A LIFE COURSE PERSPECTIVE ON SOCIAL CONNECTEDNESS AND ADULT HEALTH

by

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Dedicated to Henry, for giving me purpose and meaning I never thought imaginable.

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ABSTRACT

Functional impairment is increasingly prevalent among middle-aged and older adults, with 2 in 5 adults over the age of 65 having some form of disability, the majority being limitations on mobility. Many older adults are able to maintain functional capacity well into later life, but the factors that contribute to high levels of function and the mechanisms by which they operate are unclear, although prior work has demonstrated the importance of social relationships for health. Guided by principles from the life course perspective and perspectives on social connectedness, this dissertation examined the role of social connectedness across the life course as a predictor of functional capacity in adulthood. I used existing longitudinal data from the national Midlife in the United States (MIDUS) study to pursue three central aims.

First, Paper 1 compared theoretical and data-driven approaches to classifying life course relationships, including multiple dimensions of social connectedness at different time points across the life course. Results showed that the data-driven approach (i.e., latent profile analysis) was a stronger predictor of functional limitations than the theoretical approach and revealed relationship trajectories consistent with life course cumulative processes. Second, using the profiles obtained from Paper 1, Paper 2 probed the association between life-course social connectedness and functional limitations by examining the potential mediating role of candidate biological and behavioral mechanisms, and moderation by socioeconomic status (SES). Paper 2 findings suggested that observed differences in later-life functional limitations based on life-course social connectedness can be at least partially explained by physical activity, but do not vary by SES. Contrary to hypotheses, inflammation was not a significant mediator. Third, Paper 3 used monozygotic twin data and within-family analyses to sharpen the focus on potential causal associations between life-course social connectedness and adult functional status. Results suggested that the association is likely driven by genetic and/or shared environmental influences.

Taken together, these results add to our understanding of social connectedness and health and address important gaps in the literature. These findings are used to generate theory- and intervention-relevant insights into the successful maintenance of health, independence, and function across the lifespan.

CHAPTER 1. INTRODUCTION, BACKGROUND, AND OVERVIEW

Advancing age is associated with increased risk for functional limitations and disability. According to the Centers for Disease Control and Prevention (CDC), 2 in 5 adults over age 65 have some form of disability, the majority being limitations on mobility (CDC, 2020). This trend is a pressing public health concern as long-term care demands for the baby boom generation are expected to peak around 2030, when 1 in 5 persons in the United States will be 65 years or older (Colby & Ortman, 2015). However, many older adults are able to maintain functional capacity well into later life, although the factors that contribute to high levels of function and the mechanisms by which they operate are unclear. Social relationships have been linked to longevity and health as well as biological markers of disease risk (Holt-Lunstad et al., 2010, 2015, 2018; Miller et al., 2009; Shor et al., 2013) with associations comparable in magnitude to those for physical inactivity, smoking, and obesity (Holt-Lunstad et al., 2010, 2015). Moreover, some research suggests that functional capacity in later life is linked to experiences and exposures from earlier in the life course (Freedman et al., 2008; Iveson et al., 2020; Kelley-Moore & Huang, 2017; Sauerteig et al., 2022). Given the rapidly aging population and the detrimental impact of functional decline in old age, identifying predictors of functional health as well as mechanisms by which they operate are important health priorities.

This document is organized as follows: the current chapter provides a summary of the background literature and an overview of the conceptual frameworks used in this dissertation. The following three chapters present Papers 1-3, respectively, and Chapter 5 offers a summary of key findings and the broader implications of this work.

Functional Limitations and Disability

The Disablement Process Model was developed as a framework to predict disability trajectories (Verbrugge & Jette, 1994). The model presents a pathway in which disease pathology leads to impairments, which then predict functional limitations that ultimately lead to disability. The Disablement Process Model does not assume that everyone with a chronic disease or with functional limitations eventually becomes disabled. Instead, the model includes multiple intra-individual and extra-individual factors that play a role in the progression of disability. Thus, risk

factors, psychological resources, health behaviors, economic resources (e.g., socioeconomic status), and social factors (e.g., social support) can all help explain why some people may become immobile while others have no disability at all.

Research supports the proposed relationships in the Disablement Process Model, particularly between functional limitations and disability (Fauth et al., 2007; Teas et al., 2021; Verbrugge et al., 2017). Functional limitations refer to individual capability in a situation-free manner (e.g., walking, balancing). Disability, on the other hand, is considered a social process and is observed as a gap between personal capability and environmental demand.

Functional limitations and disability are often measured by assessing difficulties in performing specific activities. Specifically, instrumental activities of daily living (IADLs) evaluate difficulties with activities required to live independently (e.g., shopping, cleaning, using the telephone). More severe limitations, known as activities of daily living (ADLs), measure difficulties with personal care tasks (e.g., bathing, dressing, eating). Mobility limitations assess difficulties with tasks such as walking a block, carrying groceries, or climbing a flight of stairs. Although some researchers disagree on the categorization, according to the Disablement Process Model, IADLs, ADLs, and mobility limitations are aspects of disability (Verbrugge & Jette, 1994) as they are activities a person does as a member of society that depend on basic physical capabilities (functional limitations). My focus in this dissertation is on functional limitations (primarily assessing mobility limitations), the most common type of functional limitation and a widely used measure of disability.

As the U.S. population ages, concerns have mounted about meeting the healthcare needs of older adults. Although disability rates significantly declined through the 1980s and 1990s, those trends have stalled or reversed in recent decades in the U.S. (Chen & Sloan, 2015; Choi et al., 2022; Choi & Schoeni, 2017; Freedman et al., 2013; Martin et al., 2010). Specifically, increases in disability seem to be most apparent in middle-aged adults (i.e., those 51 to 64 years old; Freedman et al., 2013; Waidmann et al., 2019). One analysis of trends from 2000-2008 showed that there was a levelling of functional limitations in the 65-74 and 75-84 age group, sandwiched between increases for those aged 55-64 and decreases among those aged 85 and older (Freedman et al., 2013). Women appear to be more likely than men to develop functional limitations (Freedman et al., 2016; Johnson & Wiener, 2006). Some evidence also suggests that economic hardship may contribute to increasing disability among middle-aged adults, which is more

pronounced among lower-income families (Choi et al., 2016; Zajacova & Montez, 2018). There are differential trends in disability by income groups for adults aged 55-64 years, with less favorable trends for lower income versus higher income groups (Tipirneni et al., 2021). Thus, there is significant variability in the experience of disability among middle-aged and older adults, particularly at different socioeconomic strata.

Functional limitations and disability are of particular interest because of the associated economic costs, the burden placed on caregivers, and the overall quality of life that adults experience in later life. The healthcare costs of physical dependency at older ages are large and projected to grow rapidly (Johnson & Wiener, 2006). One study examining the health trends of adults aged 51 to 61 between the mid-1990s and mid-2010s confirmed increases in the prevalence of disability among men and women (Waidmann et al., 2019) and showed an increase in the expected effect of disability on the demand for public disability benefits (i.e., from the Social Security Disability Insurance and Supplemental Security Income programs). This increase in demand is expected to be larger for men than for women. In addition to the demand placed on formal services, adults with disabilities often receive assistance from family and friends (i.e., informal caregivers). Many older adults with functional limitations wish to remain in their homes, where they are more likely to need assistance from informal caregivers (Marasinghe, 2016). In 2002, 61% of frail older adults who did not live in nursing homes received help with basic personal activities (e.g., bathing) or household chores (e.g., cooking) from caregivers (Johnson & Wiener, 2006). Caregiving responsibilities, often taken on by a spouse or adult child, can create a substantial burden for caregivers that can affect their own health, work, and well-being. Caregivers who report providing substantial help to family members are significantly more likely to experience physical, emotional, and financial difficulties, as well as work productivity loss (Wolff et al., 2016). Finally, helping older adults who are experiencing declines in functioning maintain a high quality of life is a fundamental societal concern. As life expectancy for adults in the U.S. has increased, greater emphasis has been placed on the quality of those extended years (Freedman et al., 2016). Overall, the short- and long-term effects of increasing rates of disability highlight the importance of studying modifiable predictors of later-life functional health.

Importantly, many older adults maintain high levels of function well into later-life; experiencing disability is not inevitable (Freedman et al., 2013, 2016; Tangen & Robinson, 2020). Using six dimensions of health data from the Health and Retirement Study (HRS), Tang (2014)

identified a successful aging group (40% of the sample) who had low levels of disability and functional limitations. Indeed, there is extensive heterogeneity and variability in the rates of disability and functional limitations in middle- and later-life (Bolano et al., 2019; Freedman et al., 2013; Manini, 2012). Given that 2 in 5 adults over the age of age 65 have some form of disability (CDC, 2020), this implies that more than half (60%) of adults over the age of 65 do not have a disability. However, the factors that contribute to high levels of function and the mechanisms by which they operate are unclear. Based on existing empirical work and guided by the conceptual frameworks outlined in the following section, in this dissertation I aim to identify factors and mechanisms that may impact later-life functional health, with a specific focus on social connectedness, physical activity, and inflammation. Due to socioeconomic differences in rates of disability, and potential differential associations because of the increased vulnerability faced by low-SES adults, SES is also an important consideration. A better understanding of predictors of later-life functional health will help inform theory, intervention, and policy development.

Conceptual Frameworks

Guided by a life course perspective (Elder, 1998; Elder et al., 2003) and informed by social relationship frameworks (Holt-Lunstad, 2018; Ryff, 1989; Ryff & Singer, 2008), the overarching objectives of the three papers in this article-style dissertation are to better understand the effects of personal and interpersonal factors on functional aging, including the mechanisms through which these factors exert their effects and potential divergent trajectories.

Specifically, Paper 1 (*Life-course social connectedness: Comparing data-driven and theoretical classifications as predictors of functional limitations in adulthood*) is a methodological paper that examines theoretical versus data-driven approaches to characterizing relationships, specifically high-quality relationships, across the life span. Papers 2 and 3 subsequently use a data-driven approach to better understand how, for whom, and under what circumstances life-course social connectedness may impact later-life functional capacity. Paper 2 (*Social connectedness across the life course and later-life functional capacity: Mechanisms and divergent associations*) examines the potential mediating role of behavioral and biological mechanisms as well as differential associations by SES. However, even if hypotheses are supported, the results still leave open the possibility that stable person-level characteristics (e.g., genetic and/or familial factors) could predispose toward both high-quality life-course social connections and high levels of

functional capacity in adulthood. To examine this possibility, Paper 3 (*Discordance in life-course social connectedness and later-life health outcomes among monozygotic twins*) uses data on monozygotic (MZ) twins, who share identical DNA, to control for genetic and shared environmental confounders. The following sections are focused on the life course perspective and social connectedness and, importantly, my integration of the two frameworks for this dissertation.

Life Course Perspective

This dissertation is grounded in the life course perspective, a framework for understanding the human life course that emerged during the 1990s as a set of five paradigmatic principles (Elder, 1998; Elder et al., 2003; Settersten et al., 2021). The principle of *linked lives* states that individual lives are interdependent and interwoven with those of significant others. *Timing* emphasizes the importance of when life events occur, and how the consequences of those may vary based on their timing in a person's life. The principle of *lifespan development* recognizes that human development is a lifelong process extending from birth to death. *Human agency* reflects that individuals have active roles in the choices and actions they take, although these decisions are constrained by life circumstances and relationships. Finally, the principle of *historical time and place* underscores that an individual's life is situated within and influenced by historical times and places they experience over their lifetime (including events, social conditions, and shifts marked by birth cohorts).

The life course perspective provides broader theoretical background as well as specific theoretical principles (i.e., timing, linked lives, and lifespan development) that will directly inform this dissertation. Due to limitations of the data, I cannot directly apply the tenets of certain principles of the life course perspective, namely historical time and place and human agency. Below, I provide more detail on the principles of linked lives, timing, and lifespan development, and how each is relevant to this dissertation.

Linked Lives

The principle of linked lives refers to the ways in which significant others' lives are interlocked. Specifically, the life course perspective proposes that the lives of family members are connected such that when something happens to one member of the family, the lives of other

family members are also changed (Allen & Henderson, 2016; Elder et al., 2003). For example, the experience of a middle-aged mother being diagnosed with cancer would also affect her children, who would likely be worried and concerned about their mother's health, as well as the mother's own aging parents, particularly as parent's well-being is greatly tied to their relationships with their adult children (Allen & Henderson, 2016; Suitor et al., 2011). Because of their familial nature, these linked relationships often – but not always – constitute less voluntary membership.

One powerful dimension of the linked lives principle is its applicability across life stages. Family structure and close relationships are not stagnant over time and individuals defined as "significant others" naturally evolve. In early life, the closest people to a child are likely to be parents, siblings, and other relatives (e.g., Dunn, 1983). Throughout adolescence, these same relationships are likely to remain close with the addition of friendships (Rubin et al., 2005). In young adulthood, friendships and romantic relationships are expected to take precedence over some familial relationships. In middle and old age, there may be fluctuations in closeness of relationships based on circumstances (e.g., widowhood) and friendships or adult children may become more important (Allan, 2010; Umberson et al., 2010).

While the linked lives principle includes consideration of the salience of relationships at different life stages, the next section reviews the principle of timing and the ways in which these relationship experiences are linked over time within individuals. A life course perspective thus helps synthesize the separate literatures on childhood, adolescence, adulthood, and old age by underscoring the inseparable links between these life stages (Umberson & Thomeer, 2020) and highlighting the fact that different relationships have different meanings at different times. Although the principle of linked lives is important for understanding social relationships across the life course, it is not directly testable in this dissertation. However, it informed my selection of relationship variables, and specifically the domain of such relationship variables (i.e., parental, friends, family, spouse/partner), at different life stages (i.e., childhood and adulthood).

Timing

The life course perspective posits that the timing of events or experiences in an individual's life matters. In other words, the same experience can affect people in different ways depending on when it occurs in the life course. For example, experiencing a divorce at the age of 30 would be much different than experiencing a divorce at the age of 50. An earlier divorce leaves open the

possibility of remarrying and/or having (additional) children, whereas remarriage may still be an option after a later divorce, but child-rearing years are generally over. In the context of social relationships, this idea can be extended to understanding whether or not people have the types of relationships they need when they need them. The emphasis on timing in the life course perspective is related to the notion of a "developmental match" between an individual's social needs and that with which they are provided (Chen et al., 2017). Importantly, the timing of relationship transitions and interactions can place people on different developmental pathways across the life course.

Several researchers have explored the idea of "the long arm of childhood", studying the early origins of later-life outcomes. Hayward and Gorman (2004) used a life course approach to study the origins of adult mortality, finding that childhood conditions (i.e., SES, family living arrangements, mother's work status, rural residence, and parents' nativity) were associated with men's mortality. The long arm of childhood hypothesis was also supported in a study showing that lack of material resources in childhood (an indicator of low SES) was associated strongly with lower gait speed and moderately to worse episodic memory and higher depression (Tampubolon, 2015). Drawing on the idea of long arm effects, this dissertation addresses the long-term impact of childhood relationships as well as the consideration of other childhood measures (e.g., residential instability, parental divorce) that may impact later-life health.

There is extensive research supporting the long arm hypothesis, as numerous studies have identified associations between childhood experiences and later-life outcomes (e.g., Chen et al., 2017; Haas, 2008; Lee et al., 2019). Importantly, there are several mechanisms by which childhood experiences may exert a long arm effect on later-life outcomes. Some research has suggested that childhood circumstances have a direct, immediate association with the health of adults by permanently altering life outcomes. For example, children who experience high levels of stress during childhood may experience consistently elevated levels of cortisol, resulting in biological stress response systems becoming dysregulated, leading to risk for a variety of health issues later in life (Miller et al., 2009). However, the effects of some disadvantages early in the life course may not manifest until much later in life. These "sleeper effects" may occur only once a certain developmental period is reached or a specific experience occurs. For example, children of divorced parents may not show any adjustment difficulties until young adulthood (Sarigiani & Spierling, 2011), when they are more likely to experience more emotional and relational difficulties (D'Onofrio et al., 2006) and their own divorce (Amato & Sobolewski, 2001).

A central premise of the life course perspective is the notion that changing lives in a changing social context alter developmental trajectories (Elder, 1998). Using a life course lens, Vable and colleagues (2019) examined whether childhood disadvantage could be overcome through upward social mobility later in life, or if childhood socioeconomic disadvantage set people on a trajectory to have worse health in adulthood (even if they were upwardly mobile). Using median splits, they created four life course trajectory groups: stable low SES, downward mobility, upward mobility, and stable high SES. The authors found that the upwardly mobile group was able to overcome the "long arm" of socioeconomic disadvantage and achieve health equity with the stable high SES group for measures of gait speed, grip strength, and lung function. These results suggest that early socioeconomic disadvantage does not guarantee worse outcomes in adulthood, but instead can be overcome through adulthood circumstances. In this dissertation, I use the idea of developmental trajectories to categorize life-course social relationships and ultimately interpret patterns of relationships over time.

Related to the concept of trajectories, the cumulative (dis)advantage model suggests that social, environmental, and behavioral exposures accumulate over the life course, and that these exposures alter later-life social and health outcomes (Dannefer, 2003; see also Ferraro & Shippee, 2009 for an introduction to cumulative inequality theory, an integration of cumulative disadvantage and life course theories). The cumulative (dis)advantage model has frequently been applied in the context of SES. From a life course perspective, the accumulation of inequality beginning early in life is associated with poor health outcomes in later life (Dannefer, 2003). Thus, experiencing low SES at an early life stage and at the adult stage may be more problematic for later health outcomes than experiencing low SES during only childhood or adulthood (Cohen et al., 2010; see also Graham, 2002).

The cumulative (dis)advantage model includes the possibility of both accumulation and contingency effects, additional mechanisms by which childhood experiences can impact later-life outcomes. From an accumulation perspective, experiences and exposures accumulate over the life course, resulting in trajectories of overall good or overall bad experiences (Ferraro & Morton, 2018; Lee & Park, 2020; Thomas et al., 2022; Umberson & Montez, 2010). From a contingency perspective, early life experiences may constrain the range of possible later experiences or provide more opportunities for positive experiences (Erickson & Macmillan, 2018; Ferraro & Morton, 2018). For example, those who experience early success in a scientific career have more

opportunities for further advancement; not all "early bloomers" reach career notoriety, but they have greater opportunity for development than those with a less positive start (Merton, 1968). In a study on disability and the transition to adulthood, Erickson and Macmillan (2018) found that cognitive disability, but not physical disability, was associated with disadvantaged life course trajectories, largely due to disruptions in educational attainments, thus limiting later-life opportunities. I use the cumulative (dis)advantage model to 1) examine the accumulation of positive or negative social relationships over the life course, and 2) interpret trajectories of life-course social connectedness with a lens of potential contingency effects.

Although much of the work has focused on cumulative effects of socioeconomic conditions, the same principle can be applied to studying social relationships. In other words, positive early life relationships provide greater opportunity and resources for people to continue cultivating relationships across the life course and ultimately benefit from positive later life relationships as well. On the other hand, unsupportive relationships and high levels of relationship conflict in childhood can lead to an increased risk for depression, poor health habits, and emotion dysregulation, resulting in worse health and negative interactional styles in other relationships across the life course (Chen et al., 2017; Umberson & Montez, 2010). Using life course typologies that included childhood and adulthood relationships, in addition to childhood and adulthood SES, Singer and Ryff (1999) found that compared to other life course groups, groups featuring high-quality life course relationships – a combination of warm parental relationships in childhood and positive relationships with spouse/partner in adulthood – exhibited the lowest levels of allostatic load in adulthood.

Because there is an abundance of evidence supporting the early origins of adult health, some research has shifted to identifying pathways through which advantages or disadvantages early in life may indirectly influence later-life health outcomes. For example, Lee and colleagues (2019) examined the link between childhood experiences (psychosocial stressors, SES, and close relationships) and later-life longevity through specific midlife risk and resilience pathways. For the vulnerability (or risk) pathways, there was robust evidence for stress continuity as a risk transmission mechanism; in other words, greater exposure to psychosocial stressors in childhood was associated with more stressful life events in midlife, which in turn reduced later-life longevity. On the other hand, results for the resilience pathways suggested that higher levels of optimism in midlife mediated the pathway from higher childhood SES to greater longevity. Similarly, Thomas

and colleagues (2022) found that higher levels of childhood stressors were indirectly associated with lower levels of later-life cognitive health through social support and strain in adulthood relationships. Specifically, participants who reported a greater number of childhood stressors also reported less social support and more social strain in adulthood, which were in turn associated with worse cognitive health. This indirect effect was in addition to a significant direct effect of childhood stressors on cognitive health over time, suggesting multiple mechanisms of a long arm effect of childhood stress on adult cognition. Likewise, both childhood and adulthood stressors have been shown to increase the occurrence and severity of later-life functional limitations, with childhood stressors exhibiting both direct and indirect effects through adulthood stressors (Sauerteig et al., 2022). Participants who reported a greater number of childhood stressors also reported more adulthood stressors, which were in turn associated with an elevated occurrence and greater severity of functional limitations. Although the effect of adult stressors accounted for more variance in functional limitations, and thus was more consequential, the influence of child stressors was still significant, supporting the long-lasting influence of early-life experiences. Overall, studies on cumulative dis(advantage), and timing more generally, highlight potential chains of risk and opportunities originating in early life, leading to inequalities or advantages that accumulate across the life course.

For purposes of this dissertation, I pull from the broad notion of the long arm of childhood experiences and specifically developmental trajectories and cumulative (dis)advantage. Some of these concepts (i.e., developmental trajectories, cumulative (dis)advantage accumulation effects) are applied directly in identifying life-course social connectedness patterns, whereas others are used more to guide the study design and interpret findings (i.e., long arm of childhood, cumulative (dis)advantage contingency effects).

Lifespan Development

The principle of lifespan development emphasizes that human development is a lifelong process, not stopping at adulthood, but extending from birth to death. Moreover, each phase of life (e.g., adolescence, young adulthood, middle age) is unique and significant, and each includes gains as well as losses. The characteristics and salience of relationships are unique to each stage of life, and these experiences are highly influenced by the societal and historical context. For example, marital transitions are increasingly common in old age and although widowhood was historically

the main pathway out of marriage, the rates of "gray" divorce have increased dramatically (Carr & Utz, 2020). In fact, gray divorce (i.e., divorce after the age of 50) accounts for one third of all later-life dissolutions (Brown & Wright, 2017). Interestingly, while divorce rates have increased among older Americans, divorce rates among younger adults have continued to decline (Smock & Schwartz, 2020). Relationships and relationship transitions can have different impacts depending on the phase of life they are experienced.

No phase of life can be understood as a snapshot, removed from the other phases. Rather, each phase is important and affects the development of subsequent phases. For example, relationships in one phase of life can affect relationships in later phases of life. In studying older women's friendships and marital histories, Ermer and Matera (2021) found that transitions into and out of marriage shaped long-term trajectories of friendships. The experience of divorce often resulted in participants losing friends and renegotiating their friendships. However, experiencing widowhood led to participants placing greater emphasis on friendships. Thus, there appears to be a divergent pattern of friendship restructuring after a marital loss depending on if the catalyst was divorce or widowhood. Participants also indicated that marriage shifted them away from individual friendships. The experience of marriage, whether their own or others' marriages, may distance friends from one another as married individuals' primary attention is often to their spouses. Overall, it seems that married and unpartnered individuals experience friendships differently, and the reason for being unpartnered (e.g., divorced, widowed) affects the role of friendships throughout the life course. A life course perspective on marital transitions thus sheds light on the development and maintenance of other close relationships at specific stages of life.

Additionally, friendship patterns in older age are diverse. As experiences and conditions change in the later phases of life, the friendships that people maintain also change. For example, some friendships may revolve around work and are not sustained once people enter retirement. Later life may also offer new opportunities for involvement with their friends, particularly when there is more time available for leisure activities due to entering retirement (Allan, 2010).

Although considerably understudied, research on sibling relationships – the longest-lasting relationships in most people's lives – provides an illustration of how long-term relationships can change during midlife and older adulthood (Gilligan et al., 2020). For example, sibling conflict is typically lower among older adult siblings than in childhood, adolescence, and young adulthood (Stocker et al., 2019). One potential explanation for this is that older adults tend to avoid negative

interactions and to focus on maintaining positive relationships with the people with whom they are closest, more so than younger adults (Charles & Carstensen, 2010).

The lifespan development principle, in combination with the timing principle, provides a framework in this dissertation for understanding the development of relationships across different life stages (e.g., adolescence, old age) as well as across different types of relationships (e.g., romantic, friend). In other words, prior stages and relationships (or relationship transitions) can affect similar or different types of relationships in subsequent phases of life. As some of the examples above illustrate, certain relationships can be more or less salient at specific points in the life course. I apply the lifespan development principle in this dissertation by considering different relationships at different points in the life course as well as the links between childhood and adulthood relationships.

Social Connectedness

For conceptual clarity, the focus of this dissertation is social connectedness, a term that acknowledges diversity in conceptions and measures of social relationships. Social connectedness is consistent with the systems perspective described by Holt-Lunstad (2018) that argues for the conceptualization of structural (e.g., number of ties to others and community), functional (e.g., perceived social support), and quality (e.g., satisfaction with diverse relationships) aspects of social relationships as distinct phenomena that may have discrete associations with health outcomes. This conceptualization of social connectedness includes relationship quality, an aspect of social relationships that has received less attention than measures such as social integration and social support. This research brings together elements from two intellectual traditions that bear on social connectedness: social relationship science (e.g., social support) and philosophical perspectives (Ryff, 1989) on what it means to lead a 'good life' (e.g., positive relations with others).

In the following paragraphs I first define these different domains of social connectedness and then discuss their associations with health, particularly functional limitations and disability.

Structural and Functional Measures of Social Relationships

Structural indicators of connection are usually quantitative in nature (Holt-Lunstad, 2018). Structural measures attempt to capture the existence of relationships and their influence on an

individual's life. Social integration is a common structural measure that has typically been defined as having a diverse range of relationships (Cohen et al., 1997; Thoits, 1983) or involvement in a range of social activities (e.g., House et al., 1982). Individuals are said to be socially "integrated" into the larger society in which they live based on their attendance at community events or memberships in community organizations. Network size and frequency of contact with network members are also common measures of social integration. Social networks represent the web of social relationships an individual has, including romantic relationships, acquaintances, family ties, and more formal relationships (e.g., colleagues). Other structural measures that are often considered components of social integration composite measures include marital status and whether or not someone lives alone (Holt-Lunstad, 2018). Overall, structural indicators of social connection, such as social integration, have long-standing associations with health and longevity (Berkman et al., 2000; Holt-Lunstad, 2018; Seeman, 1996).

In contrast, functional indicators revolve around actual or perceived availability of support or resources that relationships may provide (Cohen, 2004; Cohen & Syme, 1985; Holt-Lunstad, 2018; Shumaker & Brownell, 1984). Social support is one of the most well-documented social influences on psychological and physical health outcomes (Cohen, 2004; Cohen & Syme, 1985; Holt-Lunstad et al., 2010; Shor et al., 2013). Traditionally, social support encompasses three types of resources: instrumental, informational, and emotional (Cohen, 2004; Heinze et al., 2015; Kahn & Antonucci, 1980). Instrumental support refers to the provision of tangible (e.g., money, help with daily tasks) assistance. Informational support involves the provision of relevant information (e.g., advice). Emotional support encompasses the expression of empathy, concern, or reassurance. Overall, social support is known to be important for health, both for its direct effects and its ability to protect people from adverse effects of stress (i.e., buffering effects).

Quality of Social Relationships

To date, most of the epidemiological literature has largely focused on structural and functional components of social connection. However, an increasing body of evidence has shown that the quality (i.e., positive and negative) aspects of these relationships is vitally important. A meta-analysis identified robust associations between marital quality and health, including morbidity, mortality, and biological markers (Robles et al., 2014). There is some divergence on the measurement of marital quality, but positive marital quality is usually operationally defined as

high relationship satisfaction, positive subjective attitudes/feelings towards one's partner, and positive or optimistic global evaluations of one's marriage (Fincham & Bradbury, 1987; Robles et al., 2014). Low, or negative marital quality, is characterized by low relationship satisfaction, negative or hostile attitudes/feelings towards one's partner, and negative evaluations of one's marriage (Fincham & Bradbury, 1987; Robles et al., 2014). Nonetheless, most studies of relationship quality involve assessments of marital satisfaction (Robles et al., 2014; Rook & Charles, 2017), whereas quality of other types of relationships has largely been understudied.

Philosophical perspectives on what it means to live a good life provide another approach to understanding the quality component of social connectedness. As acknowledged by Aristotle and others, social connections consisting of love, deep friendship, and empathy are essential components of a well-lived life (Ryff & Singer, 2008). This conceptualization is neither structural nor functional. Rather, it centers on the extent to which an individual cultivates warm, meaningful, and trusting connections with other people – another interpretation of what it means to have high-quality relationships. One operationalization of this philosophical perspective is the measure of positive relations with others, a dimension from the Psychological Well-Being Scales (Ryff, 1989) that assesses the extent to which individuals form and nurture warm, trusting relationships. The different scale items refer to "friends," "family members and friends," or simply "others", thus allowing a liberal definition of social connections, irrespective of domain.

Social Connectedness and Functional Health

Social integration has frequently been linked to functional capacity. Participants in the Americans' Changing Lives survey who had high or increasing levels of social engagement over a 16-year period accumulated fewer physical limitations over time than participants who were less socially engaged (Thomas, 2011). Social engagement was measured using a latent variable comprising five observed variables representing frequency of contact with friends and family (over the phone and in person), participation in community groups, attendance at religious services, and volunteer work. Due to the longitudinal nature of the study, results suggest that high levels of social engagement have potentially protective effects on functional decline. Similarly, Avlund and colleagues (2004) found that a high diversity in social relations and high social participation predicted less functional disability over a 1.5-year follow-up period among older adults. Diversity in social relations was conceptualized as the number of categories with whom participants had

personal contact at least once per month, from the following: children, grand/great grandchildren, siblings, other relatives, and friends/acquaintances. Participants with higher social participation reported engaging in three activities (paying visits to others, receiving visits at home, and participating in social activities outside the home) weekly. The onset of functional disability was based on the amount of help participants reported needing for six mobility-related activities. Interestingly, diversity in social relations and high social participation predicted less disability onset among the 75-year-old participants but not among the 80-year-old participants.

Overall, there are several reasons why social integration may be associated with functional limitations or disability. One theory is that people who are more socially integrated experience more motivation and social pressure to take better care of their health because they are interacting with people on a more regular basis than those who are less integrated (Berkman, 2000). Additionally, social participation provides opportunities for engagement, which in turn can provide a sense of belonging and attachment. Feeling obligated and attached to one's community may help give meaning and value to an individual's life, thus encouraging them to stay active so they can continue participating in society (Berkman, 2000).

