)	p=0.15	2.89 (2.29)	p=0.21
Female (ref. Male)	**-4.61 (2.1)**	**p=0.03**	-3.94 (2.11)	p=0.06
Age	0.09 (0.15)	p=0.55	0.1 (0.15)	p=0.48
BMI	**-0.39 (0.16)**	**p=0.01**	**-0.39 (0.16)**	**p=0.02**
Less than high school (ref. ≥high school)	1.5 (2.72)	p=0.58	1.93 (2.71)	p=0.48
Health insurance (ref. no insurance)	-12.59 (8.99)	p=0.16	-13.61 (8.98)	p=0.13
Number of comorbidities	-1.08 (0.63)	p=0.09	-1.05 (0.63)	p=0.20
Physical activity	-0.46 (1.76)	p=0.79	-0.26 (1.76)	p=0.88
Perceived neighborhood social cohesion, [a]	-0.43 (0.34)	p=0.20	-0.45 (0.34)	p=0.19
Perceived neighborhood resources for physical activity and walking,[a]	-0.01 (0.22)	p=0.96	-0.01 (0.22)	p=0.96
Perceived neighborhood safety,[a]	0.29 (0.57)	p=0.61	0.31 (0.57)	p=0.58
Level 2 Fixed Effects				
Neighborhood poverty,[b]			0.02 (0.11)	p=0.83
Perceived neighborhood social cohesion,[b]			**-1.65 (0.79)**	**p=0.04**
Perceived neighborhood resources for physical activity and walking,[b]			-0.24 (0.28)	p=0.39
Perceived neighborhood safety,[b]			**2.59 (1.18)**	**p=0.03**
Model Fit				
Akaike information criterion (AIC)	3782.2		3775.0	
Bayesian information criterion (BIC)	3786.6		3779.4	

Notes
Boldface denotes a significant effect at p<0.05
[a] variables were group mean centered to estimate pure within effects
[b] variables were grand mean centered to estimate pure between effects

Figures for Study 1

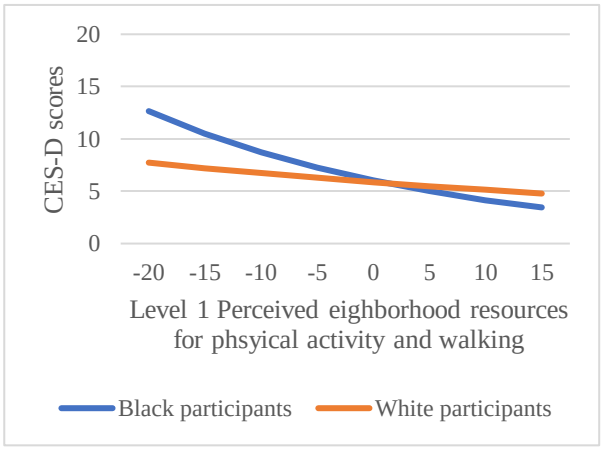
Figure 2. Interactions among neighborhood context and key individual-level characteristics among adults with knee OA, n=656, from the T2 wave of the Johnston County Osteoarthritis Project, Johnston County, North Carolina, 2006-2011

Figure 2a. Neighborhood poverty, safety, and reported knee impact scores

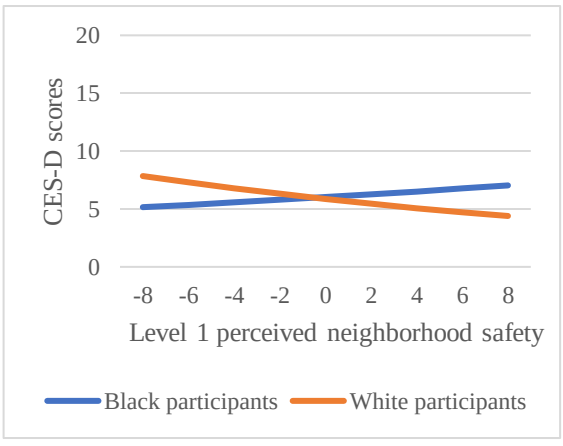


Note: only the slope for medium and high poverty are significant at p<.05. Level 1 variables refer to "within-neighborhood" or "individual-level perceptions" whereas Level 2 variables refer to "between-neighborhood" variables or "aggregated perceptions."

Figure 2b. Interactions among race, neighborhood context, and CES-D scores

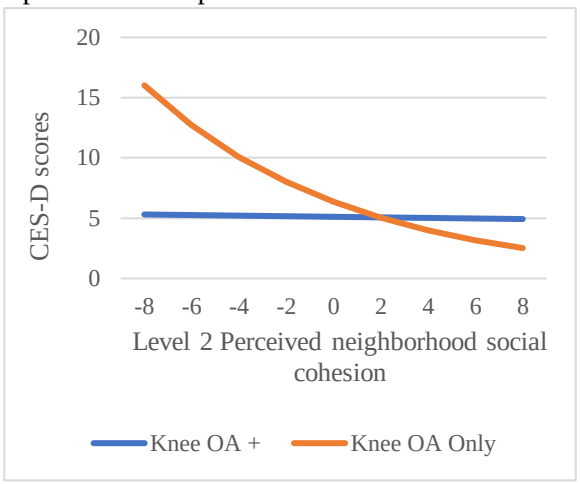


Note: the slopes for both Black participants and White participants are significant at p<.05, but the slope is stronger for Black participants.

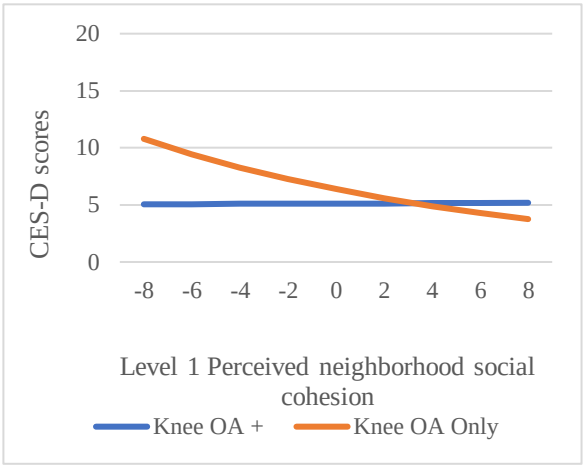


Note: only the slope for White participants is significant at p<.05.

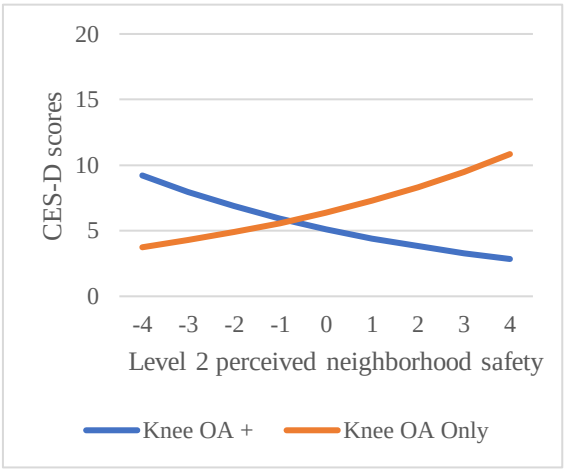
Figure 2c. Interactions among presence of comorbidities, neighborhood context, CES-D scores, and reported knee impact scores



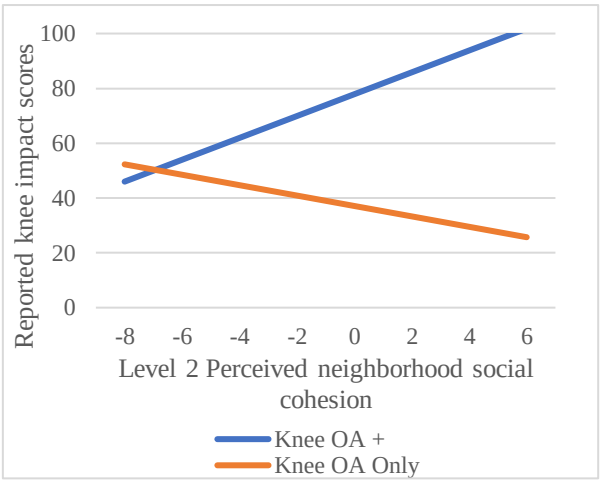
Note: only the slope for individuals with knee OA only is significant at p<.05.



Note: only the slope for individuals with knee OA only is significant at p<.05.

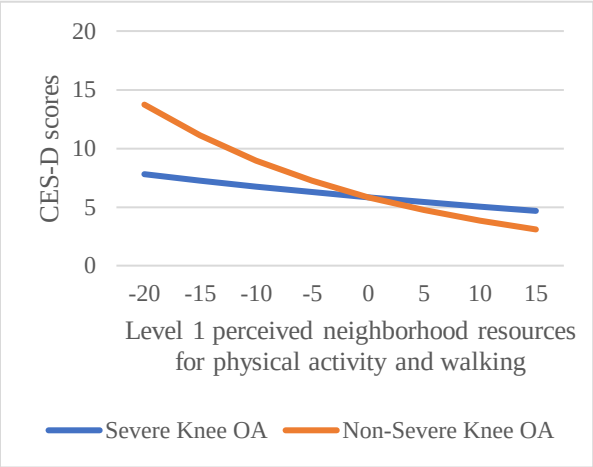


Note: the slopes for individuals with knee OA and individuals with knee OA+ are both significant at p<.05.

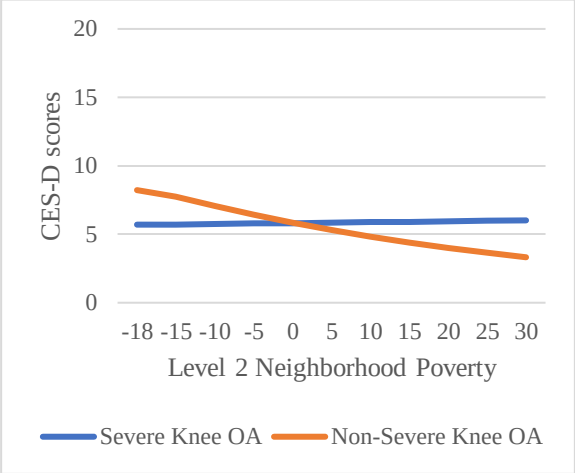


Note: only the slope for individuals with knee OA+ is significant at p<.05.

Figure 2d. Interactions among knee OA severity, neighborhood context, and CES-D scores



Note: the slopes for individuals with severe knee OA and non-severe knee OA are both significant at p<.05, but the slope is stronger for individuals with non-severe knee OA.



Note: only the slope for individuals with non-severe knee OA is significant at p<.05.

CHAPTER 5: STUDY 2

Introduction

More than half of all adults in the US—117 million people—have a chronic condition.[1,2] In addition to accounting for most of the US' health care expenditures (86%),[4] chronic diseases are often associated with considerable decline in quality of life, increased risk of mortality, and decreased psychosocial and psychological functioning.[5] The burden and patterning of chronic diseases are clear—individuals marginalized by social, economic, and geographic structures are disproportionately burdened.[6] Indeed, an extensive litany of meta-analyses and reviews have documented the robust and consistent effects of neighborhood characteristics on mortality,[50] mental health,[35-39] chronic diseases,[51-53] health behaviors, such as physical activity,[54-58] and other metrics of wellbeing, including biological markers, such as cortisol levels.[59] Because residential areas are also segregated, typically by income and/or race / ethnicity, and marked by unequal distribution of resources, neighborhoods not only affect health outcomes but also contribute to health disparities.[34,60] Despite the growing prominence of research on neighborhoods and the robustness of neighborhoods' effects on health, a number of gaps remain.

Although there has been longstanding interest in how neighborhoods and communities affect health, studies examining the effects of neighborhood characteristics on health only began in earnest in the late 1980s / early 1990s.[34] Most of these early studies, e.g., Hann et al. (1987),[79] examined whether neighborhood poverty, SES, or disadvantage were associated with health outcomes and/or mortality. While subsequent neighborhood studies began to focus on additional neighborhood characteristics, e.g., social and physical features, economic conditions remain some of the most studied structural factors relevant to health status and few studies have examined social and physical environment features.[80] Even today, few studies assess neighborhood characteristics using area-level indicators that are independent of residents' perceptions (such as neighborhood poverty measured through census indicators) and self-

reported neighborhood characteristics (such as individuals' perceptions of neighborhood safety), which is important since many neighborhood characteristics cannot be measured without self-report (e.g., social cohesion[81]) and area-level indicators and self-reported neighborhood measures are associated with health in different, but important ways.[82]

In addition to limiting their foci to one or two neighborhood characteristics, most neighborhood studies have only examined one health outcome or condition, namely those related to physical health, as indicated by the substantial evidence linking neighborhoods to obesity, chronic disease risk and management, morbidity, and mortality.[34] While at least six systematic reviews in the past decade[35-40] have documented how neighborhood features may be associated with depression and mental health, most of these studies only focused on neighborhood SES. Indeed, one of the six reviews focused exclusively on neighborhood SES,[35] three of the reviews included a majority of articles that focused only on neighborhood SES,[36,37,39] and two of the reviews included characteristics of the built environment, but mostly assessed factors like housing quality, residential density, air quality, etc., without examining other features of the built environment, such as accessibility or availability of physical activity or walking resources.[38,40]

Moreover, most of these studies were conducted in urban environments, with few studies examining whether associations between neighborhood context in health extend to rural and suburban areas.[41] The narrow focus of these studies (one neighborhood characteristic, one health outcome, mostly urban settings) has limited interpretability and comparison of results across studies. Indeed, more research is needed on a) neighborhoods and mental health, b) characteristics of neighborhoods' social and built environments, including walkability, on mental health c) research on neighborhoods and health in rural areas, and d) interactions of different neighborhood domains (e.g., social and built environment features of rural neighborhoods).

Finally, since the 1980s, researchers have developed a number of theories and conceptual frameworks to illustrate how neighborhoods affect health (see work on social determinants of health,[42] social disorganization theory[43] and conceptual models from Diez & Roux,[34] Brown et al.,[44] Carpiano,[45]

Blair et al.,[46] and Kawachi & Berkman[81]), yet these models have rarely been empirically tested. In these models, characteristics of the neighborhood economic environment (e.g., which can refer to both neighborhood disadvantage and compositional features of neighborhoods, such as racial segregation, that have been used as proxies for economic disadvantage) are thought to influence characteristics of the neighborhood physical environment (e.g., environmental exposures, food, physical activity, and recreation resources, services), and characteristics of the neighborhood social environment (e.g., safety, norms, cohesion, capital).[34] In turn, characteristics of the neighborhood physical and social environments are then associated with health outcomes both directly and indirectly through various mediators, including but not limited to:

4) Psychosocial processes (e.g., social support, stress, resiliency, sense of control, sense of fear and anxiety)[34,46]
5) Health behaviors, including physical activity [34,42-45,90,91]
6) Access to resources, medical care and quality[34,42,44,91]

Most of these conceptual models were built for general use, without regard to specific populations. However, some research suggests that neighborhoods are particularly important for older adults since they 1) are less mobile than younger adults,[47] which may make them more likely to rely on resources within their neighborhoods; 2) may lose social contacts as they age,[48] thereby increasing the importance of social cohesion, and 3) may not leave their neighborhoods as much as younger adults who may be working or have other obligations.[41] In addition, most older adults (nearly 80%) own their homes[93] and have lived in their neighborhoods for a number of years, thereby increasing aggregate exposure to residential neighborhood effects. Finally, most older adults (more than 80%) currently have at least one chronic condition,[3] and chronic disease management is associated with neighborhood characteristics.[34] The number and magnitude of these factors suggest that older adults may be more vulnerable to certain neighborhood features and make research on neighborhoods and older adults especially useful.[41,94]

The present study builds on previous research in two ways. First, using theory, this research specifies ways in which four neighborhood characteristics may influence depressive symptoms among older adults in a rural setting. Second, this study used SEM, which is a powerful analytical technique that can allow researchers to model complex relationships.

Methods

Participants and Procedures

Data for this study come from a population-based prospective cohort of knee and hip OA among African American and Caucasian individuals (the JOCO OA project).[129] Although the parent study was designed to capture OA prevalence and risk factors, I took advantage of the opportunity to examine how neighborhood characteristics were associated with wellbeing among a large sample of older adults. I therefore did not exclude participants based on OA status. Recruitment occurred in Johnston County, NC, which at the time of this study, was classified as a mostly rural county.[130] Details on the study design, data collection procedures, and study population are detailed in previous publications.[129] In brief, the study was designed to be representative of civilian, non-institutionalized African Americans and Caucasians over the age of 45 who resided in one of six towns or townships in Johnston County, NC for at least one year, were living in the county at the time of study enrollment, and physically and mentally capable of completing the study protocol. All participants completed an initial home interview, a limited clinical and functional examination, which included an assessment of weight and height and radiographic examination of the knees, and an additional home interview approximately 2 weeks after the clinic visit. At baseline, all participants provided informed written consent at the time of recruitment. The study was approved by the Institutional Review Boards of the University of North Carolina Schools of Medicine and Public Health and the CDC. The analytical sample for this study uses the T2: 2006-2011 cohort of adults.

Measures

Outcome. I used the CES-D to assess depressive symptoms. The CES-D is one of the most widely used self-report scales to assess current levels of depressive symptomology.[131] Developed in 1977, the CES-D was intended to assess epidemiology of depression in the *general population*, rather than

diagnosis at clinical intake.[131] While items were chosen from previously validated depression scales and based on symptoms of depression in clinical cases, the CES-D was not designed to reflect diagnostic criteria of depression at the time of its development.[131] Indeed, some diagnostic criteria are not reflected (e.g., suicidality) and many "healthy" or "normal" people could experience some of the symptoms reflected in CES-D items. In contrast to other widely used measures, such as the Beck Depression Inventory, the CES-D focuses more on affective aspects of depression, rather than depression cognitions.[132]

The CES-D contains 20 items that assess symptoms that occurred in the week prior to the interview. Response options range from 0 to 3, which refer to frequency of the symptoms (i.e., "rarely of none of the time" to "all of the time"). The CES-D was originally posited to have a four-factor structure model composed of depressed affect, positive affect, somatic activity, and interpersonal issues.[131] For instance, the item "I felt depressed" would belong to the depressed affect factor, "I felt hopeful about the future" would belong to the positive affect factor, "my sleep was restless" would belong to the somatic activity factor, and "people were unfriendly" would belong to the interpersonal issues factor. However, more than 20 alternative factor structures—including a unidimensional factor structure,[133]—have been reported.[134] In practice, many researchers (including Radloff, the original developer of the CES-D) report a total score, thereby treating the measure as unidimensional.[133] I therefore analyzed depressive symptoms as a unidimensional latent factor. Although a cut-off point of 16 has been used in previous research to indicate risk for moderate or severe depression,[135] I conceptualized and analyzed CES-D scores as a continuum (not merely in dichotomous terms). For consistency, I refer to the latent variable comprised of CES-D items as "depressive symptoms" throughout this manuscript.

Neighborhood characteristics. I measured four neighborhood characteristics.

Neighborhood poverty. I defined neighborhood poverty as the percentage of households with income below the poverty line within a census block group. I compiled these data from the 2010 U.S. Census, that bounded the time in which T2 data were gathered, 2006-2011. I used census block groups as

the unit of analysis, since they are the smallest administrative boundary from the census that includes economic data. Census block groups generally contain between 600 and 3,000 people.[144]

Perceived neighborhood social cohesion. I measured perceived neighborhood social cohesion using Sampson et al.'s 5 item measure of Social Cohesion and Trust.[145] An example item is: "people around here are willing to help their neighbors." I assessed all items on a 5-point likert response scale (1=strongly agree to 5=strongly disagree). Previous studies have found high reliability for this scale (Cronbach's alpha over 0.80) and consistency over time (test-retest intra class correlation, ICC: 0.90; 95% CI: 0.84, 0.94).[146] Supporting validity, the scale has also been used in a variety of research studies assessing social cohesion / social capital.[25,37,147]

Perceived neighborhood resources for physical activity and walking. I measured perceived neighborhood resources for physical activity and walking using 11 items from the Walking and Exercise Environment scale. This scale assesses opportunities for exercise in individuals' neighborhoods. An example item is: "my neighborhood offers many opportunities to be physically active." I assessed all items on a 5-point likert response scale (1=strongly agree to 5=strongly disagree). Previous studies have shown this scale to have high reliability and consistency over time (test-retest ICC: 0.88; 95% CI: 0.79, 0.93).[146]

Perceived neighborhood safety. I measured perceived neighborhood safety with three items. An example item is: "I feel safe walking in my neighborhood during the evening." All items were assessed on a 5-point likert response scale (1=strongly agree to 5=strongly disagree). Previous studies have demonstrated these items to be reliable and consistent over time (test-retest ICC: 0.80; 95% CI: 0.67, 0.88).[146]

Mediators. I selected three mediators based on their importance in previous research and theory.