Functional aspects of social relationships are also often associated with functional health. Lachman and Agrigoroaei (2010) found that perceptions of high social support and low social strain were associated with less decline in functional health over a period of 8-10 years. Social support and social strain were averaged across the family, friend, and spouse/partner domains. The authors were also interested in assessing the role of a protective composite that consisted of high social support, low social strain, high control beliefs, and frequent physical activity. Results suggested that each of the factors had a unique contribution, and there was evidence for the additive value of these factors (and the more of them the better in terms of functional health outcomes). Thus, social support and social strain were important factors in predicting changes in functional health over time through independent as well as compounding effects. These findings suggest that it may be important to consider multidimensional influences (and multidimensional interventions) for improving later-life health.

In a national sample of couples aged 51 years and older, Ryan and colleagues (2014) examined the cross-sectional associations between physical health and social support and strain, specifically in the marital context. This study considered both positive (support) and negative (strain) dimensions of spousal relations. Individual perceptions of support, but not strain, were

significantly associated with fewer functional limitations, suggesting that a psychological pathway between social relationships and health may operate through the positive side (i.e., support, and not strain), possibly as a stress buffer. Moreover, partner perceptions of higher spousal support and lower spousal strain were associated with fewer functional limitations. Additionally, the protective effect of an individual's perceived support on functional limitations was greater for those with a spouse reporting low perceived strain. Contrary to some prior work, Ryan and colleagues (2014) did not find a significant differential effect of support/strain on health for husbands versus health for wives. Overall, the findings suggest that both individuals' and their spouses' relationship perceptions play an important role in functional health.

In terms of associations between relationship quality and functional health, most of the research has focused on marital quality. Choi and colleagues (2016) examined associations between positive marital quality and disability among married couples aged 50 or older using three waves of data from the HRS. Similar to the study by Ryan and colleagues (2014), this study involved married couples in order to examine how participants' marital relationship affected their own and each other's health (i.e., actor-partner model). Positive marital quality was assessed with three items (e.g., "How much do they really understand the way you feel about things?"). Outcomes included functional limitations and disability. Functional limitations were measured by participants rating whether they had any difficulty with sitting for two hours, getting up from a chair, stooping, kneeling or crouching, and pushing or pulling large objects. Disability was measured using the ADL and IADL scales. Positive marital quality reported by the 'actor' was significantly associated with disability over a 4-year period, where an increase in positive marital quality was associated with a decrease in one's own disability. Increases in 'partner' positive marital quality were significantly associated with both decreases in the number of functional limitations and disability in the actor. Importantly, results showed that the actor and partner effects did not differ between husbands and wives.

Positive marital quality, although generally beneficial for health, is not necessarily equally beneficial across different groups of people (e.g., individuals with varying levels of SES). For example, Choi and Marks (2013) found that increases in marital happiness were longitudinally associated with increases in self-rated health for individuals with more education, whereas increases in marital conflict were linked to greater increases in functional impairment for persons with lower income. Functional limitations measured whether participants were limited in their

ability to perform five tasks (e.g., climbing a flight of stairs). Negative marital quality was assessed with an index of marital conflict, and positive marital quality was assessed with a one-item marital happiness measure. The strength of association between marital conflict and functional limitations was greater for participants with a lower income, whereas marital happiness was not associated with functional limitations. Thus, marital conflict may be more detrimental and marital happiness less beneficial for functional health among those with lower SES. The results are important for understanding the distinctive role SES (e.g., income) may play in the way that marital quality (and relationship quality more generally) influences functional health. Combined with the emphasis on contextual factors from the life course perspective, these empirical findings inform my consideration of SES as a moderator in this dissertation.

One of the few studies examining links between positive relations with others and functional health showed that higher ratings on positive relations with others was associated with fewer functional limitations in a cross-national comparison of U.S. and Japanese samples, although the association was cross-sectional (Choi et al., 2020). More recently, positive relations with others was associated with fewer functional limitations, and slower accumulation of limitations over time, independent of social integration and social support (Friedman et al., under review). These findings suggest that positive relations with others captures a unique aspect of the link between social connectedness and functional health that is not accounted for by structural and functional measures.

Of the three dimensions of social connectedness outlined by Holt-Lunstad (2018), relationship quality remains the least studied. The literature on marital quality and health is abundant, but there is a need to consider other conceptualizations of relationship quality, particularly in the context of non-marital relationships, given the potentially fluctuating importance of other relationships across the life course as outlined by the lifespan development principle. In this dissertation, I include a measure of positive relations with others that captures the quality of relationships that may include, but is not limited to, marital relationships.

Theoretical Integration: A Life Course Perspective on Social Connectedness

This dissertation builds on prior work by examining the life-course timing of specific types of social connectedness (e.g., with parents; with friends, family members, and spouses), with an emphasis on the quality of these connections. I place particular importance on the positive nature of these life-course relationships due to the direct (e.g., Lee & Schafer, 2021; Lee et al., 2019;

Uchino, 2006) and buffering (e.g., Chen et al., 2011; Chiang et al., 2018) effects of positive relationship dimensions. The life course perspective, and in particular the principle of timing, emphasizes the necessity of considering the ways in which experiences are linked over time within individuals. Additionally, the principle of lifespan development underscores the salience of relationships that are unique to each stage of life. Moreover, most of the research on social relationships and health have focused on one dimension of relationships (i.e., typically structural or functional measures). Thus, this dissertation incorporates relationships at multiple time points (childhood and adulthood), multiple types of relationships (e.g., parental, spouse/partner) to account for the changing salience of relationships, and multiple dimensions of relationships (e.g., functional and quality).

Relationship quality in childhood is known to be important for adult health. Specifically, parental relationships in childhood can exert both direct and buffering effects on physical and psychological health. For example, one study found that cherished children (i.e., those who endorsed positive relationships, milder forms of parental discipline, and positive parental and self-regard) had higher later-life autonomy than those who experienced ordinary childhoods (Lee et al., 2015). Cherished children also had greater social support in midlife than those who were harshly disciplined or experienced ordinary childhoods, which was in turn associated with greater well-being in later life. Moreover, maternal warmth has been shown to buffer the negative effects of childhood adversity (e.g., low SES) on later-life immune function (Chen et al., 2011). Children who experienced low SES, but high maternal warmth, exhibited reduced pro-inflammatory signaling compared to those who had low SES in early life but experienced low maternal warmth.

Few studies have examined social connectedness across the life course as a predictor of adult health outcomes. Singer and Ryff (1999) found that high-quality life course relationships – both warm parental relationships in childhood and positive relationships with spouse/partner in adulthood – predicted lower levels of allostatic load in adulthood. However, this sample was small and only measured connection to a spouse or significant other to represent adult relationships. Using a life course model, Yang and colleagues (2016) integrated data from four large, longitudinal studies to assess the association between social relationships (social integration, social support, and social strain) and a diverse set of biomarkers. At four different points in the life course – adolescence through late adulthood – greater social integration and lower strain were associated with better physiological regulation, although relationship quality was not considered.

Creating groups, or typologies, of life course relationships can be advantageous for several reasons, and there are multiple ways to implement a person-centered approach to studying social relationships. In Paper 1, I explore the properties of two different analytic approaches to studying life course relationships. Specifically, I compare two methods for classifying social relationships: 1) a priori, or theoretical, classification strategies, and 2) latent profile analysis (LPA), in which classifications arise from data patterns.

Candidate Mediators Linking Social Connectedness to Health: Inflammation and Physical Activity

The Disablement Process Model is a sociomedical model of disability that, for purposes of this dissertation, is embedded within the life course framework. The model includes risk factors, extra-individual factors, and intra-individual factors that influence the pathway to disability over time. Importantly, many of these factors, such as social environment (e.g., support or strain) and health behaviors (e.g., physical activity), are developed over the life course and do not just manifest in old age. Moreover, pathology of disease, one of the precursors to functional limitations and disability in the Disablement Process Model, can be understood through a multitude of biological processes (e.g., inflammation) that also arise over the life course with early- and later-life influences.

A substantial amount of empirical work has attempted to identify potential mechanisms, including inflammation and physical activity, through which social relationships may influence health. A number of studies suggest that greater social integration and social support are longitudinally linked to better immune functioning, whereas greater social strain substantially increases systemic inflammation (Elliot et al., 2018; Kiecolt-Glaser et al., 2010; Yang et al., 2014). Moreover, people with supportive close relationships across the lifespan generally have lower levels of systemic inflammation (Fagundes et al., 2011). Independent of disease, higher levels of inflammation are also cross-sectionally associated with more functional limitations (Brinkley et al., 2009; Cohen et al., 1997) and with greater risk of disability over time (Penninx et al., 2004). Although multimorbidity is known to predict functional limitations (Calderón-Larrañaga et al., 2018; Teas et al., 2021; Wolff et al., 2005) a longitudinal analysis found that inflammation partially mediated the association (Friedman et al., 2019), suggesting that inflammation is a possible mechanistic influence on functional health.

Social connectedness is also associated with better health practices (Watt et al., 2014). Specifically, greater social support and broader social networks have been linked to higher levels of physical activity among older adults (Cotter & Lachman, 2010), whereas loneliness is considered a risk factor for physical inactivity (Hawkley et al., 2009). Regular physical activity also consistently confers a reduced risk of functional limitations and disability in older age (Paterson & Warburton, 2010). Further, one study showed that leisure-time physical activities mediated the link between social relationships – level of social support and strain – and a variety of physical health outcomes (Chang et al., 2014). Inflammation and physical activity are thus viewed as potential mediators of the link between life course social connectedness and functional limitations, and this possibility is one of the aims of Paper 2.

Moderation by Socioeconomic Status (SES)

As supported by empirical work described in the section on social connectedness (specifically marital quality) and functional health, the socioeconomic context that one lives in can alter the impact that social relationships have on health. Socioeconomic status (SES: typically measured as educational attainment, income, and/or occupational status) is a powerful predictor of physical health generally (Adler & Ostrove, 1999; Chen & Miller, 2013) and physical functioning specifically (Freedman & Martin, 1999; Grundy & Glaser, 2000; Hemingway et al., 1997). Freedman and Martin (1999) showed that having less than a high school education was associated with having about twice the odds of having a functional limitation in later life compared to having more than a high school education. More recently, Choi and colleagues (2022) found that between 2002 and 2016, the difference in disability between low- and high-income adults widened, particularly for the middle-aged group. Specifically, those in the top 20th income percentile reported a disability prevalence of 5% from 2010-2016, whereas prevalence for those in the bottom 20th percentile was 38%.

SES also moderates the associations of diverse predictors, including social relationships, with health outcomes. For example, longitudinal data shows that positive relationships relate to better cardiovascular and inflammatory outcomes among low-SES but not high-SES adults (Vitaliano et al., 2001). In assessing the health benefits of marriage, Choi and Marks (2013) found that marital happiness was positively associated with self-rated health only for individuals with more education, while marital conflict was linked to greater increases in functional impairment for

persons with lower income. Similarly, Singer and Ryff (1999) showed that the importance of social relationships for health was more robust for those with low household income compared to those with high household income. Specifically, among those who started out relatively disadvantaged economically in childhood, the presence of consistent positive relationships across the life course yielded better health outcomes compared to those without such relationships. Conversely, persistent negative relationships across the life course appeared to exacerbate the negative impact of any economic adversity. In this dissertation, I examine SES as a potential moderator of the association between life course social connectedness and health outcomes (a second aim of Paper 2), extending prior research to include quality of both marital and non-marital relationships in adulthood and an explicit focus on functional limitations.

Issues of Causality

A central feature of this dissertation is the application of rigorous methods designed to better understand potentially causal processes predicting adult functional capacity. Papers 1 and 2 will involve analyses of data collected longitudinally, taking advantage of temporal ordering to bolster potentially causal explanations of associations between life course connectedness and adult health outcomes. In other words, measuring the predictor before the mediators, which also precede the outcome, helps rule out non-causal explanations, making causal interpretations slightly more plausible. On the other hand, non-significant associations may suggest that the hypothesized link between social connectedness and health outcomes are not causal, although several alternative explanations could exist (e.g., incorrect time scale measurement, measured or unmeasured confounders). However, even if my hypotheses are supported, the results will still leave open the possibility that stable person-level characteristics could predispose toward both high-quality life-course social connections and high levels of functional capacity in adulthood. To examine this possibility, I use data on monozygotic (MZ) twins, who share identical DNA and their rearing environment, to examine between- and within-family associations of social connectedness and functional limitations (Paper 3).

The discordant MZ twin design is the strongest within-family design because it controls for genetics as well as measured and unmeasured familial confounds (Vitaro et al., 2009). This analysis could provide evidence that the twin in a pair who has had better relationships across the life course also has better health outcomes relative to their co-twin, which would strengthen

evidence of a potentially causal association of relationships and health outcomes over time. The concern with observational or non-experimental approaches to causal inference rests on two alternative explanations: reverse causation and confounding (McGue et al., 2010). The MZ twin design helps address the issue of confounding by controlling for genetics and familial confounds that could influence the outcome (functional limitations), thus minimizing the possibility that participants' genetic makeup and shared life experiences are systematically confounded with the predictor and outcome. Conversely, if within-family associations are not present, the link between social connectedness and health outcomes cannot be causal (i.e., it is more likely confounded by familial influences). The proposed approach is innovative in that it is the first of which I am aware to apply the MZ twin design (and more specifically, a moderated mediation analysis within an MZ twin design) to examine social connectedness across the life course and functional health outcomes. Collectively, the longitudinal analyses and MZ twin design increase the scientific rigor of this dissertation and detection of potential causal associations.

Description of MIDUS Data

In this dissertation, I use existing longitudinal data from the Midlife in the United States (MIDUS) study. MIDUS is a national survey of the physical and mental health of middle-aged and older adults. The first wave of MIDUS (N = 7,108; MIDUS 1) included a national probability sample of non-institutionalized English-speaking adults living in the United States recruited by random digit dialing, monozygotic and dizygotic twin pairs recruited from a national twin registry, siblings of some of the random digit dialing participants, and oversamples of selected cities. The first wave of MIDUS data collection (MIDUS 1) was completed in 1995-1996, and two follow-up studies (MIDUS 2 and MIDUS 3) were completed in 2004-2006 and 2013-2014, respectively. At MIDUS 1, participants ranged in age from 25 – 74 years. Mortality-adjusted retention was 75% from MIDUS 1 to MIDUS 2 and 72% between MIDUS 2 and MIDUS 3, excellent retention for studies of this kind (Radler & Ryff, 2010). To improve racial/ethnic diversity in the MIDUS cohort, a new sample of African American residents of Milwaukee County, WI (n = 592) was recruited at MIDUS 2. A representative (Love et al., 2010) subsample of MIDUS 2 participants (biomarker subsample; n = 1,255) took part in clinic-based data collection at one of three regional General Clinic Research Centers. These participants completed medical histories, clinical assessments, and additional questionnaires.

Given the multi-project nature of the MIDUS study, sample sizes for variables of interest will vary (see Table 1 for key measures for the three papers, sources, and N's). I use data from all three waves of MIDUS to test the central hypothesis that life course social connectedness is associated with functional capacity through physical activity and inflammation, particularly in low-SES adults. Further, I take a data-driven, person-centered approach by identifying profiles of social connectedness across child and adult relationships (Paper 1).

Table 1. Details for Each Key Measure

Measure	**Measurement**	**Ref.**	**N**
Social connectedness			
Parental affection	SAQ	Rossi, 2001	6882
Parental discipline	SAQ	Rossi, 2001	6880
Social support	SAQ	Grzywacz & Marks, 1999; Schuster et al., 1990; Walen & Lachman, 2000	6856
Social strain	SAQ	Grzywacz & Marks, 1999; Schuster et al., 1990; Walen & Lachman, 2000	6856
PRWO	SAQ	Ryff, 1989; Ryff & Keyes, 1995	6705
Inflammation	CRP, IL-6, sIL-6r, fibrinogen, E-Selectin, ICAM-1 in serum	Friedman et al., 2019	1255
Physical activity	SAQ	Rector et al., 2020	4457
Functional limitations	SAQ	Syddall et al., 2009; Ware & Sherbourne, 1992	3292
SES			
Composite	Phone interview	Glei et al., 2020	7700

Note: Measures that are indented comprise the italicized variable directly above. SAQ = self-administered questionnaire. SES composite consists of the educational attainment and occupational socioeconomic index of the respondent (and their spouse/partner, if applicable), household income, and net assets of the respondent and spouse/partner combined.

Study Aims

The overarching aim of this dissertation is to positively impact the field by generating theory- and intervention-relevant insights into the successful maintenance of health, independence, and function across the lifespan. This objective will be achieved by addressing the following aims across three papers.

Paper 1: Life-course social connectedness: Comparing data-driven and theoretical classifications as predictors of functional limitations in adulthood

Aim 1: Determine if specific demographic, health behavior, and health outcome variables map onto theory-driven social relationship groups similarly to data-driven profiles.

Aim 2: Examine whether empirical or theoretically derived profiles better predict later-life functional limitations.

Paper 2: Social connectedness across the life course and later-life functional limitations: Mechanisms and divergent associations

Aim 1: Determine whether social connectedness across the life course predicts functional limitations in later life by promoting physical activity and/or reducing inflammation.

Aim 2: Identify potential divergent associations between life-course connectedness and health at different SES levels.

Paper 3: Discordance in life-course social connectedness and later-life health outcomes among monozygotic twins

Aim 1: Examine the link between life-course connectedness and health using a discordant MZ twin design.

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CHAPTER 2. LIFE-COURSE SOCIAL CONNECTEDNESS: COMPARING DATA-DRIVEN AND THEORETICAL CLASSIFICATIONS AS PREDICTORS OF FUNCTIONAL LIMITATIONS IN ADULTHOOD (PAPER 1)

This paper was published in Advances in Life Course Research (https://doi.org/10.1016/j.alcr.2023.100529).

Abstract: A life course perspective on social relationships highlights the importance of specific relationships at specific times in life, but analyses that account for life course trajectories in social relationships are rare. This study compares theoretical and data-driven approaches to classifying life course relationships, including multiple dimensions of social connectedness at different time points across the life course. We examine each approach's ability to predict later-life functional limitations, given that functional impairment is prevalent among middle-aged and older adults. Data were from three waves of the Midlife in the United States (MIDUS) study (n = 6,909). Relationship variables (parental affection, parental discipline, social support, social strain, and positive relations with others) were from wave 1 or wave 2. Functional limitations were measured at wave 3. Results showed that the data-driven approach had more predictive power than the theoretical approach. Additionally, results suggested that including only positive relationship features was nearly as robust as including both positive and negative relationship features. Overall, the data-driven approach outperformed the theoretical approach and revealed relationship trajectories consistent with life course cumulative processes.

Introduction

Social relationships are consistently and robustly associated with physical (Berkman & Seeman, 1986; Cacioppo & Cacioppo, 2014; Holt-Lunstad et al., 2010) and psychological (Santini et al., 2015; Umberson et al., 1996) well-being. However, the current approach to studying social relationships and health tends to be piecemeal, with studies often examining one type of relationship (e.g., spouse, parent), relationship factors of one valence (e.g., positive elements such as social support), or relationships at one point in time (e.g., older adulthood). Our understanding of social relationships and health could be improved by determining how multiple important relationships at important times in the life course work together to predict later-life health outcomes. A life course perspective on social relationships highlights the salience of specific types of relationships at specific times in life. Using a life course perspective, the present study examines three analytic approaches for classifying life course relationships and how each approach predicts later-life health, specifically functional limitations.

Social Connections and Health

Social connectedness has been linked to longevity and health with associations comparable in magnitude to those for physical inactivity, smoking, and obesity (Holt-Lunstad et al., 2010; 2015). Social relationships in adulthood, such as support from friends, family members, and partners, are linked to diverse health outcomes (Cohen, 2004; Holt-Lunstad et al., 2010; Rook & Charles, 2017; Uchino, 2006). Adult health is also influenced by the quality of earlier social connections. Adverse social experiences in childhood, typically in the context of parent-child relationships, predict poorer mental and physical health in adulthood (Chen et al., 2017). Conversely, greater parental affection in childhood predicts better health in adulthood, and parental warmth can buffer against the adverse health effects of other childhood exposures, including low socioeconomic status (Chen et al., 2017).

For the purposes of examining the health correlates of life course social connections, we focus specifically on functional impairment in middle and later life, an increasingly prevalent health concern among middle-aged and older adults (CDC, 2020). Functional limitations refer to restrictions in performing basic daily activities (e.g., climbing stairs; Verbrugge & Jette, 1994). Specific to the present study, social relationships are frequently associated with functional capacity.

Over a 16-year period, participants with high or increasing levels of social engagement accumulated fewer physical limitations over time than participants who were less socially engaged (Thomas, 2011). In another study, perceptions of high social support and low social strain were associated with less decline in functional health over a period of 8-10 years (Lachman & Agrigoroaei, 2010). Among married couples, an individual's own positive marital quality and their spouse's positive marital quality were both associated with less disability onset for the individual over time (Choi et al., 2016).

Theoretical Foundation

The current study brings a life course lens to the study of social connections and health. The life course perspective (Elder, 1998; Elder et al., 2003; Settersten et al., 2021) is a framework for understanding the human life course and consists of five paradigmatic principles: linked lives, timing, historical time and place, human agency, and lifespan development. The principles of timing and lifespan development are particularly relevant for the present study. The principle of *timing* emphasizes the importance of when life events occur, how the consequences of those events may vary based on their timing in a person's life, and the particular significance of early-life experiences (e.g., "the long arm of childhood", or the early origins of later-life outcomes; Chen et al., 2017; Haas, 2008; Hayward & Gorman, 2004; Lee et al., 2019). For example, developmentally it may be more important to have warm, supportive parental relationships in childhood than it is to have them in adulthood. The principle of *lifespan development* emphasizes that human development is a lifelong process, extending from birth to death. Moreover, each phase of life (e.g., adolescence, young adulthood, middle age) is unique and significant, and each includes gains as well as losses. Prior stages and relationships (or relationship transitions) can influence similar or different types of relationships in subsequent phases of life. The life course principles of timing and lifespan development guide the present study in its focus on typologies of social connections across different life stages (e.g., childhood, adulthood) and across different types of relationships (e.g., parent-child; romantic; friendships).

Leveraging the principles of timing and lifespan development, the cumulative (dis)advantage model describes two mechanisms by which childhood experiences can impact later-life outcomes. Experiences and exposures can accumulate over the life course, resulting in trajectories of overall good or overall bad experiences (i.e., accumulation effects; Ferraro &

Morton, 2018; Lee & Park, 2020; Thomas et al., 2022a; Umberson & Montez, 2010). Early life experiences may also constrain the range of possible later experiences or provide more opportunities for positive experiences (i.e., contingency effects; Erickson & Macmillan, 2018; Ferraro & Morton, 2018). The cumulative (dis)advantage model will guide interpretation of the social relationship groups developed in the current study.

For clarity, the focus of this paper is social connectedness, a term that acknowledges diversity in conceptions and measures of social relationships. Consistent with the life course perspective and the cumulative (dis)advantage model, we focus specifically on age-relevant social connections at two points in the life course – parental relationships in childhood and multiple aspects of social connectedness in adulthood – to create life course typologies of social connectedness. Life course typologies of social connectedness that incorporate social relationships at multiple time points can help uncover unique patterns across time to further our understanding of the association between social relationships and health.

Diversity in Types and Quality of Social Connections

There are many formulations of social connectedness in existing literature, but they broadly sort themselves into three categories: structure, function, and quality (Holt-Lunstad, 2018). Most studies examining links between social connections and health have focused on structure and function. Structurally, social integration – having multiple points of connection to one's community (e.g., being married; number of friends; memberships in community organizations) – is associated with better health and greater longevity (Berkman et al., 2000; Holt-Lunstad et al., 2010). Social support (both perceived and received) is the most commonly assessed functional dimension of social connectedness, and support from family, friends, and/or partner has been widely shown to predict better health (Shor et al., 2013; Uchino, 2006). Less examined are the ways in which the quality of social connections is linked to health (Holt-Lunstad, 2018), and most studies to date have focused on the quality of marital relationships specifically; these have typically shown that better marital quality predicts better overall health (Robles et al., 2014; Ryan et al., 2014). Fewer studies have probed the quality of other types of relationships as a correlate of adult health. Those that have suggest a positive association between good relationship quality and better health (Rook & Charles, 2017). One aim of the current study is to advance our understanding of links between the quality of social connections in particular and adult health. To this end, in

addition to assessing social support and strain in adulthood (measures of both function and quality), we also assess positive relations with others (PRWO), a dimension of eudaimonic well-being (Ryff, 1989; Ryff & Keyes, 1995) capturing the extent to which people report having warm, committed, and trusting relationships with others.

Social connections can also be both positive and negative, and poor-quality social relationships can have adverse effects on health and can be a significant source of stress (Rook & Charles, 2017). Negative aspects of social relationships, such as conflict and strain, have harmful effects on physiological markers, morbidity, and mortality (see Brooks & Dunkel Schetter, 2011 for a review). In this study, we conceptualize "negative" features of social relationships as including social strain and parental discipline. We use this terminology because the bulk of the literature shows that social strain and parental discipline – specifically, harsh, physical, and overreactive discipline – have a wide range of negative outcomes (Mackenbach et al., 2014; Rook, 2015; Weiss et al., 1992). However, we acknowledge these relationship dimensions are not unequivocally detrimental for health and sometimes, counterintuitively, demonstrate positive health effects. For example, appropriate (as opposed to harsh, physical, or overreactive) discipline is positive for development and establishing boundaries in parent-child relationships (Grusec et al., 2017; Sege & Siegel, 2018). Additionally, in a nationally representative sample, higher levels of both social support and strain were associated with greater physical activity and better cognitive health (Thomas et al., 2022a; Thomas et al., 2022b).

Moreover, the effects of positive aspects of social relationships may depend on negative aspects, and vice versa. For example, positive features of relationships, such as social support, can buffer the detrimental effects of strained social interactions (Fiori et al., 2012; Walen & Lachman, 2000). Similarly, harsh parenting and high parental discipline seem to be more harmful when parental warmth is low (Beckmann, 2021; South & Jarnecke, 2015; Wang, 2019).

Positive aspects of social relationships can also buffer the impact of other negative influences on health. For example, maternal warmth during childhood has been shown to buffer the negative effects of childhood adversity (e.g., low socioeconomic status) on later-life immune function (Chen et al., 2011). Collectively, this work highlights the complexity of the association between social connections and health and the importance of examining both positive and negative relationship characteristics over time.

Classifying Life Course Relationships

A snapshot of social relationships is often not sufficient to understand the influence of social connectedness across the life course on health and well-being. Indeed, both childhood and adulthood social relationships are important for health in adulthood as outlined by the timing principle. However, few studies have examined social relationships across the life course as a predictor of adult health outcomes (see Singer & Ryff, 1999 and Yang et al., 2016 for some exceptions).

Creating groups, or typologies, of life course relationships can be advantageous because they allow researchers to move beyond examining single relationship attributes (e.g., social support) experienced at one or more point(s) in time, to capture the patterning of relationship experiences across multiple dimensions (e.g., positive and negative relationship characteristics) and multiple time points (e.g., childhood and adulthood). This approach is consistent with the call for person-oriented (as opposed to variable-oriented) analytic approaches (e.g., Lindwall et al., 2017). In general, a variable-oriented analysis is less able to capture the push and pull of different characteristics, experiences, or exposures of the person and how these patterns give rise to specific behaviors or health outcomes.

Person-centered approaches may be particularly informative when it comes to studying relationships (Whiteman & Loken, 2006). Consideration of both positive and negative relationship characteristics often predict health independently or above and beyond direct effects of either the positive or the negative characteristics of relationships (Ross et al., 2019). Some studies assess only social support or social strain, but not both, whereas other studies may measure both aspects but emphasize the strength of their independent associations with health outcomes. Although informative, these approaches do not fully capture how positive and negative aspects of relationships might work together to predict physical and psychological health and may miss unique relationship processes that can only be detected when multiple aspects of social relationships are considered together.

Methods for Classifying Life Course Relationships

Assessing social connectedness from a person-centered perspective can be accomplished in different ways. For example, sequence analysis and latent curve models are both sophisticated

techniques that have been used to examine life course trajectories of socioeconomic and health factors (Haas, 2008; Pollock, 2007). Broadly, several theoretical (e.g., life course cube; Bernardi et al., 2019) and statistical (e.g., event history analysis, sequence analysis; Piccarreta & Studer, 2019) approaches can be used to classify life course trajectories. These methods often differ in their theoretical concepts and goals (Piccarreta & Studer, 2019). Our aim in this study is to explore the properties of two specific approaches for classifying social relationships: 1) a priori, or theoretical, classification strategies, and 2) latent profile analysis (LPA), in which classifications arise from data patterns. We begin by discussing the strengths and weaknesses of each method.

A Priori Theoretical Classification Strategies

One common strategy to classify relationship phenomena across the life course is to create life histories based on predetermined criteria (e.g., Singer & Ryff, 1999; Whiteman & Loken, 2006). Drawing on the support for "long arm" effects (e.g., Lee et al., 2019), the present study includes an examination of the long-term association of childhood relationships with later-life health. Consistent with the cumulative (dis)advantage model, we also examine the accumulation of positive or negative social relationships over the life course and interpret trajectories of life-course social connectedness.

This theoretical approach has some distinct advantages. First, it is generally simple and straightforward to create the groups. Second, because groups are defined based on a theoretical framework, the groupings should be substantively meaningful and relevant to a specific research question. However, there are also disadvantages to this approach. Transforming continuous data into categorical data (e.g., dichotomizing a measure of support into "high" or "low") may lead to valuable information being lost. Additionally, creating groups based on specific relationship dimensions only allows the researcher to focus on a limited number of relationship attributes. For example, if four relationship attributes are dichotomized to "low" or "high", the resulting typology would include 16 groups, often too many for meaningful group comparisons. Further, the theoretical approach requires the researcher to categorize measures into categories that are typically understood as "good" (e.g., high on a positive attribute) or "bad" (high on a negative attribute). However, what we consider negative relationship attributes are not ubiquitously harmful and may even be beneficial in some circumstances, as mentioned above. Given the ambiguity of the role of certain levels and types of negative relationship features (particularly out of context),

there is not theoretical ground to dichotomize these negative measures. Thus, the focus of the theoretical approach is necessarily limited to positive relationship features.

The present study uses the life course perspective to create theoretically informed groups from positive relationship attributes. In conceptualizing life course trajectories, and acknowledging heterogeneity in aging (Ferraro, 2018), there are people who may be less advantaged during early life who nevertheless have positive health and social outcomes in later life (and vice versa). The principles of timing and lifespan development might guide researchers to categorize people into consistently high positive relationships (high positive childhood, high positive adulthood), consistently low positive relationships (low positive childhood, low positive adulthood), increasingly positive relationships (low positive childhood, high positive adulthood), and decreasingly positive relationships (high positive childhood, low positive adulthood).

Latent Profile Analysis

A second approach for creating life course trajectory groups is through latent profile analysis (LPA), which is a technique that allows groups to arise naturally from the data. The assumption underlying LPA is that there exist underlying clusters, or groups, of observations (i.e., people) that have similar values on specified indicators. Indicators can be continuous or categorical, so groups can take on any value rather than a categorical value imposed in the theoretical approach, better preserving the distribution of data. Additionally, the use of LPA does not force the researcher to impose a specific number of profiles or to restrict the number of relationship indicators. Compared to the theoretical approach, including four relationship attributes as indicators does not automatically result in a certain number of profiles, limiting the likelihood that "too many" groups will emerge from the data. Because of this, and since the LPA does not require a priori categorization of measures, the LPA technique permits the inclusion of both positive and negative dimensions of social relationships.

There are some drawbacks associated with LPA. Estimation can become difficult, and potentially meaningless, as the number of profiles grows, particularly if profiles include few individuals. Additionally, LPA can be sample-specific in that the optimal solution in one sample may differ from another sample. This can cast some doubt on the validity of one solution versus another. However, this concern is largely attenuated in the present study by using a large, national sample and input variables that are widely used measures.

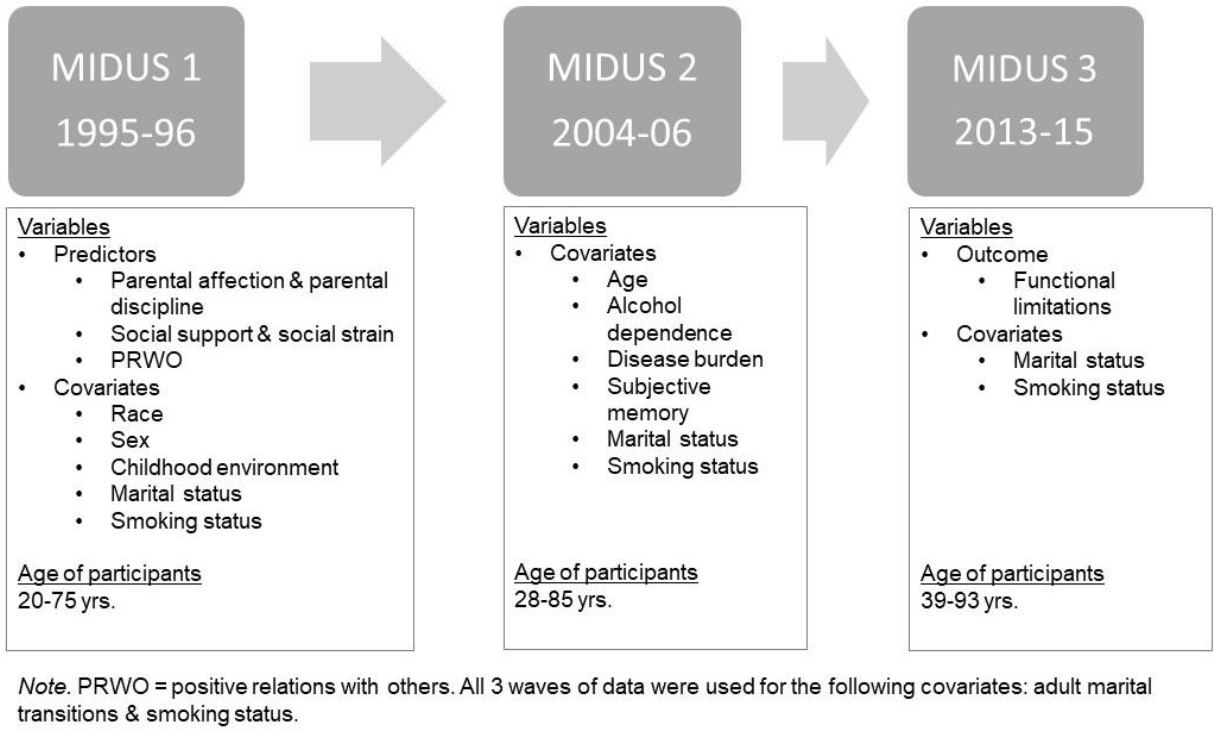
The Present Study

The present study is framed by the life course perspective and includes consideration of multivalent (both positive and negative) dimensions of social relationships. We examine whether a priori theoretically derived life-course relationship groups and empirically derived (i.e., LPA) profiles similarly predict later-life functional limitations. The a priori theoretically derived groups include only positively valanced relationship features for two main reasons. First, conceptually, the negatively valanced relationship factors included in this study (parental discipline and social strain) are more ambiguous to interpret and demonstrate mixed findings. Moreover, there is not strong theoretical ground for how to include discipline and strain. As mentioned above, compared to the positive relationship features, there are no clear cutoffs for discipline and strain so we cannot dichotomize them into "low" or "high" values in a meaningful way. Second, the emphasis on positive relationship features is consistent with the focus on relationship quality and the unique buffering effects of positively valanced relationship features. Therefore, we employ two empirical approaches. One LPA consisted of positive relationship measures (i.e., positive LPA) only as a direct comparison to the theoretically defined groups. The second included both positive and negative relationship dimensions (i.e., multivalence LPA) to determine whether including positive and negative valanced measures better predicted functional limitations compared to the positive LPA.

Aim 1 was to assess the utility of data-driven vs. a priori theoretical constructions of life course relationship groups in capturing relationship patterns across the life course, and to compare how the positive LPA profiles and positive theoretical groups predict later-life functional limitations. Aim 2 was to examine potentially different profile characterizations based on the valence of the relationship information included by comparing the multivalence LPA to the positive LPA. In both aims, we examine how each approach predicts later-life functional limitations and if groups differ on a pre-determined set of demographic, health, and childhood environment covariates. Both aims are exploratory, and results will help generate theoretical and methodological insights into our understanding of life course social connectedness. Specifically, results may inform the conceptualization of social relationships across the life course in future studies as well as broaden our understanding of the association between multiple dimensions of social relationships and later-life health.

Method

We used data from the Midlife in the United States (MIDUS) study. MIDUS is a national survey of the physical and mental health of middle-aged and older adults. The first wave of MIDUS data collection (MIDUS 1; N = 7,108) was completed in 1995-1996, and two follow-up studies (MIDUS 2 and MIDUS 3) were completed in 2004-2006 and 2013-2014, respectively. At MIDUS 1, participants ranged in age from 25 – 74 years. To improve racial/ethnic diversity in the MIDUS cohort, a new sample of African American residents of Milwaukee County, WI (n = 592) was recruited at MIDUS 2. Data collection at each wave involved a telephone interview and self-administered questionnaire (SAQ). The present study uses data from all three waves of MIDUS, including the Milwaukee sample (see Figure 1).



Note. PRWO = positive relations with others. All 3 waves of data were used for the following covariates: adult marital transitions & smoking status.

Figure 1. Timeline of Variables Used and Age of Participants

Measures

Example items for each main variable are included below, and all items can be found on OSF (social relationship variables in M1 documentation; functional limitations in M3 documentation). Summary tables of each of the variables used in the present study are on pp. 2-8 of the Technical Report on OSF.

Social Connectedness

We considered five dimensions of social connectedness, spanning both childhood (parental affection, parental discipline) and adulthood (social support, social strain, positive relations with others).

Parental Affection and Discipline. Parent-child relationships were measured retrospectively at MIDUS 1 (MIDUS 2 for the Milwaukee sample) using maternal and paternal affection and discipline scales (Rossi, 2001). Maternal affection ($\alpha = .91$) and paternal affection ($\alpha = .93$), as well as maternal discipline ($\alpha = .77$) and paternal discipline ($\alpha = .83$), were assessed separately. The affection scales contained 7 items (e.g., "How much love and affection did [s]he give you?") and the discipline scales comprised 4 items (e.g., "How harsh was [s]he when [s]he punished you?"). Responses ranged from 1 (not at all) to 4 (a lot) for all the discipline items and six of the affection items, while the seventh affection item ranged from 1 (poor) to 5 (excellent) and asked respondents to rate their relationship with each parent during their childhood. Following MIDUS protocol (see M1 documentation on OSF), this item was multiplied by a .75 factorial to maintain continuity with other items. For the present study, we created a parental affection score by averaging the maternal and paternal affection scales; similarly, we created a parental discipline score by averaging the maternal and paternal discipline scales. Scores for parental affection and parental discipline ranged from .96 – 3.96 and 1 – 4, respectively. These scales have previously been used in examination of social relationships as protective factors using MIDUS data (Schuster et al., 1990).

Perceived Social Support and Social Strain. Participants' social support and social strain were assessed at MIDUS 1 (MIDUS 2 for the Milwaukee sample) across three domains: family, spouse/partner, and friends. Four items were used for both support and strain for family and friends; 6 items were used for support and strain for spouse/partner. Example items for support included

"How much can you open up to them if you need to talk about your worries?" and "How much can you rely on them for help if you have a serious problem?". Example items for strain included "How often do they criticize you?" and "How often do they get on your nerves?". Responses ranged from 1 (not at all) to 4 (a lot) and participants' responses to items for support and strain from family, spouse/partner, or friend (6 scales total) were averaged separately (social support range 1.25 – 4; social strain range 1 – 4). Reliability coefficients for family, spouse/partner, and friend support were .84, .90, and .88, respectively. Reliability coefficients for family, spouse/partner, and friend strain were .79, .87, and .79, respectively. Participants' responses related to support and strain were then averaged across domains (i.e., spouse, friends, family) to create one total social support score and one total social strain score, similar to a prior study using MIDUS data showing associations between aggregate measures of social support/strain and health outcomes (Walen & Lachman, 2000).

Positive Relations with Others. Participants also reported on quality of relationships using the 3-item version of the positive relations with others (PRWO; $\alpha = .59$) sub-scale from the Ryff Psychological Well-Being Scales (Ryff, 1989; Ryff & Keyes, 1995). This measure assesses the extent of having satisfying relationships with others (e.g., "I have not experienced many warm and trusting relationships with others" [reverse coded]). Responses ranged from 1 (strongly disagree) to 7 (strongly agree), and item responses were averaged (range 1 – 7).

Functional Limitations

In the SAQ at MIDUS 3, all participants were asked how much their health limited their ability to perform a set of eight mobility-related activities (e.g., climbing one flight of stairs). Items were from the Physical Functioning subscale from the SF-36 Health Survey (Ware & Sherbourne, 1992). Item responses (1 = not at all; 4 = a lot) were averaged for each participant (range 1 – 4).

Covariates

Covariates included demographics, health behaviors, adult marital transitions, health conditions, and childhood environment. These specific covariates were chosen based on established associations with social connectedness and/or functional limitations. For example, women (Freedman et al., 2016; Johnson & Wiener, 2006), smokers (Strand et al., 2011), and heavy

alcohol users (Cawthon et al., 2007; Moore et al., 2003) are known to be at higher risk for functional limitations in mid- and later-life. Experiencing marital transitions, particularly into widowhood, is also a risk factor for developing limitations (van den Brink et al., 2004). Chronic disease burden (Friedman et al., 2019; Teas et al., 2021) and subjective memory (Blankevoort et al., 2013) are highly positively correlated with functional limitations. Residential instability and parental divorce during childhood are both associated with parent-child relationships (Riina et al., 2016; Zill et al., 1993) and later-life relationships (Amato & Sobolewski, 2001).

Demographics. A continuous variable for participants' age was used. Dichotomous variables were used for sex (1 = female), marital status at MIDUS 1 (1 = married), and race (1 = white). We opted to collapse the race variable due to lack of racial diversity; of the participants who did not report being white, about 75% identified as Black.

Health Behaviors. A dichotomous variable was used to indicate whether participants reported being a smoker at any of the three waves (1 = yes). We used a count variable to represent participants' alcohol dependence at MIDUS 2, which consisted of a sum of 6 potential alcohol problems, similar to Magidson et al., 2017. Four items (e.g., emotional or psychological problems as a result of use, strong desire or urge to drink) were measured dichotomously (1 = yes). Two additional questions (drinking more or using longer than intended and being under the effects of alcohol at work or school) were rated on a 6-point scale (1 [never] to 6 [more than 20 times]), which were dichotomized (0 = never, 1 = all other responses), consistent with the original scoring. The alcohol dependence score ranged from 0 – 6.

Adult Marital Transitions. We created marital transition variables to indicate whether or not they occurred at any point between MIDUS 1 and MIDUS 3. Transitions included divorce, widowhood, and marriage. All three variables were dichotomous (1 = known occurrence). Participants whose marital status did not change or who only had data at MIDUS 1 were coded as 0 for all three variables.

Health Conditions. Functional decline often results from disease, particularly chronic disease. Burden of chronic medical conditions was assessed using a weighted index (Wei et al., 2016). A total of 26 chronic conditions from the phone survey and SAQ were assigned weights based on their propensity to result in disability, with weights ranging from -.068 for skin cancer to 10.6 for multiple sclerosis; the aggregate weighted score (range: -.068-32.912) was used as an index of disease burden. Due to the positive associations between cognitive and functional health

(Blankevoort et al., 2013; Sprague et al., 2019; Voelcker-Rehage et al., 2010), we also included subjective assessments of memory. In the MIDUS 2 SAQ, all participants reported how their memory compared to others their age (range: 1-5; 1 = poor, 5 = excellent) and to their own memory 5 years earlier (range: 1-5; 1 = gotten a lot worse, 5 = improved a lot).

Childhood Environment. Recalled family stability may influence reports of childhood relationships with parents. Similar to prior work (Bures, 2003; Slopen et al., 2017), we created a dichotomous residential instability variable, where residential instability is characterized by ≥3 number of times moved to a new neighborhood or town during childhood. We also used dichotomous measures of parental divorce/separation (1 = parents divorced/separated during childhood) and parental death (1 = mother and/or father died during childhood).

Analytic Strategy

We first examined the distribution of all variables and bivariate correlations for variables of interest. We also confirmed linearity of associations between predictors and outcome. The functional limitations outcome variable was positively skewed, and we opted to log transform it to normalize the distribution to meet assumptions of the regression models predicting functional limitations. All code and analytic decisions are available at OSF.

Theory-Based Groups

As noted above, creating theory-based groups involves dichotomizing each measure into "high" or "low" categories, and then assigning participants into key theoretical groups based on their values of each dichotomized measure. We determined the cutoff point for each measure based on scale items. For example, the response options for the parental affection scale included not at all (1), a little (2), some (3), and a lot (4). We categorized participants as "positive" on the parental affection measure if their average score was 2.5 or higher, as this would indicate that they mostly reported some or a lot of affection (i.e., the presence of affection). Similar strategies were adopted for each of the relationship measures. See Table 2 for a contingency table for theoretical group assignment.

Table 2. Contingency Table of Theoretical Groups (n = 6834)

	Affection		Support		PRWO
Consistently high positive (n = 5162)	+	AND	+	OR	+
Consistently low positive (n = 148)	-	AND	-	AND	-
Increasing positive (n = 1426)	-	AND	+	OR	+
Decreasing positive (n = 98)	+	AND	-	AND	-

Note. PRWO = Positive relations with others
Affection + > 2.5, - ≤ 2.5; Support + > 2.5, - ≤ 2.5; PRWO + > 4, - ≤ 4

Latent Profile Analyses

Mplus software (version 8.8; Muthén & Muthén, 2022) was used to estimate both LPAs. Model parameters were computed using maximum likelihood estimation. For the first aim, the indicator variables for the positive LPA included parental affection, social support, and PRWO to mirror the theoretical approach. For the second aim (multivalence LPA vs. positive LPA), the indicator variables for the multivalence LPA comprised the same positive relationship variables plus parental discipline and social strain.

We estimated the LPAs in several steps to identify the optimal number of latent profiles. We compared a sequence of nested models to determine if more complex models (with more profiles) fit the data better than more parsimonious models (with fewer profiles). We tested models with one to nine profiles. Based on recommendations from prior research, several criteria were used to determine the optimal number of profiles (Henson et al., 2007; Nylund et al., 2007; Ram & Grimm, 2009). The Akaike Information Criteria (AIC), the Bayesian Information Criterion (BIC), and the sample-size adjusted BIC (SSA-BIC) were examined, with lower values indicating better model fit. The Lo-Mendel-Rubin Adjusted likelihood ratio test (LMR Adj-LRT) and the Bootstrapped Likelihood Ratio Test (BLRT) were used to compare the fit of a k-profile solution to a k-1-profile solution, where a statistically significant p-value supports the k-profile solution.

The entropy criterion was examined to assess classification accuracy. Ranging from 0 to 1, a higher entropy value indicates a better fit for a given solution. Although subject to interpretability and theory, a good rule of thumb when judging the usefulness of the profiles is that each latent profile should include at least 5% of the total number of participants (Stanley et al., 2017). The resulting profiles should also make sense theoretically (Lubke & Muthén, 2005), so we examined the mean scores of each of the variables across profiles to assess profile distinctiveness.

Comparison of Approaches

We compared a) the positive LPA and theory-based approach (Aim 1) and then b) the two LPAs (Aim 2). Specifically, we examined the composition of groups by creating crosstabs of participant distributions. To assess certain characteristics (e.g., age, sex, childhood environment) of each group, we examined the mean of each covariate for each group for each classification strategy. We used t-tests and chi-squared tests to determine if group means significantly differed from the overall mean.

To determine whether one approach better predicted functional limitations, we modeled the connectedness groups predicting functional limitations, including all covariates, in Mplus. For the theoretical groups, we ran a multiple group analysis. For the LPAs, we used the manual Bolck-Croon-Hagenaars (BCH) method, which accounts for the uncertainty of profile membership (i.e., measurement error) and prevents class shifting when including auxiliary variables (Asparouhov & Muthén, 2014). For all approaches, we used loglikelihood comparisons to determine whether constraining functional limitations across certain classes resulted in a better or worse fitting model. Specifically, we compared the fit statistics of the unconstrained model (i.e., functional limitations mean and variance could differ across each group) to a model in which the functional limitations mean and variance were constrained to be equal across two groups (e.g., profiles 1 and 2); if the constrained model was better fitting than the unconstrained model, this would suggest that functional limitations were not significantly different across profiles 1 and 2. We followed this approach for each combination of groups. The goal was to determine whether one approach was more sensitive in differentiating between groups' predicted functional limitations. In other words, the approach that resulted in more models that could not be constrained based on the functional limitations intercept was judged to be a better predictor of functional limitations.

Results

Overall, participants reported moderately high levels of affection (M = 2.98, SD = .65) and discipline (M = 2.94, SD = .60), high levels of social support (M = 3.38, SD = .49), low levels of social strain (M = 2.07, SD = .47), and high levels of PRWO (M = 5.38, SD = 1.37). Most participants reported no or few difficulties with performing daily activities, but almost a third of participants reported at least a few difficulties (functional limitations M = 1.76, SD = .87).

Table 3 shows the descriptive statistics and correlations among the five relationship variables and the functional limitations outcome. Parental affection and discipline were positively correlated (r = .20, p < .001). Social support was negatively associated with social strain (r = -.38, p < .001). Among the relationship variables, the only non-significant correlation was between parental discipline and PRWO. All of the relationship variables were significantly correlated with functional limitations. In the following sections, we detail each of the three approaches and their corresponding aim.

Table 3. Correlation Table of Relationship Variables and Functional Limitations (n = 6909)

	Affection	Discipline	Support	Strain	PRWO
Discipline	.20***				
Support	.34***	.05***			
Strain	-0.21***	.07***	-.38***		
PRWO	.28***	.01	.46***	-.26***	
FL	-.05*	.04*	-.11***	.08***	-.09***
Mean	2.98	2.94	3.38	2.08	5.38
SD	0.65	.60	.49	.47	1.37
Range	0.96 – 4.0	1 – 4	1 – 4	1 - 4	1 - 7

Note. PRWO = positive relations with others; FL = functional limitations
*p < .05; **p < .01; ***p < .001

Positive Theoretical Groups

Using the contingency table described in the Analytic Strategy (Table 2), we assigned participants to a priori determined relationship groups based on their scores on parental affection, social support, and PRWO. This approach resulted in 4 groups. The first group (n = 5162), labeled *consistently high positive* (i.e., *high positive*), was the largest group. Participants who reported low scores for all three relationship dimensions were placed into the *consistently low positive* (i.e., *low positive*) group (n = 148). Participants who reported low parental affection but high social support or high PRWO were assigned to the *increasing positive* group (n = 1426). Finally, the decreasing positive group (n = 98) consisted of participants who reported high parental affection but low

social support and PRWO. There were 75 participants who did not meet the criteria for any of the theoretical groups, thus bringing the sample size to 6,834.[1]

Covariates

Participants in the *high positive* group were more likely to be married at baseline, Black, and male. In contrast, participants in the *increasingly positive* group were more likely to be white and female. Participants in the *high positive* group were less likely to report alcohol abuse or be smokers (and vice versa for the *low positive* group). There were additional group differences for experienced divorce, disease burden, subjective memory, residential instability, and parental divorce/separation. Figure 2 shows the significant differences across all four groups. See Appendix A, Table A.1. for the specific covariate means and SDs.

Predicting Functional Limitations

We ran a multiple group analysis in Mplus, modeling the same pathways as with the data-driven groups. To compare results against the positive LPA, we used a similar baseline model: covariate regression coefficients and covariate correlations were constrained across groups, and covariate means and variances could differ across groups. Using log likelihood comparisons, results suggested that functional limitations could be constrained across all groups (see Table 7A on OSF). In other words, no group was significantly different from another group in terms of predicted functional limitations intercepts.

Positive LPA

We used step 1 of the BCH method to identify the latent profiles for the positive LPA. For clarity, we present the fit statistics and group numbers for the first 5 models tested in Table 4 (for all 9 models tested, see OSF). Using model fit criteria and interpretability, we selected the 4-profile solution. Although the entropy was higher for the 5-profile solution, the LMR Adj-LRT was no longer significant (p = .08). Additionally, the smallest group for the 5-profile solution consisted of

[1] When we performed the latent profile analysis on this subsample (n = 6,834), the results were the same as the full sample (n = 6,909), and the 4-profile solution was considered optimal. See Table 6 in OSF for the fit statistics.

229 participants (about 3.3% of the sample), whereas the smallest group for the 4-profile solution comprised about 9% of the sample, representing a more interpretable and reliable group. A plot of the indicator variable means for each profile is shown in Figure 3A.

Profile 1 (*n* = 3786) represents an *optima*l profile, with average parental affection and high PRWO and support. Profile 2 (*n* = 629) is characterized by the *least optimal* relationship characteristics: low affection and PRWO and very low support. Profiles 3 and 4 both reported average affection, but Profile 3 (*n* = 625; *average + low support* profile) reported average PRWO and low support, and profile 4 (*n* = 1869; *average + low PRWO* profile) reported average support but low PRWO.

Table 4. Summary of Model Fit for Positive Latent Profile Models (*n* = 6909)

# classes	AIC	BIC	SSA-BIC	Entropy	p-value for LMR Adj- LRT	Groups
1	46468.702	46509.746	46490.679	-	-	-
2	43525.849	43594.255	43562.477	0.76	< .001	1 - 2328 2 - 4581
3	42659.095	42754.863	42710.375	0.76	< .001	1 - 637 2 - 2029 3 - 4243
4	**42122.691**	**42245.822**	**42188.622**	**0.76**	**< .001**	**1 - 3786** **2 - 629** **3 - 625** **4 - 1869**
5	41611.888	41762.381	41692.47	0.85	0.08	1 - 229 2 - 392 3 - 2092 4 - 3176 5 - 1020

Note. The chosen model is displayed in bold. AIC = Akaike information criteria; BIC = Bayesian information criteria; SSA-BIC = sample-size adjusted BIC; LMR Adj-LRT = Lo-Mendell-Rubin adjusted likelihood ratio test.

Covariates

Participants in the *optimal* profile were more likely to be older, white, married at baseline, and female; they were less likely to be smokers. These participants reported significantly less alcohol abuse, lower disease burden, and better subjective memory. In terms of childhood environment, participants in the *optimal* profile reported significantly less residential instability

and parental divorce/separation. Figure 2 shows the significant differences for all four profiles. See Appendix A, Table A.1. for the specific covariate means and SDs.

Predicting Functional Limitations

Step 2 of the BCH method was used to model the 4-profile LPA solution predicting later-life functional limitations. Using the optimal baseline model[2], we used loglikelihood comparisons to determine whether constraining functional limitations across certain classes resulted in a better or worse fitting model. Results (Table 7B on OSF) suggested two groups could not be constrained: the *optimal* and *least optimal* profiles, and the *optimal* and *average + low PRWO* profiles. The predicted functional limitations intercept was significantly lower for the *optimal* profile (0.95) compared to the *least optimal* profile (1.04, $p < .001$) and the *average + low PRWO* profile (1.02, $p < .01$). Table 6 and Figure 4 on OSF show the predicted intercepts and significant comparisons.

[2] The BCH default is for all covariate correlations to be constrained across classes. Given that we had no prior hypotheses about the covariate correlations, we kept the default setting and did not allow these to vary across classes. We used log likelihood comparisons to compare various model constraints to an unconditional model to determine the best fitting baseline model. Constraints involved the covariate regression coefficients, means, and variances. Log likelihood comparisons suggested that covariate regression coefficients should be constrained but all covariate means and variances could differ across profiles. Data showing the model comparisons can be found in Table 8 on OSF.

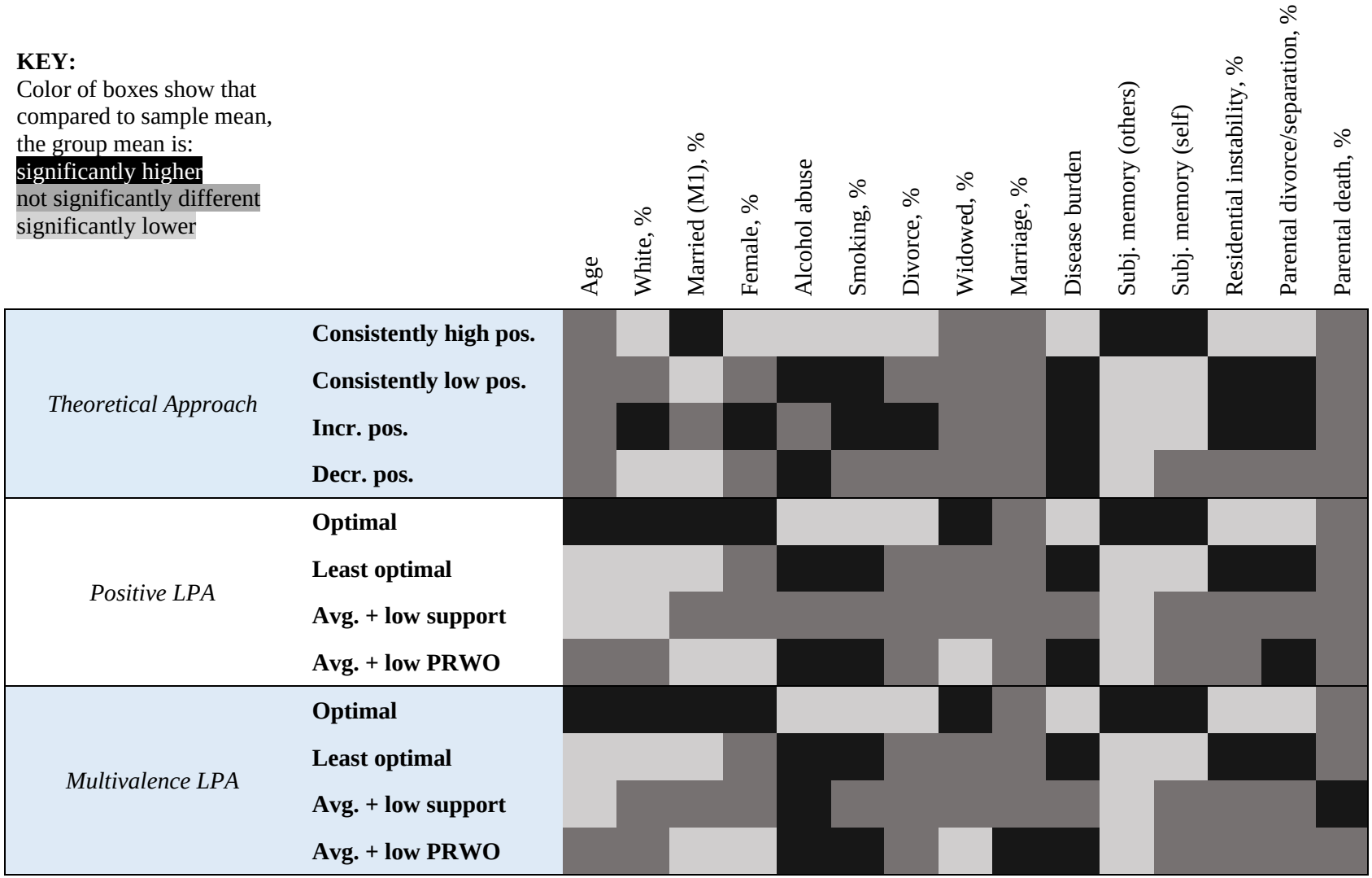


Figure 2. Heat Map of Covariates Across Groups for Each Approach

Multivalence LPA

Step 1 of the BCH method was used to identify the latent profiles. We present the fit statistics and group numbers for the first 5 models tested in Table 5 (for all 9 models tested, see OSF). Using model fit criteria and interpretability, we selected the 4-profile solution. Although the entropy was higher and the LMR Adj-LRT was significant for the 5-profile solution, the 4-profile solution was considered optimal for two main reasons. First, the smallest group for the 5-profile solution consisted of 195 participants (about 2.8% of the sample). The smallest group for the 4-profile solution comprised roughly 10% of the sample, representing a more interpretable and reliable group. Second, the percentage change in SSA-BIC, an indicator of how much the fit is improving as number of profiles increases, was roughly the same when moving from 2 to 3 profiles and from 3 to 4 profiles but was reduced by half when moving from 4 to 5 profiles. This suggests the improvement in fit after the 4-profile solution is less substantial. A plot of the indicator variable means for each profile is shown in Figure 3B.

Table 5. Summary of Model Fit for Multivalent Latent Profile Models (*n* = 6909)

# classes	AIC	BIC	SSA-BIC	Entropy	p-value for LMR Adj-LRT	Groups: *n*
1	68144.462	68212.868	68181.09	-	-	-
2	64441.959	64551.409	64500.564	0.75	< .001	1 - 5207 2 - 1702
3	63571.57	63722.062	63652.152	0.72	< .001	1 - 558 2 - 2409 3 - 3942
4	**62860.269**	**63051.806**	**62962.828**	**0.74**	**< .001**	**1 - 3551** **2 - 719** **3 - 889** **4 - 1750**
5	62519.05	62751.63	62643.586	0.76	0.01	1 - 808 2 - 1552 3 - 3340 4 - 195 5 - 1014

Note. The chosen model is displayed in bold. AIC = Akaike information criteria; BIC = Bayesian information criteria; SSA-BIC = sample-size adjusted BIC; LMR Adj-LRT = Lo-Mendell-Rubin adjusted likelihood ratio test.

The profiles for the multivalence LPA matched those from the positive LPA. Profile 1 (*n* = 3551) represents an *optimal* profile, with average parental discipline and affection, high PRWO and support, and average strain. Profile 2 (*n* = 719) is characterized by the *least optimal* relationship characteristics: average discipline, low affection, low PRWO, very low support, and high strain. Profiles 3 and 4 both reported average discipline, affection, and strain, but profile 3 (*n* = 889; *average + low support* profile) reported average PRWO but low support, and profile 4 (*n* = 1750; *average + low PRWO* profile) reported average support but low PRWO.