Physical activity. I assessed physical activity using items from the 2001-2009 BRFSS.[152] The physical activity BRFSS items assess two types of physical activity—moderate and vigorous—and classifies individuals as[152]:

- Inactive (Respondent reports doing no moderate or vigorous physical activity)

- Insufficiently active (Respondent reports doing insufficient moderate or vigorous physical activity to meet recommendations)
- Active (Respondent reports doing enough moderate or vigorous physical activity to meet the recommendations)

Following guidelines for use of the BRFSS,[152] to be classified as meeting recommended goals for moderate activity, a respondent needed to report 5 or more days of moderate activity with 30 or more minutes per day. To be classified as meeting recommended goals for vigorous activity, a respondent needed to report 3 or more days of vigorous activity with 20 or more minutes per day. An individual who met the moderate goal, the vigorous goal, or both was classified as "active" while an individual who reported some moderate activity, vigorous activity, or both but did not meet the goals for either moderate or vigorous activity was classified as insufficiently active. Otherwise, individuals were classified as "inactive." The BRFSS questionnaire has been used to assess national trends in physical activity and can be used to assess level of physical activity among adults in accordance with national guidelines.[163]

Social support. I assessed social support using four items from the Strong Ties scale, which assesses the degree to which individuals are bothered by not having a close companion, enough people to whom they are close, enough friendships, and someone who shows them love and affection. All items were assessed on a 5-point likert response scale (1=strongly agree to 5=strongly disagree). This scale has been found to have moderately high reliability (Cronbach's alpha = 0.72)[164] and has been used in previous studies.[165]

Perceived individual control. To assess perceived individual control, I used two items from Israel et al.'s Perceived Control Scale.[166] These items were: "I have control over the decisions that affect my life" and "I am satisfied with the amount of control I have over decisions that affect my life." These items were assessed on a 5-point likert response scale (1=strongly agree to 5=strongly disagree) and reverse-coded, so that higher scores indicate more control. These items have been used previously and found to be reliable (Cronbach's alpha = 0.83). [167-169]

Control variables. Control variables assessed were race / ethnicity (White or Black / African American), education (categorized as less than high school or high school or greater), BMI (as a continuous variable), gender (male or female), age (as a continuous variable), health insurance status (categorized as health insurance or no health insurance), and number of comorbidities (defined using the Disease Inventory). I also assessed knee OA status as a control variable using radiography and the Kellgren and Lawrence (KL) grade, which scores OA severity on a scale of 0-4.[16] I classified individuals with scores of 2-4 as having knee OA. Otherwise, I classified individuals as not having knee OA.

Data Analysis

Descriptive statistics. Descriptive statistics included means, standard deviations, and frequencies of all identified demographic variables, neighborhood variables, and depressive symptoms.[157] Bivariate correlation analyses were used to assess relationships among neighborhood variables and depressive symptoms. I conducted descriptive statistics using SAS version 9.4 survey procedures (SAS Inc., Cary, NC, USA).

Confirmatory factor analysis and structural equation modeling. To examine how neighborhood characteristics were related to depressive symptoms through the proposed mediators, I used SEM. SEM is an analytical approach for data analysis that allows researchers to test multiple regression relationships among latent variables and between observed and latent variables and allows for models in which one or more variables are simultaneously predicted and predictor variables, thereby making it a powerful analytical technique.[88] Using MPlus version 7, I followed a two-step structural equation modeling approach to establish the quality of the measurement model and test the full general SEM.[170] Using this two-step approach (also called a "jigsaw piecewise" approach) has been recommended by several researchers[88,171] because it allows one to isolate factors and items that may be problematic and/or lead to poor fit.

I first used Confirmatory Factor Analysis (CFA) to evaluate the fit of six latent variables: 1) perceived neighborhood social cohesion, 2) perceived neighborhood resources for physical activity and walking, 3) perceived neighborhood safety, 4) social support, 5) perceived individual control, and 6)

depressive symptoms. These variables were specified as latent variables because they represent unobservable (i.e., latent) constructs and they were measured using multiple items (combined into scales), which thereby makes CFA appropriate. I examined neighborhood poverty as an observed variable since I only had one item to define this construct. I also examined physical activity as an observed variable. Although I was able to measure multiple types of physical activity (e.g., moderate and vigorous) and the amount of time people devote to those activities, I followed BRFSS guidelines and analyzed physical activity as a single outcome with three response levels (inactive, insufficiently active, active).[152] I entered the remaining control variables into the models as observed variables.

After determining adequate fit of the measurement models and making any necessary modifications, I assessed the fit of the structural model controlling for clustering at the neighborhood census block group level (using type=complex). As seen in Figure 3, our SEM contains three main pathways: 1) the pathway from neighborhood poverty to perceived neighborhood environment, 2) the pathway from perceived neighborhood environment to the proposed mediators, and 3) the pathway from the proposed mediators to depressive symptoms.

To determine the fit of the measurement model and SEM, I used a priori, well-established criteria, including the chi-square test (p-value should be >0.05; however, model fit can still be adequate if this p-value value is <0.05 since chi-square is dependent on sample size[172]); the Comparative Fit Index (CFI) and Tucker-Lewis Index (TLI) (CFI, TLI should be >0.95[173,174]); the root mean square error of approximation (RSMEA, should be <0.06[175,176]); and standardized factor loadings (should be >0.30[177]). The model illustrated in Figure 1 was tested. For all paths, significance was set at $p < 0.05$. Given that all latent variables were ordinal (measured on a 1-5 scale), I used weighted least squares means and variance adjusted (WLSMV) estimation, which is appropriate for data with non-normal distributions.[88] For all models, full information maximum likelihood (FIML) was used, which has been found to be superior to pairwise deletion, listwise deletion, and multiple imputation for data that are not missing at random and when missing rates are small.[88,178,179] In our structural equation models, 139 cases (approximately 8.2% of

the sample) were missing some of the observed exogenous variables (i.e., control variables) and excluded by MPlus. For all analyses, I set critical $\alpha = .05$ and used 2-tailed statistical tests.

Sensitivity Analyses

I conducted two sensitivity analyses. In the first, I analyzed separately somatic and non-somatic depressive symptoms on the CES-D, since it is possible that they would be differentially associated with neighborhood characteristics. Somatic symptoms included items 1, 2, 5, 7, 11, and 20 from the CES-D and referred to whether individuals were bothered by things, had a poor appetite, had trouble keeping their mind on what they were doing, felt that everything was an effort, had restless sleep, and could not get going.[134]

Second, I excluded individuals without a chronic condition to determine if results differed for only those individuals with at least one chronic condition. Our list of chronic conditions included: knee and hip OA, heart disease (heart attack, angina, congestive heart failure or other heart condition), hypertension, lung disease (including asthma, tuberculosis, chronic bronchitis, emphysema, chronic allergy or other chronic lung problem), vascular disease (including: stroke or circulation problems), liver disease, cancer, diabetes, and kidney disease/renal failure. I selected these chronic conditions because 1) they are common chronic conditions in the US,[180] 2) they are leading causes of death and disability,[181] and 3) they share many of the same risk factors.[7] I measured all conditions using the Disease Inventory Index, except for knee and hip OA where I used radiography and KL scores.[16]

Results

Descriptive Statistics

Table 9 provides details on the demographic characteristics of participants. Our sample was composed of adults who were on average 68.1 years old (SD: 9.1). Participants were diverse, with a substantial number of African Americans (31.2%) and individuals without a high school degree (21.8%). Almost half of participants (44.5%) had knee OA and on average, had 1.7 other comorbidities. Additionally, participants reported few depressive symptoms (mean: 6.6, SD: 7.5, possible range: 0-60), although 11.4% had scores at or above 16 indicative of being at risk for moderate or severe depression.

Confirmatory Factor Analysis

The measurement model with no modifications had a moderate fit to the data (Table 10). Two latent variables had poor initial fit: measures for perceived neighborhood resources for physical activity and walking and social support. After reviewing correlation matrices for the 11 items making up the factor for neighborhood resources for physical activity and walking, I included 4 items in the revised model ("My neighborhood offers many opportunities to be physically active," "It is pleasant to walk in my neighborhood," "There are enough trees in my neighborhood to provide shade," and "In my neighborhood, the streets or sidewalks are in good condition"). I chose these items based on both empirical (inter-item correlations > 0.40) and theoretical evidence from previous literature, suggesting streets, shade, and neighborhood aesthetics are important domains for walkability in rural neighborhoods.[95] For social support, although the RMSEA value (0.10; 95% CI: 0.07, 0.13) was above the desired 0.06 cut-off,[175,176] the model demonstrated adequate fit based on the other indices and modifications would not have been theoretically or empirically based.

Bivariate Correlations

Bivariate analyses revealed significant relationships among most latent and observed variables in the hypothesized directions (Table 11). Correlations of neighborhood poverty with other neighborhood variables ranged from -0.11 to -0.26 (all p-values <0.05), while correlations among perceived neighborhood social cohesion, perceived neighborhood resources for physical activity and walking, and perceived neighborhood safety were moderate to high, ranging from 0.66 to 0.75 (all p-values <0.001). These three neighborhood characteristics were all significantly associated with the three selected mediators (physical activity, social support, and perceive individual control), with correlations ranging from 0.13 to 0.65 (all p-values <0.001). Finally, depressive symptoms were moderately associated with all variables, except for neighborhood poverty where there was a weak, but still significant association (r=0.08, p=0.03).

Structural Equation Model

The initial hypothesized structural equation model had a relatively good fit to the data, but several of the associations among perceived neighborhood social cohesion, perceived neighborhood resources for physical activity and walking, perceived neighborhood safety, and the proposed mediators were not in the expected direction based on bivariate correlational results. I hypothesized that this was due to multicollinearity among the three neighborhood characteristics. When collinearity is present, the introduction of additional predictors into the model can diminish the regression coefficient and significance of a predictor, and the regression coefficient can even reverse in sign.[182] I therefore fit a model with a higher order factor (labeled "perceived neighborhood environment"), which was comprised of these three neighborhood characteristics (social cohesion, resources for physical activity/walking, safety) and only specified pathways that were significant in the bivariate correlations at $p<.05$.

Results from the structural equation model can be seen in Table 12. I found the model represented in Figure 4 demonstrated adequate fit with respect to the following metrics: RMSEA = 0.02 (95% CI: 0.02, 0.02), CFI = 0.96, and TLI =0.96. Although, the p-value associated with the chi-square value (1711.46, $p < 0.001$) was significant, research suggests that the significance of the chi-square value is contingent on sample size, such that with larger samples, it becomes more difficult to obtain a non-significant chi-square value.[88] As a result, I selected this model as the final model.

I found neighborhood poverty was significantly negatively associated with perceived neighborhood environment (B=-0.16, $p<0.001$) and physical activity (B= -0.06, p=0.04), but not with depressive symptoms. In turn, perceived neighborhood environment was significantly associated with physical activity (B=0.09, p=0.005), social support (B=0.41, $p<0.001$), and perceived individual control (B=0.61, $p<0.001$), but not depressive symptoms, despite their significance in bivariate correlations. All three mediators were significantly associated with depressive symptoms (physical activity and depressive symptoms: B=-0.13, $p<0.001$; social support and depressive symptoms: B=-0.48, $p<0.001$; and perceived individual control and depressive symptoms: B=-0.12, p=0.01).

In addition, I observed a number of indirect effects. The pathways from perceived neighborhood environment to depressive symptoms through the proposed mediators were all significant (standardized beta coefficients ranging from B= -0.01 to B= -0.19, p-values <0.05). Specifically, the indirect effect for perceived neighborhood environment on depressive symptoms through social support was B= -0.19; 95% CI: -0.16, -0.22; p<0.001; the indirect effect through perceived individual control was B= -0.07; 95% CI: -0.02, -0.12; p=0.02; and the indirect effect through physical activity was B= -0.01; 95% CI: -0.01, -0.02; p=0.003. Social support emerged as the strongest of the three mediators, as demonstrated through the non-overlapping 95% confidence intervals of the indirect effects.

In addition, poverty was significantly associated with depressive symptoms through physical activity and perceived neighborhood environment (B= 0.002, p= 0.02) and significantly associated with physical activity through perceived neighborhood environment (B= -0.02, p= 0.01).

Overall, all variables (neighborhood and control) explained 41% of the variance in depressive symptoms, 20% of the variance in social support, 37% of the variance in perceived individual control, and 13% of the variance in physical activity. Alone (including direct and indirect effects), neighborhood variables explained 12% of the variance in depressive symptoms, 15% of the variance in social support, 37% of the variance in perceived individual control, and 4% of the variance in physical activity.

Sensitivity Analysis

Results from sensitivity analyses can be seen in Appendix E. When analyzing somatic and non-somatic depressive symptoms separately, all paths noted above were confirmed, with the exception that perceived individual control no longer mediated the effects of perceived neighborhood characteristics on somatic depressive symptoms (B= -0.06, p=0.08), but significantly mediated the effects of perceived neighborhood characteristics on non-somatic depressive symptoms (B= -0.08, p=0.02). In addition, I found that results did not change when only including adults with at least one chronic disease; all indirect and direct effects remained significant and parameter estimates were of similar magnitude.

Discussion

Among this sample of older adults—91% of whom reported having at least one chronic condition—several neighborhood characteristics were associated with depressive symptoms. Within this pattern of results, three interesting findings were observed. First, neighborhood factors were strongly associated with depressive symptoms and this relationship was mediated by individual-level variables. This observation suggests that both individual-level and neighborhood-level characteristics may be important for future interventions looking to improve mental health outcomes. Second, this study focused on older adults (the majority of whom had at least one chronic condition), which suggests that future interventions, especially those focused on comorbid depressive symptoms and chronic disease management, may therefore look to the potential of neighborhood characteristics and mediators in improving outcomes. Finally, I found that social support emerged as the strongest mediator of neighborhood characteristics on depressive symptoms. These findings have a number of important implications for public health practice and research.

Little research has examined *how* neighborhood characteristics are associated with health. In this study, I found three variables completely mediated the effects of perceived neighborhood environment on depressive symptoms. These results suggest the importance of these three variables—physical activity, social support, and perceived individual control—as behavioral and psychosocial mediators of the effects of neighborhood factors on depression. Additionally, while I found that physical activity, social support, and perceived individual control fully mediated the effects of the perceived neighborhood environment on depressive symptoms, perceived neighborhood environment only partially mediated the effects of poverty on physical activity. In other words, poverty was associated with physical activity both directly and indirectly through its influence on perceived neighborhood environment. These findings suggest that enhancements of neighborhood social cohesion, safety, and the built environment may partly buffer the effects of poverty on physical activity and depressive symptoms. While randomized controlled trials changing neighborhood disadvantage are almost nonexistent,[66] there are innovative ways to encourage social interaction in neighborhoods (increasing vegetation and common spaces,[183] designing homes with

porches or stoops[184]), and encourage self-care behaviors, such as physical activity, through improvements to infrastructure like lighting or sidewalks.[185]

Interestingly, the strongest pathway through which neighborhood characteristics influenced depressive symptoms was social support. Social relationships are fundamental among primates[104] and directly influence biological processes undermining health outcomes.[186] Indeed, in a meta-analysis of 148 longitudinal studies, Holt-Lundstad et al. found a 50% reduction in mortality for individuals with strong social relationships which was comparable with reductions in mortality attributable to smoking.[106] Our findings suggest that interventions designed to improve depression among older adults in rural neighborhoods may choose to focus on social support. This need not be to the exclusion of perceived individual control and physical activity however that also emerged as significant, but weaker, mediators.

Also of interest, results held when only individuals with chronic diseases were included. It should be noted that depression has emerged as an important outcome of chronic disease management and care in its own right.[187] Intervention features that may influence depression are important in building comprehensive approaches to chronic disease management. Together and along with the other mediating and control variables in the final model, neighborhood characteristics explained 41% of the variance in depressive symptoms. Future interventions, especially those focused on comorbid depressive symptoms and chronic disease management, may therefore look to the potential of neighborhood characteristics and mediators in improving outcomes, especially for those attempting to manage complex health conditions.[188] Interestingly, adults in this sample reported relatively few depression symptoms despite having on average 2 comorbidities in addition to knee OA. This finding aligns with a paradox of aging that mental health improves with age, despite declines in physical and cognitive functioning.[189]

In our study and as in previous research,[82] I found stronger associations with depressive symptoms for neighborhood perceptions versus area-level measures of the neighborhood environment that are independent of residents' perception (in this case, neighborhood poverty). While self-reported measures may more directly align with individual's experiences and reflect how individuals interact with their neighborhoods, they are typically limited by same source bias. In other words, individuals with a

particular disposition (i.e., individuals who are less physically active or individuals with more chronic conditions) may rate their environments as less satisfactory than individuals with a different disposition.[82] Importantly, with SEM, I am able to partly control for these effects by regressing neighborhood perceptions on individual-level characteristics, such as age, race, BMI, and others.[82] While it is possible that other unmeasured variables may have affected individuals' perceptions of their neighborhood environments, our analyses begin to disentangle the potential bias that self-reported assessments of neighborhoods may contain.[82]

Finally, this is one of few studies that has focused on neighborhood characteristics among older adults in rural neighborhoods. In 2014, 14.5% (46 million) of the US population was aged 65 or older; by 2060, this figure will reach 23.5% (98 million).[190] As adults continue to live longer, health care spending will likely increase, particularly for chronic diseases, which represent 95% of all health care costs for older adults in the US.[191] Innovative strategies to maintain and promote the quality of life of older adults are needed. One such strategy is allowing older adults to "age in place" or allowing them to stay in their own "homes and communities safely, independently, and comfortably, regardless of age, income, or ability level."[192] Despite the importance of both home and community environments, most interventions tailored to older adults have focused on making improvements to homes (e.g., making modifications and adaptions to homes in order to prevent accidents or falls, improving functional ability of features in homes, providing services in homes, removing barriers that would prevent older adults from continuing to live at home, etc.).[193] The results from this dissertation suggest that both poverty and perceived neighborhood environment are important determinants of quality of life that should be taken into consideration when designing public health interventions for older adults in rural areas.

Strengths and Limitations

This study had a number of strengths, including our examination of four different neighborhood characteristics (neighborhood poverty, perceived neighborhood social cohesion, perceived neighborhood resources for physical activity and walking, perceived neighborhood safety), appropriate statistical techniques (e.g., SEM and controlling for clustering by neighborhoods and a number of individual-level

control variables), innovative research questions (i.e., mediation analyses), and a key population and setting (i.e., older adults living in primarily rural neighborhoods).

However, there are several limitations to our findings. First, because I used cross-sectional, observational data, I was unable to infer causality. There are a number of reasons why associations could be occurring. Most notably, 1) individuals may select into certain neighborhoods, based on individual attributes, which are themselves associated with health (termed "selection bias") and 2) individuals with certain dispositions may rate their neighborhoods more or less favorably and these dispositions might be then responsible for observed associations (termed "same source bias"). Regarding the former, while it is possible that selection issues may have biased results, given the number of people who reported being born in Johnston County (almost 60% at the beginning of the parent study in 1990-1997) and the length of time individuals reported living at their residence (average of 45 years at the beginning of the parent study), this bias is not likely. Regarding the later, I partly controlled for same source bias by regressing neighborhood perceptions on individual-level characteristics, such as age, race, BMI, and others. However, it is possible that other unmeasured or omitted variables influenced how participants perceived and reported neighborhood characteristics. Regardless, I am careful to not make claims of causal inference or causal mediation, which are of growing interest to social epidemiologists.[194]

Second, I did not control for individual-level income data, which may have accounted for the observed effects, especially those related to neighborhood poverty. While I included a measure of education and health insurance status, which have been used as proxies of income in previous studies, further research controlling for income *and* examining interactions between neighborhood income and individual income will be important. Third, I did not estimate multilevel SEM models due to the minimal amount of clustering by census block group in most of the variables. Research on multilevel SEM is useful for its ability to disentangle between-group and within-group variation in variables. Future investigations using multilevel SEM, particularly with datasets designed to explore multilevel associations, will help progress research on neighborhoods and health. Third, there was a limited amount of missing data for control variables and a small number of observations (approximately 8.2% of the

sample) were excluded from analyses, which could have biased results. Fourth, this study relied on a specific population—older adults in Johnston County, NC. The use of this specific population limits generalizability to other settings, such as other counties in NC or states in the US and other populations.

Finally, it is also important to note that participants included these analyses were selected from a prospective cohort study and originally invited to participate between 1991-1997 (baseline) or 2003-2004 (for cohort enrichment). By the T2 wave of data collection (2006-2011), many individuals had died. Therefore, individuals sampled at the T2 wave of data collection may have been healthier at baseline than those not sampled at T2; in other words, individuals sampled at T2 could represent the "survivors" or the "heartiest" participants. Accordingly, results may not generalize to community samples of older adults. Indeed, at baseline, compared to participants *not included* in the T2 wave, participants included in the T2 wave were significantly more likely to:

- Be younger
- Be female
- Be White
- Have a high school degree or higher
- Have a BMI of 30 or greater
- Have fewer comorbidities
- Have a high SES job
- Have lower CES-D scores, and
- Live in a neighborhood with fewer households below the poverty line at baseline

These additional analyses can be found in Appendix F.