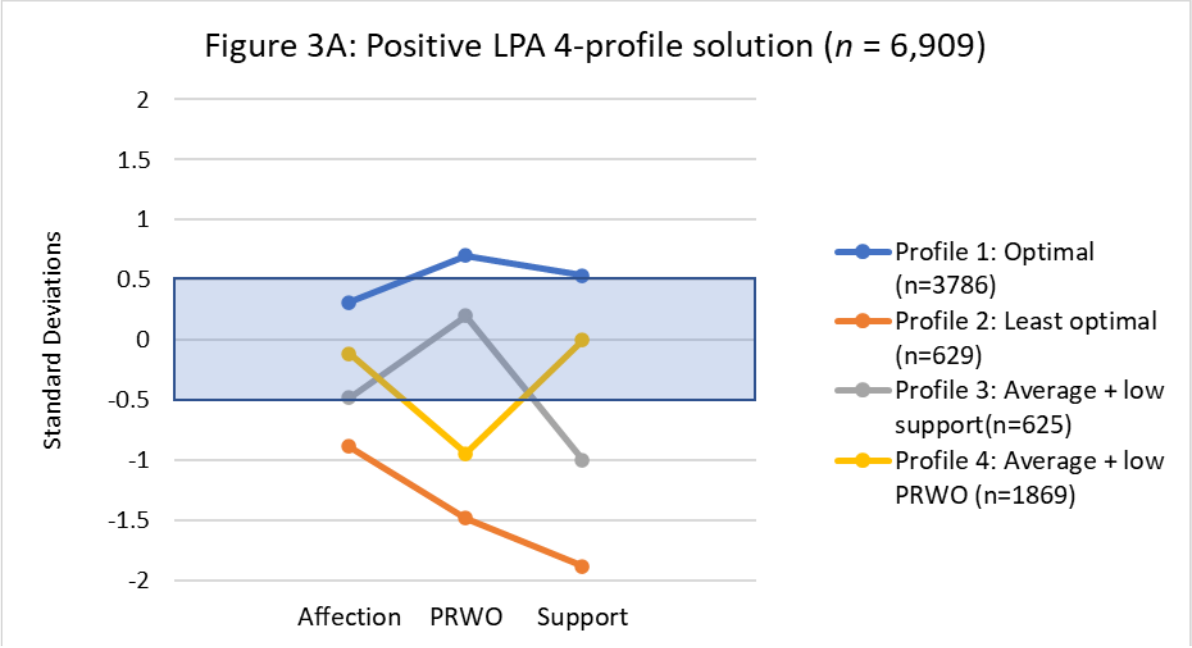
Covariates

Participants in the *optimal* profile were more likely to be older, white, married at baseline, and female. Participants in the *least optimal* and the *average + low support* profiles were more likely to be younger and less likely to be white. Moreover, participants in the *least optimal* profile reported higher levels of childhood residential instability and parental divorce/separation. Figure 2 shows the significant differences for all four profiles. See Appendix A, Table A.1. for the specific covariate means and SDs.

Predicting Functional Limitations

Step 2 of the BCH method was used to model the 4-profile LPA solution predicting later-life functional limitations. For the sake of comparison, we adopted the same baseline model (i.e., covariate regression coefficients constrained across classes, covariate means and variances could differ). As the default, covariate correlations were constrained across classes.

Log likelihood comparisons (Table 7C on OSF) suggested three contrasts could not be constrained: the *optimal* and *least optimal* profiles, the *optimal* and *average + low PRWO* profiles, and the *optimal* and *average + low support* profiles. The predicted functional limitations intercept was significantly lower for the *optimal* profile (0.94) compared to the *least optimal* (1.03, $p < .001$), the *average + low PRWO* (1.03, $p < .001$), and the *average + low support* (1.00, $p = .045$) profiles. Table 6 and Figure 4 on OSF show the predicted intercepts and the comparisons that were significant.



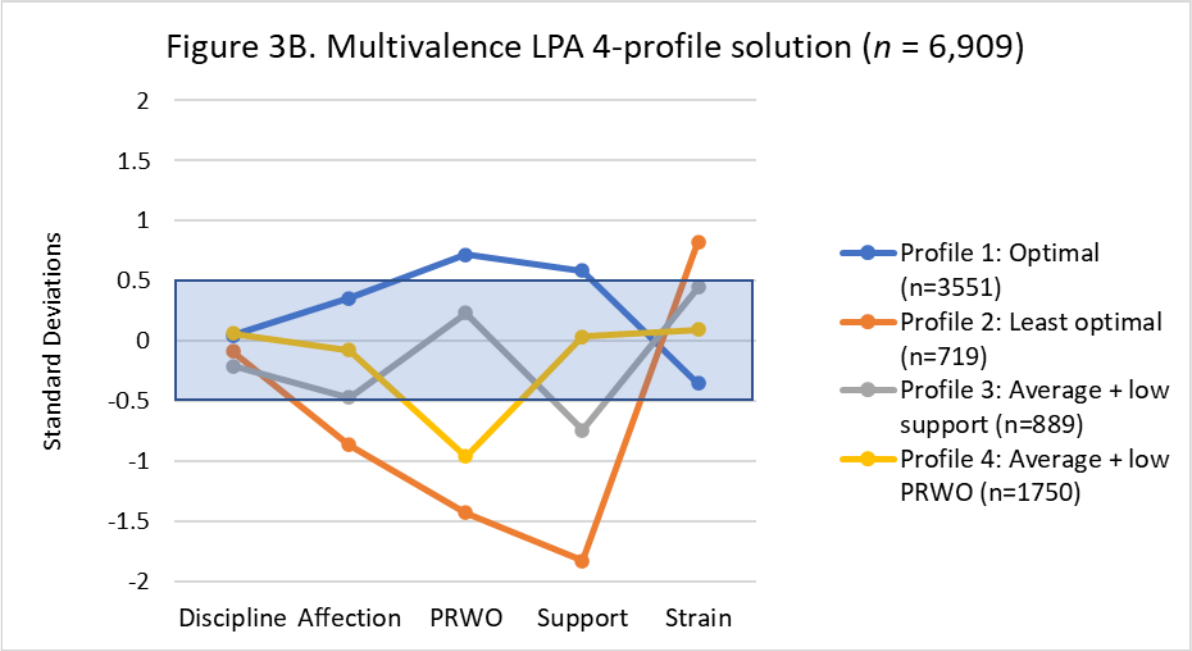


Figure 3. LPA Solutions for Positive LPA and Multivalence LPA

Note. PRWO = positive relations with others. The shaded box in the middle represents average scores between -0.5 and 0.5 SDs from the mean; values outside of this range indicate what we consider high/low.

Table 6. Predicted Functional Limitations Intercepts

		FL intercept	
		Model 1	*Post-Hoc*
Multivalence LPA	*Optimal*	0.939883 [a, b, c]	0.721805 [a, b, c]
	Least optimal	1.033551	0.890475
	Avg. + low support	1.003005	0.80493 [a]
	Avg. + low PRWO	1.032518	0.829444 [a]
Positive LPA	*Optimal*	0.953134 [a, c]	0.733447 [a, b, c]
	Least optimal	1.042894	0.903933
	Avg. + low support	1.016129	0.815462
	Avg. + low PRWO	1.02429	0.824482 [a]
Theoretical Approach	*High positive*	1.020201	0.800115
	Low positive	1.018163	0.871099 [d]
	Incr. positive	1.026341	0.832768 [d]
	Decr. positive	1.006018	0.872843

Note. FL = functional limitations. All pairwise comparisons were made within each approach. Model 1 = all covariates included; Post-Hoc = potential pathway covariates (smoking, alcohol dependence, disease burden, subjective memory, adult marital transitions) removed. Superscripts represent significant differences with indicated group at the $p<.05$ level: [a]least optimal; [b]avg. + low support; [c]avg. + low PRWO; [d]high positive

Aim 1: Comparison of Positive Theoretical Approach to Positive LPA

For parsimony, we compare the *optimal* profile from the positive LPA to the *high positive* group from the theoretical approach, and the *least optimal* profile to the *low positive* group. However, the remaining two profiles from the LPA do not conceptually map on to the two remaining groups from the theoretical approach.

Appendix A, Table A.2. shows a cross tab of participant distribution across approaches. Compared to the *optimal* profile (n = 3786) from the positive LPA, considerably more participants were placed in the *high positive* (n = 5162) theoretical group. Notably, the *high positive* group was over 35% larger than the *optimal* profile. Participants in the *high positive* group primarily came from the *optimal* profile and the *average + low PRWO* profile. The *low positive* and *decreasing positive* groups were both small; members of these two groups belonged to only the *least optimal* profile from the positive LPA. The *increasing positive* group comprised participants from all four LPA profiles, primarily the *average + low PRWO* and *optimal* profiles.

Similar to the *optimal* profile from the positive LPA, the *high positive* theoretical group was more likely to be married. However, although the *optimal* profile was more likely to be older,

white and female, the *high positive* group was less likely to be white and more likely to be male (and showed no significant difference for age). The means for the health behaviors and health outcomes, although slightly varied across approaches, were consistent in that the *optima*l profile and *high positive* group reported the "better" means (e.g., less alcohol abuse, better subjective memory) and the *least optimal* profile and *low positive* group reported the "worse" means (e.g., more alcohol abuse, worse subjective memory). See Appendix A, Table A.1.

The theoretical approach did not identify any significant differences in predicted functional limitations intercepts across groups. Compared to the positive LPA, there was less variation in functional limitations across the theoretical groups (range: 1.01 – 1.03; see Table 6). Specifically, the *high positive* group had a higher predicted functional limitations intercept than the *optimal* profile in the positive LPA, thus hindering the likelihood of identifying significant differences among the groups, particularly since the significant differences for the positive LPA were between the *optimal* profile and one of the other profiles.

Aim 2: Comparison of Positive LPA to Multivalence LPA

Although the multivalence and positive LPAs both resulted in 4-profile solutions, the composition of those profiles did vary. Appendix A, Table A.3. shows a cross tab of participant distribution across LPA approaches. The largest shift (n = 225) occurred for participants who were assigned to the *optimal profile* for the positive LPA but moved to the *average + low support* profile when parental discipline and social strain measures were added for the multivalence LPA. Comparing scores for those who stayed in the same profile across the two LPAs to those who switched to a different profile when discipline and strain were added, a few findings emerged (see pp. 27-28 of the Technical Report on OSF). First, scores on discipline were not meaningfully different for participants who switched profiles compared to those who did not switch. Second, participants who switched profiles reported strain scores that differed from those who did not switch, suggesting some within-group differences in strain. Finally, adding discipline and strain in the multivalence LPA helped tease apart more nuanced differences in some of the positive relationship dimensions. For example, participants who were in the *average + low PRWO* profile for both LPAs reported lower PRWO than those who switched from the *average + low PRWO* profile to the *optimal* or the *average + low support* profiles in the multivalence LPA.

The covariates mapped onto the positive LPA profiles in similar ways as the multivalence LPA profiles (see Figure 2). For example, although the covariate means slightly differed for some variables, the *optimal* profile was more likely to be older, white, married at baseline, and female for both approaches. Moreover, although the two LPA approaches show some differences in terms of which covariates are significantly different from the sample mean, the actual covariate values are the same or very similar (Appendix A, Table A.1.).

The multivalence LPA suggested one additional, though trivial, significant difference (the *optimal* profile vs. the *average + low support* profile) compared to the positive LPA. The predicted functional limitations intercept for the *average + low support* profile was similar across LPAs (1.00 for the multivalence LPA, 1.02 for the positive LPA). Moreover, the p-values for this specific contrast were similar across LPAs (.045 for the multivalence, .056 for the positive; Tables 7B and 7C on OSF) but only one reached significance. Although the multivalence LPA detected one more significant difference than the positive LPA, the LPAs do not appear to meaningfully differ in predicted functional limitations.

Post-Hoc Analysis

It is possible that some of the covariates of interest are on the causal pathway between social relationships and functional limitations (i.e., are mediators; see Limitations). To account for this possibility, we compared the approaches with only the demographic and childhood environment covariates (i.e., age, sex, race, marital status at baseline, residential instability, parental divorce/separation, and parental death). In this post-hoc analysis, the predicted functional limitations intercepts and resulting group comparisons differed (see Table 6). Overall, all predicted functional limitations intercepts were lower when fewer covariates were included. Compared to the model with all covariates, two additional significant group differences emerged for each of the three approaches when we removed the potential pathway covariates (i.e., smoking, alcohol dependence, disease burden, subjective memory, and adult marital transitions).

Discussion

Past research has highlighted the significant, albeit complex, association between relationships and health across the life course. The present study advanced this work by examining

three analytic approaches that account for life course trajectories of social relationships and their associations with later-life functional limitations. Our findings suggested that the data-driven approach was a stronger predictor of functional limitations than the theoretical approach. Moreover, comparing the two LPA approaches, the positive relationship indicators performed equally well as the multivalent relationship indicators.

Theory vs. Positive LPA

Our first aim compared the a priori theoretical approach to the positive LPA approach. Overall, the theoretical approach revealed different patterns of association compared to the data-driven approach. Specifically, some demographic covariates substantially varied across approaches; most notably, the *consistently high positive* group in the theoretical approach was less likely to be white and female, whereas the *optimal* LPA profile was more likely to be white and female. Despite some demographic differences, the theoretical groups were similar to the LPA profiles on several health measures. For example, both the *high positive* group and *optimal* profile reported significantly less alcohol abuse and smoking; less disease burden; and better subjective memory. Finally, compared to the data-driven approach, the theoretical approach was less sensitive in detecting significant differences in functional limitations.

These results suggest that the data-driven approach was more discriminating than the theoretical solution. Moreover, the group assignment across approaches varied considerably. As noted in the results, the criteria used for the theoretical approach resulted in a *high positive* group that was over 35% larger than the *optimal* profile from the positive LPA. A majority of the participants in the *average + low PRWO* profile from the LPA were placed into the *high positive* group for the theoretical approach. Thus, one possible explanation for why the theoretical approach was less discriminating overall is that there is something inherently different about participants in the *average + low PRWO* profile. Based on the criteria used in the theoretical approach, participants could be placed into the *high positive* group if they reported high levels of parental affection and high levels of social support, regardless of their scores on PRWO. One interpretation of our findings is that the PRWO relationship measure is tapping into something unique and influential, potentially driving differences in functional limitations and some of the covariates. Because PRWO is a measure of relationship quality, this highlights the importance of considering

relationship quality (outside of the marital domain) to understand associations between social relationships and health.

Valence of Relationships

With our second aim, we sought to compare LPA approaches that included differently valanced relationship information. Overall, the LPA approaches were very similar to each other in terms of covariates and ability to predict later-life functional limitations.

Prior research suggests that including multivalent relationship information can often be more informative than including only positive or only negative aspects of relationships (e.g., Rook, 2015). In the present study, the multivalence LPA included the same measures as the positive LPA with the addition of parental discipline and social strain. Although social strain did yield some differences in profile characterizations, results suggested that the parental discipline measure did not contribute much to the distribution of the profiles. There are several reasons why this may have been the case.

Some research suggests only fair agreement between adolescents' self-reports and their adult retrospective reports of parental discipline practices (Offer et al., 2000; White et al., 2007), and recall of negative childhood experiences may be particularly susceptible to memory inaccuracy (Raphael et al., 2001). Moreover, parental characteristics, child temperament, and social context may all contribute to the type and frequency of discipline used (Wade & Kendler, 2001), as well as the consequence of the discipline. Perhaps most importantly, the retrospective measure of parental discipline in the present study was likely too non-specific to be informative. Although there is extensive research documenting the effects of specific types of discipline (e.g., harsh discipline; Mackenbach et al., 2014), the discipline items used in this study were more general and did not tap into an unambiguous, well-studied type of discipline. In other words, the discipline measure may not have been contextualized enough to be useful.

Application of Theory

Much of the existing research on social connectedness and health is limited in its narrow conceptualization of social relationships. For example, most of the literature on social relationships and functional limitations focuses on one stage of the life course (often exclusively on older

adulthood; e.g., Ryan et al., 2014; Thomas, 2011). Research has consistently shown that social connectedness in adulthood is inversely related to functional limitations and protects against functional decline (e.g., Choi et al., 2016; Lachman & Agrigoroaei, 2010; Thomas, 2011). The present study extends this work by including social relationships in childhood *and* adulthood to examine how life course relationship typologies predict functional limitations.

Although the LPA performed better than the theoretical approach in predicting functional limitations, the patterns identified by the LPA highlight important theoretical processes. Specifically, the *optimal* and *least optimal* profiles underscore the influence of potential cumulative processes. Participants who reported cumulatively positive relationships (i.e., *optimal* profile) fared better in terms of functional health and other health covariates compared to those who reported cumulatively poor relationships (i.e., *least optimal* profile) as well as those who reported mostly average relationships (i.e., *average + low PRWO* profile).

The results from the LPA did not, however, evoke all of the processes from the life course timing principle. Based on the timing principle and observed heterogeneity in aging, we would theoretically expect that it would be plausible for people who are less advantaged in early life to still have positive health and social outcomes in later life (and vice versa). The LPA did not suggest a profile that fit these characteristics. Rather, in addition to the *optimal* profile (cumulatively good) and *least optimal* profile (cumulatively bad), the remaining two profiles reported average social relationships across the life course aside from differences in social support and PRWO in adulthood. These findings could be a function of the relationship measures used, and more comprehensive measures of relationships in childhood might suggest different trajectories more consistent with the timing principle.

Limitations, Strengths, and Conclusions

Some limitations should be considered. Although parent-child relationships are arguably the most important for young children and have life-long health effects (Chen et al., 2011; Luecken et al., 2013), other early relationships (e.g., those with peers or siblings) that might also influence adult health are not included in MIDUS and so could not be evaluated.

As noted above, self-reported, retrospective measures of childhood relationships may be subject to measurement error due to imperfect memory or response bias. Additionally, the parental discipline measure was included in the multivalence LPA to attempt to balance the parental

affection measure and provide a more complete picture of the parent-child relationship. However, in this study the parental discipline measure did not meaningfully contribute to our understanding of relationship typologies. One potential explanation could be that there was very limited variability in the discipline measure. Moreover, consistent with the conceptual ambiguity related to the parental discipline measure, it could be that this measure of discipline is not a negative relationship characteristic. Future research may want to consider other measures of parent-child relationships that could better capture the negative or strained aspects of the relationship. For example, less ambiguous negative measures, such as harsh discipline, could be more informative. The MIDUS dataset does include measures of physical abuse and emotional neglect experienced during childhood (elements of the Childhood Trauma Questionnaire), but these are only included in the biomarker subsample (n = 1,255).

As noted in the post-hoc analysis, some of the covariates we included may function as mediators in the association between life-course social connectedness and later-life functional limitations. The results changed when these covariates were removed, which suggests that this may be a possibility worth exploring in future work but is beyond the scope of the present study.

Finally, functional limitations were measured using a self-reported assessment, which is not always the most reliable. That said, self-reports of functional limitations do seem to be slightly positively biased but reasonably accurate and reliable (Bravell et al., 2011; Brazier et al., 1992). The current results could be bolstered by analyses involving objective assessments of functional capacity.

Despite the limitations, this study also has several strengths. MIDUS is a large, demographically diverse national sample with assessments spanning multiple decades that permit the examination of different life course stages and a longer period than other aging studies. The rich data included in MIDUS also allowed for the inclusion of multiple social relationship variables and several important covariates. Additionally, a significant strength of this study is the use of the life course framework to better understand different types of relationships across multiple stages of the life course and their association with later-life functional limitations.

Moreover, including both positive and negative relationship characteristics in the multivalence LPA allowed us to consider positive and negative aspects of social ties together, a current priority in relationship research (Rook, 2015). In the present study, results were very similar across LPA approaches, although the multivalence LPA was slightly more discriminating

in terms of profile assignment and predicting functional limitations. This suggests that in this particular dataset, the positive relationship measures were fundamentally equally as informative as both the positive and negative relationship measures together.

Interestingly, in both the multivalence and positive LPAs, the *optimal* profile was characterized as the oldest and most healthy (e.g., fewest functional limitations). This could be partly due to survivor bias; in other words, the participants who make it to older age and continue participating in the study may be generally healthier than those who do not. Although not a primary interest of this study, it would be interesting to examine these analytic approaches in primarily younger or primarily older samples, particularly since relationships may have differing influences depending on when they occur in the life course (Elder, 1998). Given the large age range of MIDUS, our conceptualization of adult social connectedness (measured at Wave 1) could have different meaning based on participants' age. For example, the social connectedness measures may tap into something different for a 25-year-old than a 75-year-old, but both participants' data would be included at Wave 1. Similarly, the association between social connectedness and functional limitations over a 20-year period may differ based on participants' starting age.

The results of this study provide important insights into how future researchers should apply theory to understanding relationship trajectories across the life course. As demonstrated in this study, the theoretical foundations (i.e., life course perspective and cumulative [dis]advantage) are currently not specific enough to determine which groups, or patterns of relationship characteristics, are likely to be most populated and important. Knowing which constellations are likely to be most important could help narrow the groups (i.e., using four relationship indicators wouldn't necessarily result in 16 groups) and more accurately classify people into certain groups. In order to improve the theoretical specification of life course relationship trajectories, future work should be done to better redefine theory to inform the a priori groupings. Greater theoretical specificity could also provide insight into how early relationships should be measured and defined. Overall, the data driven approaches in this study provided robust support for cumulative processes (less so for the timing and life course development principles). Improving theoretical specifications could help advance these findings. When researchers can accurately implement both data-driven and theoretical approaches, they can corroborate the findings more so than using only one approach or the other, thus increasing our confidence in the results.

Researchers should carefully consider the pros and cons of the particular approach they choose to examine relationships across the life course. In a large, national sample, this study demonstrated that the data-driven profiles had more predictive power than theory-based groups, which is theoretically and methodologically meaningful for understanding associations between life-course relationships and health.

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CHAPTER 3. SOCIAL CONNECTEDNESS ACROSS THE LIFE COURSE AND LATER-LIFE FUNCTIONAL CAPACITY: MECHANISMS AND DIVERGENT ASSOCIATIONS (PAPER 2)

Abstract: Older adults are particularly susceptible to functional limitations and disability, although many maintain high levels of function well into later life. Despite the extensive heterogeneity in the rate of disability and functional limitations in middle- and later-life, the factors that contribute to high levels of function and the mechanisms by which they operate are unclear. Good quality social relationships are known to predict better health, including lower rates of functional impairment. In earlier work using latent profile analyses we examined social connectedness across the life course (parental relationships in childhood; diverse aspects of social connectedness in adulthood) and found that having high quality social relationships across the life course (*optimal* profile) predicted fewer functional limitations than any other profile (e.g., high parental affection but low-quality adult relationships; low parental affection and low-quality relationships in adulthood; etc.). This project builds on these findings by examining 1) the potential mediating roles of physical activity (Model 1) and inflammation (Model 2), and 2) the moderating role of socioeconomic status (SES). Data were from three waves of the Midlife in the United States (MIDUS) study (n = 6909 for Model 1; n = 1225 for Model 2). Relationship variables (parental affection, parental discipline, social support, social strain, and positive relations with others (PRWO)) and SES were from wave 1, moderate-to-vigorous physical activity was self-reported at wave 2, Inflammation was measured in the biomarker subsample at wave 2, and functional limitations were measured at wave 3. In Model 1, physical activity partially mediated two of the group contrasts (*optimal* vs. *least optimal*; p = .01; *optimal* vs. *average + low PRWO*; p = .04). SES did not moderate any of these mediation effects. In Model 2, inflammation did not significantly mediate any of the group contrasts, and there was no moderated mediation by SES. Results therefore suggest that observed differences in later-life functional limitations based on life-course social connectedness can be at least partially explained by differences in physical activity in middle and later life, but these associations do not vary by SES. Practical implications include an emphasis on physical activity, particularly for people who have less-than-optimal social relationships, and consideration of other behavioral or biological mechanisms.

Introduction

Functional limitations and disability are prevalent among older adults. According to the Centers for Disease Control and Prevention (CDC), 2 in 5 adults over age 65 have some form of disability with the majority being limitations on mobility (CDC, 2020). However, many older adults are able to maintain high levels of function well into later-life, and experiencing disability is not inevitable (Freedman et al., 2013, 2016; Tang, 2014). Although there is extensive heterogeneity and variability in the rates of disability and functional limitations in middle- and later-life, the factors that contribute to high levels of function and the mechanisms by which they operate are unclear.

Social relationships have been linked to longevity and disease risk (Cohen, 2004; Holt-Lunstad, 2018; Holt-Lunstad et al., 2010, 2015; Shor et al., 2013; Uchino, 2006) with associations comparable in magnitude to those for physical inactivity, smoking, and obesity (Holt-Lunstad et al., 2010, 2015). Moreover, research suggests that early-life experiences are associated with later-life functional health (Freedman et al., 2008; Iveson et al., 2020; Kelley-Moore & Huang, 2017; Sauerteig et al. 2022). This study examined social relationships across the life course as predictors of functional capacity in later life, the potential mediating role of candidate behavioral and biological mechanisms, and moderation by socioeconomic status (SES).

Social Connectedness and Functional Health

The focus of this research is social connectedness, a term that recognizes diversity in definitions and measures of social relationships. Social connectedness is consistent with the systems perspective described by Holt-Lunstad (2018) that includes structural (e.g., number of ties to others and community), functional (e.g., perceived social support), and quality (e.g., satisfaction with diverse relationships) aspects of social relationships. While structural and functional aspects of social connectedness have been robustly linked to health, relationship quality has been understudied in the context of health, the exception being quality of marital relationships (Robles et al., 2014; Rook & Charles, 2017).

Structural measures of connection are usually quantitative in nature (Holt-Lunstad, 2018). Social integration is a common structural measure that is typically defined as having diverse relationships (Cohen et al., 1997; Thoits, 1983) or involvement in a range of social activities

(House et al., 1982). Social integration has frequently been linked to functional capacity. For example, high levels of social engagement are linked to fewer physical activity limitations over time (Thomas, 2011), whereas less frequent social activities (i.e., volunteering, attending religious services) are associated with increased risk of incident disability (James et al., 2011).

Functional indicators describe actual or perceived availability of support or resources that relationships may provide (Cohen & Syme, 1985; Cohen, 2004; Holt-Lunstad, 2018; Shumaker & Brownell, 1984). Social support is known to be important for health, both for its direct effects and its buffering effects. Functional aspects of social connectedness – particularly perceived support and strain – are often associated with functional health. When social support and strain were averaged across the family, friend, and spouse/partner domains, perceptions of high social support and low social strain were associated with less decline in functional health over a period of 8-10 years (Lachman & Agrigoroaei, 2010).

To date, most of the epidemiological literature has largely focused on structural and functional components of social connection, and most studies of relationship quality involve assessments of marital satisfaction (Robles et al., 2014; Rook & Charles, 2017); quality of other types of relationships has largely been understudied. However, one longitudinal study found that positive marital quality was associated with less disability over time, and an individual's spouse's perceptions of positive marital quality were also associated with fewer functional limitations and less disability (Choi et al., 2016). Philosophical perspectives on what it means to live a good life provide another approach to understand the quality component of social connectedness, as social connections consisting of love, deep friendship, and empathy are essential components of a well-lived life (Ryff & Singer, 2008). One operationalization of this perspective is the measure of positive relations with others (PRWO), a dimension from the Psychological Well-Being Scales (Ryff, 1989) that assesses the extent to which individuals form and nurture warm, trusting relationships. Cross-sectionally, higher ratings on PRWO were associated with fewer functional limitations in a cross-national comparison of US and Japanese samples (Choi et al, 2020). This paper builds on these findings by examining both functional (e.g., social support) and quality (e.g., PRWO) aspects of social connections across multiple relationship domains, including intimate partnerships, familial ties, and friendships.

Life Course Perspective on Social Connectedness

This work is further informed by the life course perspective, a framework for understanding the human life course that consists of relevant principles such as *timing*, *linked lives*, and *lifespan development* (Elder, 1998; Elder et al., 2003; Settersten et al., 2021). In this study, we examine the presence of specific types of social connectedness at periods of the life course in which they are most salient (e.g., relationships with parents in childhood; relationships with friends, family members, and spouses in adulthood), with an emphasis on the quality of these connections. Childhood experiences, and childhood relationships in particular, can have a lasting impact on health across the life course. Specifically, high quality parental relationships in childhood have both direct and buffering effects on later-life physical and psychological health. For example, one study found that cherished children (i.e., those who endorsed positive relationships, milder forms of parental discipline, and positive parental and self-regard) had greater social support in midlife than those who were harshly disciplined or experienced ordinary childhoods (Lee et al., 2015). Additionally, maternal warmth may buffer the negative effects of childhood adversity (e.g., low SES) on later-life immune function (Chen et al., 2011).

Few studies have examined social connectedness across the life course as a predictor of adult health outcomes (see Singer & Ryff, 1999 and Yang et al., 2016 for exceptions). More recently, a life course conceptualization of social connectedness that included parental affection, parental discipline, social support, social strain, and PRWO identified a direct effect between life-course social connectedness and later-life functional limitations (Teas et al., 2023). Results indicated that warm, supportive relationships across the life course were favorably associated with functional limitations. Building on this work, in the present study we probe the association between life-course social connectedness and functional limitations by examining the potential mediating roles of physical activity and inflammation as well as moderation by SES.

Mediators Linking Social Connectedness to Health: Physical Activity and Inflammation

Physical activity and inflammation are two potential mechanisms through which social relationships may influence health. Social connectedness is generally associated with better health practices (Watt et al., 2014), and greater social support and broader social networks have been linked to higher levels of physical activity among older adults (Cotter & Lachman, 2010).

Loneliness, on the other hand, is considered a risk factor for physical inactivity (Hawkley et al., 2009). Regular physical activity also consistently confers a reduced risk of functional limitations in older age (Paterson & Warburton, 2010). Further, one study showed that leisure-time physical activities mediated the link between social relationships – level of social support and strain – and a variety of physical health outcomes (e.g., number of comorbidities; Chang et al., 2014).

Additionally, several studies suggest that greater social integration and social support are longitudinally linked to better immune functioning, whereas greater social strain increases systemic inflammation (Elliot et al., 2018; Kiecolt-Glaser et al., 2010; Yang et al., 2014). Moreover, people with supportive close relationships across the lifespan generally have lower levels of chronic inflammation (Fagundes et al., 2011). Independent of disease, higher levels of inflammation are also cross-sectionally associated with more functional limitations (Brinkley et al., 2009; Cohen et al., 1997) and with greater risk of disability over time (Penninx et al., 2004). Although multimorbidity is known to predict functional limitations (Calderón-Larrañaga et al., 2018; Teas et al., 2021; Wolff et al., 2005), a longitudinal analysis found that inflammation partially mediated the association (Friedman et al., 2019), suggesting that inflammation is a possible mechanistic influence on functional health. Thus, physical activity and inflammation are viewed as potential mediators of the link between life course social connectedness and functional limitations. Examining this possibility is the first aim of the present study.

Moderation by Socioeconomic Status (SES)

Socioeconomic status (SES) is a strong predictor of physical functioning (Freedman & Martin, 1999; Grundy & Glaser, 2000; Hemingway et al., 1997). Freedman and Martin (1999) showed that having less than a high school education was associated with having about twice the odds of having a functional limitation in later life compared to having more than a high school education. More recently, Choi and colleagues (2022) found that between 2002 and 2016, the difference in disability between low- and high-income adults widened, particularly for the middle-aged group. Because those with low SES are considered more vulnerable in terms of health outcomes, there is more opportunity for potential protective factors to have significantly positive effects. For example, although greater educational attainment is associated with lower levels of inflammation, higher psychological well-being is associated with less inflammation among those with less education (Morozink et al., 2010).

Research supports the role of SES as a moderator of the association between social relationships and health. Longitudinal data show that positive relationships are associated with better cardiovascular and inflammatory outcomes among low-SES but not high-SES adults (Vitaliano et al., 2001). Additionally, Choi and Marks (2013) found that increases in marital conflict were linked to greater increases in functional impairment for persons with lower income. Singer and Ryff (1999) showed social relationships were more beneficial for health for those with low household income, compared to those with high household income. The current study examines SES as a potential moderator of the association between life course social connectedness and health outcomes, extending prior research to include more comprehensive measures of relationships in adulthood and an explicit focus on functional limitations.

The Present Study

The purpose of this study is to examine social connectedness across the life course as a predictor of functional limitations in later life, with consideration of potential behavioral and biological mechanisms as well as differential associations by SES. Prior work has established a direct effect between our conceptualization of life-course social connectedness (using a latent profile analysis) and later-life functional limitations (Teas et al., 2023). Specifically, people who were in the *optimal* social connectedness profile reported significantly fewer functional limitations compared to those in the three other profiles. This study builds on those findings to assess potential mechanisms and interaction effects. The first objective of this study is to determine whether social connectedness across the life course predicts functional capacity in later life by promoting physical activity and/or reducing inflammation. This will test the hypothesis that physical activity and/or inflammation will at least partially mediate the effect of life-course social connectedness on functional limitations. The second objective is to test the hypothesis that high quality relationships across the life course may be more robustly associated with functional capacity at low levels of SES than high levels.

Method

Data for this study come from the Midlife in the United States (MIDUS) study. MIDUS contains rich data on the physical, psychological, and social health of middle-aged and older adults

as well as diverse retrospective assessments of childhood circumstances. The first wave of MIDUS (*N* = 7,108; MIDUS 1) included a national probability sample of non-institutionalized English-speaking adults living in the United States. Participants ranged in age from 25 – 74 years at MIDUS 1. MIDUS 1 was completed in 1995-1996, and two follow-up studies (MIDUS 2 and MIDUS 3) were completed in 2004-2006 and 2013-2014, respectively. To improve racial/ethnic diversity, a new sample of African American residents of Milwaukee County, WI (*n* = 592) was recruited at MIDUS 2. A representative (Love et al., 2010) subsample of MIDUS 2 participants (biomarker subsample; *n* = 1255) participated in clinic-based data collection. These participants completed medical histories, clinical assessments, and additional questionnaires. The present study uses data from all three waves of MIDUS, including the biomarker subsample. The full sample consisted of the first wave of MIDUS participants plus the Milwaukee sample. There were 791 participants in the full sample and 30 participants in the biomarker subsample who were missing data on all of the social connectedness variables, so the sample size for Model 1 (i.e., physical activity as mediator) and Model 2 (i.e., inflammation as mediator) were 6909 and 1225, respectively. This study's hypotheses and planned analyses were preregistered on Open Science Framework (https://osf.io/k6y83) prior to any analyses being conducted.

Measures

Social Connectedness

We modeled life-course social connectedness using a latent profile analysis (LPA) based on childhood relationships (parental affection, parental discipline) and adult relationships (social support, social strain, positive relations with others). Parent-child relationships were measured retrospectively at MIDUS 1 (MIDUS 2 for the Milwaukee sample) using maternal and paternal affection and discipline scales (Rossi, 2001). Items were averaged, so that there is one score for parental (both maternal and paternal) affection and one score for parental discipline. Participants' adult relationships were measured at MIDUS 1 (MIDUS 2 for the Milwaukee sample). Social support and social strain were assessed across three domains: family, spouse/partner, and friends. Responses were averaged across domains to create one total social support score and one total social strain score. Finally, participants reported on quality of relationships using the 3-item version of the positive relations with others (PRWO) sub-scale from the Ryff Psychological Well-

Being Scales (Ryff, 1989; Ryff & Keyes, 1995) that assesses the extent of having satisfying relationships with others.

Further details on each of the relationship measures and the LPA have been previously published (Teas et al., 2023). Briefly, the LPA suggested a 4-profile solution best represented the data. The largest group reported average affection and discipline in childhood, with high support, high PRWO, and average strain in adulthood (i.e., *optimal* profile). Two groups were characterized by average reports on every indicator but diverged on social support and PRWO, with one group reporting low support (*average + low support*) and one group reporting low PRWO (*average + low PRWO*). The smallest group was considered the *least optimal*, with low parental affection, very low social support, and high social strain.

Outcome

To assess functional limitations, at MIDUS 3 participants were asked how much their health limited their ability to perform eight mobility-related activities (e.g., carrying groceries, walking one block). Items were from the Physical Functioning subscale from the SF-36 Health Survey (Ware & Sherbourne, 1992). Two items related to moderate and vigorous physical activity were omitted to avoid confounding with the physical activity mediator. Responses (1=Not at all; 4=A lot) were averaged (range 1 – 4).

Mediators

Physical Activity. At MIDUS 2, participants were asked to rate the frequency of moderate and vigorous physical activity during the summer and winter. Response options ranged from 1 – 6 (1=never, 3=once a month, 6=several times a week). Similar to procedures outlined by Rector and colleagues (2020), we created a standardized latent physical activity score that represented overall moderate and vigorous physical activity (MVPA).

Inflammation. Fasting blood samples were collected from each participant in the biomarker subsample between 0800 and 1000 on Day 2 of their overnight clinic stay. Serum was isolated and stored at -80°C for analysis. IL-6 was measured using high-sensitivity enzyme-linked immunosorbent assays according to manufacturer guidelines (R&D Systems, Minneapolis, MN). CRP was measured using a particle enhanced immunonepholometric assay (BNII nephelometer,

Dade Behring Inc., Deerfield, IL). Fibrinogen was measured using a semiautomated modification of the Clauss method (Clauss, 1957) on a BNII nephelometer (Dade Behring). Assays for IL-6 were completed in the laboratory of Dr. Christopher Coe at the University of Wisconsin-Madison, and those for CRP and fibrinogen were completed in the laboratory of Dr. Russell Tracy at the University of Vermont. The laboratory intra- and inter-assay coefficients of variance for all protein assays were in acceptable ranges (<10%). Distributions for IL-6 and CRP values were positively skewed and were log-transformed for statistical analyses. CRP, IL-6, and fibrinogen were used to create a standardized latent inflammation variable, similar to prior work (Friedman et al., 2019).

Moderator

We used a composite measure of SES as constructed by Glei and colleagues (2020). The composite measure was based on the educational attainment and occupational socioeconomic index of the respondent (and their spouse/partner, if applicable), household income, and net assets of the respondent and spouse/partner combined. For education, participants reported highest degree completed using 12 categories (e.g., 1=no school/some grade school; 5=graduated from high school; 12=PhD, EdD, MD, DDS, LLB, LLD, JD, or other professional degree). The occupational socioeconomic index (Hauser & Warren, 1997) was based on 1980 census occupational codes with scores ranging from 7.1 (shoe machine operator) to 80.5 (physician). Income and assets were both reported in categories, and these were recoded to the midpoint of the range within each category. See supplementary material from Glei and colleagues (2020) for more information about the calculation of household income and assets. The six items were standardized and averaged to create a composite measure.

The SES variables were measured at MIDUS 1; importantly, not all variables (e.g., total assets) used to form the composite were assessed at MIDUS 2 (baseline for the Milwaukee sample). Since we could not create a comparable SES composite variable for the Milwaukee sample, their values were imputed in all analyses. However, the composite measure is multidimensional and thus a more robust indicator of socioeconomic status than a single metric.

Covariates

We included the following covariates in all models: age measured continuously; dichotomous sex (1=female); race (1=white); and marital status at baseline (1=married). Prior to adding SES as a moderator, we controlled for SES in the mediation models. For Model 2, use of participant-reported medications (from a questionnaire checklist) potentially associated with inflammation was also included as a covariate. Specifically, we used a dichotomous variable (1=yes) to indicate whether participants took non-steroidal anti-inflammatory drugs (NSAIDs) as these are known to influence inflammation.

Analytic Strategy

We first examined bivariate correlations and confirmed linearity between predictors and outcome (see OSF for scatterplots). We also checked the distribution of all variables. Due to the positive skew of the functional limitations outcome variable, we opted to log transform it. Using a criterion of 3 standard deviations from the mean, we identified 28 outliers for CRP, 2 of which were considered extreme outliers. We winsorized 26 outliers to 3 standard deviations above the mean and the 2 extreme outliers to a value slightly higher than 3 standard deviations above the mean in order to differentiate the outliers from the extreme outliers. After winsorizing, the CRP variable was still positively skewed so we log-transformed it for analyses. For IL-6, we winsorized 32 outliers to 3 standard deviations above the mean. Due to positive skew, we also log-transformed the IL-6 variable. We identified 9 outliers for fibrinogen, 4 of which were winsorized to 3 standard deviations above the mean, 4 extreme outliers that were winsorized to a value slightly higher than 3 standard deviations above the mean, and 1 value that was winsorized to 3 standard deviations below the mean. Because the outliers were all biologically plausible values, we opted for winsorizing instead of deleting. All code and analytic decisions are available at OSF.

We used a structural equation modeling (SEM) framework with the manual Bolck-Croon-Hagenaars (BCH) method (Asparouhov & Muthén, 2021) in Mplus (version 8.8; Muthén & Muthén, 1998-2014), a process which accounts for the uncertainty of profile membership (i.e., measurement error) in hypothesis testing models. The SEM included relationship profiles as a nominal predictor (implemented in BCH via a multi-group framework), one mediator (MVPA or inflammation), one outcome (functional limitations), and relevant covariates, resulting in two

separate models. For the model with inflammation as a mediator (Model 2; n = 1225), the biomarker subsample covariates were added. To assess the proposed mediation between relationship profiles and functional capacity, each of the two SEM models (one for each mediator) assessed potential indirect effects using model constraints and approaches that are robust to non-normality and non-independence of observations, such as the MLR estimator. Full information maximum likelihood was used to account for missing data. In order to test the hypothesis that high quality relationships across the life course may be more robustly associated with functional limitations at low levels of SES than high levels, we added SES as a moderator in the analyses described above. Specifically, the SES moderation of the association between life-course social connectedness profiles and functional limitations were assessed through mixture regression modeling with the manual BCH method (McLarnon & O'Neill, 2018). To assess SES moderation, the interaction coefficients between SES and functional limitations were estimated separately for each profile contrast, with the *optimal* profile as the reference group.

Sensitivity Analyses

We refined the analyses in two ways. First, general health could affect physical activity, inflammation, and functional limitations. To account for general physical health while avoiding the risk of overcontrolling (Wysocki et al., 2022) and/or incorrectly specifying potential pathway variables as covariates, we included self-reported health at MIDUS 1 as a covariate as a proxy measure of overall health (Yamada et al., 2012). Second, given the different sample sizes for Model 1 (MVPA as a mediator; n = 6909) and Model 2 (inflammation as a mediator; n = 1225), we examined Model 1 with the sample size restricted to the biomarker subsample (n = 1225) to determine if results were robust to different sample characteristics.

Results

Participants' mean age at MIDUS 2 was 55 years. Slightly more than half of participants were female (52%) and primarily reported their race as white. See Table 7 for participant characteristics for all covariates.

Table 7. Participant Characteristics (*n* = 6909)

	Mean (SD)	Range
Age at MIDUS 2 (years)	55.27 (12.44)	30 - 85
Sex (female, %)	53.37%	
Race (white, %)	81.97%	
Marital status at baseline (married, %)	64.31%	
Self-rated health	3.49 (1.00)	

Table 8 shows descriptive statistics of the mediators (MVPA and inflammation) and socioeconomic moderator for the total sample broken down by social connectedness profile (see Appendix B, Table B.1. for descriptives for the biomarker subsample). Less than a third of all participants reported no difficulties with performing daily activities (functional limitations M = 1.76, SD =.87). Participants in the *optimal* profile reported the most MVPA and highest SES, whereas participants in the *least optimal* profile had the least amount of MVPA and lowest SES.

Table 8. Descriptives of Key Variables for Total Sample and Each Profile

			Total sample	Profile 1 (Optimal)	Profile 2 (Least optimal)	Profile 3 (Avg. + low support)	Profile 4 (Avg. + low PRWO)
Mediators	MVPA	Mean (SD)	2.39 (.99)	2.44 (1.02)	2.28 (.97)	2.39 (.92)	2.34 (.99)
		Range	.32 – 3.97	.34 – 3.91	.33 – 3.91	.33 – 3.91	.32 – 3.97
		n	6909	3551	719	889	1750
	Inflammation	Mean (SD)	.41 (.81)	.40 (.80)	.50 (.84)	.39 (.79)	.41 (.81)
		Range	-2.11 – 2.83	-1.78 – 2.75	-1.55 – 2.42	-1.45 – 2.78	-2.11 – 2.83
		n	1225	647	137	147	294
Moderator	SES Composite	Mean (SD)	.02 (.98)	.15 (.96)	-.23 (1.01)	-.00 (.96)	-.13 (.98)
		Range	-2.60 – 4.01	-2.37 – 3.84	-2.37 – 3.94	-2.12 – 3.52	-2.60 – 4.01
		n	6277	3243	634	821	1579
Outcome	Functional Limitations	Mean (SD)	1.76 (.87)	1.68 (.83)	2.00 (.97)	1.79 (.89)	1.84 (.89)
		Range	1 – 4	1 – 4	1 – 4	1 – 4	1 – 4
		n	3292	1723	297	410	785

Note. MVPA and inflammation are both latent variables. MVPA = moderate-to-vigorous physical activity. PRWO = positive relations with others. SES = socioeconomic status.

Bivariate correlations (Table 9) showed that functional limitations were significantly negatively associated with MVPA (r = -.24, p < .001) and SES (r = -.25, p < .001) and positively correlated with inflammation (r = .33, p < .001). The correlations were similar for the biomarker subsample, as shown in Table 9. Tables B.2. and B.3. in Appendix B show the correlations broken down by social profiles for the full sample and biomarker subsample, respectively.

Table 9. Correlation Table of Key Variables for Full Sample (n = 6909) and Biomarker Subsample (n =1225)

	FL	MVPA	Inflammation	SES
FL		-.25***	.32***	-.21***
MVPA	-.24***		-.18***	.23***
Inflammation	.33***	-.18***		-.14***
SES	-.25***	.20***	-.14***	

Note. PRWO = positive relations with others; FL = functional limitations
*p < .05; **p < .01; ***p < .001
Below diagonal: full sample; Above diagonal: biomarker subsample

Model 1: Physical Activity as Mediator

For all analyses below, profile 1 (the *optimal* profile) was the reference profile (i.e., for every effect, each profile was compared to profile 1). As we previously found (Teas et al., 2023), there were significant group differences in predicted functional limitations for all group contrasts.

Optimal (Profile 1) vs. Least Optimal (Profile 2)

When MVPA was added to the model as a mediator, the direct effect was significant (b = .25, p = .001). In other words, the *least optimal* profile had significantly more functional limitations than the *optimal* profile. The *least optimal* profile also had significantly less MVPA than the *optimal* profile (b = -.14, p < .01). The indirect effect was also significant, suggesting that MVPA mediated the association between profile membership and functional limitations, where participants in the *optimal* profile, compared to the *least optimal* profile, reported greater MVPA and in turn fewer functional limitations. The total effect was also significant for this contrast (see Figure 4A). When SES was added as a moderator, significant effects from the mediation model

remained significant. However, the moderated indirect effect was not significant (b = -.09, p = .38). See Figure 5A.

Optimal (Profile 1) vs. Average + Low Support (Profile 3)

In comparing the *optimal* profile to the *average + low support* profile, only the direct effect (b = .18, p = .03) and total effects were significant. The *average + low support* profile reported significantly more functional limitations than the *optimal* profile. There was no significant mediation by MVPA (see Figure 4B). When SES was added as a moderator, significant effects from the mediation model remained significant, but no additional significant effects emerged (Figure 5B).

Optimal (Profile 1) vs. Average + Low PRWO (Profile 4)

With MVPA as a mediator, there were no significant direct or indirect effects. However, the *average + low PRWO* profile reported significantly less MVPA (b = -.08, p = .03) compared to the *optimal* profile (Figure 4C). When SES was added as a moderator, this effect remained significant and two additional significant effects emerged. The direct effect was significant (b = .12, p = .03), suggesting participants in the *average + low PRWO* profile had fewer functional limitations than the *optimal* profile. Additionally, there was a significant indirect effect through MVPA (b = .01, p = .04). The moderated mediation effect was not significant. See Figure 5C.

Model 2: Inflammation as Mediator

Similar to Model 1, profile 1 (the *optimal* profile) was the reference profile for all analyses below. Model 2 analyses consisted of only the biomarker subsample (n = 1225). Even though the sample was substantially smaller than Model 1, we found significant group differences in functional limitations for two of the group contrasts, suggesting this finding is robust to sample size and sample characteristics.

Optimal (Profile 1) vs. Least Optimal (Profile 2)

With inflammation as the mediator in Model 2, there was a significant direct effect (b = .19, p = .001), suggesting that the *least optimal* profile reported more functional limitations than the

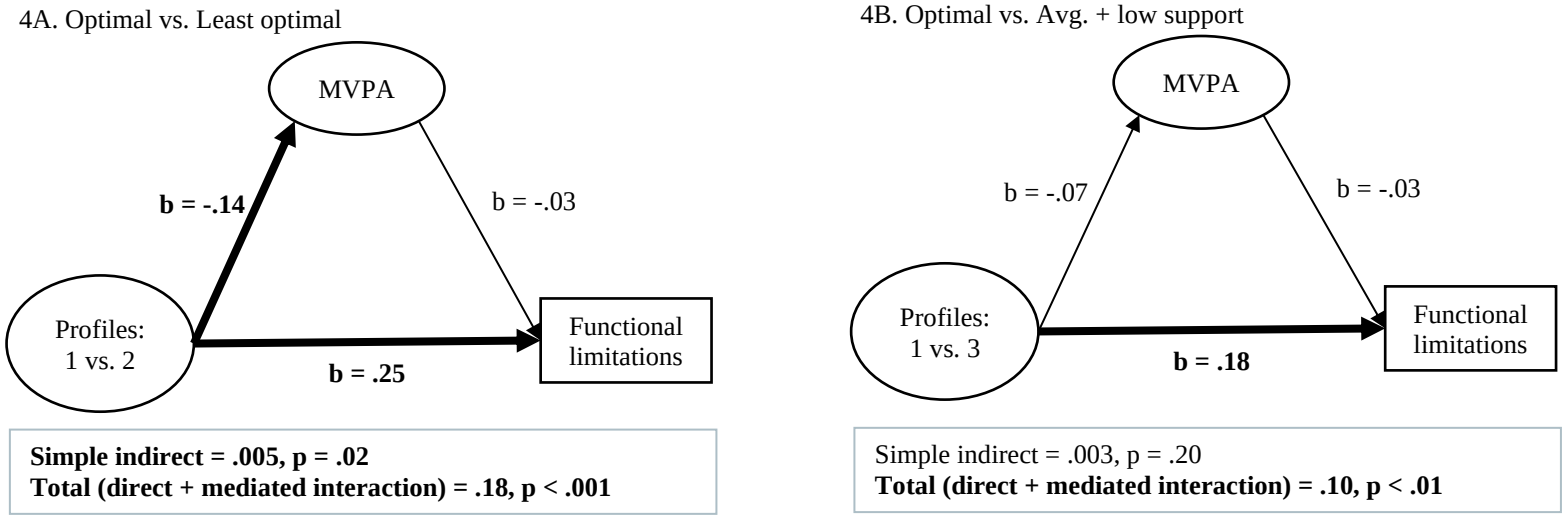
optimal profile. However, there was no significant group difference in predicted inflammation (*b* = .01, *p* = .94). Although the total effect was significant, the simple indirect effect was not (see Figure 6A). When SES was added as a moderator, the two significant effects remained significant; the moderated-mediated effect was not significant (*b* = -.09, *p* = .06) and no other significant effects emerged (see Figure 7A).

Optimal (Profile 1) vs. Average + Low Support (Profile 3)

Comparing the *optimal* profile to the *average + low support* profile, there were no significant differences in predicted functional limitations (*b* = .06, *p* = .22) or inflammation (b = -.03, *p* = .76). See Figure 6B. Additionally, the moderated mediated effect (*b* = .02, *p* = .76) was not significant in the subsequent model (see Figure 7B).

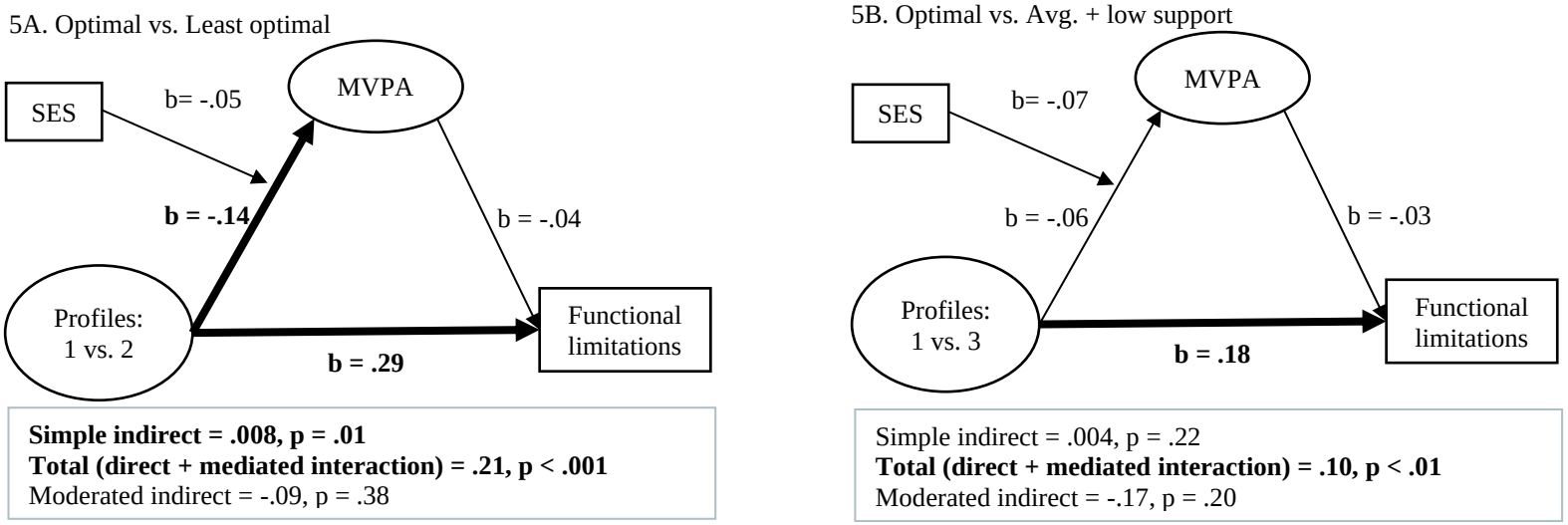
Optimal (Profile 1) vs. Average + Low PRWO (Profile 4)

The *average + low PRWO* profile reported significantly more functional limitations than the *optimal* profile (*b* = .17, *p* < .001). However, there were no significant differences in predicted inflammation (*b* = -.03, *p* = .72) nor was the indirect effect significant. The total effect was significant, as shown in Figure 6C. When SES was added as a moderator, the direct and total effects remained significant, but the moderated mediated effect was not significant (*b* = -.05. *p* = .30). See Figure 7C.



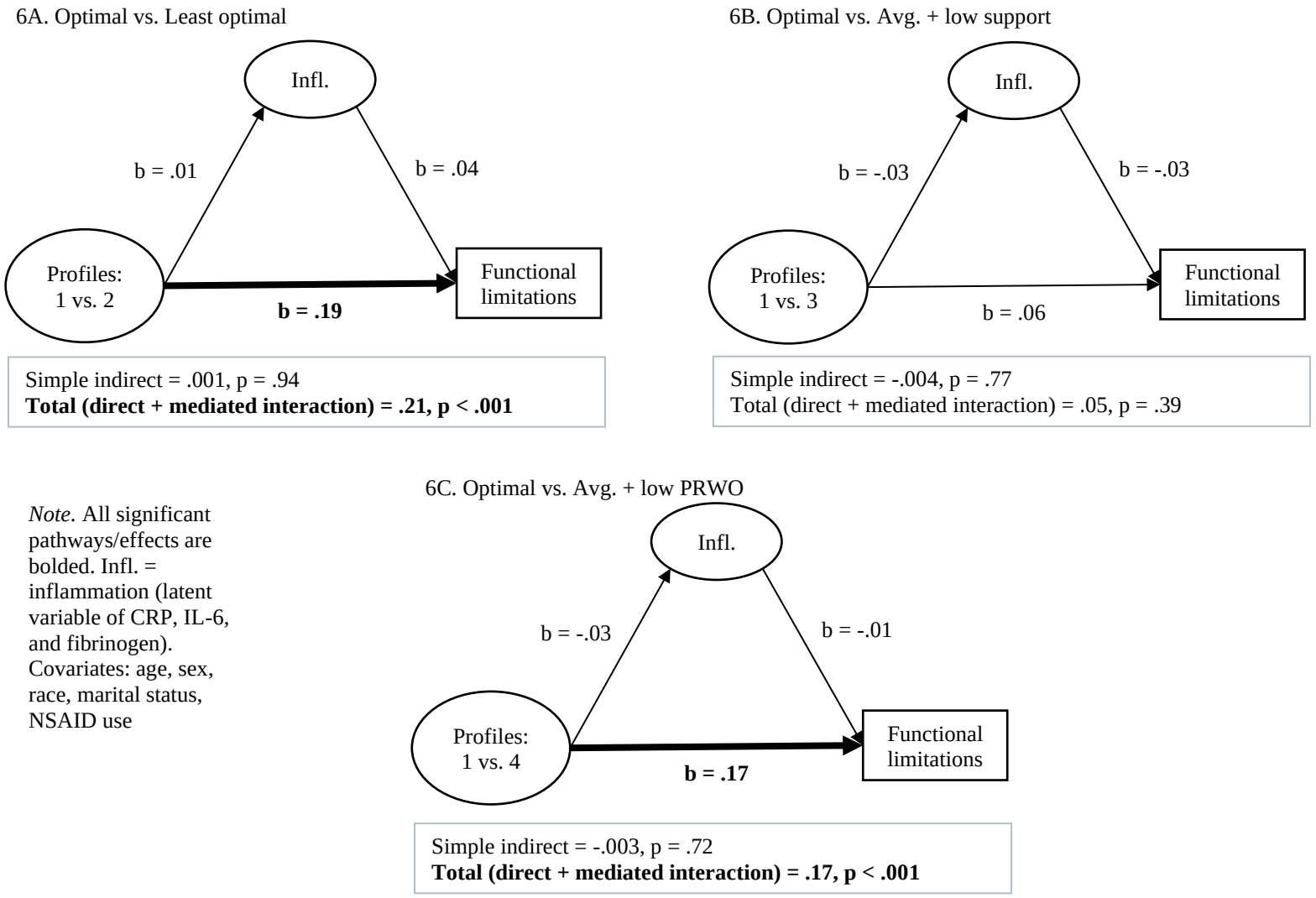
Note. All significant pathways/effects are bolded. MVPA = moderate-to-vigorous physical activity. Covariates: age, sex, race, & marital status

Figure 4. Mediation Results for Model 1 (n = 6909)



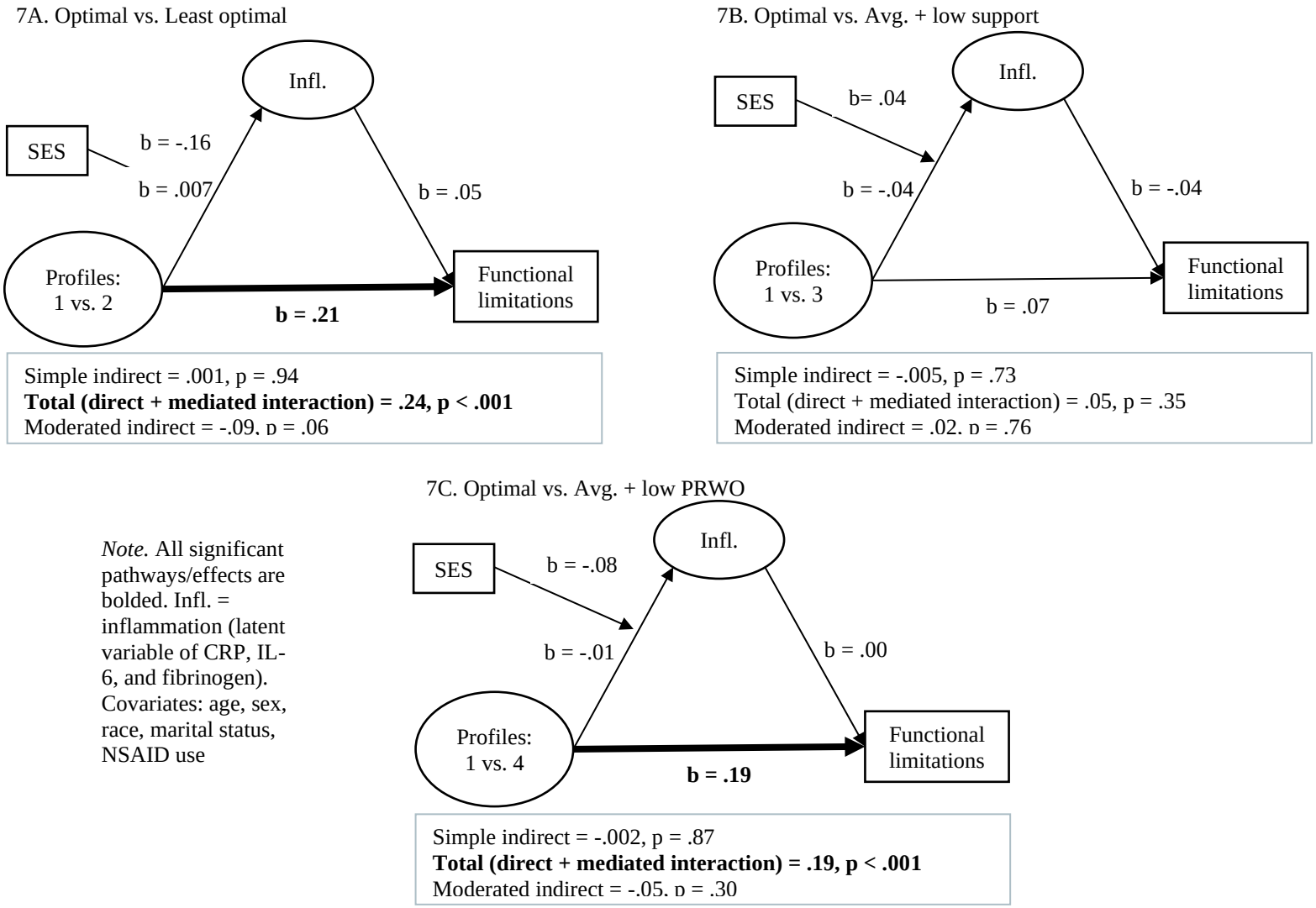
Note. All significant pathways/effects are bolded. MVPA = moderate-to-vigorous physical activity. Covariates: age, sex, race, & marital status

Figure 5. Moderated Mediation Results for Model 1 (n = 6909)



Note. All significant pathways/effects are bolded. Infl. = inflammation (latent variable of CRP, IL-6, and fibrinogen). Covariates: age, sex, race, marital status, NSAID use

Figure 6. Mediation Results for Model 2, Biomarker Subsample (n = 1225)



Note. All significant pathways/effects are bolded. Infl. = inflammation (latent variable of CRP, IL-6, and fibrinogen). Covariates: age, sex, race, marital status, NSAID use

Figure 7. Moderated Mediation Results for Model 2, Biomarker Subsample (n = 1225)

Sensitivity Analyses

When we added self-rated health as an additional covariate to Model 1 (i.e., the MVPA mediation model), some results changed. Specifically, the following associations were significant without self-rated health as a covariate and became nonsignificant when self-rated health was added: the indirect effect (b = .003, p = .06) for the *optimal* vs. *least optimal* contrast; the direct effect (b = .12, p = .11) on functional limitations for the *optimal* vs. *average + low support* contrast; and the difference in MVPA (b = -.06, p = .09) for the *optimal* vs. *average. + low PRWO* contrast. See Figure B.1. in Appendix B. With SES as a moderator in Model 1, the indirect effect (b = .01, p = .049) for the *optimal* vs. *least optimal* contrast became significant again, whereas the indirect effect (b = .003, p = .10) for the *optimal* vs. *average + low PRWO* contrast was no longer significant when self-rated health was added to the model. Additional changes in effects are shown in Figure B.2. in Appendix B.