Conclusions

In this sample of mostly rural, older adults with chronic diseases, poverty and perceived neighborhood environment (namely social cohesion, safety, and access to physical activity and walking resources) were associated with reports of depressive symptoms through social support, perceived

individual control, and physical activity. Specifically, poverty was associated with worse perceived neighborhood environment. In turn, perceived neighborhood environment was associated with more social ties, an increased sense of control, and increased physical activity, which were then associated with fewer depressive symptoms, altogether accounting for 41% of the variance in depressive symptoms (along with control variables). Alone (including direct and indirect effects), neighborhood variables explained 12% of the variance in depressive symptoms, 15% of the variance in social support, 37% of the variance in perceived individual control, and 4% of the variance in physical activity. These findings suggest that both individual-level mediators *and* neighborhood context are important determinants of depressive symptoms among older adults.

Tables for Study 2

Table 9. Participant characteristics of adults from the T2 wave of the Johnston County Osteoarthritis Project, Johnston County, North Carolina, 2006-2011, n=1697

Characteristic	**N (%) or mean (SD)**
Race	
Caucasian	1167 (68.8)
African American or Black	530 (31.2)
Gender	
Male	552 (32.5)
Female	1145 (67.5)
Age (range 50-95), mean (SD)	68.1 (9.1)
BMI (range 12.6-78.1), mean (SD)	31.5 (7.2)
Education	
High school or greater	1297 (78.2)
Less than high school	362 (21.8)
Health insurance	
No	109 (6.4)
Yes	1588 (93.6)
Number of comorbidities (range 0-11)	1.7 (1.3)
Knee OA	
No	910 (55.5)
Yes	729 (44.5)
At least one chronic condition present [a]	
No	152 (9.1)
Yes	1520 (90.9)
Neighborhood poverty (range 0-44), mean (SD)	16.7 (10.3)
Perceived neighborhood social cohesion (range 5-25), mean (SD)	18.9 (3.6)
Perceived neighborhood resources for physical activity and walking (range 11-55), mean (SD)	35.9 (6.2)
Perceived neighborhood safety (range 3-15)	11.0 (2.3)
Social support (range 4-20), mean (SD)	17.8 (2.7)
Perceived individual control (range 2-10), mean (SD)	8.0 (1.5)
Physical activity	
Inactive	484 (28.7)
Insufficiently active	627 (37.2)
Sufficiently active	573 (34.0)
Depressive symptoms (range 0-60), mean (SD)	6.6 (7.5)

Note:
[a] Chronic conditions include: knee and hip OA, heart disease (heart attack, angina, congestive heart failure or other heart condition), hypertension, lung disease (including asthma, tuberculosis, chronic bronchitis, emphysema, chronic allergy or other chronic lung problem), vascular disease (including: stroke or circulation problems), liver disease, cancer, diabetes, and kidney disease/renal failure. I measured all conditions using the Disease Inventory Index, except for knee and hip OA where I used radiography and KL scores.

Table 10. Model fit from the confirmatory factor analyses for adults from the T2 wave of the Johnston County Osteoarthritis Project, Johnston County, North Carolina, 2006-2011, n=1697

Variable	Items	Modifications	Chi-Square (p-value) [a,b]	CFI [a,c]	TLI [a,c]	RMSEA [a,d]
Depressive symptoms	All 20 items	--	810.71 (p<.0001)	0.96	0.95	0.05 (0.05, 0.05)
Perceived neighborhood social cohesion	All 5 items	--	386.66 (p<.0001)	0.95	0.89	0.21 (0.20, 0.23)
	All 5 items	Correlated two items, which were reverse coded.	27.61 (p<.0001)	0.99	0.99	0.06 (0.04, 0.08)
Perceived neighborhood resources for physical activity and walking	All 11 items	--	6995.897 (p<.0001)	0.66	0.57	0.31 (0.30, 0.31)
	4 items (8, 10, 11, 16)	Only included 4/11 items since the initial model had poor fit. [f]	7.71 (p=0.02)	0.99	0.99	0.04 (0.01, 0.07)
Perceived neighborhood safety [e]	3 items	--	--	--	--	--
Social support	All 4 items	--	51.70 (p<.0001)	0.99	0.96	0.12 (0.10, 0.15)
Perceived individual control [e]	2 items	--	--	--	--	--
Perceived neighborhood environment [e]	Higher order factor comprised of neighborhood social cohesion, access to physical activity and walking resources, and safety	--	--	--	--	--

Notes:
[a] All CFAs controlled for clustering using type=complex
[b] Chi-square test (p-value should be >0.05; however, model fit can still be adequate if this p-value value is <0.05 since chi-square is dependent on sample size[172])
[c] The Comparative Fit Index (CFI) and Tucker-Lewis Index (TLI) (CFI, TLI should be >0.95[173,174])
[d] The root mean square error of approximation (RSMEA, should be <0.06[175,176])
[e] The model fit of factors with 3 or less items cannot be determined since the model would be just identified or not identified.
[f] Items were selected based on empirical evidence (correlations >0.40) and previous research suggesting their importance for measuring resources for physical activity and walking in rural neighborhoods.

Table 11. Correlation matrix of observed and latent variables for adults from the T2 wave of the Johnston County Osteoarthritis Project, Johnston County, North Carolina, 2006-2011, n=1697

	1.Neighborhood poverty	2.Perceived neighborhood social cohesion	3.Perceived neighborhood resources for physical activity and walking	4.Perceived neighborhood safety	5.Physical activity	6.Social support	7.Perceived individual control	8.Depressive symptoms
1	--	**-0.18*** **	**-0.11***	**-0.26*** **	**-0.14*** **	-0.03	0.01	**0.08***
2		--	**0.66*** **	**0.74*** **	**0.13*** **	**0.34*** **	**0.45*** **	**-0.30*** **
3			--	**0.68*** **	**0.13*** **	**0.34*** **	**0.65*** **	**-0.32*** **
4				--	**0.14*** **	**0.28*** **	**0.35*** **	**-0.26*** **
5					--	**0.17*** **	0.06	**-0.22*** **
6						--	**0.36*** **	**-0.56*** **
7							--	**-0.27*** **
8								--

Note, in final structural models, a higher order factor comprised of perceived neighborhood social cohesion, perceived neighborhood resources for physical activity and walking and perceived neighborhood safety was modeled. Correlations of this factor (perceived neighborhood environment) with poverty were -0.20***, with perceived individual control were 0.58***, with physical activity were 0.16***, and with social support were 0.39*** and with depressive symptoms were -0.35.***
Boldface denotes significance at $p<0.05$

Table 12. Results from the structural equation model for adults from the T2 wave of the Johnston County Osteoarthritis Project, Johnston County, North Carolina, 2006-2011, n=1558

Exogenous variables	Endogenous variables				
	Perceived neighborhood environment	Physical activity	Social support	Perceived individual control	Depressive symptoms
Poverty	B= -0.16***	B= -0.06*	--	--	B= -0.02
Perceived neighborhood environment	--	B= 0.09**	B= 0.41***	B= 0.61***	B= -0.002
Physical activity	--	--	--	--	B= -0.13***
Social support	--	--	--	--	B= -0.48***
Perceived individual control				--	B= -0.12*

Notes
N=1558 (139 observations were deleted because they were missing on all individual control variables). All relationships controlled for race, gender, BMI, education, health insurance status, number of comorbidities, age, and knee OA status. All relationships also controlled for clustering using type=complex. Beta coefficients are standardized.

* p<.05, ** p<.01, *** p<.001

Model Fit:
Chi-Square value (p-value): 1711.46, p<.001); RMSEA: 0.02 (95% CI: 0.02, 0.02); CFI: 0.96; TLI: 0.96

Indirect Effects (only significant results presented)
- Perceived neighborhood environment → Physical activity → Depressive symptoms: B= -0.01 (95% CI: -0.01, -0.02), p=0.003
- Perceived neighborhood environment → Social support → Depressive symptoms: B= -0.19 (95% CI: -0.16, -0.22), p<0.001
- Perceived neighborhood environment → Perceived individual control → Depressive symptoms: B= -0.07 (95% CI: -0.02, -0.12), p=0.02
- Poverty → perceived neighborhood environment → Physical activity → Depressive symptoms: B=0.002 (95% CI: 0.001, 0.003), p=0.02
- Poverty → perceived neighborhood environment → Physical activity: B= -0.02 (95% CI: -0.02, -0.03), p=0.01

Figures for Study 2

Figure 3. Conceptual model for proposed structural equation model pathways for adults from the T2 wave of the Johnston County Osteoarthritis Project, Johnston County, North Carolina, 2006-2011

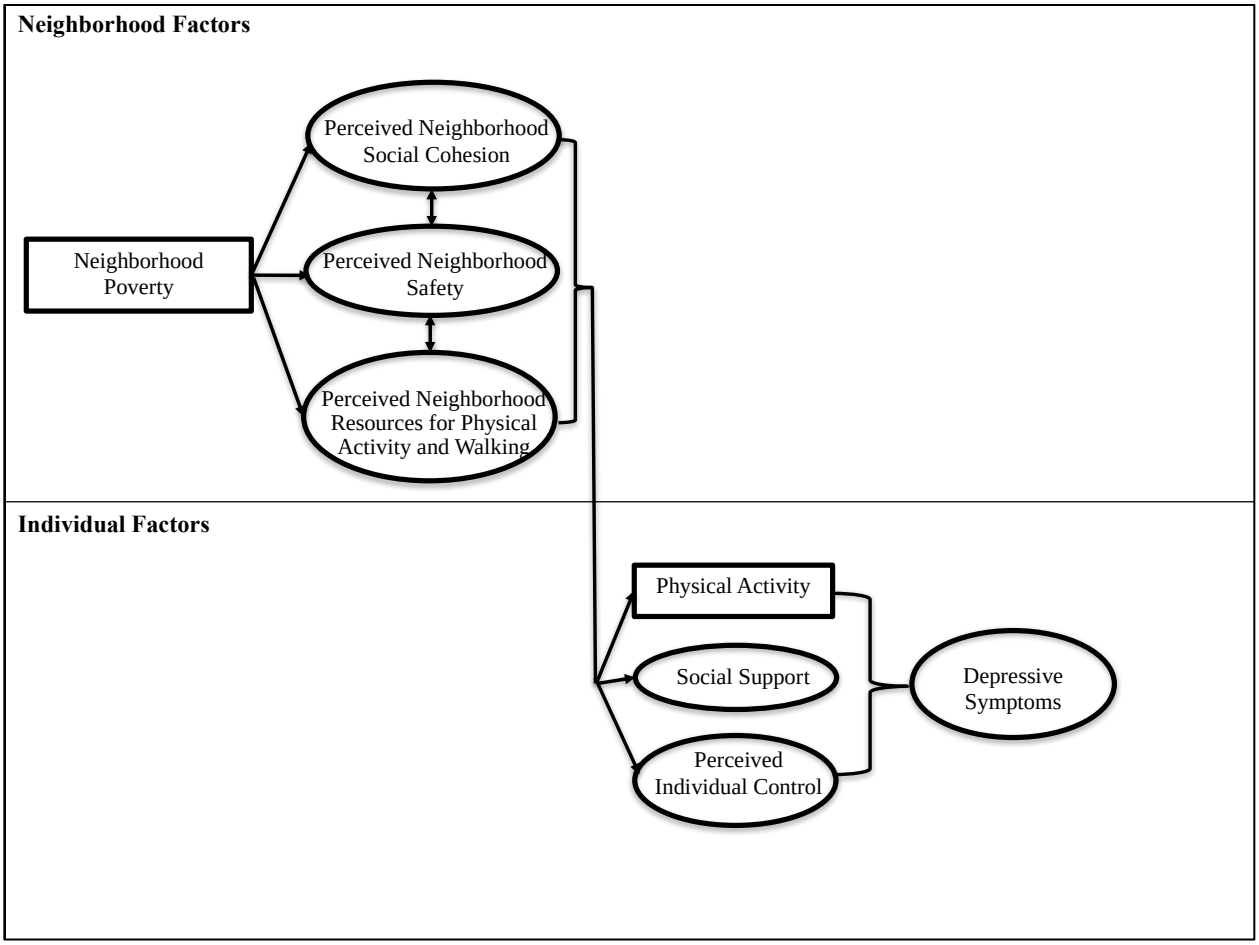
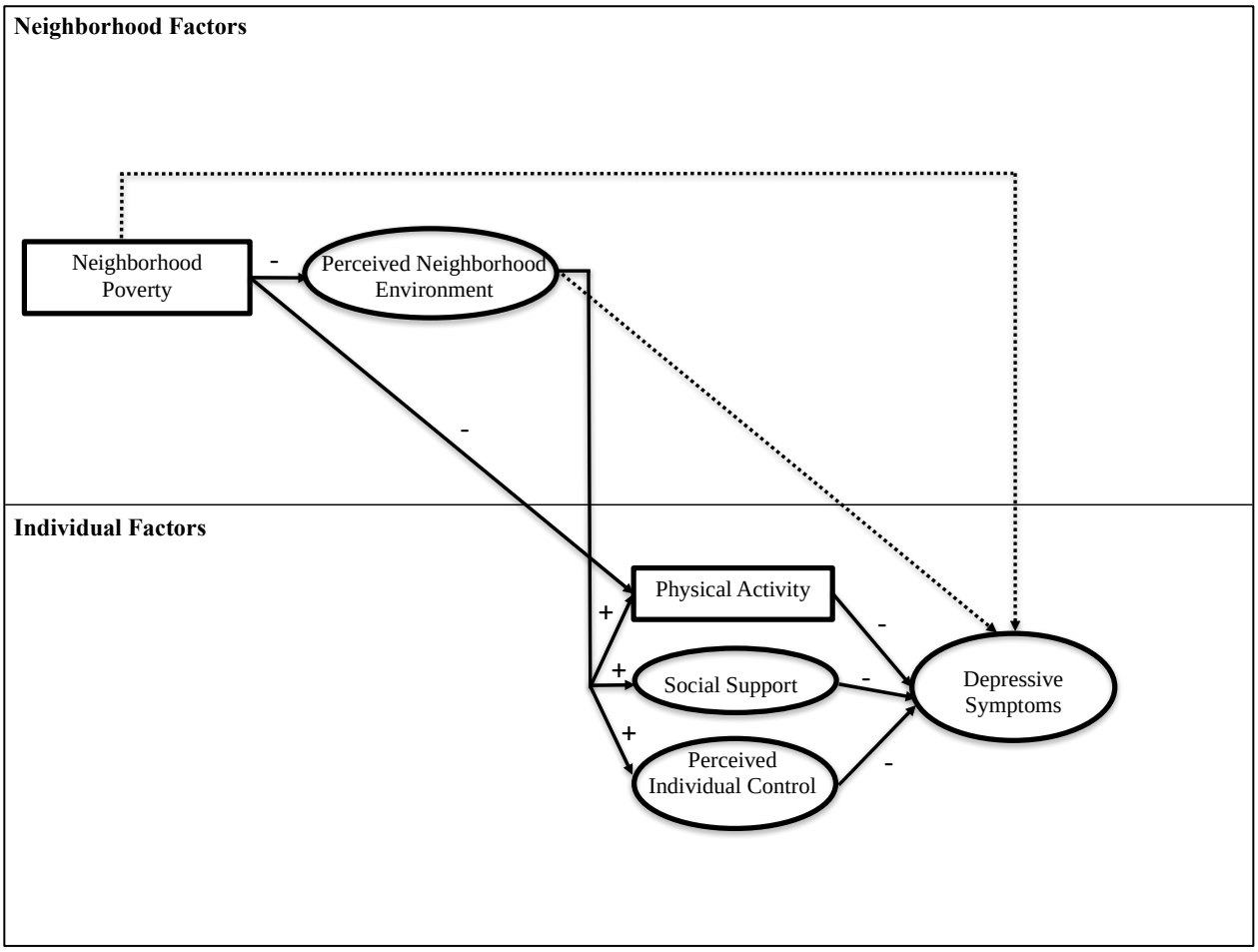


Figure 4. Final conceptual model with direction and significance of parameter estimates for adults from the T2 wave of the Johnston County Osteoarthritis Project, Johnston County, North Carolina, 2006-2011, n=1558



Note: Dashed arrows indicate non-significant pathway. All parameter estimates can be seen in Table 12.

CHAPTER 6: SYNTHESIS AND FUTURE DIRECTIONS

The purpose of this dissertation was to examine if, how, and for whom neighborhood characteristics matter for health and wellbeing. A summary of findings, including strengths / limitations and directions for further research and practice, are presented below.

Summary of Findings

Study 1

Among older adults with radiographic knee OA, Study 1 showed that perceived neighborhood social cohesion (Level 1 and Level 2) was significantly associated with depression and perceived neighborhood resources for physical activity and walking (Level 1 only) were significantly associated with reported knee impact scores and depression. Although these results were not consistent over time, I did observe a number of interactions, suggesting that less vulnerable older adults may be able to benefit more from neighborhood resources. These findings demonstrate that neighborhoods characteristics matter for both mental and physical health among older adults with at least one chronic disease.

That I observed these associations among older adults living in primarily rural neighborhoods is an important contribution to the field. Most research on neighborhoods and health has been conducted in urban areas[41,95,96] and until recently few studies have examined rural neighborhoods, despite their high burden of chronic disease.[97] Our results suggest that perceived neighborhood social cohesion and resources for physical activity and walking in rural areas are important determinants of health. While I observed no main effects of perceived neighborhood safety or poverty, future research could explore their effects among a more representative sample of older adults and examine how these variables may be associated with health in complex ways (i.e., neighborhood poverty influencing perceived neighborhood environment, which in turn could influence health outcomes). Study 2 attempts to examine these relationships, but more research in other settings beyond NC would be valuable.

Additionally, I found that most of the variation in health occurred within neighborhoods, rather than between neighborhoods. While I tested research questions using multilevel modeling, the minimal variation between neighborhoods meant that I was not able to fully determine how Level 2 neighborhood variables were associated with health. The lack of variation, however, indicates that census block groups may not be the best approximation of neighborhood boundaries. Future research using person-centered neighborhood boundaries could investigate neighborhood exposures and their associations with health.

Study 2

Among older adults (91% of whom have at least one chronic disease), Study 2 showed that neighborhood factors were strongly associated with depressive symptoms and this relationship was mediated by individual-level variables, namely physical activity, social support, and perceived individual control. This finding suggests the dual importance of both neighborhood and individual-level characteristics, particularly for interventions aiming to improve mental health outcomes of older adults. Altogether, these variables accounted for 41% of the variance in reported depressive symptoms (along with control variables). Encouragingly, these findings suggest modifiable approaches to improving depressive symptoms.

As in Study 1, there was minimal variation between neighborhoods, which meant that I was unable to estimate these pathways using a multilevel SEM approach. However, future research could build on this study's findings to examine how both Level 1 and Level 2 neighborhood variables contribute to health outcomes using even more advanced statistical techniques.

Taken together, Study 1 and Study 2 show that neighborhood factors are associated with mental and physical health outcomes of older adults living in primarily rural areas of NC. Importantly too, these studies demonstrate that psychosocial and behavioral variables mediate and interact with neighborhood context in nuanced ways. Therefore, these studies underscore the complexity of disentangling how neighborhoods affect health.

Study Strengths

This dissertation had a number of strengths. Notably, advanced statistical techniques—multilevel modeling, longitudinal data analysis, SEM—helped disentangle and appropriately assess associations among neighborhood characteristics and health outcomes. Innovative research questions were identified to understand how this dissertation could contribute to further research on neighborhoods and health. Finally, this study relied on data from an important population and setting—older adults with knee OA (Study 1) and older adults, 91% of whom have at least one chronic disease, (Study 2) living in primarily rural neighborhoods.

Advanced Statistical Techniques

Study 1 used multilevel modeling and longitudinal data analysis to assess how neighborhood characteristics were associated with health outcomes. Multilevel modeling allows for: a) simultaneous examination of neighborhood and individual-level predictors, b) non-independence of observations within neighborhoods, and c) examination of both within-neighborhood and between-neighborhood variation.[85] In other words, using multilevel modeling allows researchers to answer more complex research questions, including: How are Level 1 and Level 2 neighborhood variables associated with health? Are neighborhood-level variables related to health outcomes after controlling for individual-level variables? Do individual-level associations vary from neighborhood to neighborhood? And do neighborhood-level variables modify the effects of individual-level variables? Additionally, in Study 1, results were robust with regards to a number of assumptions (i.e., after multiple imputation, excluding individuals residing in census block groups with less than 5 individuals, and analyzing somatic and non-somatic depressive symptoms separately). Finally, Study 1 also used longitudinal data analysis to examine how relationships occurred over time.

Study 2 used SEM, which is an analytical approach for data analysis that allows researchers to test multiple regression relationships among latent variables and between observed and latent variables and allows for models in which one or more variables are simultaneously predicted and predictor variables, thereby making it a powerful analytical technique.[88] Importantly, with SEM, I was able to

partly control for selection into different neighborhood characteristics based on individual characteristics. For instance, in our study, when I estimated pathways between perceived neighborhood environment and physical activity, I controlled for race, gender, age, BMI, number of chronic conditions, education, OA status, and health insurance status. While it is possible that other unmeasured variables may have affected individuals' perceptions of their neighborhood environments, our analyses begin to disentangle the potential bias that subjective assessments of neighborhoods may produce.

Innovative Research Questions

Researchers have developed a number of theories and conceptual frameworks to illustrate how neighborhoods affect health (see work on social determinants of health,[42] social disorganization theory[43] and conceptual models from Diez & Roux,[34] Brown et al.,[44] Carpiano,[45] Blair et al.,[46] and Kawachi & Berkman[81]), yet these models have rarely been empirically tested. Specifically, these models suggest the importance of individual-level mediators and cross-level interactions. In response, both Study 1 and Study 2 examined innovative research questions involving mediation and moderation analysis. That both studies used four neighborhood characteristics (including self-reported and area-level indicators independent of residents' perceptions) facilitates comparisons of results with previous and future research. Additionally, using two health outcomes (depression and knee impact scores) in Study 1 and focusing on depression in Study 2 provides new evidence for how neighborhood context is associated with both mental and physical functioning.

Key Population and Setting

The participants included in Studies 1 and 2—older adults in primarily rural neighborhoods—represent important populations for both public health intervention and research on neighborhoods and health. Most research on neighborhoods and health has been conducted in urban areas[41,95,96] and until recently few studies have examined rural neighborhoods, despite their higher burden of chronic disease.[97] Moreover, some research suggests that neighborhoods are particularly important for older adults due to their more limited mobility,[47] shrinking social networks,[48] and increased exposure to residential

neighborhood effects.[41,49] Results from this dissertation could be used to guide additional studies focusing on older adults living in primarily rural neighborhoods.

Study Limitations

There are a number of limitations to this dissertation, including 1) the inability to infer causal relationships, 2) the inability to assess environments beyond the neighborhood in which individuals may interact and the use of census block group boundaries to represent neighborhoods, 3) minimal clustering by neighborhoods which limited my ability to detect between-neighborhood effects, 4) no measure of individual income, and 5) limited generalizability.

Inability to Infer Causal Relationships

In Study 1, I assessed cross-sectional and longitudinal associations among neighborhood characteristics and outcomes. There are a number of reasons why associations occurred that do not include a causal pathway from neighborhoods to health. These reasons include:

1. Most notably, individuals may select into certain neighborhoods, based on individual attributes, which are themselves associated with health.[195] This bias is often termed "selection bias" and violates the exchangeability assumption of causal inference.[195] Researchers attempt to control for this bias by controlling for numerous individual-level variables,[195] as I did in both studies. However, it is possible that other omitted variables (e.g., income) caused people to live in certain neighborhoods (e.g., neighborhoods with different poverty levels), and that these variables (e.g., income) are differentially associated with health outcomes (e.g., depression or knee impact scores in this case). In other words, these omitted variables could have confounded observed associations. While selection bias is a key issue in observational studies of neighborhood effects, most participants reported being born in Johnston County (60%) and reported living in the same area for an average of 45 years at the beginning of the parent study (1990-1997).
2. Relatedly, it is also possible that health (our outcomes) played a causal role in the choice of residential location (termed "reverse causation"). For example, reverse causation could mean that individuals who experience an illness may be forced to move to a worse neighborhood due to cost

of the illness or disability status resulting from the illness.[196] In our study, reverse causation could have meant that individuals with certain depression or knee impact scores chose to live in different neighborhoods. However, again, when interpreted in light of the length of time people had lived in their neighborhoods at the beginning of the parent study, this bias is perhaps not likely. Longitudinal study designs assessing a) residential mobility patterns, b) repeated measures of health status, and c) why people move to certain residential areas could help minimize this bias.[196]

3. It is also possible that individuals with certain dispositions rated their neighborhoods more or less favorably and that these dispositions were then responsible for observed associations (rather than neighborhood characteristics). This is sometimes referred to as "same source bias".[147] Study 2 partially controls for same source bias by regressing neighborhood perceptions on individual-level characteristics, such as age, race, BMI, and others.[82] Although, I can still not infer causality, previous research documenting the robust effect of neighborhoods[35-39,50-59] and randomized controlled trials demonstrating that individuals moving from high to low-poverty neighborhoods improves health,[66] support the argument that neighborhoods are at least partly responsible for health behaviors and outcomes.

Inability to Assess Environments Beyond the Neighborhood in Which Individuals May Interact and Use of Census Block Groups

In the present study, neighborhood features were evaluated at the level of the census block group. This is problematic for a number of reasons, most notably that individuals may not consider their census block groups to be their "neighborhoods," using census block groups may miss other important neighborhood features that are just outside block group boundaries, and individuals often work and interact in other areas beyond their census block group. In contrast, some of the work of Brenner and colleagues in Camden New Jersey has explored hot spots defined at more micro levels, such as buildings and neighborhood blocks,[197-199] and other researchers have proposed the idea of "spatial polygamy," which refers to the idea that individuals are exposed to multiple contexts that interact to affect health (not

just neighborhoods).[200] Future research will address these various determinants and contexts, and importantly, will need to identify levels of influence that may be actionable at the level of individual or community interventions and policies.

Minimal Clustering Limits the Ability to Find Between-Neighborhood Effects

With sufficient clustering and power, multilevel modeling allows researchers to parse out between-neighborhood variation and within-neighborhood variation. However, in the present study, I observed little between-neighborhood variation of health outcomes (i.e., depression and knee impact scores) by census block groups. This means that most of the variation in these outcomes was due to within-neighborhood variation. As a result, my ability to detect how Level 2 variables (or between-neighborhood variables) were associated with outcomes was constrained. Future research with more between-group variation will be useful to understand how both levels (Levels 1 and 2) operate to influence health.

No Measure of Individual Income

While I included individual-level control variables in the present studies, I did not have a measure of individual-level income, which could have explained these results. Although I included a measure of education and health insurance status, which have been used as proxies of income in previous studies, further research controlling for income *and* examining interactions between neighborhood income and individual income will be important.

Limited Generalizability

Finally, this study relied on a specific population—older adults in Johnston County, NC. The use of this specific population limits generalizability to other settings, such as other counties in NC, other states in the US, and other populations, such as younger adults.

Implications for Research

This study raised a number of important questions for future research. These questions are outlined and detailed below.

How Will Technology Change Assessment and Measurement of Neighborhood Characteristics and Health Outcomes?

In Studies 1 and 2, I measured neighborhood characteristics at one time point. While this approach—which relies on a static conceptualization and assessment of neighborhoods—is common in research on neighborhoods and health, it limits our understanding of 1) how neighborhoods may affect outcomes in real time and 2) how different environmental features outside of residential neighborhoods may affect health. Ecological momentary assessment (EMA) allows researchers to collect real-time data on individuals and their behaviors, moods, and social interactions. A few studies have begun combining EMA data with Global Positioning System (GPS) technology in mobile phones to geotrack individuals. This geotracking allows researchers to capture an individual's activity space (i.e., home location and other routine places individuals travel to for work, leisure, or other activities) and their real-time health behaviors. This is a new field and researchers are just beginning to demonstrate the spatial accuracy of Geographic EMA.[201-203] However, the implications for how this could advance our understanding of neighborhoods and health are exciting. For instance, one study is combining Geographic EMA with qualitative semi-structured interviews to 1) estimate associations among e-cigarette and cigarette use, 2) examine how immediate environmental and psychosocial contexts are associated with within- and between- participant differences in e-cigarette and cigarette use, and 3) examine participants' lived experiences and meanings given to environmental and psychosocial factors and their associations with smoking-related behavior.[202]

How Can We Also Assess Neighborhood Change?

While EMA studies typically occur over relatively short time periods, researchers have also begun using longer longitudinal studies (e.g., more than 10 years) with repeated measurements to examine a) how neighborhood characteristics change over time, b) how health changes over time, c) how individuals move in and out of neighborhoods with different characteristics, d) average differences in health between different individuals that is due to neighborhood characteristics, and e) variation of in health in individuals over time that is due to neighborhood characteristics. The emphasis in these studies

is placed on understanding dynamic patterns of change in neighborhoods, mobility trends, and within and between-person differences in health.[204,205] The results from these studies can be used to improve our understanding neighborhoods' causal effects on health.

How Will Advanced Statistical Methods Change Our Understanding of Complex Relationships?

The present study used advanced statistical techniques, including multilevel modeling, longitudinal data analysis, and SEM, to understand complex relationships among neighborhoods, mediators, and health outcomes. However, these techniques still limit our ability to estimate the complexity with which individuals interact with neighborhood characteristics. New techniques like agent-based modeling can advance our research questions and understanding of how neighborhoods affect health.[206-208] Agent-based modeling is a computation modeling approach, which endows agents (e.g., individuals, neighborhoods) with a set of "real-world" properties.[208] This approach allows researchers to understand complex causal effects and underlying mechanisms behind complex systems. For instance, tobacco control researchers used agent-based modeling to understand how four neighborhood policies to reduce tobacco retail density would affect accessibility of tobacco products in four hypothetical settings that varied by income and geography (rural vs. urban).[209] Results not only demonstrated which policies would be most effective, but also the additive or synergistic effects of policies, the effectiveness of policies for different settings, and which policies would reduce or exacerbate existing health disparities.[209]

How Can We Incorporate Life Course Theory into Research on Neighborhoods?

Finally, as research on neighborhoods and health advances and methods improve (e.g., longitudinal, multilevel designs), researchers have begun to incorporate new perspectives in analysis and interpretation of data. Life course epidemiology focuses on how exposures throughout life are associated with health and focuses on vulnerable periods.[196] Applying a life course perspective to neighborhood research often involves looking at health trajectories, examining neighborhood characteristics during childhood, and incorporating time, age, and developmental stages into neighborhood studies.[196] For instance, in one recent study, researchers examined how cumulative disadvantage is associated with health transitions, using multiple waves of a 15-year study of adults.[210] Other researchers have begun

teasing out developmentally-sensitive time periods in which certain neighborhood characteristics (or interactions among neighborhood characteristics) may be important.[196]

Implications for Practice

This study raised a number of important questions for interventions, as detailed below.

Focusing Resources on Neighborhood-Level Characteristics

Study 1 found consistent effects of perceived neighborhood social cohesion and resources for physical activity and walking on reported knee impact scores and depression scores for individuals with knee OA. National agencies, like the CDC and the Arthritis Foundation already recognize the importance of neighborhoods for OA prevention and management.[59] Findings from Study 1 move these recommendations forward by providing more concrete guidance on what neighborhood characteristics should be addressed, individuals who represents priority populations for interventions, and how neighborhood characteristics interact with key individual-level characteristics to influence health.

Specifically, for older adults with knee OA, interventions designed to improve neighborhood social cohesion and resources for physical activity and walking, could improve depression scores and/or reported knee impact scores. There are innovative ways to encourage social interaction in neighborhoods (increasing vegetation and common spaces,[183] designing homes with porches or stoops[184]), and encourage self-care behaviors, such as physical activity, through improvements to infrastructure like lighting or sidewalks.[185] In addition, campaigns designed to inform residents about neighborhood resources for physical activity and walking or ways residents can take advantage of resources could improve perceptions of neighborhood characteristics and therefore health outcomes. Although results suggested that less vulnerable older adults (e.g., adults with non-severe knee OA or adults without heart disease or diabetes) may be more able to benefit from neighborhood characteristics, care should be taken to focus on and include a variety of older adults, as well as considering focusing on those neighborhood characteristics that would be important for more vulnerable older adults.

Recognizing and Valuing the Role of Individual-Level Characteristics

Study 2 extended the findings from Study 1 and found associations between neighborhood poverty and depressive symptoms to be mediated by perceived neighborhood environment, as well as social support, physical activity, and perceived individual control. Together, these findings demonstrate the importance of *both* neighborhood-level characteristics and mediators at the individual-level. Multilevel level interventions, which target behavioral change at more than one ecological level,[211] are important tools in improving health and reducing health disparities. Yet, most public health interventions are targeted at intrapersonal and interpersonal levels.[64] This is likely due to a number of reasons, including but not limited to: lack of training or resources for health professionals seeking to implement institutional, community, or policy-level programs; lack of theories or training in theories for creating interventions to change upper ecological levels; fewer metrics to evaluate changes at upper ecological levels; and added financial and logistical difficulty in trying to address upper ecological determinants. Transdisciplinary approaches, in which theories and methods are integrated across disciplines, may be particularly beneficial in disseminating lessons learned for future research on neighborhoods and health.[212] For example, collaborations among public health, medicine, public policy, and city and regional planning, among others could help broaden the scope of our research questions, change and improve our interventions, and assist with integration of theories—thereby increasing the chances of successful community and neighborhood-level interventions.[212]

Intervening with Rural, Older Adults

Finally, older adults are a priority population. In 2014, 14.5% (46 million) of the US population was aged 65 or older; by 2060, this figure will reach 23.5% (98 million).[190] As adults continue to live longer, health care spending will likely increase, particularly for chronic diseases, which represent 95% of all health care costs for older adults in the US.[191] Innovative strategies to maintain and promote the quality of life of older adults are needed. One such strategy is allowing older adults to "age in place" or allowing them to stay in their own "homes and communities safely, independently, and comfortably, regardless of age, income, or ability level."[192] Despite the importance of both home and community

environments, most interventions tailored to older adults have focused on making improvements to homes (e.g., making modifications and adaptions to homes in order to prevent accidents or falls, improving functional ability of features in homes, providing services in homes, removing barriers that would prevent older adults from continuing to live at home, etc.).[193] The results from this dissertation suggest that both poverty and perceived neighborhood environment are important determinants of quality of life that should be taken into consideration when designing public health interventions for older adults in rural areas.

APPENDIX A. MEASURES

Construct and time point if applicable	Scale Name	Item(s)	Notes
Depression (T2)	CES-D	• I was bothered by things that usually don't bother me. • I did not feel like eating; my appetite was poor. • I felt that I could not shake off the blues even with help from my family or friends. • I felt I was just as good as other people. • I had trouble keeping my mind on what I was doing. • I felt depressed. • I felt that everything I did was an effort. • I felt hopeful about the future. • I thought my life had been a failure. • I felt fearful. • My sleep was restless. • I was happy. • I talked less than usual. • I felt lonely. • People were unfriendly. • I enjoyed life. • I had crying spells. • I felt sad. • I felt that people dislike me. • I could not get "going."	Response options range from 0 (rarely or none of the time) to 3 (most or all of the time), which refer to frequency of the symptoms in the past week. I did not calculate score totals for individuals with more than four missing responses. After reverse coding, items are summed to create a total score that ranged from 0 (best possible) to 60 (worst).
Depression (T3)	PROMIS-D	• In the past 7 days, I felt worthless. • In the past 7 days, I felt that I had nothing to look forward to. • In the past 7 days, I felt helpless. • In the past 7 days, I felt sad. • In the past 7 days, I felt like a failure. • In the past 7 days, I felt depressed. • In the past 7 days, I felt unhappy. • In the past 7 days, I felt hopeless.	Each item on the measure is rated on a 5-point scale (1=never; 2=rarely; 3=sometimes; 4=often; and 5=always) with higher scores indicating greater severity of depression. Raw scores are summed are then converted to standardized scores.
Knee impact (T2)	KOOS Quality of Life, Function in Daily	• (see items below corresponding to the three sub-scales)	I calculated the mean of the 30 items representing the 3 KOOS sub-scales below and

	Living, and Pain sub-scales		transformed scores to a 0-100 scale, with zero representing extreme impact of knee OA and 100 representing little impact of knee OA. I did not calculate score totals for individuals with more than half of the items missing responses.
	KOOS Knee-Related Quality of Life sub-scale	• How often are you aware of your knee problems? • Have you modified your lifestyle to avoid potentially damaging activities to your knee? • How troubled are you with lack of confidence in your knee? • In general, how much difficulty do you have with your knee?	Response options determine the frequency of knee-related quality of life problems (e.g., 0=never, 1=monthly, 2=weekly, 3=daily, 4=always and 0=not at all, 1=mildly, 2=moderately, 3=severely, 4=totally) and each item is scored 0 to 4. I reverse coded necessary items so that higher scores indicate fewer problems.
	KOOS Function in Daily Living sub-scale	What degree of difficulty do you have • Descending stairs (going down stairs) due to your knee? • Ascending stairs (going up stairs) due to your knee? • Rising from sitting due to your knee? • Standing due to your knee? • Bending to the floor to pick up an object due to your knee? • Walking on a flat surface due to your knee? • Getting in / out of cars due to your knee? • Going shopping due to your knee? • Putting on socks / stockings due to your knee? • Rising from bed due to your knee? • Taking off socks / stockings due to your knee? • Lying in bed (turning over, maintaining hip position) due to your knee?	Response options determine the extent of knee-related problems (e.g., 0=none, 1=mild, 2=moderate, 3=severe, 4=extreme) and each item is scored 0 to 4. I reverse coded necessary items so that higher scores indicate fewer problems.

		• Getting in / out of baths due to your knee? • Sitting due to your knee? • Getting on / off toilet due to your knee? • Heavy domestic duties due to your knee? • Light domestic duties due to your knee?	
	KOOS Pain sub-scale	• How often do you experience knee pain? How much pain do you have • In your knee while walking on a flat surface? • In your knee while going up or down stairs? • In your knee at night while in bed? • In your knee while sitting or lying down? • In your knee while standing upright? • In your knee while twisting / pivoting? • While straightening your knee fully? • Bending your knee fully?	Response options determine the frequency and extent of knee pain (e.g., 0=never, 1=monthly, 2=weekly, 3=daily, 4=always and 0=none, 1=mild, 2=moderate, 3=severe, 4=extreme) and each item is scored 0 to 4. I reverse coded necessary items so that higher scores indicate fewer problems.
Knee Impact (T3)	KOOS Quality of Life, Function in Daily Living, and Pain sub-scales	• (see items below corresponding to the three sub-scales)	For each knee pair, I took the highest score. For instance, if someone scored a 4 on their left knee for "how often are you aware of your knee problem?" and a 0 on their right knee for the same question, their score would be 4 for that item. I calculated the mean of the 17 items and transformed scores to a 0-100 scale, with zero representing extreme impact of knee OA and 100 representing little impact of knee OA. I did not calculate score totals for individuals with more than half of the items missing responses.

	KOOS Knee-Related Quality of Life	• How often are you aware of your knee problem? (left) • How often are you aware of your knee problem? (right) • Have you modified your lifestyle to avoid potentially damaging activities to your knee? (left) • Have you modified your lifestyle to avoid potentially damaging activities to your knee? (right) • How troubled are you with lack of confidence in your knee? (left) • How troubled are you with lack of confidence in your knee? (right) • In general, how much difficulty do you have with your knee? (left) • In general, how much difficulty do you have with your knee? (right)	Response options determine the frequency of knee-related quality of life problems (e.g., 0=never, 1=monthly, 2=weekly, 3=daily, 4=always and 0=not at all, 1=mildly, 2=moderately, 3=severely, 4=totally) and each item is scored 0 to 4. I reverse coded necessary items so that higher scores indicate fewer problems.
	KOOS Function in Daily Living sub-scale	What degree of difficulty do you have • Rising from sitting due to your knee (left)? • Rising from sitting due to your knee (right)? • Bending to the floor to pick up an object due to your knee (left)? • Bending to the floor to pick up an object due to your knee (right)? • Putting on socks / stockings due to your knee (left)? • Putting on socks / stockings due to your knee (right)? • Rising from bed due to your knee (left)? • Rising from bed due to your knee (right)? •	Response options determine the extent of knee-related problems (e.g., 0=none, 1=mild, 2=moderate, 3=severe, 4=extreme) and each item is scored 0 to 4. I reverse coded necessary items so that higher scores indicate fewer problems.
	KOOS Pain	• How often do you experience knee pain (left)? • How often do you experience knee pain (right)? How much pain do you have… • In your knee while walking on a flat surface (left)? • In your knee while walking on a flat surface (right)? • In your knee while going up or down stairs (left)? • In your knee while going up or down stairs (right)? • In your knee at night while in bed (left)? • In your knee at night while in bed (right)?	Response options determine the frequency and extent of knee pain (e.g., 0=never, 1=monthly, 2=weekly, 3=daily, 4=always and 0=none, 1=mild, 2=moderate, 3=severe, 4=extreme) and each item is scored 0 to 4. I reverse coded necessary items so that higher scores indicate fewer problems.