With self-rated health as a covariate in Model 2 (i.e., the inflammation mediation model), all significant effects decreased in magnitude but remained significant. This trend was also consistent when SES was added as a moderator. See Figures B.3 and B.4. in Appendix B.

When we examined Model 1 restricting the sample size to the biomarker subsample, the results differed from the full sample (Figures B.5. and B.6. in Appendix B). For the *optimal* vs. *least optimal* contrast, the difference in MVPA (b = -.15, p = .26) was no longer significant, nor was the indirect effect (b = .01, p = .29) through MVPA. For the *optimal* vs. *average + low support* comparison, the direct effect (b = -.01, p = .92) and total effect (b = .04, p = .54) were no longer significant, but a significant difference in MVPA (b = -.33, p = .04) emerged. Finally, the difference in MVPA (b = -.21, p = .06) was no longer significant in the *optimal* vs. *average + low PRWO* contrast. When SES was added as a moderator, some of the effects slightly shifted, but like the model with the full sample, there were no significant moderated mediation effects.

Discussion

In the present study, we sought to probe the association between life-course social connectedness profiles and later-life functional limitations. Specifically, we examined potential behavioral and biological mechanisms and moderation by SES. We hypothesized that physical activity and inflammation would mediate the association between social connectedness and

functional health, and this association would be further modified by SES. Overall, our hypotheses were partially supported. Results suggested that observed differences in later-life functional limitations based on life-course social connectedness can be at least partially explained by physical activity, but these associations do not vary by SES.

Model 1: Physical Activity as Mediator

In Model 1, we consistently found a significant indirect effect for the contrast between the *least optimal* and *optimal* profiles. This suggests that, compared to those who have less optimal relationships across the life course (i.e., low parental affection in childhood, low support and high strain in adulthood), those who have more optimal relationships (i.e., high parental affection in childhood, high support and low strain in adulthood) also engage in more moderate-to-vigorous physical activity, and in turn have fewer functional limitations in later life.

Social support from family and friends has been linked to higher levels of physical activity in middle-aged and older adults (Cotter & Lachman, 2010; Scarapicchia et al., 2017). Optimal social connectedness could foster greater physical activity participation in several ways. Feeney and Collins (2014) offer a view of social support in which social relationships can promote thriving in times of adversity *and* in times of opportunity. Specifically, social support can function as a *relational catalyst* that acts through diverse mechanisms to spur individual behavior such as physical activity participation. Social support for physical activity, for example, increases self-efficacy to engage in physical activity (Ayotte et al., 2010; Orsega-Smith et al., 2007) which then predicts greater physical activity. Although we did not specifically assess social support as a relational catalyst or support for physical activity in particular, it is reasonable to assume that the general measure of social support used in our social connectedness measure captured at least some of these processes. Moreover, those who are socially connected – as defined by the measure used in the present study – are more likely to have relationships that provide support in the contexts described above. Having good quality social relationships can also foster physical activity by providing accountability, others to engage in physical activity with, and support for being physically active (Smith et al., 2017). Those who are socially connected to others, for example, are more likely to engage in physical activity if their social partners are physically active (e.g., Franks et al., 2012).

When SES was added as a moderator for Model 1, there were no significant moderated indirect effects. The direct effect between social connectedness and functional limitations, as well as the indirect effect through MVPA, did become significant for the comparison between the *optimal* and *average + low PRWO* profiles, however. These effects may be a result of suppression or statistical artifacts. Because the p-values for these effects were hovering near the .05 level in the mediation model but reached significance when SES was added as a moderator, it could be that these are small effects that are only observable under certain conditions. Since these effects were consistent with hypotheses, future studies should investigate these associations further, perhaps at different gradients of SES. Taken together, results from Model 1 suggest that physical activity partially mediates the association between life-course social connectedness, particularly for the *optimal* vs. *least optimal* profiles, but this association is not moderated by SES.

The finding that the link between social connectedness and physical activity was not influenced by socioeconomic resources suggests that the association does not vary at different SES levels. This was surprising, given that others have shown SES to be a moderator of the association between social relationships and various health outcomes (Choi & Marks, 2013; Singer & Ryff, 1999; Vitaliano et al., 2001). One potential explanation could be due to the composite SES measure we used. Past studies have typically focused on a single measure of SES. For example, Choi and Marks (2013) focused on educational attainment and Singer & Ryff (1999) used income as a measure of SES. Although the composite measure is arguably a more comprehensive and robust indicator of SES, moderation may involve specific aspects of SES. The lack of moderation could also be due to the lack of socioeconomic variability in the MIDUS sample; participants were relatively well off socioeconomically, and future work should examine the proposed moderation in a more socioeconomically diverse sample. It may also be beneficial to consider changes in SES over time, given the long intervals between each wave of measurement.

The fact that we did not have comparable data for the SES composite for the Milwaukee sample was also a limitation. Given the SES composite variable was imputed for the Milwaukee sample, which may introduce bias, we also ran the models with educational attainment – a relatively stable measure of SES – as an observed variable for the entire sample (i.e., main MIDUS sample and Milwaukee sample). Importantly, the results were largely the same and the moderated-mediation effects remained nonsignificant in every model (data not shown).

The sensitivity analyses suggest that self-rated health plays a role in the identified associations between social connectedness and health. However, these findings do not undermine the association between social connectedness and functional limitations but instead indicate that self-rated health accounts for additional variance in functional limitations above and beyond the predictor and other covariates. The associations between self-rated health and health are not surprising given that self-rated health is a holistic variable and a powerful predictor of morbidity and mortality (Idler & Benyamini, 1997). Thus, it may be expected that the significance of the mediated pathways and other effects were reduced when self-rated health was included as a covariate. Further, it is not well understood what information people use to make assessments about rating their own health (Jylha, 2009). For example, a person's evaluation is dependent on their understanding of what "health" is and what information they use to evaluate their health. It may therefore be difficult to interpret what the change in effects as a result of self-rated health means. Although our decision to include self-rated health as a covariate was based on a desire to account for a wide range of health variables, future work may want to consider including more specific health-related covariates to better understand their influence on the mediated pathways.

Moreover, the sensitivity analysis results with the MVPA mediation in the biomarker subsample suggests that the MVPA mediation results may not be robust to different sample characteristics. In the biomarker subsample, the largest simple indirect effect was for the contrast between the *optimal* and *average + low support* profiles (b = .019, p = .08), which was the smallest effect for the main sample (b = .003, p = .20). These results suggest that physical activity, and its role as a mediator between social connectedness and functional limitations, may depend on certain sample attributes. Although the biomarker subsample is similar to the full sample on many characteristics (e.g., age, sex, income; Love et al., 2010) and Table 3 shows that the correlations among the key variables are similar across samples, there may be other unmeasured variables that differ across the samples that affect these associations. An alternative explanation for the different results in the biomarker subsample could be due to sample size and issues of power. Although the indirect effect for the *optimal* vs. *least optimal* contrast was significant in the main sample but not the biomarker subsample, the size of the effect was almost twice as large in the biomarker subsample compared to the full sample. Moreover, although none of the moderated mediation effects were significant, the effect size for the *optimal* vs. *least optimal* contrast in the biomarker

subsample (b = .55) was very large. Thus, it could be that some of the effects in the biomarker subsample were not significant due to issues of power because of the smaller sample size.

Model 2: Inflammation as Mediator

In Model 2, we did not find evidence that inflammation mediated the association between life-course social connectedness and functional limitations. The only significant effects were direct effects between social profiles and functional limitations, suggesting that the *optimal* profile reported significantly fewer functional limitations than two of the three other relationship profiles. There were no significant group differences in predicted inflammation, which may partially explain why no significant mediation or moderated mediation effects emerged.

Although much of the literature supports an association between social relationships and inflammation (e.g., Elliot et al., 2018; Yang et al., 2014) and inflammation and functional health (Cohen et al., 1997; Penninx et al., 2004), our results were not consistent with this work. One potential explanation for our null findings could be due to the measurement of inflammation and the time scale in which the proposed mediation may occur. In MIDUS, inflammation was only measured at one time point, and one measure of inflammation may not be an accurate assessment of chronic inflammation. Inflammatory markers such as CRP and IL-6 are dynamic and prone to fluctuations (Danesh et al., 2008), and a single measurement may not provide a stable assessment. A recent meta-analysis found that single assessments of inflammatory biomarkers may be an adequate index of stable individual differences for the short term (i.e., < 6 months), but repeated measures are necessary for time periods greater than 3 years (Walsh et al., 2023). Thus, given the time lapse between MIDUS 1 and MIDUS 2, and MIDUS 2 and MIDUS 3, multiple assessments of the inflammatory markers may be necessary to obtain an accurate and stable assessment of inflammation. Moreover, prolonged elevated inflammation over multiple time points may be a better indicator in the proposed associations.

Additionally, prior work supporting the hypothesized associations between social relationships, inflammation, and functional limitations differed from the current work in important ways. For example, although Yang and colleagues (2014) found a significant association between social relationships and inflammation in the MIDUS sample, they used a summary index of inflammation burden based on 5 dichotomous measures of CRP, IL-6, fibrinogen, E-Selectin, and ICAM-1. In their analyses, inflammation was strongly associated with social strain but only

modestly associated with social support. Similarly, another examination of MIDUS data found that social support was associated with lower IL-6 specifically in older women (60 years and older; Elliot et al., 2018). Interestingly, social support was only associated with higher CRP at younger ages (less than 55 years). Thus, these findings suggest that the association between social relationships and inflammation may be nuanced and likely depends on the specific inflammation measure, the social relationship measure, and the roles of sex and age. Although our latent measures of social connectedness and inflammation are more comprehensive, they may be less sensitive in detecting associations that have been previously identified in MIDUS.

In our mediation and moderated-mediation models, we surprisingly found no significant effects between inflammation and functional limitations for any of the profile contrasts. Similar to the explanation above, this could be due to the inflammation measure used as others who have found a significant association between inflammation and function have often used just one marker of inflammation (e.g., IL-6; Cohen et al., 1997). Additionally, although Penninx and colleagues (2004) found inflammation significantly predicted incident mobility limitations over 30 months, the time between inflammation and functional limitations in the present study (roughly 7-8 years) may have been too long to detect an effect. It is also worth noting that there was a significant pairwise correlation between inflammation and functional limitations in the present study for the entire biomarker subsample and for each of the profiles. However, this association was not significant in the models once the mediation/moderated mediation and covariates were added. This suggests that, as expected, certain covariates may confound the association between inflammation and functional limitations. This is also consistent with some prior work that suggests associations involving inflammation may differ based on sex and age (two covariates included in our models; Elliot et al., 2018).

Taken together, our results combined with previous work suggest that for associations involving inflammation, there are differences in findings across social relationship measures and markers of inflammation. This raises the need to better elucidate the specific physiological processes linking social relationships to physical health outcomes.

Limitations and Strengths

We acknowledge several limitations in this study. First, physical activity was self-reported rather than objectively measured (e.g., accelerometry), and there are often low correlations

between self-report and objective measures of physical activity (e.g., Banda et al., 2010). Second, there was a large time lag between measurement of relationships and measurement of the mediators and between the mediators and the functional limitations outcome (i.e., roughly 10 years between each time point). As noted above, the timescale that the hypothesized mediation occurs on, particularly for inflammation, may be much shorter than modeled in this study. Third, the participants in this study were predominantly White, potentially limiting the generalizability of the results. Finally, we recognize that there may be other unmeasured confounders (e.g., other health behaviors) that affect our estimates of the indirect effects via physical activity and inflammation. We attempted to address this concern by including self-rated health as a covariate in sensitivity analyses, and the fact that some of the results did shift suggests that this may be a suitable consideration in future work.

This study also has a number of strengths. Although observational, the use of longitudinal data allowed us to model these associations with proper temporal ordering (i.e., relationship variables measured prior to mediators, which were measured prior to the outcome). Additionally, rather than single parameters of SES and inflammation, both complex constructs, we used a multidimensional composite measure of SES that incorporated multiple indicators and a latent factor for inflammation indicated by IL-6, CRP, and fibrinogen, three widely used measures of inflammation. Similarly, our measure of social connectedness comprised social relationship measures that captured multiple relationship attributes across multiple dimensions and time points. This allowed us to examine the effect of relationships across the life course rather than at one point in time. Finally, MIDUS is a national sample of participants across a wide age range, allowing us to examine the long-term impact of social connectedness on functional health across middle and later life in community-dwelling adults.

Conclusions

This study suggests that social connectedness across the life course predicts better functional capacity in middle and later life across socioeconomic strata, and that this association is partially explained by greater physical activity participation. These results add to the growing literature on the long-term impact of childhood experiences, particularly the presence of high-quality social relationships. One practical implication of this work is that it may be important to target physical activity interventions to people who have less-than-optimal social relationships.

Future work may also consider other behavioral (e.g., diet) or biological (e.g., autonomic; neuroendocrine) mechanisms linking social relationships to later-life health. As the development of functional limitations, and the mechanisms that influence them, occur over time, a life course lens helps shed light on how these processes unfold.

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CHAPTER 4. DISCORDANCE IN LIFE-COURSE SOCIAL CONNECTEDNESS AND LATER-LIFE HEALTH OUTCOMES AMONG MONOZYGOTIC TWINS (PAPER 3)

Abstract. Functional limitations are particularly common among older adults. In earlier work we examined social connectedness across the life course (parental relationships in childhood; social connectedness in adulthood) and found that having high quality social relationships across the life course predicted fewer functional limitations than any other typology (e.g., high parental affection but low-quality adult relationships; low parental affection and low-quality relationships in adulthood; etc.). However, these results leave open the possibility that stable person-level characteristics (e.g., genetic and/or familial factors) could predispose toward both high-quality life-course social connections and high levels of functional capacity in adulthood. To examine this possibility, this paper uses data on monozygotic (MZ) twins, who share identical DNA, to identify potential discordance in life-course social connectedness and functional limitations within MZ twin pairs. We also examined mediation by physical activity and moderation by socioeconomic status (SES). Data were from the MZ twins subsample of the Midlife in the United States (MIDUS) study (n = 632 twins). Relationship variables (parental affection, parental discipline, social support, social strain, and positive relations with others) and SES were from wave 1; physical activity was self-reported at wave 2; and functional limitations were measured at wave 3. In multilevel structural equation modeling analyses, there was a significant between-family association (b = -.14, p = .02) between social connectedness and functional limitations but no within-family association (b = -.02, p = .77). Additionally, there were no significant within-family mediation or moderated-mediation effects. Results therefore suggest that the association between social connectedness and functional outcomes is driven by genetic and/or familial influences, thus ruling out a causal association at the individual level. By controlling for shared familial and genetic factors, our findings contribute to research on social relationships and health and may inform future work in identifying potential familial influences of interest.

Introduction

Numerous studies demonstrate the significant associations between social relationships and health outcomes (Holt-Lunstad et al., 2010; Robles et al., 2014; Uchino et al., 2006), including functional limitations. Functional limitations are common in midlife and later life and have broad implications for mortality, healthcare costs, and quality of life (Chatterji et al., 2015; Choi & Schoeni, 2017; Freedman et al., 2013; Johnson & Wiener, 2006). Although the proportion of people with functional limitations has steadily increased since 1995 across all age groups (Chatterji et al., 2015), there is heterogeneity in the experience of functional limitations as many older adults are able to maintain high levels of function well into later-life (Freedman et al., 2013, 2016). Social relationships are thought to be a potential protective factor, as several dimensions of social relationships, including social engagement (Thomas, 2011; James et al., 2011), social support and social strain (Lachman & Agrigoroaei, 2010), and marital quality (Choi et al., 2016), predict later-life functional limitations. Early-life experiences have also been linked to later-life health outcomes (Hayward & Gorman, 2004; Morton & Ferraro, 2020; Thomas et al., 2022), including functional limitations (Freedman et al., 2008; Iveson et al., 2020; Sauerteig et al., 2022). These associations are often treated as causal, although causality is not easily established as people cannot be randomly assigned to be socially isolated or have poor-quality relationships. Given the lack of certainty surrounding causality between social relationships and functional limitations, the present study uses longitudinal monozygotic (MZ) twin data to examine associations linking life-course social connectedness and later-life functional limitations while controlling for genetic and familial influences that may contribute to functional health.

Life Course Perspective on Social Connectedness

The life course perspective is a framework for understanding development across the life course (Elder, 1998; Elder et al., 2003; Settersten et al., 2021). The life course perspective emphasizes the enduring importance of early-life experiences, and specifically how the timing of events or experiences can shift an individual's developmental trajectory across the life course. This perspective also underscores the value of considering how experiences during each stage of the life course impact subsequent stages.

In terms of the associations between social relationships and functional limitations, the focus is often on adult relationships and adult health or child relationships and child health. Several studies have examined child relationships and adult health outcomes (e.g., Chen et al., 2011), but few studies assess relationships across the life course (i.e., both childhood and adulthood relationships) as predictors of adult health outcomes.

Moreover, many of the studies on social relationships and health focus on one relationship dimension (e.g., social support). However, more complex measures (e.g., combined structural and functional) of social relationships demonstrate stronger associations with health outcomes than simple (e.g., binary or unidimensional) measures (Holt-Lunstad et al., 2010; Holt-Lunstad & Smith, 2012). The term social connectedness has been proposed as a systems perspective of social relationships that includes structural (e.g., social integration), functional (e.g., social support), and quality (e.g., relationship satisfaction) aspects of social relationships (Holt-Lunstad, 2018).

More recently, a conceptualization of life-course social connectedness that includes multiple dimensions of social relationships across the life course (e.g., parental affection, social support, high quality social relationships in adulthood) was longitudinally linked to later-life functional limitations (Teas et al., 2023). Results showed that those who experienced positive relationships across the life course (e.g., high parental affection in childhood, high social support in adulthood) had fewer functional limitations than all other life course relationship profiles. However, the possibility remains that person-level characteristics that are stable over time could predispose toward both high-quality life-course social connections and better health outcomes in adulthood. To explore this possibility, the present study uses data on MZ twins, who share identical DNA, to examine the association between life-course connectedness and later-life functional limitations within MZ twin pairs.

Mediating and Moderating Factors

One of the primary goals of public health is disease prevention. A better understanding of how social relationships impact functional limitations can help inform disease prevention. As recently as 2014, researchers argued that the mechanisms linking relationships to health were not well understood (Feeney & Collins, 2014). Yet, some empirical work suggests plausible mechanisms, including health behaviors.

For example, greater social support and broader social networks, two measures of social connectedness, are associated with higher levels of physical activity among older adults (Cotter & Lachman, 2010). Regular physical activity can also protect against functional decline in older age (Paterson & Warburton, 2010). From a life course perspective, one prospective study showed that higher levels of physical activity from midlife onward decreased the risk of functional limitations in older age (Hillsdon et al., 2005). Relevant to the present study, in prior work (Paper 2), we established that physical activity partially mediated the association between life-course social connectedness and later-life functional limitations. Physical activity is thus viewed as a potential mediator of the link between life-course social connectedness and functional limitations.

Additionally, research suggests that social relationships may not be equally beneficial for people. Specifically, marital conflict may be more detrimental and marital happiness less beneficial for functional health among those with lower socioeconomic status (SES; Choi & Marks, 2013). Similarly, Singer and Ryff (1999) found that the importance of social relationships for health was more robust for those with low household income compared to those with high household income. The current study will thus assess SES as a potential moderator of the association between life course social connectedness and health outcomes.

Issues of Causality

Although the above literature consistently supports an association between social relationships and health, as well as the proposed mediation and moderation effects, the results are largely confounded by genetics and environmental factors. For example, it is possible that the association between social connectedness and functional health, rather than being causal, reflects lifestyle selections of genetically healthier individuals (i.e., lifestyle selection effects). In other words, this "selection problem" – also characterized as a gene-environment correlation – suggests that those with an inherited disposition for high physical functioning may be more likely to be socially connected and engage in social activities. One approach to this issue is to use a co-twin control study (detailed below), which by design adjusts for confounders linked to genetic factors and rearing environment. The goal of this approach is to remove causal ambiguity by determining whether social (e.g., social connectedness) and behavioral (e.g., physical activity) differences between genetically identical individuals are associated with differences in their functioning.

Prior studies have used twin discordant designs to study several age-related conditions. Heritability of objective measures of physical function (e.g., gait speed) ranges from 30% to 60% in studies of older twins (Foebel & Pedersen, 2016), and frailty has been shown to be 45% heritable (Young et al., 2016). Specific to the present study, McGue and Christensen (2007) found that Danish MZ twins discordant in social activity – defined as frequency of social engagement – differed in initial level but not change in physical functioning. Because the social activity measure was based on a single assessment in late life, they concluded that a broader developmental perspective, such as consideration of earlier life experiences, may be critical. Thus, consistent with this call to action and prior work on life-course social connectedness (Teas et al., 2023), in the present study we examine the association between *life-course* social connectedness and functional limitations. Specifically, being "socially connected" in this study is defined as having high parental affection in childhood and high-quality relationships in adulthood. If the association between social connectedness and functional health is a family level process (e.g., lifestyle selection effects only), then we would not expect functional health differences in MZ pairs discordant on life-course social connectedness since these twins are matched on genetic and early rearing environmental factors. This would suggest that genetic and/or early/shared environmental factors impact both life-course social connectedness and functional health. Shared environmental factors generally refer to environmental influences that make siblings more similar to one another, such as household composition, shared childhood experiences, or shared peer groups. Alternatively, functional health differences in MZ twins who are also discordant on social connectedness would suggest a potentially causally beneficial effect of social connectedness. Specifically, we would expect to find that the twin who is more socially connected, compared to their co-twin, has significantly fewer functional limitations. Given that nonshared environmental influences are characterized by unique experiences that twins do not share with each other, discordance on social connectedness implies a nonshared environmental factor. Finally, null effects between social connectedness and functional limitations would suggest that the association is neither a causal nor a family-level process.

In the present study, if mediation by physical activity is a causal process, twins who are more socially connected than their co-twin will also engage in more physical activity, and as a result report fewer functional limitations compared to their less socially connected co-twin. Alternatively, if mediation is confounded by genetic or shared environmental factors, families (i.e.,

twin pairs) who are more socially connected would engage in more physical activity, resulting in fewer functional limitations for both twins (compared to twin pairs who are less socially connected). There has been minimal work on the association between social connectedness and physical activity among adult twins. Although marital status is not a comprehensive measure of social connectedness, one study found that middle-aged male twins discordant for marital status did not differ in physical activity (Osler et al., 2008), thus suggesting the association may be driven by selection processes related to genetic or shared environmental factors. Further, studies on MZ twins have been used to better elucidate the effects of physical activity on health with mixed results. For example, midlife physical activity was not protective against dementia risk in older male twin pairs (Carlson et al., 2008) but was associated with reduced mortality among Finnish twins (Kujala et al., 1998), after genetic and other familial factors were taken into account.

MZ Discordant Design

Broadly, sibling comparison designs are genetically informed studies that control for genetic and environmental factors shared by siblings raised in the same family (D'Onofrio et al., 2013; Lahey & D'Onofrio, 2010). This approach tests whether siblings who are discordant on a hypothesized predictor are also discordant on an outcome. The strongest test of this design uses twin pairs, because with twin pairs, possible confounding factors – genetic as well as measured and unmeasured shared familial – are controlled. Dizygotic (DZ) twins (and non-twin siblings) share 50% of their genes, whereas MZ twins share 100% of their genes. Thus, using MZ twins is the most stringent design for sibling comparison studies because it controls for a greater portion of genetic influences.

In the present study, we leverage MZ twin discordance on life-course social connectedness and functional limitations to determine whether the twin in a pair with better social connectedness is also the twin with fewer functional limitations across time. This study is the first of which we are aware to apply the MZ twin design to examine connectedness across the life course and health outcomes.

The Present Study

Building on prior work (Teas et al., 2023; Paper 2), the purpose of this study is to examine the within- and between-family associations of life-course social connectedness and functional limitations in a sample of MZ twins. We expect that the results will support one of two perspectives. If there are positive within-family associations of relationship profiles and health in adulthood (i.e., the twin with more positive life-course connectedness also has better adult functional capacity than their co-twin), this would lend stronger support for a potential causal role for social connectedness. A between-family association (i.e., twins in the same family tend to have more positive life course social connections and fewer functional limitations in adulthood) would instead suggest the association is driven by familial influences, thus ruling out a causal association. Finally, we also test the mediation and moderation of the longitudinal associations of life-course social connectedness and functional limitations by physical activity and SES, respectively. This analysis thus includes a moderated mediation model within an MZ discordant design.

Method

Data for this study are from the twin subsample from the Midlife in the United States (MIDUS) survey. Begun in 1995 to 1996, MIDUS recruited 1,914 MZ and DZ twins from a national twin registry, including 894 twin pairs. Two follow-up studies (MIDUS 2 and MIDUS 3) were completed in 2004-2006 and 2013-2014, respectively. Participants completed a telephone interview and self-administered questionnaires at all three waves. Data for the current study included only MZ twins (n = 715 individual twins). We include only twin pairs (n = 316 twin pairs, n = 632 twins) in which each co-twin has valid data on the social connectedness predictor. This study was preregistered on Open Science Framework (https://osf.io/k4wds).

Measures

Social Connectedness

Our conceptualization of social connectedness was based on Teas and colleagues (2023). This approach used a latent profile analysis (LPA) to create groups of life-course social connectedness. The LPA used two measures of childhood relationships (parental affection,

parental discipline) and three measures of adulthood relationships (social support, social strain, positive relations with others (PRWO)). The LPA resulted in four profiles: an optimal profile, characterized by average parental affection and discipline, high support and PRWO, and average strain; a least optimal profile, with low parental affection, very low support, and high strain; and two profiles with mostly average relationships with one profile reporting low support and one profile reporting low PRWO. Participants in the optimal profile reported significantly fewer functional limitations than the three other profiles, though the three non-optimal profiles did not significantly differ from each other (Teas et al., 2023). Thus, as noted below in the Analytic Strategy, in this study we collapsed the three non-optimal profiles in order to compare twins in the optimal profile to their co-twins in any other profile.

All relationship measures were assessed at MIDUS 1. The parental affection and discipline measures were both measured retrospectively using maternal and paternal affection and discipline scales (Rossi, 2001). In the twins subsample, reliability coefficients were .91 and .76 for maternal affection and discipline, respectively, and .93 and .83 for paternal affection and discipline. Items were averaged, resulting in one score for parental (both maternal and paternal) affection and one score for parental discipline. Perceived social support and social strain were measured across three domains: family, spouse/partner, and friends. Reliability coefficients for family, spouse/partner, and friend support were .84, .91, and .88, respectively. Reliability coefficients for family, spouse/partner, and friend strain were .81, .88, and .82, respectively. Responses were averaged across domains to create one total social support score and one total social strain score. PRWO measured participants' quality of relationships using the 3-item sub-scale from the Ryff Psychological Well-Being Scales (Ryff, 1989; Ryff & Keyes, 1995) that assesses the extent of having satisfying relationships with others ($\alpha = .62$). More information on the social relationship measures can be found on OSF.

Outcome

Functional Limitations. At MIDUS 3, participants rated how much their health limited their ability to perform a set of eight mobility-related activities (e.g., carrying groceries, walking one block). Items were from the Physical Functioning subscale from the SF-36 Health Survey (Ware & Sherbourne, 1992). Two additional items related to moderate and vigorous physical activity

were omitted to avoid confounding with the physical activity mediator. Responses (1=Not at all; 4=A lot) were averaged (range 1 – 4).

Mediator

Physical Activity. At MIDUS 2, participants rated the frequency of moderate and vigorous physical activity they typically engaged in during the summer and winter seasons. Response options ranged from 1 – 6 (1=never, 3=once a month, 6=several times a week). As outlined by Rector and colleagues (2020), we created a latent physical activity score that represented overall moderate and vigorous physical activity.

Moderator

Socioeconomic Status. We used a composite measure of SES constructed by Glei and colleagues (2020). The composite measure was based on the educational attainment of the respondent (and their spouse/partner, if applicable), occupational socioeconomic index of the respondent (and their spouse/partner, if applicable), household income, and net assets of the respondent and spouse/partner combined. All variables were assessed at MIDUS 1. The composite measure is multidimensional and thus a more robust indicator of socioeconomic status than a single metric.

Covariates

Covariates include age measured continuously and dichotomous sex (1=female), race (1=non-white), and marital status at baseline (1=married).

Analytic Strategy

Our hypotheses were centered on understanding whether there are longitudinal, within-family associations between life-course social connectedness and functional limitations to strengthen theories of causality. Therefore, we used sibling comparison models (e.g., Marceau et al., 2018) to test hypotheses. The use of MZ twins in these models allowed us to a) control for genetic and shared familial factors and b) examine within-family associations over time to identify nonfamilial predictors that can explain discordant outcomes.