		• In your knee while sitting or lying down (left)? • In your knee while sitting or lying down (right)? • In your knee while standing upright (left)? • In your knee while standing upright (right)? • In your knee while twisting / pivoting (left)? • In your knee while twisting / pivoting (right)? • While straightening your knee fully (left)? • While straightening your knee fully (right)? • Bending your knee fully (left)? • Bending your knee fully (right)?	
Neighborhood poverty	--	Block group household poverty compiled from 2010 census data.	Analyzed as a continuous variable.
Neighborhood social cohesion	Sampson et al.'s 5 item measure of Social Cohesion and Trust	• People around here are willing to help their neighbors. • This is a close-knit or unified neighborhood. • People in my neighborhood can't be trusted. • People in my neighborhood don't get along with each other. • People in my neighborhood do not share the same values.	All items were assessed on a 5-point likert response scale (1=strongly agree to 5=strongly disagree). After reverse coding any necessary items, responses were summed and ranged from 5-25, with higher scores indicating more social cohesion. Responses of "don't know" were combined with responses that indicated "neutral", in line with Sampson et al.'s original analysis of this variable.
Neighborhood access to physical activity and walking resources	Walking and Exercise Environment scale	• My neighborhood offers many opportunities to be physically active. • Local sports clubs and other providers in my neighborhood offer many opportunities to get exercise. • It is pleasant to walk in my neighborhood. • There are enough trees in my neighborhood to provide shade. • My neighborhood has heavy traffic • There are busy roads to cross when out for walks in my neighborhood.	All items were assessed on a 5-point likert response scale (1=strongly agree to 5=strongly disagree) and after reverse coding, were summed, where higher scores indicate more access. Responses of "don't know" were

		• In my neighborhood, it is easy to walk to places. • There are stores within walking distance of my home. • On my neighborhood, the streets and sidewalks are in good condition. • I often see other people walking in my neighborhood. • I often see other people exercise (for example, jog, bicycle, play sports) in my neighborhood.	combined with responses that indicated "neutral".
Neighborhood perceived safety	--	• I feel safe walking in my neighborhood during the evening. • My neighborhood is safe from crime. • Violence is a problem in my neighborhood.	All items were assessed on a 5-point likert response scale (1=strongly agree to 5=strongly disagree) and after reverse coding any necessary items, summed, where higher scores indicate more safety. Responses of "don't know" were combined with responses that indicated "neutral".
Race / ethnicity	--	White or Black / African American	
Gender	--	Male / Female	
Age	--	Age	
BMI	--	• Measured weight (to the nearest pound) • Measured height (to the nearest .5 inch)	Calculated BMI
Education	--	What is the highest grade or year of school that you have completed, including trade or vocational school or college? • 00 through 12=Grade school • 13=GED • 14=vocational, one year • 15=vocational, two years • 16=vocational, three years • 17=college, one year • 18=college, two years • 19=college, three years • 20=college, four years • 21=graduate or professional school with advanced degrees	Education was used as a dichotomous variable indicating having completed less than 12 years of formal schooling or 12 years or more.
Health insurance	--	Do you now have health insurance through…? • None	Insurance status dichotomized as any

		• Work or union • Medicare A • Medicare B • Medicare D • Medicaid or public aid • Grange Farm Bureau • Medical Society, or Group Retirement Plan • Direct purchase from insurance company by yourself • Veterans Administration • CHAMPUS-coverage for military personnel and dependents • Any other plan?	(coded as 1) or none (coded as 0).
Number of comorbidities (T2)	Disease Inventory	Please tell me which of the following conditions or illnesses a DOCTOR, NURSE, or HEALTH PROFESSIONAL has told you that you have NOW. • Heart disease (heart attack, angina, congestive heart failure or other heart condition) • High blood pressure (hypertension) • Lung disease (asthma, TB, chronic bronchitis, emphysema, chronic allergy or other chronic lung problem) • Vascular disease (stroke or circulation problems) • Ulcer (stomach ulcer or GERD) • Liver disease • Cancer • Anxiety/depression • Anemia • Diabetes • Kidney disease (kidney stone or renal failure)	A comorbidity index of 11 diseases (heart disease, high blood pressure, lung disease, cardiovascular disease, ulcer, liver disease, cancer, anxiety/depression, anemia, diabetes, and kidney disease) was created and defined as the sum of positive responses for individual diseases.

Number of comorbidities (T3)	Charlson Comorbidity Index	Have you ever…
		• Had a heart attack?
		• Been treated for heart failure?
		• An operation to unclog or bypass the arteries in your legs?
		• Had a stroke?
		  ○ Had a cerebrovascular accident?
		  ○ Had a blood clot in the brain?
		  ○ Had bleeding in the brain?
		  ○ Had a transient ischemic attack (TIA)?
		  ○ Had difficulty moving an arm or leg as a result of the stroke or cerebrovascular accident?
		• Had asthma?
			The Charlson Comorbidity Index contains 19 categories of comorbidity and predicts the ten-year mortality for a patient who may have a range of co-morbid conditions. Each condition is assigned with a score of 1,2,3 or 4 depending on the risk of dying

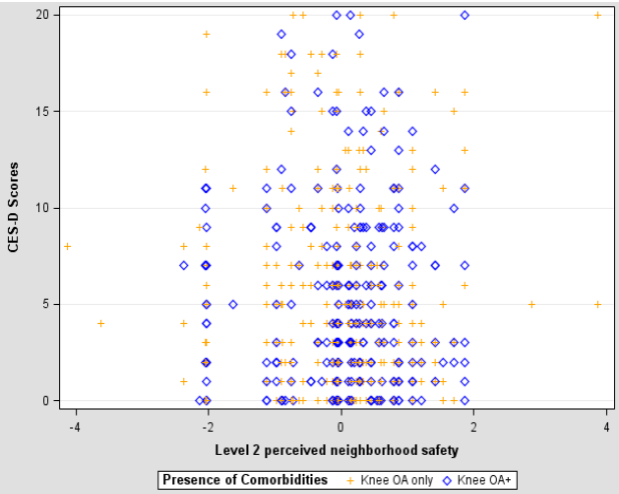
		○ Do you take medicines for your asthma? ○ Only with flare-ups of your asthma? ○ I take medicines regularly, even when I am not having a flare-up? • Do you have emphysema, chronic bronchitis, or chronic obstructive lung disease? ○ Do you take medicines for your lung disease? ○ Only with flare-ups of your lung disease? ○ Do you take medicines regularly, even when you are not having a flare-up? • Do you have stomach ulcers, or peptic ulcer disease? ○ Has this condition been diagnosed by endoscopy (where a doctor looks into your stomach through a scope) or an upper GI or barium swallow study (where you swallow chalky dye and then xrays are taken)? • Do you have diabetes (high blood sugar)? ○ Treated by modifying your diet? ○ Treated by taking medications by mouth? ○ Treated by insulin injections? ○ Has the diabetes caused problems with your kidneys? ○ Has the diabetes caused problems with your eyes, treated by an opthamologist? • Poor kidney function (blood tests show high creatinine)? ○ Have used hemodialysis or peritoneal dialysis? ○ Have received kidney transplantation? • Do you have rheumatoid arthritis? ○ Do you take medications for it regularly? ○ Do you have lupus? (systemic lupus erythematosus)? ○ Do you have Polymyalgia rheumatica? • Alzheimers Disease or other form of dementia? • Cirrhosis or serious liver damage? • Leukemia or polycythemia vera? • Lymphoma? • Cancer, other than skin cancer, leukemia or lymphoma?	associated with this condition. Higher scores indicating greater comorbidity (patients with a score > 5 have essentially a 100% risk of dying at one year). For example, a patient may have cancer, but also heart disease and diabetes so severe that the costs and risks of the treatment outweigh the short-term benefit from treatment of the cancer.

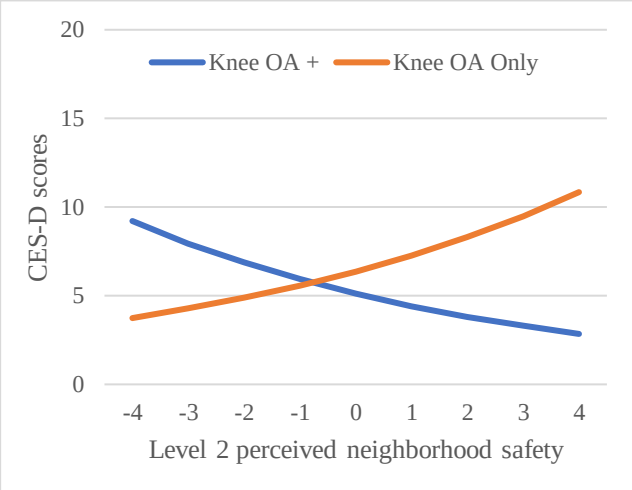
		○ Has the cancer spread, or metastasized to other parts of your body? • AIDS?	
Physical activity	Behavioral Risk Factor Surveillance System	Moderate activities are defined as any activity performed for at least 10 minutes at a time, such as brisk walking, bicycling, vacuuming, gardening, or anything else that causes some increase in breathing or heart rate. Vigorous activities are defined as any activity performed for at least 10 minutes at a time, such as running, aerobics, heavy yard work, or anything else that causes large increases in breathing or heart rate. • Thinking about the MODERATE activities that you do IN A USUAL WEEK, do you do MODERATE activities for at least 10 minutes at a time, such as brisk walking, bicycling, vacuuming, gardening or anything else that causes small increases in breathing or heart rate? • How many DAYS PER WEEK do you do these MODERATE activities for at least 10 minutes at a time? • On days when you do MODERATE activities for at least 10 minutes at a time, how much TOTAL TIME PER DAY do you spend doing these activities? (measured in hours) • On days when you do MODERATE activities for at least 10 minutes at a time, how much TOTAL TIME PER DAY do you spend doing these activities? (measured in minutes) • Now thinking about VIGOROUS physical activities you do IN A USUAL WEEK, do you do VIGOROUS activities for at least 10 minutes at a time, such as running, aerobics, heavy yard work, or anything else that causes large increases in breathing or heart rate? • How many DAYS PER WEEK do you do these VIGOROUS activities for at least 10 minutes at a time? • On days when you do VIGOROUS activities for at least 10 minutes at a time, how much TOTAL TIME PER DAY do you spend doing these activities? (measured in hours)	Based on responses to questions, individuals were classified as • Inactive (participants that report doing no moderate or vigorous physical activity). • Insufficiently active (participants that report doing insufficient moderate or vigorous physical activity to meet recommendations, i.e. participants that reported less than 5 days of moderate activity with 30 or more minutes per day and less than 3 days of vigorous activity with 20 or more minutes per day)) • Active (participants that report that report doing enough moderate or vigorous physical activity to meeting the recommendations, i.e., participants that reported 5 or more days of moderate activity with 30 or more minutes per day and/or 3 or more days of vigorous activity with 20 or more minutes per day)

		• On days when you do VIGOROUS activities for at least 10 minutes at a time, how much TOTAL TIME PER DAY do you spend doing these activities? (measured in minutes)	
Knee OA	KL scale	--	Radiographic knee OA was assessed using clinical exams. Posterior-anterior radiographs of the knee were obtained and interpreted by a radiologist who will score OA on the Kellgren-Lawrence (KL) scale from 0 to 4. Presence of radiographic OA was defined as KL grade at 2 or higher.
Severe knee OA	KL scale	--	Severe radiographic OA was defined as presence of KL score of 3 and 4.
Social support	Strong Ties scale	• How often are you bothered by not having a close companion? • How often are you bothered by not seeing people you feel close to? • How often are you bothered by not having enough close friends? • How often are you bothered by not having someone who shows you love and affection?	All items were assessed on a 5-point likert response scale (1=strongly agree to 5=strongly disagree) and summed, where higher scores indicate more support.
Perceived individual control	Perceived Control Scale	• I have control over the decisions that affect my life. • I am satisfied with the amount of control I have over decisions that affect my life.	Both items were assessed on a 5-point likert response scale (1=strongly agree to 5=strongly disagree), reverse coded, and summed, where higher scores indicate more control.

APPENDIX B. SUPPLEMENTARY FIGURES FOR STUDY 1

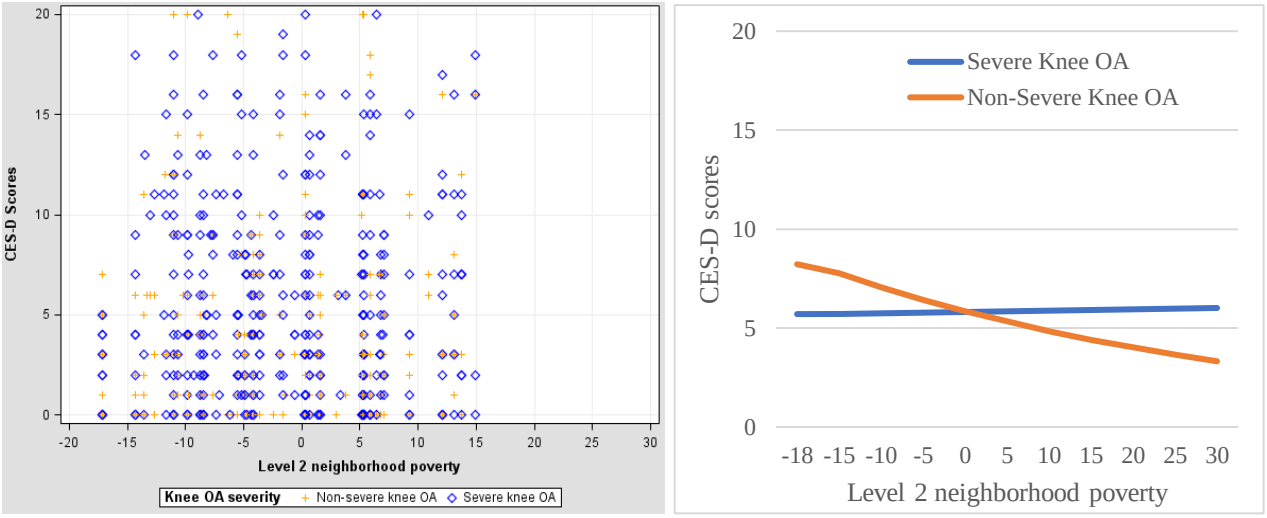
Figure B.1. Scatterplot of the interaction involving Level 2 perceived neighborhood safety, presence of comorbidities, and CES-D scores side-by-side interaction, among adults with knee OA, n=656, from the T2 wave of the Johnston County Osteoarthritis Project, Johnston County, North Carolina, 2006-2011





Note: Scatterplot indicates that there are no obvious outliers. In the interaction, the slopes for individuals with knee OA and individuals with knee OA+ are both significant at p<.05. See Figure 2c for more details.

Figure B.2. Scatterplot of the interaction involving Level 2 neighborhood poverty, knee OA severity, and CES-D scores side-by-side the interaction, among adults with knee OA, n=656, from the T2 wave of the Johnston County Osteoarthritis Project, Johnston County, North Carolina, 2006-2011



Note: Scatterplot indicates that there are no obvious outliers. In the interaction, only the slope for individuals with severe knee OA is significant at p<.05. See Figure 2d for more details.

APPENDIX C. SUPPLEMENTARY TABLES FOR STUDY 1

Table C.1 Individual and neighborhood-level correlates of CES-D scores among individuals with knee OA, excluding individuals who live in block groups with less than or equal to 5 individuals, from the T2 wave of the Johnston County Osteoarthritis Project, Johnston County, North Carolina, 2006-2011, n=619

	Model 1 individual-level correlates		Model 2 (Model 1 + Neighborhood-level)	
Variable	Regression Coefficient (SE)	p-value	Regression Coefficient (SE)	p-value
Intercept	**1.78 (0.05)**	**p<0.001**	**1.76 (0.05)**	**p<.001**
Level 1 Fixed Effects				
African American (ref. White)	0.01 (0.04)	p=0.82	0.01 (0.04)	p=0.89
Female (ref. Male)	**0.23 (0.04)**	**p<.001**	**0.24 (0.04)**	**p<.001**
Age	**-0.005 (0.002)**	**p=0.03**	**-0.005 (0.002)**	**p=0.03**
BMI	0 (0.002)	p=0.90	0 (0.002)	p=0.85
Less than high school (ref. ≥high school)	**0.1 (0.04)**	**p=0.01**	**0.1 (0.04)**	**p=0.01**
Health insurance (ref. no insurance)	**-0.21 (0.08)**	**p=0.01**	**-0.21 (0.08)**	**p=0.01**
Number of comorbidities	**0.11 (0.01)**	**p<0.001**	**0.11 (0.01)**	**p<0.001**
Insufficiently active (ref. inactive)	**-0.25 (0.04)**	**p<0.001**	**-0.25 (0.04)**	**p<0.001**
Sufficiently active (ref. inactive)	**-0.59 (0.05)**	**p<0.001**	**-0.59 (0.05)**	**p<0.001**
Neighborhood social cohesion, [a]	**-0.04 (0.01)**	**p<0.001**	**-0.04 (0.01)**	**p<0.001**
Neighborhood access to physical activity and walking resources, [a]	**-0.02 (0)**	**p<0.001**	**-0.02 (0)**	**p<0.001**
Neighborhood perceived safety, [a]	-0.02 (0.01)	p=0.07	-0.02 (0.01)	p=0.08
Level 2 Fixed Effects				
Neighborhood disadvantage, [b]			-0.002 (0.01)	p=0.73
Neighborhood social cohesion, [b]			-0.07 (0.04)	p=0.10
Neighborhood access to physical activity and walking resources, [b]			-0.02 (0.02)	p=0.29
Neighborhood perceived safety, [b]			0.02 (0.06)	p=0.79
Model Fit				
Akaike information criterion (AIC)	5402.07		5405.88	
Bayesian information criterion (BIC)	5429.92		5441.68	

Notes
Boldface denotes a significant effect p<0.05
[a] variables were group mean centered to estimate pure within effects
[b] variables were grand mean centered to estimate pure between effects
Results were estimated using a poisson multilevel model. To interpret results, regression coefficients can be added or subtracted from the intercept and exponentiated.

Table C.2. Individual and neighborhood-level correlates of reported knee impact scores among individuals with knee OA, excluding individuals who live in block groups with less than or equal to 5 individuals, from the T2 wave of the Johnston County Osteoarthritis Project, Johnston County, North Carolina, 2006-2011, n=619

	Model 1 individual-level correlates		Model 2 (Model 1 + Neighborhood-level)	
Variable	Regression Coefficient (SE)	p-value	Regression Coefficient (SE)	p-value
Intercept	**75.75 (0.83)**	**p<0.001**	**75.75 (0.83)**	**p<0.001**
Level 1 Fixed Effects				
African American (ref. White)	3.28 (1.85)	p=0.08	4.59 (2)	p=0.02
Female (ref. Male)	-3.25 (1.83)	p=0.08	-3.29 (1.85)	p=0.08
Age	0.05 (0.11)	p=0.64	0.04 (0.11)	p=0.71
BMI	**-0.82 (0.12)**	**p<0.001**	**-0.81 (0.12)**	**p<0.001**
Less than high school (ref. ≥high school)	**-6.68 (2.06)**	**p=0.001**	**-6.78 (2.08)**	**p=0.001**
Health insurance (ref. no insurance)	**9.68 (4.45)**	**p=0.03**	**9.88 (4.45)**	**p=0.03**
Number of comorbidities	**-2.77 (0.66)**	**p<.001**	**-2.75 (0.66)**	**p<.001**
Insufficiently active (ref. inactive)	**5.17 (2.07)**	**p=0.01**	**4.6 (2.09)**	**p=0.03**
Sufficiently active (ref. inactive)	**5.71 (2.18)**	**p=0.009**	**5.58 (2.19)**	**p=0.01**
Neighborhood social cohesion, [a]	-0.14 (0.29)	p=0.62	-0.14 (0.29)	p=0.63
Neighborhood access to physical activity and walking resources, [a]	**0.41 (0.18)**	**p=0.03**	**0.42 (0.18)**	**p=0.02**
Neighborhood perceived safety, [a]	**1.06 (0.51)**	**p=0.04**	**1.05 (0.51)**	**p=0.04**
Level 2 Fixed Effects				
Neighborhood disadvantage, [b]			-0.11 (0.11)	p=0.30
Neighborhood social cohesion, [b]			1.52 (0.9)	p=0.09
Neighborhood access to physical activity and walking resources, [b]			0.16 (0.3)	p=0.58
Neighborhood perceived safety, [b]			-2.01 (1.5)	p=0.18
Model Fit				
Akaike information criterion (AIC)	5477.4		5470.2	
Bayesian information criterion (BIC)	5479.4		5474.2	

Notes
Boldface denotes a significant effect p<0.05
[a] variables were group mean centered to estimate pure within effects
[b] variables were grand mean centered to estimate pure between effects

Table C.3. Individual and neighborhood-level correlates of CES-D scores among individuals with knee OA, using multiple imputation, from the T2 wave of the Johnston County Osteoarthritis Project, Johnston County, North Carolina, 2006-2011, n=729

	Model 1 individual-level correlates		Model 2 (Model 1 + Neighborhood-level)	
Variable	Regression Coefficient (SE)	p-value	Regression Coefficient (SE)	p-value
Intercept	**1.78 (0.05)**	**p<0.001**	**1.78 (0.05)**	**p<0.001**
Level 1 Fixed Effects				
African American (ref. White)	-0.04 (0.04)	p=0.29	-0.04 (0.04)	p=0.28
Female (ref. Male)	**0.19 (0.04)**	**p<.001**	**0.19 (0.04)**	**p<.001**
Age	**-0.005 (0.002)**	**p=0.01**	**-0.005 (0.002)**	**p=0.01**
BMI	-0.002 (0.002)	p=0.50	-0.002 (0.002)	p=0.47
Less than high school (ref. ≥high school)	**0.09 (0.04)**	**p=0.02**	**0.09 (0.04)**	**p=0.01**
Health insurance (ref. no insurance)	**-0.31 (0.07)**	**p<0.001**	**-0.31 (0.07)**	**p<0.001**
Number of comorbidities	**0.12 (0.01)**	**p<0.001**	**0.12 (0.01)**	**p<0.001**
Insufficiently active (ref. inactive)	**-0.26 (0.04)**	**p<0.001**	**-0.25 (0.04)**	**p<0.001**
Sufficiently active (ref. inactive)	**-0.55 (0.04)**	**p<0.001**	**-0.54 (0.04)**	**p<0.001**
Neighborhood social cohesion, [a]	**-0.03 (0.01)**	**p<0.001**	**-0.03 (0.01)**	**p<0.001**
Neighborhood access to physical activity and walking resources,[a]	**-0.03 (0.003)**	**p<0.001**	**-0.03 (0.003)**	**p<0.001**
Neighborhood perceived safety,[a]	-0.02 (0.01)	p=0.06	-0.02 (0.01)	p=0.06
Level 2 Fixed Effects				
Neighborhood disadvantage,[b]			-0.03 (0.01)	p=0.62
Neighborhood social cohesion,[b]			**-0.1 (0.03)**	**p=0.002**
Neighborhood access to physical activity and walking resources,[b]			0.01 (0.01)	p=0.53
Neighborhood perceived safety,[b]			0.1 (0.05)	p=0.07
Model Fit				
Akaike information criterion (AIC)	6302.32		6300.80	
Bayesian information criterion (BIC)	6336.68		6344.98	

Notes
Boldface denotes a significant effect p<0.05
[a] variables were group mean centered to estimate pure within effects
[b] variables were grand mean centered to estimate pure between effects
Results were estimated using a multilevel poisson model. To interpret results, regression coefficients can be added or subtracted from the intercept and exponentiated.