To account for the low sample sizes for twins in profiles 2-4 (i.e., the non-optimal profiles), we collapsed these into one group to simplify the analyses. Members of profiles 2-4 were thus compared to their co-twins in profile 1 (*optimal*), the largest group. MZ twins were 29% discordant in profile assignment (i.e., 89 discordant pairs, a number in line with other such analyses; Johnson & Krueger, 2007; Thornton et al., 2017). By comparing twins in all other groups to their co-twin in profile 1, we tested the hypothesis that twins with more favorable social connectedness profiles (i.e., profile 1, *optimal* profile) would have better health outcomes than their co-twins in other profiles.

In the first step of the sibling comparison approach, "family average" and "twin-specific relative to family average" variables were created for life-course social connectedness, covariates, the mediator (physical activity), and the moderator (SES). Family average scores were the average of twin 1 and twin 2 on that variable and indexed the between-family portion of the association. The twin-specific relative to family average variables were each twin's score centered within family. In other words, these scores were the result of subtracting the family average score from each twins' score. Twins who were concordant each had a score of 0 on the twin-specific variables. We did not create twin-specific variables for age, sex, and race/ethnicity because the twins are identical and thus cannot differ on these variables.

After creating these scores, we estimated a series of multilevel structural equation models (SEM) in Mplus (version 8.8; Muthén & Muthén, 1998-2022) using full-information maximum likelihood estimation wherein twins (level 1) are nested in twin pairs (level 2). The model-building steps consisted of the following: In step 1, an unconditional model with no predictors was estimated to determine the distribution of within- versus between-family variation in functional limitations. In step 2, we added the covariates (family-average indices of age, sex, race/ethnicity and twin-specific and family average indices of marital status at baseline). In step 3, we added twin-specific and family average indices of the focal predictor (social connectedness) to the model from step 2. In step 4, we added the twin-specific and family average indices of the mediator (physical activity). In step 5, we added the twin-specific and family-average indices of the moderator (SES) and the within-family interactions of SES with social connectedness.

Results

Twins averaged functional limitation scores of 1.56 (SD = .75, range = 1 – 4). Twins' mean age at MIDUS 1 was 44.74 years (SD = 11.85, range = 25 – 73), slightly over half (55%) were female, and most were white (92%) and married at baseline (73%). Prior to collapsing twins across social connectedness profile membership, there were 345 twins in the *optimal* profile, 55 in the *least optimal* profile, 72 in the *average + low support* profile, and 160 in the *average + low PRWO* profile.[3] For all analyses, we compared the 345 twins in the *optimal* profile to the 287 twins in all other profiles. Roughly 29% of twins were discordant for profile membership.

Means and standard deviations for all key study variables are presented in Table 1. We used a latent physical activity variable and SES composite variable. As these are not directly interpretable, we show 1) frequency data based on how many participants met physical activity guidelines (i.e., moderate or vigorous activity several times per week, with no seasonal distinction) and 2) descriptive data on the SES indicators that were used for the SES composite. Compared to the main MIDUS sample, MZ twins were younger, more likely to be white and married at baseline, and reported fewer functional limitations. Table C.1. in Appendix C shows descriptives and sample differences for key variables.

For descriptive purposes, we quantified twin discordance on all key variables to aid in interpretation. Twin discordance was computed as 0 if twins had equivalent scores and 1 if they had differing scores for marital status and the social profile predictor (dichotomous measures). For functional limitations, MVPA, and SES, twin discordance was computed as 0 if the difference between twin scores was within half a standard deviation and 1 if the difference was greater than or equal to half a standard deviation. This cutoff for amount of discordance is consistent with other analyses using MIDUS data (Johnson & Krueger, 2007; Teas et al., 2021). Based on this criterion, 39% of twins were discordant for functional limitations, 61% were discordant for MVPA, and 53% were discordant for SES. Discordance rates for all key study variables are shown in Table 10.

Bivariate correlations between all continuous study variables are shown in Table 11. Functional limitations were positively associated with age (r = .30, p < .001). Additionally, those

[3] In listwise t-test comparisons in Stata and FIML models in Mplus (two missing data strategies), functional limitations were not statistically significantly different for any group comparisons in the twins subsample. Although this suggests that the optimal profile did not report fewer functional limitations than all other profiles for the twins subsample (as in the full sample; Teas et al., 2023), these findings also do not undermine our decision to collapse the three non-optimal profiles given they were not different *from each other* in terms of functional limitations.

who engaged in more physical activity and had higher SES reported fewer functional limitations. Being of younger age and higher SES was also associated with engaging in more MVPA.

Table 10. Participant Characteristics (n = 632)

	MZ Twins	Discordance (%)
Age (years) at MIDUS 1	44.74 (11.85)	-
Sex (female), %	55.1	-
Race/ethnicity (white), %	92.2	-
Married at baseline, %	73.4	27.2
Social connectedness profiles		28.8
Optimal	345	
All other profiles	287	
Functional limitations	1.56 (0.75)	38.8[a,b]
MVPA latent variable		60.8[b]
Does meet MVPA guidelines, %	41.9	
Does not meet MVPA guidelines, %	58.1	
SES composite		53.2[b]
Educational attainment (R)[c]	6.88	
Educational attainment (S)[c]	7.00	
Socioeconomic index (R)[d]	38.07	
Socioeconomic index (S)[d]	40.15	
Household income ($1k, 1995)	85.67	
Net assets (R+S; $1k, 1995)	150.59	

Note. Values are mean (SD) unless otherwise specified. SES = socioeconomic status. R = respondent. S = spouse/partner.

[a]Discordance was only calculated for twin pairs in which both twins had functional limitation scores (116 twin pairs).

[b]Discordance for continuous variables is defined as a difference of greater than or equal to half a standard deviation between twin scores.

[c]Participants reported their highest level of educational attainment using 12 categories ranging from "no school/some grade school" to "PhD, MD, JD, or other professional degree." Sample size for R = 631, S = 489.

[d]Socioeconomic index range: 9.56 – 80.53. Sample size for R = 616, S = 476.

Table 11. Pairwise Correlations (n = 632)

	Age	Functional Limitations	MVPA
Functional Limitations	.30***		
MVPA	-.16***	-.19***	
SES	-.02	-.27***	.22***

Note. MVPA = Moderate-to-vigorous physical activity; SES = socioeconomic status.
***p < .001, **p < .01, *p < .05

Multilevel SEM Analyses

Step 1 showed that functional limitations varied substantially within families: 62% of the variance was attributable to differences between twins within families, whereas 38% of the variance was attributable to between-family differences. In step 2, covariates did not explain any of the within-family variation of functional limitations. Below are the equations for Step 3[4], where TS = twin-specific relative to family-average; FA = family average.

Level 1:

$$FunctionalLimitations_{ij} = \beta_{0j} + \beta_{1j}(\text{SocialConnectedness\_TS}) + \beta_{2j}(\text{Married\_TS}) + r_{ij}$$

Level 2:

$$\beta_{0j} = \gamma_{00} + \gamma_{01}(\text{SocialConnectedness\_FA}) + \gamma_{02}(\text{Married\_FA}) + \gamma_{03}(\text{Female\_FA}) + \gamma_{04}(\text{White\_FA}) + \gamma_{05}(\text{Age\_FA}) + \mu_{0j}$$

$$\beta_{1j} = \gamma_{10} + \mu_{1j}$$

$$\beta_{2j} = \gamma_{20}$$

There was a main effect of social connectedness on functional limitations (γ_{01} = -.14, p = .02), suggesting that on average, families with more optimal social connectedness had fewer functional limitations than families with less optimal relationships. Two additional family-level parameters were significant, suggesting that women (γ_{03} = .12, p = .01) and those who were older (γ_{05} = 1.41, p < .001) reported more functional limitations. However, the within-family parameter of social connectedness did not predict functional limitations (γ_{10} = -.02, p = .77). The random intercept

[4] For steps 3-5, the within-level effects were first modeled as random slopes. Random slopes were retained if the variances were substantial and statistically significant. Otherwise, we estimated these effects as fixed slopes to improve convergence.

indicated that there were family differences in functional limitations (μ_{0j} = .04, p = .04). The effect of social connectedness on functional limitations did not differ by family (μ_{1j} = .02, p = .90). Finally, the significant residual (r_{ij} = .10, p < .001) indicated that step 3 did not explain all the variance in functional limitations.

In the mediation model (step 4), we examined mediation at Level 1 (i.e., 1-1-1; Figure 8). Below Figure 8 are the equations for step 4, where MVPA = moderate-to-vigorous physical activity; IND = indirect effect.

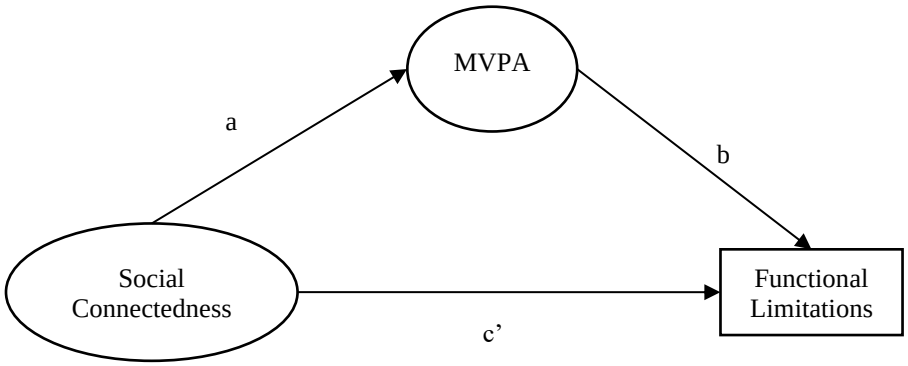

Figure 8. Conceptual Figure for Mediation Model (Step 4)

Level 1:

$$MVPA_{ij} = \beta_{0j(1)} + a_j(\text{SocialConnectedness\_TS}) + r_{ij(1)}$$

$$FunctionalLimitations_{ij} = \beta_{0j(2)} + b_j(\text{MVPA\_TS}) + c'_j(\text{SocialConnectedness\_TS}) + \beta_{1j}(\text{Married\_TS}) + r_{ij(2)}$$

Level 2:

$$\beta_{0j(1)} = \gamma_{00(1)}$$

$$a_j = \gamma_a + \mu_{aj}$$

$$\beta_{0j(2)} = \gamma_{00(2)} + \gamma_{01}(\text{SocialConnectedness\_FA}) + \gamma_{02}(\text{Married\_FA}) + \gamma_{03}(\text{Female\_FA}) + \gamma_{04}(\text{White\_FA}) + \gamma_{05}(\text{Age\_FA}) + \gamma_{06}(\text{MVPA\_FA}) + \mu_{0j}$$

$$b_j = \gamma_b$$

$$c'_j = \gamma_{c'}$$

$$IND_{MVPA} = \gamma_a * \gamma_b$$

$$\beta_{1j} = \gamma_{10}$$

There remained a main effect of family-average social connectedness on functional limitations (γ_{01} = -.14, p = .01). The family-level parameters of sex and age also remained significant predictors of functional limitations; the MVPA family-level parameter was significant (γ_{01} = -.08, p = .003), suggesting that on average, families who engaged in more MVPA reported fewer functional limitations. The within-family parameter of social connectedness did not predict MVPA (γ_a = .03, p = .82) nor functional limitations ($\gamma_{c'}$ = -.01, p = .93). The within-family effect of social connectedness on MVPA was not significant but did vary across families (μ_{aj} = .97, p =.003). Additionally, the within-family level parameter of MVPA did not predict functional limitations (γ_b = -.04, p = .19). Together, the within-family indirect effect was not significant (IND_{MVPA} = -.001, p = .83). Finally, the significant residual for functional limitations ($r_{ij(2)}$ = .10, p < .001) indicated that step 4 did not explain all the variance in functional limitations.

Step 5 involved the addition of SES as a moderator of the mediation modeled in Step 4. The equations for Step 5 are below, where SocialConnectedness_SES_TS = social connectedness x SES twin-specific interaction; ModInd = moderated indirect effect.

Level 1:

$$MVPA_{ij} = \beta_{0j(1)} + a_j(\text{SocialConnectedness\_SES\_TS}) + \beta_{1j(1)}(\text{SocialConnectedness\_TS}) + \beta_{2j(1)}(\text{SES\_TS}) + r_{ij(1)}$$

$$FunctionalLimitations_{ij} = \beta_{0j(2)} + b_j(\text{MVPA\_TS}) + c'_j(\text{SocialConnectedness\_TS}) + \beta_{1j(2)}(\text{Married\_TS}) + r_{ij(2)}$$

Level 2:

$$\beta_{0j(1)} = \gamma_{00(1)}$$

$$a_j = \gamma_a + \mu_{aj}$$

$$\beta_{1j(1)} = \gamma_{10(1)} + \mu_{1j}$$

$$\beta_{2j(1)} = \gamma_{20(1)}$$

$$\beta_{0j(2)} = \gamma_{00(2)} + \gamma_{01}(\text{SocialConnectedness\_FA}) + \gamma_{02}(\text{Married\_FA}) + \gamma_{03}(\text{Female\_FA}) + \gamma_{04}(\text{White\_FA}) + \gamma_{05}(\text{Age\_FA}) + \gamma_{06}(\text{MVPA\_FA}) + \gamma_{06}(\text{SES\_FA}) + \mu_{0j}$$

$$b_j = \gamma_b$$

$$c'_j = \gamma_{c'}$$

$$\beta_{1j} = \gamma_{10}$$

$$\text{ModInd} = \gamma_a * \gamma_b$$

There remained a main effect of family-average social connectedness on functional limitations (γ_{01} = -.12, p = .03). The family-level parameters of sex and age remained significant predictors of functional limitations; the SES family-level parameter was also significant (γ_{06} = -.10, p = .002), suggesting that on average, families with more socioeconomic resources reported fewer functional limitations. The within-family interaction of social connectedness and SES did not predict MVPA (γ_a = .00, p = .997) but did vary across families (μ_{aj} = .04, p < .001). The within-family parameter of MVPA did not predict functional limitations (γ_b = -.04, p = .16), nor did the within-family measure of social connectedness ($\gamma_{c'}$ = .00, p = .997). Together, the within-family moderated indirect effect was not significant (ModInd = .00, p = .997). Finally, the residual for functional limitations ($r_{ij(2)}$ = .10, p < .001) indicated that step 5 did not explain all the variance in functional limitations. Estimates for all models are presented in Table 12.

Table 12. Unstandardized Effects for Direct, Mediation, and Moderated Mediation Models

	Model 1. Direct	Model 2. Mediation	Model 3. Moderated Mediation
	Est. (SE)	*Est. (SE)*	*Est. (SE)*
Intercept (FL)	-.22 (.18)	-.02 (.20)	-.12 (.18)
Within-family effects on FL			
Social connectedness (TS)	-.02 (.06)	-.01 (.06)	.00 (.06)
MVPA (TS)		-.04 (.03)	-.04 (.03)
Between-family effects on FL			
Social connectedness (FA)	-.14 (.06) *	-.14 (.06) *	-.12 (.06) *
MVPA (FA)		-.08 (.03) **	-.05 (.03) ^
SES (FA)			-.10 (.03) **
Within-family covariates (FL)			
Marital status (TS)	.03 (.09)	.01 (.08)	.02 (.08)
Between-family covariates (FL)			
Female	.12 (.04) **	.12 (.04) **	.10 (.04) *
Age	1.41 (.21) ***	1.32 (.22) ***	1.27 (.21) ***
White	-.04 (.15)	-.01 (.16)	.05 (.15)
Marital status (FA)	-.00 (.08)	.02 (.08)	.04 (.07)
Intercept (MVPA)		.00 (.00)	.00 (.00)
Within-family effects on MVPA			
Social connectedness (TS)		.03 (.14)	.03 (.14)
Social connectedness x SES (TS)			.00 (.00)
SES (TS)			.21 (.09) *

Note. FL = functional limitations; TS = twin-specific relative to family average; FA = family average; MVPA = moderate-to-vigorous physical activity; SES = socioeconomic status. ***p<.001; **p<.01; *p<.05; ^p<.10

Discussion

There is abundant work supporting an association between social relationships and health, and much of this literature assumes the association is causal. However, genetics or early familial experiences may predispose some individuals to have good social relationships and good health. The purpose of the present study was to address issues of causal ambiguity by examining within-family associations of life-course social connectedness and health outcomes within MZ twin pairs. By using identical twins, we were able to control for genetic and shared familial confounds that could influence both social connectedness and functional health. The results indicated there were no within-family associations between social connectedness and later-life functional limitations, nor were there within-family mediation or moderation effects by physical activity and SES, respectively. This suggests that the association between social connectedness and functional limitations is likely not causal but is consistent with lifestyle selection effects.

Social Connectedness, Physical Activity, and Functional Limitations

Twins who were discordant on life-course social connectedness did not significantly differ on physical activity or functional limitations. These findings suggest that the social connectedness effect on health outcomes observed in prior studies (e.g., Teas et al., 2023; Paper 2) was most likely due to shared environmental and/or genetic factors. Although inconsistent with some literature that assumes social relationships causally impact health (e.g., Holt-Lunstad et al., 2010; House et al., 1988), these results are not completely incongruous with other findings. For example, in a study on Danish twins, researchers found that social activity was moderately heritable (.36 estimate; McGue & Christensen, 2007), raising the possibility that its association with late-life functional health might reflect selection processes (i.e., a gene-environment correlation). In other words, individuals with an inherited disposition for high physical functioning may be more likely to develop and cultivate high-quality social relationships than individuals without this "inherited advantage" (McGue & Christensen, 2007, p. 255). Another study found that among twins aged 40-80 years, genetic factors accounted for 15 to 58% of variation across measures of social support and strain (except family strain in males), and nonshared environmental influences also explained a substantial amount of variation (from 26 to 84%) in measures of support and strain (Kutschke et al., 2018). Shared environmental influences seemed to be more important specifically for family

strain among men, with effects ranging from 11 to 42%. Collectively, this work suggests that our measure of life-course social connectedness, which captured more than a "social activity" measure or perceived social support and strain measures, is likely also influenced at least in part by genetic, shared environmental, and nonshared environmental factors. It is worth noting, however, that genetic and environmental influences on social relationships may not be neatly separable, particularly since social relationships often involve family members (i.e., those who are biologically similar). Although not in the scope of the present study, MIDUS data provide the opportunity to parse social support and social strain measures into specific domains, so future work could examine this by removing items specific to the family domain.

In addition to genetic influences, other familial influences (i.e., shared environmental factors, which make family members more similar) may be particularly impactful for physical functioning and physical activity. In a study of environmental influences on children's physical activity, the shared environment (e.g., school environment; neighborhood) was the dominant influence on children's activity levels (Fisher et al., 2010). Moreover, results from a study on male MZ twins found that early childhood environmental factors strongly impact exercise levels throughout the lifespan (Simonen et al., 2003). Similarly, among older male twins, hand-grip strength in late adulthood was primarily driven by genetic and shared environmental influences (Carmelli & Reed, 2000). Early training and learned behaviors (i.e., shared environmental influences) associated with muscle use (e.g., leisure time activity) could explain shared environmental influences on functional health.

Although we did not find any significant within-family effects linking social connectedness and functional limitations, there were between-family effects. Specifically, family-average social connectedness was significantly negatively associated with functional limitations in each step of the model. This suggests that families (i.e., twin pairs) who reported greater social connectedness also reported fewer functional limitations. Similarly, families who engaged in more physical activity had fewer functional limitations. These findings lend support to genetic and/or shared environmental effects on social connectedness, physical activity, and functional limitations. Consistent with these results, selection effects, as detailed above, could present as familial processes given that MZ twins are genetically identical. If certain genes predispose individuals to both higher quality relationships and more physical activity/higher function, and those genes are shared in a twin pair, then both twins would be expected to report greater social connectedness and

better health. Moreover, particularly in old age, engaging in physical activity and maintaining function often becomes a social activity (Schlenk et al., 2021; Smith et al., 2017). In other words, older adults may choose healthier environments (i.e., to engage in physical activity) often with those with whom they have high quality relationships with. Thus, selection effects would be further confounded if an individual's co-twin was part of their close social network and someone they engage in physical activity with. It is important to note, however, that this family-level process could also be a result of only genetic confounding without gene-environment interactions (i.e., no selection effects).

Overall, the results from the present study suggest there is familial confounding, but the specific mechanisms (e.g., selection effects/active gene-environment correlations) are unknown. Thus, future studies, such as the bivariate Cholesky model, are needed to decompose variance in functional limitations into genetic and environmental (shared and nonshared) components. This would help clarify the relative influence of familial and non-familial factors and highlight whether there are active (i.e., selection) and/or passive gene-environment processes involved.

Role of SES

The lack of moderation by SES was a somewhat surprising finding. Other work (Krieger et al., 2005) found that lifetime socioeconomic position, but not educational attainment, influenced a wide range of adult health markers (e.g., blood pressure, cholesterol) among female twins. Using MIDUS data, Fujiwara and Kawachi (2009) similarly showed that the association between education and moderate physical activity was confounded by genetic factors among male twins and both genetic and shared environmental factors among female twins. Importantly, these findings were for both MZ and DZ twins and they used a measure of physical activity that recoded participants' responses using category midpoints, so these results are not directly comparable to the present study. However, the work cited above supports our use of a more comprehensive SES measure, rather than educational attainment. And yet, we did not find significant moderation. One potential explanation could be that in the multilevel SEM framework it can be particularly difficult to detect significant moderated-mediation effects. This idea is supported by the fact that we did find a significant within-family effect between SES and physical activity, suggesting that the twin of higher SES reported greater physical activity compared to their co-twin. Thus, our composite

measure of SES was robust enough to demonstrate potentially causal direct effects on health (i.e., physical activity), but SES may not play a moderating role in the proposed associations.

The role of SES may also be more complicated than the moderation modeled in this study. Using MIDUS data, Johnson and Krueger (2005) found that genetic variance and total variance associated with physical health (i.e., number of chronic illnesses and body mass index) decreased with increasing income. The decline in genetic variance with increasing income suggests the existence of gene-environment interactions since the extent of genetic influence depends on individuals' environments (i.e., income). This level of analysis was beyond the scope of the present study but may inform future work.

Limitations and Future Directions

There are several limitations worth noting. It is important that these results be interpreted in the context of the study design and the measurements used. We found no within-family associations between social connectedness and functional limitations, which casts doubt on a causal association at the *individual level*. It is still possible, and perhaps likely given the between-family results, that there is a causal link at the *familial level*. Moreover, all conclusions drawn from these results are limited to our measure of life-course social connectedness. In other words, social connectedness – as defined by the LPA we employed – was not causally associated with functional health at the within-family level, but specific social relationship domains (e.g., social support), including those not measured in the present study (e.g., social integration), could still be causally associated with functional limitations at the within-family (i.e., individual) level.

The time scale of assessments is critical for capturing the correct causal process. Based on prior work (McGue & Christensen, 2007), repeated assessments over smaller time increments (e.g., 2 years) may be better suited to capture the proposed mechanisms rather than the decades over which associations were modeled in the present study.

Additionally, the variable we used to conceptualize social connectedness may not represent the true variables involved in the causal processes. Our conceptualization of life-course social connectedness was used based on prior work (Teas et al., 2023) and calls to capture relationships across the life course (McGue & Christensen, 2007). However, it may be that only one or a subset of the five relationship dimensions used in the LPA are causally associated with functional limitations. Given conceptual ambiguity related to typical negative relationship characteristics

such as social strain (Teas et al., 2023), it may be beneficial to focus on one dimension of social relationships (e.g., social support, relationship quality) in future work. Similarly, the variety of measures of functional health makes the evidence difficult to compare across studies (Foebel & Pedersen, 2016).

To increase the feasibility of analysis and interpretation, we opted to collapse twins across social profiles (for all twins not belonging to the optimal profile). This decision reduced discordance in social connectedness and meant that we were unable to probe which profiles significantly differed from one another. However, comparing twins across profiles without collapsing would have produced uninterpretable results and introduced additional issues related to power due to sample size constraints. If we had chosen not to collapse across profiles, the alternative approach would have involved analyzing every specific contrast (i.e., profile 1 vs. 2; profile 1 vs. 3, etc.) since the social connectedness variable was nominal. Moreover, our decision to collapse profiles was conceptually justified based on group differences in predicted functional limitations in the full MIDUS sample: the *optimal* profile differed from the other 3 profiles, but those 3 did not differ from one another.

Since we did not find a within-family effect between social connectedness and functional limitations, this would suggest social connectedness is not a significant nonshared influence. It is important to note that within-family estimates tend to be more severely biased by non-shared confounders than unpaired estimates, and there are several caveats to interpreting within-family effects in sibling comparison studies (see Frisell et al., 2012). If, however, social connectedness is not a nonshared environmental influence on functional limitations, as the present study would suggest, other nonshared factors (e.g., health status) could still be influential. For example, in prior work we showed that in MZ twins, the twin with higher baseline disease burden also had a greater increase in functional limitations than their co-twin (Teas et al., 2021). Thus, there may be additional nonshared environmental influences that were simply not captured in the present study that future work may examine.

Additionally, the MZ twin design is limited in its statistical power (Madsen & Osler, 2009; Vitaro et al., 2009). Specifically, we may not have had sufficient power to detect within-family mediation or moderated-mediation. In prior work (Paper 2), the indirect effect through physical activity was significant but extremely small. Because the current study used a smaller sample size, we may not have had sufficient power to detect such small effects. Of note, however, despite the

reduction in power due to sample size, the current study did have increased power due to the multilevel SEM design. Moreover, the amount of discordance in social connectedness was comparable to previous studies that have found significant within-family effects (e.g., Johnson & Krueger, 2007; Teas et al., 2021).

Although prior work identified an association between the LPA conceptualization of social connectedness and functional limitations (Teas et al., 2023), the MZ twins in the present study reported fewer functional limitations than the main MIDUS sample. Thus, there may not have been sufficient functional impairment for social connectedness to causally buffer against in the present study. Finally, the MZ twins sample lacked racial diversity, with over 90% of twins identifying as white, limiting the generalizability to more diverse populations.

Strengths and Implications

Despite the limitations, there are also many strengths to the present study. The discordant MZ twin design controlled for both genetics as well as measured and unmeasured shared familial confounds. In the present study, we used only MZ twins rather than MZ and DZ twins to maximize the strengths of the design in controlling for unmeasured genetic and shared environmental confounders. Additionally, our conceptualization of social connectedness took into account important relationship measures in both childhood and adulthood, which was appropriate for a life course perspective on social connectedness and consistent with gaps in the literature. Though homogeneous in some ways (e.g., race/ethnicity), the MZ twins in the current study were drawn from a national registry of twins.

Our results also provide insight into future intervention work. Specifically, interventions aimed at improving later-life functional health and mid-life physical activity participation may achieve more beneficial long-term results by intervening on the family level (i.e., targeting families and other childhood environments) since our results suggest that the association between social connectedness and health appears to be a family-level process.

By using longitudinal MZ twin data, we were able to address issues of causality related to the immense literature on social relationships and health. Our results suggested that life-course social connectedness was likely not causally associated with later-life functional limitations, but the association was driven by genetic and/or shared environmental influences. Although our study did not find support for a potential causal association at the individual level, there are several

important takeaways. Given the consistent significant between-family effects between social connectedness and functional limitations, it is possible that there is a causal association at the familial level. In other words, shared environmental (e.g., familial) influences among twin pairs could be causally associated with functional limitations. Additionally, our results suggest a need for precision in measurement, given the extreme variability in how phenotypes (e.g., functional health) are measured. As a whole, the field needs greater specificity in what we mean by certain terms such as "social connectedness". Additionally, we should be intentional about the timescale of these potential associations. Often when we use existing data, the timescales for our models are driven by external factors (e.g., when the data was collected for the study) rather than what theory or prior research might suggest. Finally, it may be important for future work to identify possible familial influences that have long-lasting impacts on health in middle and later life. Decomposing the association between social connectedness and functional limitations could help elucidate which influences are most important in determining functional health. This exploration was beyond the scope of the present study but may provide valuable information about the most impactful intervention points across the life course.

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CHAPTER 5. SUMMARY AND CONCLUSIONS

Functional limitations and disability are increasingly common in old age. Prior research has identified social relationships as one protective factor against later-life functional decline. However, there are several gaps in the existing research. The typical approach to studying social relationships tends to be piecemeal, examining a limited number of relationship dimensions and usually at one point in time. Moreover, despite the extensive research on social relationships and health, the mechanisms by which relationships influence health are not well understood (Feeney & Collins, 2014). Finally, causality is often assumed but not easily established, as individuals cannot be assigned to have poor social relationships. The three papers in this dissertation attempt to address these existing gaps.

This dissertation used principles from the life course perspective (Elder, 1998; Elder et al., 2003) and the Disablement Process Model (Verbrugge & Jette, 1994), as well as perspectives on social connectedness (Holt-Lunstad, 2018; Ryff, 1989), to guide this examination of the association between life-course social connectedness and later-life functional limitations. Paper 1 was a methodological examination of classifications of life course relationship typologies to determine which analytic approach was best suited for predicting functional limitations. Given the emphasis on identifying the mechanisms linking relationships to health, Paper 2 assessed potential mediation and moderation to better understand how social connectedness impacts functional health. Finally, Paper 3 used a discordant monozygotic (MZ) twin study in an examination of social connectedness and health in order to address issues of causal ambiguity. This chapter offers a brief summary of overarching findings on life-course social connectedness and later-life health and concludes with key takeaways from the three papers.

Summary of Key Findings

Paper 1 compared three analytic approaches for classifying life course relationships and their associations with later-life functional limitations. Compared to the theoretical approach, the data-driven approach (i.e., latent profile analysis) was a stronger predictor of functional limitations. The patterns uncovered in the LPA were consistent with life course cumulative processes (e.g.,

Dannefer, 2003). These findings were both theoretically and methodologically meaningful for understanding social connectedness and health.

Paper 2 extended the results from Paper 1 to examine mediation by physical activity and inflammation, as well as moderation by socioeconomic status (SES). My hypotheses were somewhat supported. Physical activity partially mediated the association between life-course social connectedness and functional limitations, consistent with prior literature (e.g., Smith et al., 2017). However, contrary to what prior work may suggest (e.g., Elliot et al., 2018), inflammation was not a significant mediator. Our ability to compare these findings to other work is complicated by the variety of measures of inflammation used across studies. Additionally, our understanding of how these biomarkers function, and which biomarkers specifically, when it comes to psychosocial processes is limited. Finally, I found no moderation by SES, contrary to hypotheses. The lack of socioeconomic variability in the MIDUS sample may have prevented the detection of moderation in these analyses. Future work should examine these associations in a more socioeconomically diverse sample.

Much of the prior work on social relationships and health assumes that the association is causal; in other words, being more socially connected leads to better health. However, causality is difficult to establish. Individuals cannot be randomly assigned to have poor relationships, and even experimental interventions have their own limitations; the effects of short-term changes in psychosocial or behavioral factors (e.g., social relationships, health behaviors) may not adequately capture the "long-arm" impact of psychosocial factors that play out over the course of many years rather than just several weeks (the typical duration of interventions). Thus, Paper 3 used a discordant MZ twin design to control for genetic and shared environmental influences implicated in the association between social connectedness and functional limitations. The results suggested that my measure of life-course social connectedness was not causally associated – at least at the individual level – with functional limitations, but rather driven by genetic and/or shared environmental influences.