Table C.4. Individual and neighborhood-level correlates of reported knee impact scores among individuals with knee OA, using multiple imputation, from the T2 wave of the Johnston County Osteoarthritis Project, Johnston County, North Carolina, 2006-2011, n=729

	Model 1 individual-level correlates		Model 2 (Model 1 + Neighborhood-level)	
Variable	Regression Coefficient (SE)	p-value	Regression Coefficient (SE)	p-value
Intercept	75.54 (0.77)	**p<0.001**	75.54 (0.77)	**p<0.001**
Level 1 Fixed Effects				
African American (ref. White)	1.98 (1.72)	p=0.25	3.15 (1.85)	p=0.09
Female (ref. Male)	**-3.83 (1.72)**	**p=0.03**	**-4.07 (1.73)**	**p=0.02**
Age	0.05 (0.1)	p=0.59	0.04 (0.1)	p=0.68
BMI	**-0.83 (0.11)**	**p<0.001**	**-0.81 (0.11)**	**p<0.001**
Less than high school (ref. ≥high school)	**-5.47 (1.9)**	**p=0.004**	**-5.67 (1.91)**	**p=0.003**
Health insurance (ref. no insurance)	1.11 (3.59)	p=0.76	1.19 (3.59)	p=0.74
Number of comorbidities	-3.01 (0.62)	**p<0.001**	-2.99 (0.62)	**p<0.001**
Insufficiently active (ref. inactive)	**6.85 (1.93)**	**p=0.004**	**6.35 (1.94)**	**p=0.001**
Sufficiently active (ref. inactive)	**6.07 (2.03)**	**p=0.003**	**5.92 (2.04)**	**p=0.004**
Neighborhood social cohesion, [a]	-0.04 (0.28)	p=0.88	-0.03 (0.27)	p=0.91
Neighborhood access to physical activity and walking resources,[a]	**0.44 (0.17)**	**p=0.01**	**0.44 (0.17)**	**p=0.009**
Neighborhood perceived safety,[a]	0.85 (0.48)	p=0.08	0.82 (0.48)	p=0.09
Level 2 Fixed Effects				
Neighborhood disadvantage,[b]			-0.1 (0.09)	p=0.30
Neighborhood social cohesion,[b]			1.54 (0.82)	p=0.06
Neighborhood access to physical activity and walking resources,[b]			0.35 (0.25)	p=0.17
Neighborhood perceived safety,[b]			-2.19 (1.27)	p=0.09
Model Fit				
Akaike information criterion (AIC)	6472.1		6464.1	
Bayesian information criterion (BIC)	6474.5		6468.5	

Notes
Boldface denotes a significant effect p<0.05
[a] variables were group mean centered to estimate pure within effects
[b] variables were grand mean centered to estimate pure between effects

Table C.5. Individual and neighborhood-level correlates of CES-D scores, by somatic and non-somatic items, among individuals with knee OA, from the T2 wave of the Johnston County Osteoarthritis Project, Johnston County, North Carolina, 2006-2011, n=654

	Somatic items		Non-somatic items	
Variable	Regression Coefficient (SE)	p-value	Regression Coefficient (SE)	p-value
Intercept	**1.09 (0.04)**	**p<0.001**	**1.01 (0.07)**	**p<0.001**
Level 1 Fixed Effects				
African American (ref. White)	-0.09 (0.06)	p=0.12	0.11 (0.06)	p=0.08
Female (ref. Male)	**0.29 (0.05)**	**p<0.001**	**0.2 (0.05)**	**p<.001**
Age	0.001 (0.003)	p=0.74	-0.01 (0.003)	p=0.70
BMI	0.00 (0.003)	p=0.95	-0.001 (0.003)	p=0.90
Less than high school (ref. ≥high school)	0.09 (0.05)	p=0.11	0.09 (0.05)	p=0.11
Health insurance (ref. no insurance)	-0.08 (0.12)	p=0.50	-0.24 (0.11)	p=0.50
Number of comorbidities	**0.11 (0.02)**	**p<.001**	**0.11 (0.02)**	**p<.001**
Insufficiently active (ref. inactive)	**-0.25 (0.05)**	**p<.001**	**-0.3 (0.05)**	**p<.001**
Sufficiently active (ref. inactive)	**-0.46 (0.06)**	**p<.001**	**-0.72 (0.07)**	**p<.001**
Neighborhood social cohesion, [a]	**-0.03 (0.01)**	**p=0.002**	**-0.06 (0.01)**	**p<.001**
Neighborhood access to physical activity and walking resources,[a]	**-0.03 (0)**	**p<.001**	**-0.02 (0)**	**p<.001**
Neighborhood perceived safety,[a]	-0.02 (0.01)	p=0.21	-0.01 (0.01)	p=0.42
Level 2 Fixed Effects				
Neighborhood disadvantage,[b]	-0.005 (0.005)	p=0.35	-0.005 (0.005)	p=0.53
Neighborhood social cohesion,[b]	-0.05 (0.03)	p=0.07	-0.08 (0.04)	p=0.05
Neighborhood access to physical activity and walking resources,[b]	-0.01 (0.01)	p=0.27	0.01 (0.02)	p=0.62
Neighborhood perceived safety,[b]	0.07 (0.05)	p=0.14	0.002 (0.07)	p=0.98
Model Fit				
Akaike information criterion (AIC)	3469.52		4253.67	
Bayesian information criterion (BIC)	3513.28		4297.42	

Notes
Boldface denotes a significant effect p<0.05
[a] variables were group mean centered to estimate pure within effects
[b] variables were grand mean centered to estimate pure between effects
Results were estimated using a poisson multilevel model. To interpret results, regression coefficients can be added or subtracted from the intercept and exponentiated.

APPENDIX D. BASELINE PARTICIPANT CHARACTERISTICS ANALYSIS FOR STUDY 1

Table D.1. Baseline characteristics for participants included and not included in T2 analyses and the T2 wave for Study 1, from the Johnston County Osteoarthritis Project, Johnston County, North Carolina, 2006-2011

	Baseline characteristics for participants not included in T2 analyses N (%) or N (mean)	Baseline characteristics for participants included in T2 analyses N (%) or N (mean)	P-value	Baseline characteristics for participants not included in T2 wave N (%) or N (mean)	Baseline characteristics for participants included in T2 wave N (%) or N (mean)	P-value
Characteristic						
Age, years, mean	1008 (57.1)	656 (59.9)	p<.0001	2673 (62.7)	1664 (58.2)	p<.0001
Gender						
Male	329 (32.6)	215 (32.8)	p=0.95	1044 (39.1)	544 (32.7)	p<.0001
Female	679 (67.4)	441 (67.2)		1629 (60.9)	1120 (67.3)	
Race						
White	718 (71.2)	432 (65.9)	p=0.02	1671 (62.5)	1150 (69.1)	p<.0001
Black or African American	290 (28.8)	224 (34.2)		1002 (37.5)	514 (30.9)	
Education						
≥ High school	808 (80.6)	486 (74.4)	p=0.003	1479 (55.6)	1294 (78.1)	p<.0001
< High school	195 (19.4)	167 (25.6)		1183 (44.4)	362 (21.9)	
Health insurance						
No	50 (5.1)	31 (4.9)	p=0.84	146 (5.9)	81 (5.0)	p=0.22
Yes	933 (94.9)	607 (95.1)		2332 (94.1)	1540 (95.0)	
BMI						
<30	642 (65.6)	314 (48.5)	p<.0001	1571 (61.7)	956 (58.2)	p=0.03
≥30	352 (35.4)	334 (51.5)		976 (38.3)	686 (41.8)	
Number of comorbidities	1008 (0.97)	656 (1.1)	p=0.01	2670 (1.3)	1664 (1.0)	p<.0001
Occupation						
High SES job	518 (55.2)	296 (48.2)	p=0.007	910 (38.2)	814 (52.4)	p<.0001
Low SES job	421 (44.8)	318 (51.8)		1472 (61.8)	739 (47.6)	
CES-D scores (range 0-60), mean	1001 (6.4)	649 (6.2)	p=0.64	2620 (7.6)	1650 (6.3)	p<.0001
Neighborhood poverty	974 (18.2)	632 (10.7)	p=0.14	2556 (20.4)	1606 (18.5)	p<.0001

Table D.2. Baseline characteristics for participants included and not included in T3 analyses and the T3 wave for Study 1, from the Johnston County Osteoarthritis Project, Johnston County, North Carolina

	Baseline characteristics for participants not included in T3 analyses N (%) or N (mean)	Baseline characteristics for participants included in T3 analyses N (%) or N (mean)	P-value	Baseline characteristics for participants not included in T3 wave N (%) or N (mean)	Baseline characteristics for participants included in T3 wave N (%) or N (mean)	P-value
Characteristic						
Age, years, mean	459 (55.0)	434 (56.6)	p=0.002	3444 (62.3)	893 (55.8)	p<.0001
Gender						
Male	139 (30.3)	148 (34.1)	p=0.22	1301 (37.8)	287 (32.1)	p=0.002
Female	320 (69.7)	286 (65.9)		2143 (62.2)	606 (67.9)	
Race						
White	308 (67.1)	288 (66.4)	p=0.81	2225 (64.6)	596 (66.7)	p=0.23
Black or African American	151 (32.9)	146 (33.6)		1219 (35.4)	297 (33.3)	
Education						
≥ High school	396 (86.8)	366 (84.5)	p=0.32	2011 (58.7)	762 (85.7)	p<.0001
< High school	60 (13.2)	67 (15.5)		1418 (41.4)	127 (14.3)	
Health insurance						
No	25 (5.6)	32 (7.6)	p=0.24	170 (5.3)	57 (6.5)	p=0.15
Yes	424 (94.4)	392 (92.5)		3056 (94.7)	816 (93.5)	
BMI						
<30	290 (64.0)	231 (53.5)	p=0.001	2006 (60.7)	521 (58.9)	p=0.32
≥30	163 (36.0)	201 (46.5)		1298 (39.3)	364 (41.1)	
Number of comorbidities	459 (0.92)	434 (0.96)	p=0.55	3441 (1.3)	893 (0.9)	p<.0001
Occupation						
High SES job	249 (57.6)	224 (54.6)	p=0.38	1251 (40.5)	473 (56.2)	p<.0001
Low SES job	183 (42.4)	186 (45.4)		1842 (59.6)	369 (43.8)	
CES-D scores (range 0-60), mean	455 (6.7)	427 (6.2)	p=0.35	3388 (7.3)	882 (6.4)	p=0.008
Neighborhood poverty	439 (18.3)	422 (18.2)	p=0.89	3301 (20.1)	861 (18.3)	p<.0001

APPENDIX E. SUPPLEMENTARY TABLES FOR STUDY 2

Table E.1. Results of the structural equation model for adults with at least one chronic disease, from the T2 wave of the Johnston County Osteoarthritis Project, Johnston County, North Carolina, 2006-2011, n=1482

Exogenous variables	Endogenous variables				
	Perceived neighborhood environment	Physical activity	Social support	Perceived individual control	Depressive symptoms
Poverty	B= -0.16***	B = -0.05	--	--	B= -0.03
Perceived neighborhood environment	--	B= 0.11*	B= 0.40***	B= 0.60***	B= -0.01
Physical activity	--	--	--	--	B= -0.17***
Social support	--	--	--	--	B= -0.49***
Perceived individual control				--	B= -0.14**

Notes
All relationships controlled for race, gender, BMI, education, health insurance status, number of comorbidities, age, and knee OA status. All relationships also controlled for clustering using type=complex. Beta coefficients are standardized.

* p<.05, ** p<.01, *** p<.001

Model Fit:
Chi-Square value (p-value): 1663.95, p<.001); RMSEA: 0.02 (95% CI: 0.02, 0.02); CFI: 0.96; TLI: 0.96

Indirect Effects (only significant)
- Perceived neighborhood environment → Physical activity → Reported depressive symptoms: B= -0.02, p=0.003
- Perceived neighborhood environment → Social support → Reported depressive symptoms: B= -0.20, p<0.001
- Perceived neighborhood environment → Perceived individual control → B= -0.08, p=0.002
- Poverty → perceived neighborhood environment → Physical activity → Reported depressive symptoms: B=0.003, p=0.006
- Poverty → perceived neighborhood environment → Physical activity: B=-0.02, p=0.004

Table E.2. Results of the structural equation model, for somatic and non-somatic depressive symptoms, for adults from the T2 wave of the Johnston County Osteoarthritis Project, Johnston County, North Carolina, 2006-2011, n=1558

Exogenous variables	Endogenous variables					
	Perceived neighborhood environment	Physical activity	Social support	Perceived individual control	Depressive symptoms (somatic)	Depressive symptoms (non-somatic)
Poverty	B= -0.16***	B = -0.06*	--	--	B= -0.06	B= 0.01
Perceived neighborhood environment	--	B= 0.09**	B= 0.41***	B= 0.61***	B= -0.02	B= 0.01
Physical activity	--	--	--	--	B= -0.12***	B= -0.13***
Social support	--	--	--	--	B= -0.37***	B= -0.50***
Perceived individual control				--	B= -0.08	B= -0.13*

Notes
All relationships controlled for race, gender, BMI, education, health insurance status, number of comorbidities, age, and knee OA status. All relationships also controlled for clustering using type=complex Correlation among somatic and non-somatic symptoms was 0.83. Beta coefficients are standardized.

* p<.05, ** p<.01, *** p<.001

Model Fit:
Chi-Square value (p-value): 1642.53, p<.001); RMSEA: 0.02 (95% CI: 0.02, 0.02); CFI: 0.96; TLI: 0.96

Indirect Effects (only significant)

- Perceived neighborhood environment → Physical activity → Reported depressive symptoms (somatic): B= -0.01, p=0.003
- Perceived neighborhood environment → Physical activity → Reported depressive symptoms (non-somatic): B= -0.01, p=0.01
- Perceived neighborhood environment → Social support → Reported depressive symptoms (somatic): B= -0.15, p<0.001
- Perceived neighborhood environment → Social support → Reported depressive symptoms (non-somatic): B= -0.20, p<0.001
- Perceived neighborhood environment → Perceived individual control → Reported depressive symptoms (non-somatic) B= -0.08, p=0.02
- Poverty → perceived neighborhood environment → Physical activity → Reported depressive symptoms (somatic): B=0.001, p=0.02
- Poverty → perceived neighborhood environment → Physical activity → Reported depressive symptoms (non-somatic): B=0.002, p=0.02

APPENDIX F. BASELINE PARTICIPANT CHARACTERISTICS ANALYSIS FOR STUDY 2

Table F.1. Baseline characteristics for participants included and not included in T2 analyses for Study 2, from the Johnston County Osteoarthritis Project, Johnston County, North Carolina, 2006-2011

	Baseline characteristics for participants not included in T2 analyses N (%) or N (mean)	Baseline characteristics for participants included in T2 analyses N (%) or N (mean)	P-value	Baseline characteristics for participants not included in T2 wave N (%) or N (mean)	Baseline characteristics for participants included in T2 wave N (%) or N (mean)	P-value
Characteristic						
Age, years, mean	106 (60.5)	1558 (58.0)	p=0.006	2673 (62.7)	1664 (58.2)	p<.0001
Gender						
Male	28 (26.4)	516 (33.1)	p=0.15	1044 (39.1)	544 (32.7)	p<.0001
Female	78 (73.6)	1042 (66.9)		1629 (60.9)	1120 (67.3)	
Race						
White	68 (64.2)	1082 (69.5)	p=0.25	1671 (62.5)	1150 (69.1)	p<.0001
Black or African American	38 (35.9)	476 (30.6)		1002 (37.5)	514 (30.9)	
Education						
≥ High school	69 (68.3)	1225 (78.8)	p=0.01	1479 (55.6)	1294 (78.1)	p<.0001
< High school	32 (31.7)	330 (21.2)		1183 (44.4)	362 (21.9)	
Health insurance						
No	4 (3.9)	77 (5.1)	p=0.59	146 (5.9)	81 (5.0)	p=0.22
Yes	99 (96.1)	1441 (94.9)		2332 (94.1)	1540 (95.0)	
BMI						
<30	43 (41.4)	913 (59.4)	p=0.003	1571 (61.7)	956 (58.2)	p=0.03
≥30	61 (58.7)	625 (40.6)		976 (38.3)	686 (41.8)	
Number of comorbidities	106 (1.1)	1558 (1.0)	p=0.38	2670 (1.3)	1664 (1.0)	p<.0001
Occupation						
High SES job	40 (42.6)	774 (53.1)	p=0.05	910 (38.2)	814 (52.4)	p<.0001
Low SES job	54 (57.5)	685 (47.0)		1472 (61.8)	739 (47.6)	
CES-D scores (range 0-60), mean	105 (7.2)	1545 (6.3)	p=0.24	2620 (7.6)	1650 (6.3)	p<.0001
Neighborhood poverty	100 (18.9)	1506 (18.4)	p=0.63	2556 (20.4)	1606 (18.5)	p<.0001

REFERENCES

1. Ward BW, Schiller JS, Goodman RA. Peer reviewed: Multiple chronic conditions among us adults: A 2012 update. *Prev Chronic Dis.* 2014;11.

2. Buttorff C, Ruder T, Bauman M. *Multiple Chronic Conditions in the United States.* Santa Monica, CA: RAND Corporation; 2017.

3. Centers for Disease Control and Prevention. Percent of U.S. adults 55 and over with chronic conditions. 2009. Available at: https://www.cdc.gov/nchs/health_policy/adult_chronic_conditions.htm. Accessed October 18, 2017.

4. Gerteis J, Izrael D, Deitz D, et al. Multiple chronic conditions chartbook. Rockville (MD): Agency for Healthcare Research and Quality; 2014. AHRQ Publications; 2014.

5. Institute of Medicine. Living Well With Chronic Illness: A Call for Public Health Action. The National Academies Press Washington, DC; 2012.

6. Bauer UE, Briss PA, Goodman RA, Bowman BA. Prevention of chronic disease in the 21st century: elimination of the leading preventable causes of premature death and disability in the USA. *The Lancet.* 2014;384(9937):45-52.

7. Qin J, Theis KA, Barbour KE, Helmick CG, Baker NA, Brady TJ. Impact of arthritis and multiple chronic conditions on selected life domains - United States, 2013. *MMWR Morb Mortal Wkly Rep.* Jun 05 2015;64(21):578-582.

8. Barbour KE, Helmick CG, Boring M, Brady TJ. Vital Signs: Prevalence of Doctor-Diagnosed Arthritis and Arthritis-Attributable Activity Limitation - United States, 2013-2015. *MMWR Morb Mortal Wkly Rep.* Mar 10 2017;66(9):246-253.

9. National Institute of Arthritis and Musculoskeletal and Skin Diseases. Osteoporosis and Arthritis: Two Common But Different Conditions. 2015. Available at: http://www.niams.nih.gov/Health_Info/Bone/Osteoporosis/Conditions_Behaviors/osteoporosis_arthritis.asp. Accessed March 8, 2016.

10. Litwic A, Edwards MH, Dennison EM, Cooper C. Epidemiology and burden of osteoarthritis. *Br Med Bull.* 2013:lds038.

11. Allen KD, Golightly YM. Epidemiology of osteoarthritis: state of the evidence. *Curr Opin Rheumatol.* 2015;27(3):276.

12. Cleveland RJ, Luong ML, Knight JB, et al. Independent associations of socioeconomic factors with disability and pain in adults with knee osteoarthritis. *BMC Musculoskelet Disord.* 2013;14:297.

13. Cleveland RJ, Schwartz TA, Prizer LP, et al. Associations of educational attainment, occupation, and community poverty with hip osteoarthritis. *Arthritis Care Res (Hoboken).* Jun 2013;65(6):954-961.

14. Callahan LF, Cleveland RJ, Shreffler J, et al. Associations of educational attainment, occupation and community poverty with knee osteoarthritis in the Johnston County (North Carolina) osteoarthritis project. *Arthritis Res Ther.* 2011;13(5):R169.

15. Jordan JM, Helmick CG, Renner JB, et al. Prevalence of knee symptoms and radiographic and symptomatic knee osteoarthritis in African Americans and Caucasians: the Johnston County Osteoarthritis Project. *J Rheumatol.* Jan 2007;34(1):172-180.

16. Neogi T, Zhang Y. Epidemiology of osteoarthritis. *Rheumatic Disease Clinics of North America.* 2013;39(1):1-19.

17. National Institute of Arthritis and Musculoskeletal and Skin Diseases. What Is Osteoarthritis? 2014. Available at: http://www.niams.nih.gov/health_info/Osteoarthritis/osteoarthritis_ff.asp. Accessed March 8, 2016.

18. Blagojevic M, Jinks C, Jeffery A, Jordan KP. Risk factors for onset of osteoarthritis of the knee in older adults: a systematic review and meta-analysis. *Osteoarthritis Cartilage.* Jan 2010;18(1):24-33.

19. Luong M-LN, Cleveland RJ, Nyrop KA, Callahan LF. Social determinants and osteoarthritis outcomes. *Aging health.* 2012;8(4):413-437.

20. Brennan SL, Turrell G. Neighborhood disadvantage, individual-level socioeconomic position, and self-reported chronic arthritis: a cross-sectional multilevel study. *Arthritis Care Res (Hoboken).* May 2012;64(5):721-728.

21. Callahan LF, Martin KR, Shreffler J, et al. Independent and combined influence of homeownership, occupation, education, income, and community poverty on physical health in persons with arthritis. *Arthritis Care Res (Hoboken).* 2011;63(5):643-653.

22. Callahan LF, Shreffler J, Mielenz T, et al. Arthritis in the family practice setting: associations with education and community poverty. *Arthritis Rheum.* Jul 15 2008;59(7):1002-1008.

23. Callahan LF, Shreffler J, Mielenz TJ, et al. Health-related quality of life in adults from 17 family practice clinics in North Carolina. *Prev Chronic Dis.* Jan 2009;6(1):A05.

24. Canizares M, Power JD, Perruccio AV, Badley EM. Association of regional racial/cultural context and socioeconomic status with arthritis in the population: a multilevel analysis. *Arthritis Rheum.* Mar 15 2008;59(3):399-407.

25. Martin KR, Shreffler J, Schoster B, Callahan LF. Associations of perceived neighborhood environment on health status outcomes in persons with arthritis. *Arthritis Care Res (Hoboken).* Nov 2010;62(11):1602-1611.

26. Mingo CA, Martin KR, Shreffler J, Schoster B, Callahan LF. Individual and Community Socioeconomic Status: Impact on Mental Health in Individuals with Arthritis. *Arthritis.* 2014;2014.

27. Knight JB, Callahan LF, Luong ML, et al. The association of disability and pain with individual and community socioeconomic status in people with hip osteoarthritis. *Open Rheumatol J.* 2011;5:51-58.

28. Brennan SL, Stanford T, Wluka AE, et al. Cross-sectional analysis of association between socioeconomic status and utilization of primary total hip joint replacements 2006-7: Australian Orthopaedic Association National Joint Replacement Registry. *BMC Musculoskelet Disord.* 2012;13:63.

29. Dixon T, Urquhart DM, Berry P, et al. Variation in rates of hip and knee joint replacement in Australia based on socio-economic status, geographical locality, birthplace and indigenous status. *ANZ J Surg.* Jan 2011;81(1-2):26-31.

30. Harrison MJ, Farragher TM, Clarke AM, Manning SC, Bunn DK, Symmons DP. Association of functional outcome with both personal- and area-level socioeconomic inequalities in patients with inflammatory polyarthritis. *Arthritis Rheum.* Oct 15 2009;61(10):1297-1304.

31. Neuburger J, Hutchings A, Black N, van der Meulen JH. Socioeconomic differences in patient-reported outcomes after a hip or knee replacement in the English National Health Service. *J Public Health (Oxf).* Mar 2013;35(1):115-124.

32. White DK, Jette AM, Felson DT, et al. Are features of the neighborhood environment associated with disability in older adults? *Disabil Rehabil.* 2010;32(8):639-645.

33. Keysor JJ, Jette AM, LaValley MP, et al. Community environmental factors are associated with disability in older adults with functional limitations: the MOST study. *J Gerontol A Biol Sci Med Sci.* Apr 2010;65(4):393-399.

34. Diez Roux AV, Mair C. Neighborhoods and health. *Ann N Y Acad Sci.* Feb 2010;1186:125-145.

35. Richardson R, Westley T, Gariepy G, Austin N, Nandi A. Neighborhood socioeconomic conditions and depression: a systematic review and meta-analysis. *Soc Psychiatry Psychiatr Epidemiol.* Nov 2015;50(11):1641-1656.

36. Kim D. Blues from the neighborhood? Neighborhood characteristics and depression. *Epidemiol Rev.* 2008;30:101-117.

37. Mair C, Diez Roux AV, Galea S. Are neighbourhood characteristics associated with depressive symptoms? A review of evidence. *J Epidemiol Community Health.* Nov 2008;62(11):940-946, 948 p following 946.

38. Evans GW. The built environment and mental health. *J Urban Health.* Dec 2003;80(4):536-555.

39. Truong KD, Ma S. A systematic review of relations between neighborhoods and mental health. *J Ment Health Policy Econ.* Sep 2006;9(3):137-154.

40. Gong Y, Palmer S, Gallacher J, Marsden T, Fone D. A systematic review of the relationship between objective measurements of the urban environment and psychological distress. *Environ Int.* Nov 2016;96:48-57.

41. Glass TA, Balfour JL. Neighborhoods, aging, and functional limitations. In: Kawachi I, Berkman L, eds. *Neighborhoods and health*. Oxford, UK: Oxford University Press; 2003:303-334.

42. Braveman P, Egerter S, Williams DR. The social determinants of health: coming of age. *Annu Rev Public Health.* 2011;32:381-398.

43. Shaw CR, McKay HD. Juvenile delinquency and urban areas. *Chicago.* 1996;19421:19692.

44. Brown AF, Ettner SL, Piette J, et al. Socioeconomic position and health among persons with diabetes mellitus: a conceptual framework and review of the literature. *Epidemiol Rev.* 2004;26:63-77.

45. Carpiano RM. Toward a neighborhood resource-based theory of social capital for health: can Bourdieu and sociology help? *Soc Sci Med.* Jan 2006;62(1):165-175.

46. Blair A, Ross NA, Gariepy G, Schmitz N. How do neighborhoods affect depression outcomes? A realist review and a call for the examination of causal pathways. *Soc Psychiatry Psychiatr Epidemiol.* Jun 2014;49(6):873-887.

47. Manini TM. Mobility decline in old age: A time to intervene. *Exerc Sport Sci Rev.* Jan 2013;41(1):2.

48. Charles S, Carstensen LL. Social and Emotional Aging. *Annu Rev Psychol.* 2010;61:383-409.

49. Yen IH, Michael YL, Perdue L. Neighborhood environment in studies of health of older adults: a systematic review. *Am J Prev Med.* Nov 2009;37(5):455-463.

50. Pickett KE, Pearl M. Multilevel analyses of neighbourhood socioeconomic context and health outcomes: a critical review. *J Epidemiol Community Health.* 2001;55(2):111-122.

51. Black JL, Macinko J. Neighborhoods and obesity. *Nutr Rev.* Jan 2008;66(1):2-20.

52. Ford PB, Dzewaltowski DA. Disparities in obesity prevalence due to variation in the retail food environment: three testable hypotheses. *Nutr Rev.* Apr 2008;66(4):216-228.

53. Papas MA, Alberg AJ, Ewing R, Helzlsouer KJ, Gary TL, Klassen AC. The built environment and obesity. *Epidemiol Rev.* 2007;29:129-143.

54. Hajna S, Ross NA, Brazeau A-S, Bélisle P, Joseph L, Dasgupta K. Associations between neighbourhood walkability and daily steps in adults: a systematic review and meta-analysis. *BMC Public Health.* 2015;15(1):768.

55. Foster S, Giles-Corti B. The built environment, neighborhood crime and constrained physical activity: an exploration of inconsistent findings. *Prev Med.* Sep 2008;47(3):241-251.

56. Humpel N, Marshall AL, Leslie E, Bauman A, Owen N. Changes in neighborhood walking are related to changes in perceptions of environmental attributes. *Ann Behav Med.* Feb 2004;27(1):60-67.

57. Owen N, Humpel N, Leslie E, Bauman A, Sallis JF. Understanding environmental influences on walking; Review and research agenda. *Am J Prev Med.* Jul 2004;27(1):67-76.

58. Saelens BE, Handy SL. Built environment correlates of walking: a review. *Med Sci Sports Exerc.* Jul 2008;40(7 Suppl):S550-566.

59. Hosseini F, Adha N, Zainol R, Isahak M, Nemati N. Neighborhood-Level Stress and Circadian Cortisol: A Systematic Review and Meta-Analysis. *Iran J Public Health.* Oct 2014;43(10):1324-1334.

60. Larson NI, Story MT, Nelson MC. Neighborhood environments: disparities in access to healthy foods in the U.S. *Am J Prev Med.* Jan 2009;36(1):74-81.

61. Koh HK, Piotrowski JJ, Kumanyika S, Fielding JE. Healthy people: a 2020 vision for the social determinants approach. *Health Educ Behav.* Dec 2011;38(6):551-557.

62. Hill J, Nielsen M, Fox MH. Understanding the social factors that contribute to diabetes: a means to informing health care and social policies for the chronically ill. *The Permanente Journal.* 2013;17(2):67.

63. Stellefson M, Dipnarine K, Stopka C. Peer Reviewed: The Chronic Care Model and Diabetes Management in US Primary Care Settings: A Systematic Review. *Prev Chronic Dis.* 2013;10.

64. Golden SD, Earp JA. Social ecological approaches to individuals and their contexts: twenty years of health education & behavior health promotion interventions. *Health Educ Behav.* Jun 2012;39(3):364-372.

65. Auchincloss AH, Mujahid MS, Shen M, Michos ED, Whitt-Glover MC, Diez Roux AV. Neighborhood health-promoting resources and obesity risk (the multi-ethnic study of atherosclerosis). *Obesity (Silver Spring).* Mar 2013;21(3):621-628.

66. Ludwig J, Sanbonmatsu L, Gennetian L, et al. Neighborhoods, obesity, and diabetes--a randomized social experiment. *N Engl J Med.* Oct 20 2011;365(16):1509-1519.

67. Semenza JC, Krishnasamy PV. Design of a health-promoting neighborhood intervention. *Health Promot Pract.* Jul 2007;8(3):243-256.

68. Jetten J, Haslam C, Haslam SA, eds. *The Social Cure: Identity, Health and Well-Being.* New York: Psychology Press; 2012.

69. Coghill CL, Valaitis RK, Eyles JD. Built environment interventions aimed at improving physical activity levels in rural Ontario health units: a descriptive qualitative study. *BMC Public Health.* 2015;15.

70. Barnard DK, Hu W. The Population Health Approach: health GIS as a bridge from theory to practice. *Int J Health Geogr.* Oct 06 2005;4:23.

71. The Centers for Disease Control and Prevention and the Arthritis Foundation. A National Public Health Agenda for Osteoarthritis. 2010. Available at: http://www.cdc.gov/arthritis/docs/oaagenda.pdf. Accessed July 17, 2016.

72. Jacob K. Depression: a major public health problem in need of a multi-sectoral response. *Indian J Med Res.* Oct 2012;136(4):537-539.

73. Kim KW, Han JW, Cho HJ, et al. Association between comorbid depression and osteoarthritis symptom severity in patients with knee osteoarthritis. *J Bone Joint Surg Am.* Mar 16 2011;93(6):556-563.

74. Axford J, Butt A, Heron C, et al. Prevalence of anxiety and depression in osteoarthritis: use of the Hospital Anxiety and Depression Scale as a screening tool. *Clin Rheumatol.* 2010;29(11):1277-1283.

75. Somers TJ, Keefe FJ, Godiwala N, Hoyler GH. Psychosocial factors and the pain experience of osteoarthritis patients: new findings and new directions. *Curr Opin Rheumatol.* Sep 2009;21(5):501-506.

76. Rosemann T, Gensichen J, Sauer N, Laux G, Szecsenyi J. The impact of concomitant depression on quality of life and health service utilisation in patients with osteoarthritis. *Rheumatol Int.* Jul 2007;27(9):859-863.

77. Cubbin C, Egerter S, Braveman P, Pedregon V. Where we live matters for our health: Neighborhoods and health. 2008. Available at: http://www.rwjf.org/en/library/research/2011/05/neighborhoods-and-health-.html. Accessed March 20, 2016.

78. Centers for Disease Control and Prevention. Vital Signs telebriefing on heart disease and stroke deaths. 2013. Available at: http://www.cdc.gov/media/releases/2013/t0903-vs-heart-disease.html. Accessed March 20, 2016.

79. Haan M, Kaplan GA, Camacho T. Poverty and health. Prospective evidence from the Alameda County Study. *Am J Epidemiol.* Jun 1987;125(6):989-998.

80. Wen M, Browning CR, Cagney KA. Poverty, affluence, and income inequality: neighborhood economic structure and its implications for health. *Soc Sci Med.* Sep 2003;57(5):843-860.

81. Kawachi I, Berkman LF. Social Cohesion, Social Capital, and Health. In: Berkman LF, Kawachi I, Glymour M, eds. *Social epidemiology*. Second ed: Oxford University Press; 2014.

82. Weden MM, Carpiano RM, Robert SA. Subjective and objective neighborhood characteristics and adult health. *Soc Sci Med.* 2008;66(6):1256-1270.

83. van der Pas S, Schaap LA, Castell MV, et al. Availability and use of neighborhood resources by older people with osteoarthritis: Results from the European Project on OSteoArthritis. *Health Place.* Jan 2016;37:1-7.

84. Martin KR, Schoster B, Woodard J, Callahan LF. What community resources do older community-dwelling adults use to manage their osteoarthritis? A formative examination. *J Appl Gerontol.* Oct 1 2012;31(5):661-684.

85. Diez-Roux AV. Multilevel analysis in public health research. *Annu Rev Public Health.* 2000;21(1):171-192.

86. Thornton LE, Pearce JR, Kavanagh AM. Using Geographic Information Systems (GIS) to assess the role of the built environment in influencing obesity: a glossary. *Int J Behav Nutr Phys Act.* 2011;8:71.

87. Diez Roux AV. Neighborhoods and health: where are we and were do we go from here? *Rev Epidemiol Sante Publique.* Feb 2007;55(1):13-21.

88. Bowen NK, Guo S. *Structural equation modeling.* Oxford University Press; 2011.

89. Preacher KJ, Zhang Z, Zyphur MJ. Alternative methods for assessing mediation in multilevel data: The advantages of multilevel SEM. *Structural Equation Modeling.* 2011;18(2):161-182.

90. Browning CR, Cagney KA. Neighborhood structural disadvantage, collective efficacy, and self-rated physical health in an urban setting. *J Health Soc Behav.* 2002:383-399.

91. Brown AF, Ang A, Pebley AR. The relationship between neighborhood characteristics and self-rated health for adults with chronic conditions. *Am J Public Health.* May 2007;97(5):926-932.

92. Margaretten M, Barton J, Julian L, et al. Socioeconomic determinants of disability and depression in patients with rheumatoid arthritis. *Arthritis Care Res (Hoboken).* Feb 2011;63(2):240-246.

93. Pew Research Center. In a recovering market, homeownership rates are down sharply for blacks, young adults. 2016. Available at: http://www.pewsocialtrends.org/2016/12/15/in-a-recovering-market-homeownership-rates-are-down-sharply-for-blacks-young-adults/. Accessed October 18, 2017.

94. Berkman LF, Glass T. Social integration, social networks, social support, and health. *Social epidemiology.* 2000;1:137-173.

95. Kegler MC, Alcantara I, Haardorfer R, Gemma A, Ballard D, Gazmararian J. Rural Neighborhood Walkability: Implications for Assessment. *J Phys Act Health.* Jun 16 2015;12 Suppl 1:S40-45.

96. Kegler MC, Alcantara I, Veluswamy JK, Haardorfer R, Hotz JA, Glanz K. Results from an intervention to improve rural home food and physical activity environments. *Prog Community Health Partnersh.* Fall 2012;6(3):265-277.

97. Bennett KJ, Olatosi B, Probst JC. Health disparities: a rural-urban chartbook. *Health disparities: a rural-urban chartbook.* 2008.

98. Yousefian A, Hennessy E, Umstattd MR, et al. Development of the Rural Active Living Assessment Tools: measuring rural environments. *Prev Med.* Jan 2010;50 Suppl 1:S86-92.

99. Umstattd MR, Baller SL, Hennessy E, et al. Development of the Rural Active Living Perceived Environmental Support Scale (RALPESS). *J Phys Act Health.* Jul 2012;9(5):724-730.

100. Sullivan SM, Peters ES, Trapido EJ, Oral E, Scribner RA, Rung AL. Assessing mediation of behavioral and stress pathways in the association between neighborhood environments and obesity outcomes. *Prev Med Rep.* Dec 2016;4:248-255.

101. De Jesus M, Puleo E, Shelton RC, Emmons KM. Associations between Perceived Social Environment and Neighborhood Safety: Health Implications. *Health Place.* Sep 2010;16(5):1007-1013.

102. Rogers EM. The diffusion of innovations model. *Nato Asi Series D Behavioural And Social Sciences.* 1993;70:9-9.

103. Chuang YC, Chuang KY, Yang TH. Social cohesion matters in health. *Int J Equity Health.* 2013;12:87.

104. Harlow HF, Harlow M. Learning to love. *American Scientist* 1966;54:244-272.

105. Fisher EB, Coufal MM, Parada H, et al. Peer Support in health care and prevention: Cultural, organizational, and dissemination issues. *Annu Rev Public Health.* 2014;35:363-383.

106. Holt-Lunstad J, Smith TB, Layton JB. Social relationships and mortality risk: a meta-analytic review. *PLoS Med.* Jul 2010;7(7):e1000316.

107. Browning CR. The span of collective efficacy: Extending social disorganization theory to partner violence. *Journal of Marriage and Family.* 2002;64(4):833-850.

108. Institute of Medicine. The National Academies Collection: Reports funded by National Institutes of Health. In: Woolf SH, Aron L, eds. *U.S. Health in International Perspective: Shorter Lives, Poorer Health*. Washington (DC): National Academies Press (US) National Academy of Sciences.; 2013.

109. Drewnowski A, Aggarwal A, Tang W, et al. Obesity, diet quality, physical activity, and the built environment: the need for behavioral pathways. *BMC Public Health.* Nov 10 2016;16(1):1153.

110. Garfinkel-Castro A, Kim K, Hamidi S, Ewing R. Obesity and the built environment at different urban scales: examining the literature. *Nutr Rev.* Jan 2017;75(suppl 1):51-61.

111. Glanz K, Davis EL. Built environment assessment and interventions for obesity prevention: moving the field forward. *Am J Prev Med.* May 2015;48(5):613-614.

112. Xu Y, Wang F. Built environment and obesity by urbanicity in the U.S. *Health Place.* Jul 2015;34:19-29.

113. Allen KD, Helmick CG, Schwartz TA, DeVellis RF, Renner JB, Jordan JM. Racial differences in self-reported pain and function among individuals with radiographic hip and knee osteoarthritis: the Johnston County Osteoarthritis Project. *Osteoarthritis Cartilage.* 2009;17(9):1132-1136.

114. Allen KD, Chen JC, Callahan LF, et al. Racial differences in knee osteoarthritis pain: potential contribution of occupational and household tasks. *J Rheumatol.* Feb 2012;39(2):337-344.

115. Dieppe P, Basler HD, Chard J, et al. Knee replacement surgery for osteoarthritis: effectiveness, practice variations, indications and possible determinants of utilization. *Rheumatology (Oxford).* Jan 1999;38(1):73-83.

116. Do DP, Finch BK, Basurto-Davila R, Bird C, Escarce J, Lurie N. Does place explain racial health disparities? Quantifying the contribution of residential context to the Black/white health gap in the United States. *Soc Sci Med.* Oct 2008;67(8):1258-1268.

117. Puenpatom RA, Victor TW. Increased prevalence of metabolic syndrome in individuals with osteoarthritis: an analysis of NHANES III data. *Postgrad Med.* 2009;121(6):9-20.

118. Murphy L, Helmick CG. The impact of osteoarthritis in the United States: a population-health perspective. *AJN The American Journal of Nursing.* 2012;112(3):S13-S19.

119. Rachele JN, Giles-Corti B, Turrell G. Neighbourhood disadvantage and self-reported type 2 diabetes, heart disease and comorbidity: a cross-sectional multilevel study. *Ann Epidemiol.* Feb 2016;26(2):146-150.

120. Jarvholm B, Lewold S, Malchau H, Vingard E. Age, bodyweight, smoking habits and the risk of severe osteoarthritis in the hip and knee in men. *Eur J Epidemiol.* 2005;20(6):537-542.

121. Apold H, Meyer HE, Nordsletten L, Furnes O, Baste V, Flugsrud GB. Risk factors for knee replacement due to primary osteoarthritis, a population based, prospective cohort study of 315,495 individuals. *BMC Musculoskelet Disord.* 2014;15:217.

122. Dinas PC, Koutedakis Y, Flouris AD. Effects of exercise and physical activity on depression. *Ir J Med Sci.* Jun 2011;180(2):319-325.

123. Mammen G, Faulkner G. Physical activity and the prevention of depression: a systematic review of prospective studies. *Am J Prev Med.* Nov 2013;45(5):649-657.

124. Stubbs B, Aluko Y, Myint PK, Smith TO. Prevalence of depressive symptoms and anxiety in osteoarthritis: a systematic review and meta-analysis. *Age Ageing.* Mar 2016;45(2):228-235.

125. Lin EH. Depression and osteoarthritis. *Am J Med.* Nov 2008;121(11 Suppl 2):S16-19.

126. Ibrahim SA, Siminoff LA, Burant CJ, Kwoh CK. Understanding ethnic differences in the utilization of joint replacement for osteoarthritis: the role of patient-level factors. *Med Care.* Jan 2002;40(1 Suppl):I44-51.

127. Dominick KL, Bosworth HB, Dudley TK, Waters SJ, Campbell LC, Keefe FJ. Patterns of opioid analgesic prescription among patients with osteoarthritis. *J Pain Palliat Care Pharmacother.* 2004;18(1):31-46.

128. Dominick KL, Bosworth HB, Jeffreys AS, Grambow SC, Oddone EZ, Horner RD. Racial/ethnic variations in non-steroidal anti-inflammatory drug (NSAID) use among patients with osteoarthritis. *Pharmacoepidemiol Drug Saf.* Oct 2004;13(10):683-694.

129. Jordan JM. An Ongoing Assessment of Osteoarthritis in African Americans and Caucasians in North Carolina: The Johnston County Osteoarthritis Project. *Trans Am Clin Climatol Assoc.* 2015;126:77-86.

130. U.S. Census Bureau. 2010 Census Urban and Rural Classification and Urban Area Criteria. 2015. Available at: https://www.census.gov/geo/reference/ua/urban-rural-2010.html. Accessed October 17, 2017.

131. Radloff LS. The use of the Center for Epidemiologic Studies Depression Scale in adolescents and young adults. *J Youth Adolesc.* Apr 1991;20(2):149-166.

132. Muñoz RF, Ying Y-W. *The prevention of depression: Research and practice.* JHU Press; 2002.

133. Edwards MC, Cheavens JS, Heiy JE, Cukrowicz KC. A Reexamination of the Factor Structure of the Center for Epidemiologic Studies Depression Scale: Is a One-Factor Model Plausible? *Psychol Assess.* Sep 2010;22(3):711-715.

134. Carleton RN, Thibodeau MA, Teale MJ, et al. The center for epidemiologic studies depression scale: a review with a theoretical and empirical examination of item content and factor structure. *PLoS One.* 2013;8(3):e58067.

135. Weissman MM, Sholomskas D, Pottenger M, Prusoff BA, Locke BZ. Assessing depressive symptoms in five psychiatric populations: a validation study. *Am J Epidemiol.* Sep 1977;106(3):203-214.

136. Cella D, Riley W, Stone A, et al. The Patient-Reported Outcomes Measurement Information System (PROMIS) developed and tested its first wave of adult self-reported health outcome item banks: 2005-2008. *J Clin Epidemiol.* Nov 2010;63(11):1179-1194.

137. Choi SW, Schalet B, Cook KF, Cella D. Establishing a common metric for depressive symptoms: linking the BDI-II, CES-D, and PHQ-9 to PROMIS depression. *Psychol Assess.* Jun 2014;26(2):513-527.

138. PROMIS. Depression: A brief guide to the PROMIS depression instrument. 2015. Available at: https://assessmentcenter.net/documents/PROMIS%20Depression%20Scoring%20Manual.pdf. Accessed May 21, 2016.

139. Pilkonis PA, Yu L, Dodds NE, Johnston KL, Maihoefer CC, Lawrence SM. Validation of the depression item bank from the Patient-Reported Outcomes Measurement Information System (PROMIS) in a three-month observational study. *J Psychiatr Res.* Sep 2014;56:112-119.

140. Roos EM, Lohmander LS. The Knee injury and Osteoarthritis Outcome Score (KOOS): from joint injury to osteoarthritis. *Health Qual Life Outcomes.* 2003;1:64.

141. Collins NJ, Misra D, Felson DT, Crossley KM, Roos EM. Measures of knee function: International Knee Documentation Committee (IKDC) Subjective Knee Evaluation Form, Knee Injury and Osteoarthritis Outcome Score (KOOS), Knee Injury and Osteoarthritis Outcome Score Physical Function Short Form (KOOS-PS), Knee Outcome Survey Activities of Daily Living Scale (KOS-ADL), Lysholm Knee Scoring Scale, Oxford Knee Score (OKS), Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC), Activity Rating Scale (ARS), and Tegner Activity Score (TAS). *Arthritis Care Res (Hoboken).* Nov 2011;63 Suppl 11:S208-228.

142. Vennu V, Bindawas SM. Relationship between falls, knee osteoarthritis, and health-related quality of life: data from the Osteoarthritis Initiative study. *Clin Interv Aging.* 2014;9:793-800.

143. Hoogeboom TJ, den Broeder AA, de Bie RA, van den Ende CH. Longitudinal impact of joint pain comorbidity on quality of life and activity levels in knee osteoarthritis: data from the Osteoarthritis Initiative. *Rheumatology (Oxford).* Mar 2013;52(3):543-546.

144. U.S. Census Bureau. Geographic Terms and Concepts - Block Groups. 2012. Available at: https://www.census.gov/geo/reference/gtc/gtc_bg.html. Accessed Nov 28, 2017.

145. Sampson RJ, Raudenbush SW, Earls F. Neighborhoods and violent crime: a multilevel study of collective efficacy. *Science.* Aug 15 1997;277(5328):918-924.

146. Echeverria SE, Diez-Roux AV, Link BG. Reliability of self-reported neighborhood characteristics. *J Urban Health.* Dec 2004;81(4):682-701.

147. Mair C, Diez Roux AV, Shen M, et al. Cross-sectional and longitudinal associations of neighborhood cohesion and stressors with depressive symptoms in the multiethnic study of atherosclerosis. *Ann Epidemiol.* Jan 2009;19(1):49-57.

148. Centers for Disease Control and Prevention. Arthritis as a potential barrier to physical activity among adults with heart disease--United States, 2005 and 2007. *MMWR Morb Mortal Wkly Rep.* Feb 27 2009;58(7):165-169.

149. Centers for Disease Control and Prevention. Arthritis as a potential barrier to physical activity among adults with diabetes--United States, 2005 and 2007. *MMWR Morb Mortal Wkly Rep.* May 09 2008;57(18):486-489.

150. Ettinger WH, Davis MA, Neuhaus JM, Mallon KP. Long-term physical functioning in persons with knee osteoarthritis from NHANES. I: Effects of comorbid medical conditions. *J Clin Epidemiol.* Jul 1994;47(7):809-815.

151. Miksch A, Hermann K, Rölz A, et al. Additional impact of concomitant hypertension and osteoarthritis on quality of life among patients with type 2 diabetes in primary care in Germany – a cross-sectional survey. *Health Qual Life Outcomes.* 2009;7:19.

152. Centers for Disease Control and Prevention. A Data Users Guide to the BRFSS Physical Activity Questions. 2011. Available at: http://www.cdc.gov/brfss/pdf/PA%20RotatingCore_BRFSSGuide_508Comp_07252013FINAL.pdf. Accessed May 21, 2016.

153. Enders CK, Tofighi D. Centering predictor variables in cross-sectional multilevel models: a new look at an old issue. *Psychol Methods.* Jun 2007;12(2):121-138.

154. Hayes AF. A primer on multilevel modeling. *Human Communication Research.* 2006;32(4):385-410.

155. Lambert MT, Terrell JE, Copeland LA, Ronis DL, Duffy SA. Cigarettes, alcohol, and depression: characterizing head and neck cancer survivors in two systems of care. *Nicotine Tob Res.* 2005;7(2):233-241.

156. Sterne JA, White IR, Carlin JB, et al. Multiple imputation for missing data in epidemiological and clinical research: potential and pitfalls. *BMJ.* 2009;338:b2393.

157. *SAS Version 9.3* [computer program]. Cary, North Carolina.

158. Mendes de Leon CF, Cagney KA, Bienias JL, et al. Neighborhood social cohesion and disorder in relation to walking in community-dwelling older adults: a multilevel analysis. *J Aging Health.* Feb 2009;21(1):155-171.

159. Rios R, Aiken LS, Zautra AJ. Neighborhood contexts and the mediating role of neighborhood social cohesion on health and psychological distress among Hispanic and non-Hispanic residents. *Ann Behav Med.* Feb 2012;43(1):50-61.

160. Patterson JM, Eberly LE, Ding Y, Hargreaves M. Associations of smoking prevalence with individual and area level social cohesion. *J Epidemiol Community Health.* Aug 2004;58(8):692-697.

161. Kegler MC, Escoffery C, Alcantara I, Ballard D, Glanz K. A qualitative examination of home and neighborhood environments for obesity prevention in rural adults. *Int J Behav Nutr Phys Act.* 2008;5:65.

162. U.S. Census Bureau. Population Density, Sex, Age, Race, Poverty Status for Population Age 18 to 64, 2010. Prepared by Social Explorer. 2010. Available at: https://www.socialexplorer.com/. Accessed February 11, 2018.

163. Keadle SK, McKinnon R, Graubard BI, Troiano RP. Prevalence and trends in physical activity among older adults in the United States: A comparison across three national surveys. *Prev Med.* May 16 2016;89:37-43.

164. Miller E. *Do place and space matter? A systematic comparison of the homeless circumstance in Birmingham, AL and northwest Arkansas*. , University of Arkansas; 2008.

165. Dean A, Lin N. The stress-buffering role of social support. Problems and prospects for systematic investigation. *J Nerv Ment Dis.* Dec 1977;165(6):403-417.

166. Israel BA, Checkoway B, Schulz A, Zimmerman M. Health education and community empowerment: conceptualizing and measuring perceptions of individual, organizational, and community control. *Health Educ Q.* 1994;21(2):149-170.

167. Taylor AW, Chittleborough C, Gill TK, et al. Relationship of social factors including trust, control over life decisions, problems with transport and safety, to psychological distress in the community. *Soc Psychiatry Psychiatr Epidemiol.* Mar 2012;47(3):465-473.

168. Taylor AW, Kelly G, Dal Grande E, et al. Population levels of wellbeing and the association with social capital. *BMC Psychol.* 2017;5.

169. Kim J-R, Jeong B, Park K-S, Kang Y-S. Association of social capital at the individual level with physical activity in communities with high mortality in Korea. *Health Promot Int.* 2016:daw017.

170. Anderson JC, Gerbing DW. Structural equation modeling in practice: A review and recommended two-step approach. *Psychol Bull.* 1988;103(3):411.

171. Bollen KA. *Structural equations with latent variables.* John Wiley & Sons; 2014.

172. Jöreskog KG. A general approach to confirmatory maximum likelihood factor analysis. *Psychometrika.* 1969;34(2):183-202.

173. Tucker LR, Lewis C. A reliability coefficient for maximum likelihood factor analysis. *Psychometrika.* 1973;38(1):1-10.

174. Bentler PM. Comparative fit indexes in structural models. *Psychol Bull.* Mar 1990;107(2):238-246.

175. Steiger JH, Lind JC. Statistically based tests for the number of common factors. Paper presented at: annual meeting of the Psychometric Society, Iowa City, IA1980.

176. Kline RB. *Principles and practice of structural equation modeling.* Guilford press; 2011.

177. Cabrera-Nguyen P. Author guidelines for reporting scale development and validation results in the Journal of the Society for Social Work and Research. *Journal of the Society for Social Work and Research.* 2010;1(2):99-103.

178. Acock AC. Working with missing values. *Journal of Marriage and Family.* 2005;67(4):1012-1028.

179. Collins LM, Schafer JL, Kam CM. A comparison of inclusive and restrictive strategies in modern missing data procedures. *Psychol Methods.* Dec 2001;6(4):330-351.

180. Ward BW, Schiller JS, Goodman RA. Multiple chronic conditions among US adults: a 2012 update. *Prev Chronic Dis.* Apr 17 2014;11:E62.

181. National Center for Health Statistics. Health, United States, 2015: With Special Feature on Racial and Ethnic Health Disparities. 2016. Available at: https://www.cdc.gov/nchs/data/hus/hus15.pdf#019. Accessed February 11, 2018.

182. Pedhazur E. Multiple regression in behavioral research: Explanation and prediction . United States: Thomson Learning. Inc; 1997.

183. Kweon B-S, Sullivan WC, Wiley AR. Green Common Spaces and the Social Integration of Inner-City Older Adults. *Environment and Behavior.* November 1, 1998 1998;30(6):832-858.

184. Brown SC, Mason CA, Lombard JL, et al. The relationship of built environment to perceived social support and psychological distress in Hispanic elders: the role of "eyes on the street". *J Gerontol B Psychol Sci Soc Sci.* Mar 2009;64(2):234-246.

185. Hajna S, Ross NA, Joseph L, Harper S, Dasgupta K. Neighbourhood Walkability and Daily Steps in Adults with Type 2 Diabetes. *PLoS One.* 2016;11(3):e0151544.

186. Uchino BN. Social support and health: a review of physiological processes potentially underlying links to disease outcomes. *J Behav Med.* Aug 2006;29(4):377-387.

187. Holt RI, de Groot M, Lucki I, Hunter CM, Sartorius N, Golden SH. NIDDK International Conference Report on Diabetes and Depression: Current Understanding and Future Directions. *Diabetes Care.* Aug 2014;37(8):2067-2077.

188. Fisher E, Chan J, Kowitt S, Nan H, Sartorius N, Oldenburg B. Conceptual Perspectives on the Co-Occurrence of Mental and Physical Disease: Diabetes and Depression as a Model. In: Sartorius N, Holt R, M M, eds. *Comorbidity of Mental and Physical Disorders.* Vol 179. Basel: Karger; 2015:1-14.

189. Thomas ML, Kaufmann CN, Palmer BW, et al. Paradoxical Trend for Improvement in Mental Health With Aging: A Community-Based Study of 1,546 Adults Aged 21-100 Years. *J Clin Psychiatry.* Aug 2016;77(8):e1019-1025.

190. U.S. Census Bureau. Projections of the Size and Composition of the U.S. Population: 2014 to 2060. 2015. Available at: https://www.census.gov/content/dam/Census/library/publications/2015/demo/p25-1143.pdf. Accessed Dec 18, 2017.

191. Hoffman C, Rice D, Sung HY. Persons with chronic conditions. Their prevalence and costs. *JAMA.* Nov 13 1996;276(18):1473-1479.

192. Centers for Disease Control and Prevention. Healthy Places Terminology. 2009. Available at: https://www.cdc.gov/healthyplaces/terminology.htm. Accessed December 18, 2017.

193. Wiles JL, Leibing A, Guberman N, Reeve J, Allen RES. The Meaning of "Aging in Place" to Older People. *The Gerontologist.* 2012;52(3):357-366.

194. Preacher KJ. Advances in mediation analysis: a survey and synthesis of new developments. *Annu Rev Psychol.* Jan 3 2015;66:825-852.

195. Diez Roux AV. Estimating neighborhood health effects: the challenges of causal inference in a complex world. *Soc Sci Med.* May 2004;58(10):1953-1960.

196. Osypuk TL. Future Research Directions for Understanding Neighborhood Contributions to Health Disparities. *Rev Epidemiol Sante Publique.* Jun 2013;61(0 2):S61-68.

197. Burton J, Eggleston B, Brenner J, Truchil A, Zulkiewicz BA, Lewis MA. Community-Based Health Education Programs Designed to Improve Clinical Measures Are Unlikely to Reduce Short-Term Costs or Utilization Without Additional Features Targeting These Outcomes. *Popul Health Manag.* Apr 2017;20(2):93-98.

198. Gross K, Brenner JC, Truchil A, Post EM, Riley AH. Building a citywide, all-payer, hospital claims database to improve health care delivery in a low-income, urban community. *Popul Health Manag.* 2013;16 Suppl 1:S20-25.

199. Kaufman S, Ali N, DeFiglio V, Craig K, Brenner J. Early efforts to target and enroll high-risk diabetic patients into urban community-based programs. *Health Promot Pract.* Nov 2014;15(2 Suppl):62s-70s.

200. Matthews SA, Yang TC. Spatial Polygamy and Contextual Exposures (SPACEs): Promoting Activity Space Approaches in Research on Place and Health. *Am Behav Sci.* Aug 01 2013;57(8):1057-1081.

201. Kirchner TR, Shiffman S. Spatio-temporal determinants of mental health and well-being: advances in geographically-explicit ecological momentary assessment (GEMA). *Soc Psychiatry Psychiatr Epidemiol.* Sep 2016;51(9):1211-1223.

202. Pearson JL, Smiley SL, Rubin LF, et al. The Moment Study: protocol for a mixed method observational cohort study of the Alternative Nicotine Delivery Systems (ANDS) initiation process among adult cigarette smokers. *BMJ Open.* Apr 22 2016;6(4):e011717.

203. Mennis J, Mason M, Ambrus A, Way T, Henry K. The spatial accuracy of geographic ecological momentary assessment (GEMA): Error and bias due to subject and environmental characteristics. *Drug Alcohol Depend.* Sep 01 2017;178:188-193.

204. Airaksinen J, Hakulinen C, Elovainio M, et al. Neighborhood effects in depressive symptoms, social support, and mistrust: Longitudinal analysis with repeated measurements. *Soc Sci Med.* Jul 2015;136-137:10-16.

205. Jokela M. Are neighborhood health associations causal? A 10-year prospective cohort study with repeated measurements. *Am J Epidemiol.* Oct 15 2014;180(8):776-784.

206. Malanson GP, Walsh SJ. Agent-based models: Individuals interacting in space. *Applied Geography.* 2015(56):95-98.

207. Li Y, Kong N, Lawley M, Weiss L, Pagan JA. Advancing the use of evidence-based decision-making in local health departments with systems science methodologies. *Am J Public Health.* Apr 2015;105 Suppl 2:S217-222.

208. Li Y, Lawley MA, Siscovick DS, Zhang D, Pagan JA. Agent-Based Modeling of Chronic Diseases: A Narrative Review and Future Research Directions. *Prev Chronic Dis.* May 26 2016;13:E69.

209. Luke DA, Hammond RA, Combs T, et al. Tobacco Town: Computational Modeling of Policy Options to Reduce Tobacco Retailer Density. *Am J Public Health.* May 2017;107(5):740-746.

210. Clarke P, Morenoff J, Debbink M, Golberstein E, Elliott MR, Lantz PM. Cumulative Exposure to Neighborhood Context: Consequences for Health Transitions over the Adult Life Course. *Res Aging.* Nov 19 2013;36(1):115-142.

211. Sallis JF, Owen N, Fisher EB. Ecological models of health behavior. *Health behavior and health education: Theory, research, and practice.* 2008;4:465-486.

212. Wallerstein NB, Yen IH, Syme SL. Integration of social epidemiology and community-engaged interventions to improve health equity. *Am J Public Health.* 2011;101(5):822.