Collectively, the results of these three papers add to our understanding of social connectedness and health. The LPA approach appears to be a useful method to conceptualize life-course social connectedness, at least in its association with functional limitations and given the relationship measures available in MIDUS. Optimal relationships across the life course are protective against functional decline, compared to other relationship typologies. Moreover,

physical activity, specifically moderate-to-vigorous physical activity, is one mechanism by which social connectedness is associated with functional limitations. Finally, the association between social connectedness and functional limitations seems to be a family-level process. In other words, genetic and/or shared familial factors primarily drive the association.

The Life Course Perspective and Social Connectedness

The Introduction to this dissertation presented two conceptual frameworks, the life course perspective and social connectedness. To contextualize the results from this dissertation, the following paragraphs discuss these two frameworks in light of my findings.

Overall, principles from the life course perspective were supported in this dissertation. Consistent with the lifespan development principle, both childhood and adulthood are unique, significant phases of life that are connected. Those who reported high parental affection during childhood plus supportive and high-quality relationships in adulthood had the fewest functional limitations and best overall health. In other words, these results demonstrate there are links between childhood and adulthood relationships that have implications for later-life health outcomes. Moreover, the nature of MIDUS data allowed for the examination of "the long arm" of early- and mid-life social connectedness. Cumulative processes, consistent with the timing principle, were associated with health outcomes over the span of almost two decades.

It is also interesting to speculate how linked lives might apply in future analyses, particularly among twins given the results from Paper 3. Research suggests that shared environmental influence gets smaller and twins tend to become less similar over time (Knopik et al., 2017; Polderman et al., 2015), but sibling relationships also tend to become more important in old age, particularly since the sibling relationship is often an individual's longest lasting relationship (Gilligan et al., 2020). When it comes to social connectedness, this phenomenon might apply even more so for twins as research suggests that emotional closeness between twins decreases after early adulthood but increases again in old age (Neyer, 2002). If twins become even more linked to one another in old age, what does that mean for the magnitude of genetic and both shared and nonshared environmental influences on social relationships and health?

Given the abundance of literature on the importance of social connectedness for health, the results from Paper 3 are particularly interesting. Epidemiological studies provide convincing evidence for the link between social relationships and health, and although randomized controlled

trials for social connection are generally lacking, many researchers have assumed and argued for the causal nature of the social relationships to health link (e.g., Holt-Lunstad et al., 2017). The push for including social connection as a public health priority to address the "loneliness epidemic" is even a global issue; the World Health Organization lists "social inclusion" as a social determinant of health, and the United Kingdom recently instituted a minister of loneliness.

Although intervention research would support claims of causality and help identify the best ways to improve social connectedness (Farrell et al., 2022), identifying intervention targets to improve health via social relationships has proven difficult and there are several obstacles. First, among the intervention work that does exist, there is insufficient evidence that intervening on social connectedness would help improve health outcomes (Cohen & Janicki-Deverts, 2009). Second, some researchers have experimentally manipulated social functioning to observe biological responses in a controlled lab setting (Hostinar et al., 2014), using these findings to support the association between social connection and health; however, it remains unclear how to effectively intervene in natural social networks. Third, there is some promising work on "relationship interventions", or interventions at the dyadic or group level (e.g., Martire et al., 2003), and although this work may provide avenues towards better health that involve social contact or social relationships, they do not fully capture social connection constructs such as social integration or relationship quality. Similarly, interventions to improve health indices based on Self-Determination Theory invoke relatedness supportive strategies (Ntoumanis et al., 2020) that tap into social acceptance and sense of belonging but do not generally encapsulate what it means to be "socially connected". Finally, there is ongoing disagreement in the field about what type of social intervention is best and what specifically to emphasize in an intervention (Brown & Rook, 2022).

It is worth reiterating that the conclusions drawn from Paper 3 apply to the LPA conceptualization of life-course social connectedness. Although I did not find significant within-family associations between my measure of social connectedness and functional limitations, there may be significant within-family associations between social connectedness and functional health for other specific dimensions (e.g., social support, social integration) of social relationships, which would lend support for a potential causal association at the individual level for that particular measure of social connectedness. Additionally, these results do not suggest that we should abandon all efforts in improving social connectedness, but we should think critically about where

to focus our attention. Given the significant between-family effects in Paper 3, earlier social interventions, particularly at the family level, may be a promising direction.

Conclusions and Implications for Future Work

These findings point towards several directions for future work. First, although the data-driven approach was marginally better than the theoretical approach in Paper 1, there may have been a mismatch between the theoretical principles employed and the relationship measures available. Greater theoretical specificity of life course relationship trajectories and more precise relationship measures (e.g., parental discipline, non-marital relationship quality), particularly for childhood relationships and "negative" relationship dimensions, are needed. Second, although I identified one mechanism (i.e., physical activity) by which social connectedness is associated with functional limitations, there are most certainly other mechanisms involved. Other health behaviors (e.g., diet), physiological responses (e.g., stress reactivity), and self-evaluations (e.g., self-efficacy) may be mechanisms worth exploring.

Additionally, a latent measure of inflammation was not a significant mediator in Paper 2. In order for future work to use the most appropriate measures of inflammation (i.e., specific markers and timing of measurement), we need to contend with both conceptual and measurement issues. The measure of inflammation (a latent variable comprising CRP, IL-6, and fibrinogen) used in this dissertation was not significantly associated with social connectedness or functional limitations, whereas other work using the same sample have found these associations using only one marker (e.g., IL-6; Elliot et al., 2018) or other composite measures of inflammation (e.g., Yang et al., 2014). Additionally, Elliot and colleagues (2018) found different associations between social support and inflammation depending on which inflammation measure (i.e., CRP vs. IL-6) was used. Thus, it is currently unclear whether it is the *process* of inflammation that is linked to social relationships and health or whether it is specific *proteins*. Moreover, what does it mean if one measurement of inflammation is associated with social connectedness, but another measurement is not? Relatedly, inflammatory measures, like most biological markers, have both volatile and stable components. Given the use of existing data, I was limited to one measurement of inflammation in MIDUS, although recent work suggests that repeated measures are needed for time periods greater than 3 years to obtain an adequate estimate of stable levels of inflammation (Walsh et al., 2023). Thus, results from this dissertation suggest there are both conceptual and

measurement issues for future work to address in order to better understand how inflammatory processes are implicated in social relationships.

Findings from Paper 3 suggest that there may be important genetic and shared environmental factors that influence the association between social connectedness and functional health. In future work, it may be helpful to employ decomposition studies (e.g., the bivariate Cholesky model) to disentangle these specific influences.

A common theme that emerged across all three papers was the importance of covariates. In Paper 1, I first included a broad range of possible covariates in the analyses. In the post-hoc analysis, I removed some of the covariates that could function as mediators. The results, including some of the significant group differences, slightly differed when fewer covariates were included. In Paper 2, I included a sensitivity analysis that added self-rated health as a "proxy" covariate in an attempt to capture the effect of general health on the modeled associations. Although self-rated health is not a specific measure of health (e.g., disease burden), the significance of the mediated pathways and other effects were reduced when self-rated health was included as a covariate, suggesting that it did capture some of the unexplained variance in predicted functional limitations. Finally, in Paper 3 I mostly focused on family-average demographic covariates. Because every model suggested there was a significant amount of unexplained variance in functional limitations, it could be that important covariates were missing from the models. In general, future work should be intentional about covariate selection to ensure appropriate confounders are included without the risk of overcontrolling. Importantly, race/ethnicity was treated as a covariate in these analyses, but given the lack of racial diversity in MIDUS, these results should be replicated in a more racially diverse sample.

There are several strengths to this dissertation worth restating. Overall, this dissertation advances the work on social relationships and health by integrating important theoretical principles, incorporating multiple biopsychosocial and behavioral influences, and applying rigorous analytical methods. The conceptualization of social connectedness *across the life course*, rather than only one point in time, is novel. This conceptualization was particularly valuable in this dissertation, given that functional limitations often surface in later life but are influenced by factors that unfold over the life course. Similarly, because of the longitudinal nature of MIDUS data, the associations modeled in this dissertation had proper temporal ordering, a necessary but not

sufficient requirement for examining causality. Finally, MIDUS is an age diverse sample with data collected over multiple decades, ideal for examining how life course processes unfold.

Findings from this dissertation contribute to the existing literature in three major ways. First, by proposing a useful method for classifying social relationship typologies across the life course in future research; second, by furthering our understanding of how social relationships may impact functional health; and third, by elucidating influences, namely genetic and shared environmental, that may impact the link between social connectedness and functional health. These insights are important for informing future research as well as the development of prevention and intervention programs to promote functional health.

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APPENDIX A. PAPER 1 SUPPLEMENTAL TABLES & FIGURES

Table A.1. Means and Standard Deviations for All Covariates by Group for Each of the Three Analytic Approaches

	Theoretical Approach				*Positive LPA*				*Multivalence LPA*			
	Cons. high pos.	Cons. low pos.	Incr. pos.	Decr. pos.	Opt.	Least opt.	Avg. + low supp.	Avg. + low PRWO	Opt.	Least opt.	Avg. + low supp.	Avg. + low PRWO
Age	55.38 (12.77)	54.16 (9.93)	55.30 (11.46)	53.42 (10.20)	55.85 [a] (12.78)	53.44 [b] (11.13)	54.00 [b] (11.60)	55.05 (12.32)	56.06 [a] (12.87)	53.36 [b] (11.07)	53.81 [b] (11.53)	55.08 (12.35)
White, %	0.82 [b] (.38)	0.82 (.38)	0.88 [a] (.33)	0.71 [b] (.45)	0.85 [a] (.36)	0.79 [b] (.41)	0.79 [b] (.40)	0.82 (.39)	0.85 [a] (.36)	0.79 [b] (.41)	0.81 (.39)	0.82 (.39)
Married, %	0.66 [a] (.47)	0.41 [b] (.49)	0.64 (.48)	0.37 [b] (.48)	0.71 [a] (.45)	0.48 [b] (.50)	0.61 (.49)	0.58 [b] (.49)	0.71 [a] (.45)	0.49 [b] (.50)	0.64 (.48)	0.57 [b] (.49)
Female, %	.51 [b] (.50)	.53 (.50)	.62 [a] (.49)	.54 (.50)	.57 [a] (.50)	.50 (.50)	.51 (.50)	.48 [b] (.50)	.57 [a] (.50)	.52 (.50)	.52 (.50)	.48 [b] (.50)
Alcohol abuse	.34 [b] (.80)	.75 [a] (1.53)	.38 (.82)	.60 [a] (1.38)	.29 [b] (.69)	.59 [a] (1.26)	.40 (.88)	.42 [a] (.94)	.28 [b] (.66)	.58 [a] (1.24)	.42 [a] (.87)	.42 [a] (.96)
Smoking, %	.51 [b] (.50)	.66 [a] (.47)	.60 [a] (.49)	.58 (.50)	.50 [b] (.50)	.61 [a] (.49)	.53 (.50)	.56 [a] (.50)	.50 [b] (.50)	.61 [a] (.49)	.55 (.50)	.56 [a] (.50)
Divorce, %	.08 [b] (.26)	.12 (.33)	.13 [a] (.33)	.07 (.26)	.08 [b] (.27)	.10 (.30)	.10 (.30)	.10 (.29)	.08 [b] (.27)	.10 (.30)	.10 (.30)	.09 (.29)
Widowed, %	.07 (.26)	.05 (.23)	.07 (.25)	.03 (.17)	.08 [a] (.27)	.05 (.22)	.07 (.25)	.05 [b] (.22)	.08 [a] (.27)	.05 (.22)	.07 (.25)	.05 [b] (.22)
Marriage, %	.06 (.24)	.09 (.28)	.06 (.24)	.03 (.17)	.06 (.23)	.05 (.23)	.06 (.24)	.07 (.25)	.06 (.23)	.05 (.22)	.07 (.25)	.07 [a] (.26)
Disease burden	2.10 [b] (3.29)	3.04 [a] (3.50)	2.38 [a] (3.34)	3.06 [a] (4.77)	1.97 [b] (3.06)	3.04 [a] (4.02)	2.10 (3.23)	2.44 [a] (3.69)	1.95 [b] (2.99)	2.99 [a] (3.94)	2.07 (3.36)	2.48 [a] (3.75)
Subj. mem (others)	3.54 [a] (.91)	3.04 [b] (1.08)	3.41 [b] (.91)	3.02 [b] (1.16)	3.62 [a] (.88)	3.07 [b] (1.05)	3.37 [b] (.89)	3.40 [b] (.91)	3.63 [a] (.88)	3.08 [b] (1.04)	3.37 [b] (.91)	3.42 [b] (.91)
Subj mem (self)	2.67 [a] (.72)	2.35 [b] (.91)	2.56 [b] (.75)	2.60 (.95)	2.69 [a] (.69)	2.40 [b] (.86)	2.63 (.76)	2.61 (.75)	2.70 [a] (.69)	2.39 [b] (.83)	2.60 (.78)	2.63 (.76)
Res. Inst., %	.25 [b] (.43)	.41 [a] (.49)	.33 [a] (.47)	.31 (.46)	.25 [b] (.43)	.35 [a] (.48)	.28 (.45)	.29 (.45)	.25 [b] (.43)	.35 [a] (.48)	.29 (.45)	.28 (.45)
Par. Div./sep. %	.08 [b] (.27)	.18 [a] (.38)	.18 [a] (.38)	.07 (.26)	.09 [b] (.28)	.15 [a] (.36)	.11 (.31)	.11 [a] (.32)	.08 [b] (.28)	.14 [a] (.35)	.12 (.32)	.11 (.31)
Par. death, %	.07 (.25)	.09 (.28)	.08 (.27)	.03 (.17)	.07 (.25)	.07 (.25)	.08 (.28)	.06 (.25)	.07 (.25)	.06 (.24)	.09 [a] (.28)	.07 (.25)

Note. Mean (SD) for continuous variables; if "%" indicated, proportions reported. See OSF for output, which includes regression coefficients for each covariate.

Table A.2. Cross Tab of Profile Assignment in Positive LPA and Theoretical Approach (Aim 1; *n* = 6834)

	Theoretical Groups				
Positive LPA Profiles	Consistently high positive	Consistently low positive	Increasing positive	Decreasing positive	*Total*
Optimal	3310	0	458	0	3768
Least optimal	153	148	202	98	601
Avg. + low support	339	0	279	0	618
Avg. + low PRWO	1360	0	487	0	1847
Total	5162	148	1426	98	6834

Note. The total sample size was 6909; however, 75 participants did not meet the criteria for any of the theoretical groups. PRWO = positive relations with others.

Table A.3. Cross Tab of Profile Assignment in Multivalence LPA and Positive LPA (Aim 2; *n* = 6909)

	Positive LPA Profiles				
Multivalence LPA Profiles	Optimal	Least optimal	Avg. + low support	Avg. + low PRWO	*Total*
Optimal	3503	0	14	34	3551
Least optimal	0	616	27	76	719
Avg. + low support	225	3	582	79	889
Avg. + low PRWO	58	10	2	1680	1750
Total	3786	629	625	1869	6909

Note. PRWO = positive relations with others.

APPENDIX B. PAPER 2 SUPPLEMENTAL TABLES & FIGURES

Table B.1. Descriptives of Key Variables for Total Sample and Each Profile Within Biomarker Subsample

			Total sample	Profile 1 (Optimal)	Profile 2 (Least optimal)	Profile 3 (Avg. + low support)	Profile 4 (Avg. + low PRWO)
Mediators	MVPA	Mean (SD)	2.55[a] (1.21)	2.65 (1.19)	2.44 (1.24)	2.42 (1.24)	2.45 (1.20)
		Range	.33 – 3.97	.34 – 3.91	.33 – 3.91	.34 – 3.91	.33 – 3.97
		n	1225	647	137	147	294
	Inflammation	Mean (SD)	.41 (.81)	.40 (.80)	.50 (.84)	.39 (.79)	.41 (.81)
		Range	-2.11 – 2.83	-1.78 – 2.75	-1.55 – 2.42	-1.45 – 2.78	-2.11 – 2.83
		n	1225	647	137	147	294
Moderator	SES Composite	Mean (SD)	.31[a] (.95)	.41 (.89)	.08 (.98)	.32 (1.04)	.18 (.97)
		Range	-2.02 – 3.94	-1.70 – 3.47	-1.57 – 3.94	-1.50 – 3.52	-1.77 – 3.42
		n	1052	566	101	121	235
Outcome	Functional Limitations	Mean (SD)	1.73 (.85)	1.62 (.80)	2.01 (.93)	1.69 (.81)	1.86 (.89)
		Range	1 – 4	1 – 4	1 – 4	1 – 4	1 – 4
		n	1066	560	111	128	251

Note. MVPA and inflammation are both latent variables. MVPA = moderate-to-vigorous physical activity. PRWO = positive relations with others. SES = socioeconomic status.
[a]Significantly greater than the full sample

Table B.2. Correlations for Key Variables and Functional Limitations by Social Profile (*n* = 6909)

	FL	MVPA	Inflammation	SES	FL	MVPA	Inflammation	SES
FL		-.24***	.34***	-.22***		-.24***	.27**	-.26***
MVPA	-.23***		-.18***	.23***	-.22***		-.15	.18***
Inflammation	.39***	-.25**		-.10*	.31***	-.12*		-.12
SES	-.16*	.19***	-.25*		-.30***	.19***	-.22***	

Note. FL = functional limitations; MVPA = moderate-to-vigorous physical activity; SES = socioeconomic status
*$p < .05$; **$p < .01$; ***$p < .001$
Left hand side, above diagonal: Optimal (1)
Left hand size, below diagonal: Least optimal (2)
Right hand side, above diagonal: Avg. + low support (3)
Right side, below diagonal: Avg. + low PRWO (4)

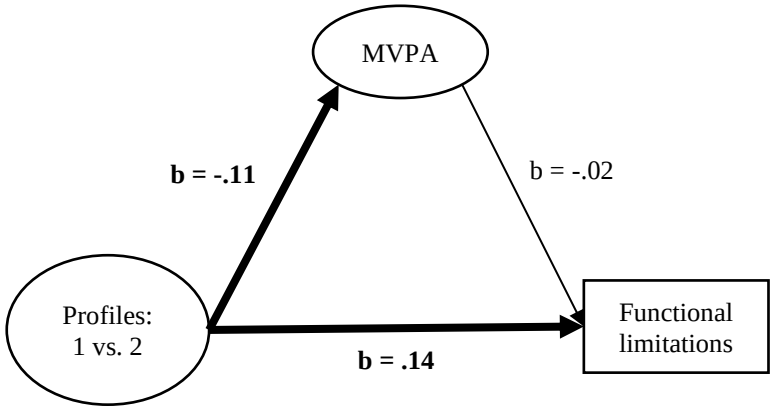
Table B.3. Correlations for Key Variables and Functional Limitations by Social Profile (Biomarker Subsample, *n* = 1255)

	FL	MVPA	Inflammation	SES	FL	MVPA	Inflammation	SES
FL		-.26***	.34***	-.13**		-.21*	.27**	-.33***
MVPA	-.31***		-.18***	.20***	-.20**		-.15	.29**
Inflammation	.39***	-.25**		-.10*	.32***	-.12*		-.12
SES	-.23*	.28**	-.25*		-.27***	.27***	-.22***	

Note. FL = functional limitations; MVPA = moderate-to-vigorous physical activity; SES = socioeconomic status
*$p < .05$; **$p < .01$; ***$p < .001$
Left hand side, above diagonal: Optimal (1)
Left hand size, below diagonal: Least optimal (2)
Right hand side, above diagonal: Avg. + low support (3)
Right side, below diagonal: Avg. + low PRWO (4)

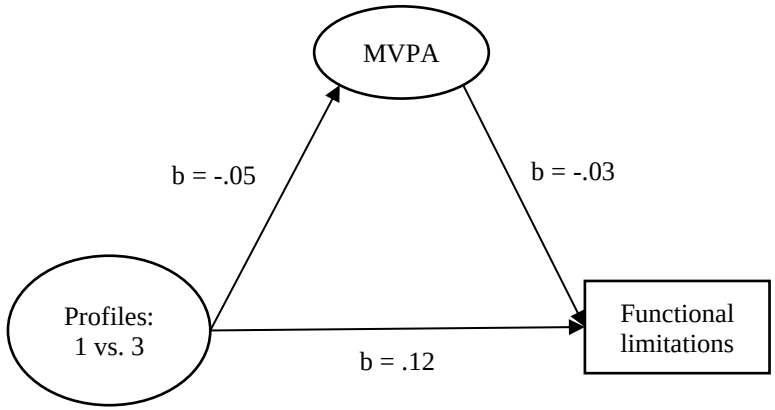
Figure B.1. Mediation Results for Model 1 (*n* = 6909) with Self-Rated Health as a Covariate

A. Optimal vs. Least optimal



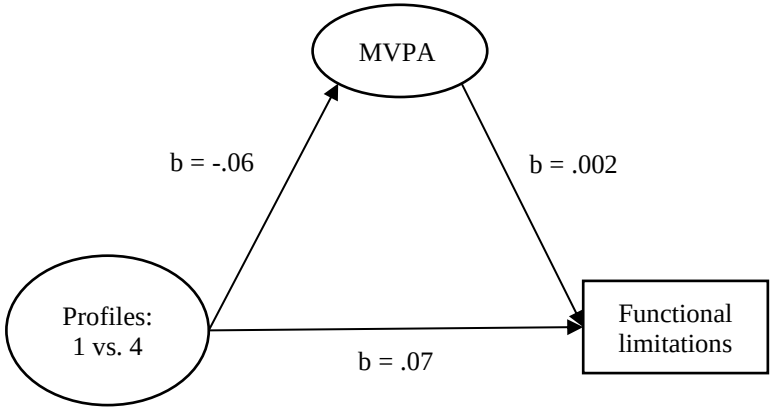
Simple indirect = .003, p = .056
Total (direct + mediated interaction) = .10, p = .001

B. Optimal vs. Avg. + low support



Simple indirect = .002, p = .33
Total (direct + mediated interaction) = .06, p = .04

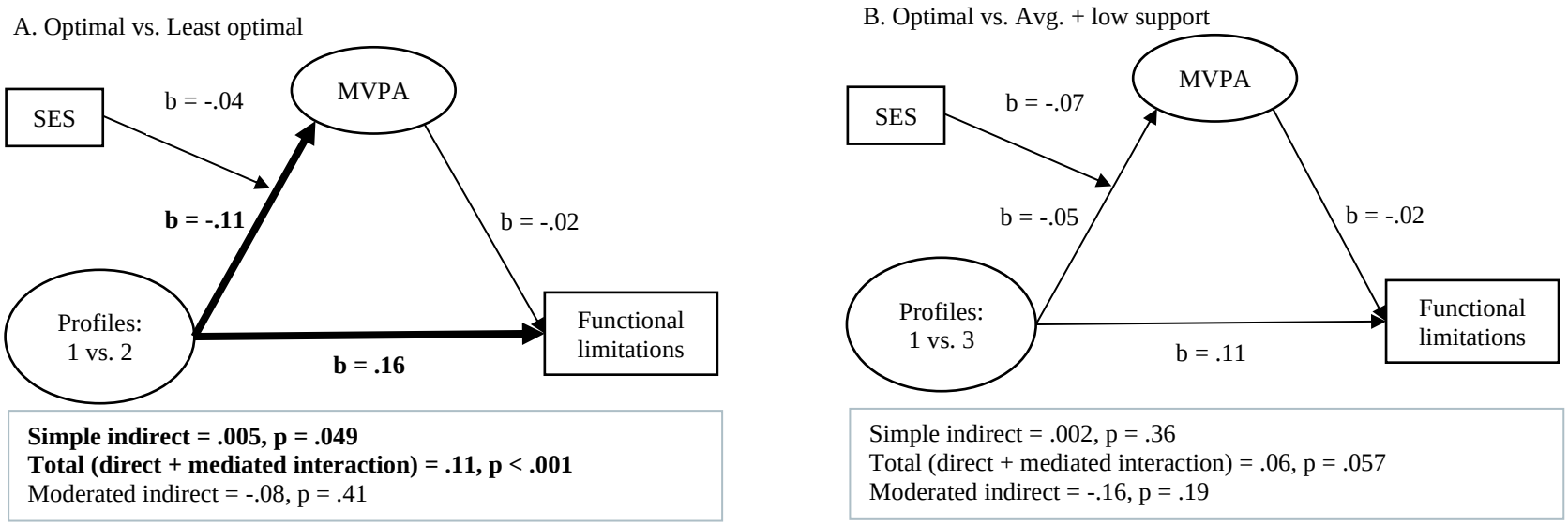
C. Optimal vs. Avg. + low PRWO



Simple indirect = .002, p = .13
Total (direct + mediated interaction) = .07, p < .01

Note. All significant pathways/effects are bolded. MVPA = moderate-to-vigorous physical activity. Covariates: age, sex, race, marital status, & self-rated health.

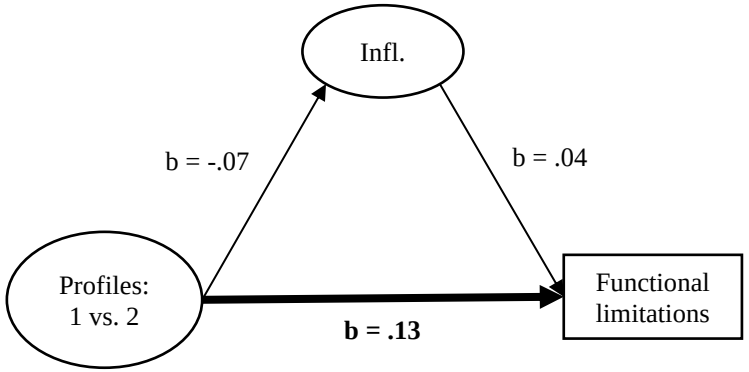
Figure B.2. Moderated Mediation results for Model 1 (n = 6909) with Self-Rated Health as a Covariate



Note. All significant pathways/effects are bolded. MVPA = moderate-to-vigorous physical activity. Covariates: age, sex, race, marital status, & self-rated health.

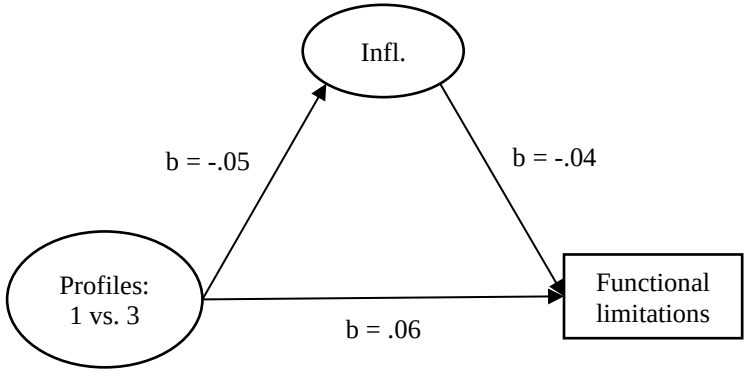
Figure B.3. Mediation Results for Model 2 with Self-Rated Health as a Covariate, Biomarker Subsample (*n* = 1225)

A. Optimal vs. Least optimal



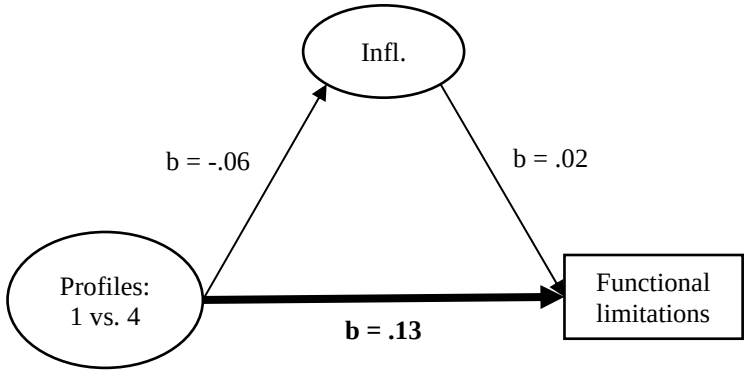
Simple indirect = -.007, p = .44
Total (direct + mediated interaction) = .17, p < .01

B. Optimal vs. Avg. + low support



Simple indirect = -.005, p = .63
Total (direct + mediated interaction) = .012, p = .86

C. Optimal vs. Avg. + low PRWO

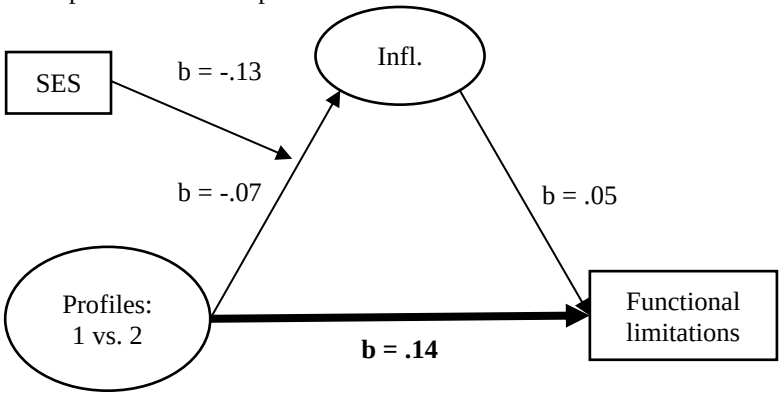


Simple indirect = -.006, p = .42
Total (direct + mediated interaction) = .15, p < .01

Note. All significant pathways/effects are bolded. Infl. = inflammation (latent variable of CRP, IL-6, and fibrinogen). Covariates: age, sex, race, marital status, NSAID use, & self-rated health.

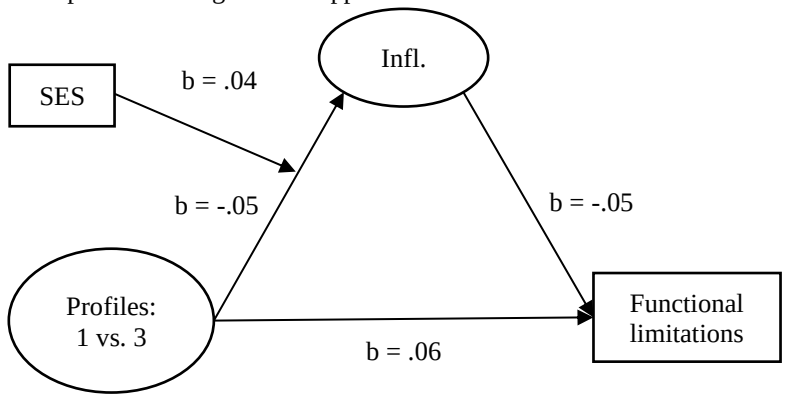
Figure B.4. Moderated Mediation Results for Model 2 with Self-Rated Health as a Covariate, Biomarker Subsample (*n* = 1225)

A. Optimal vs. Least optimal



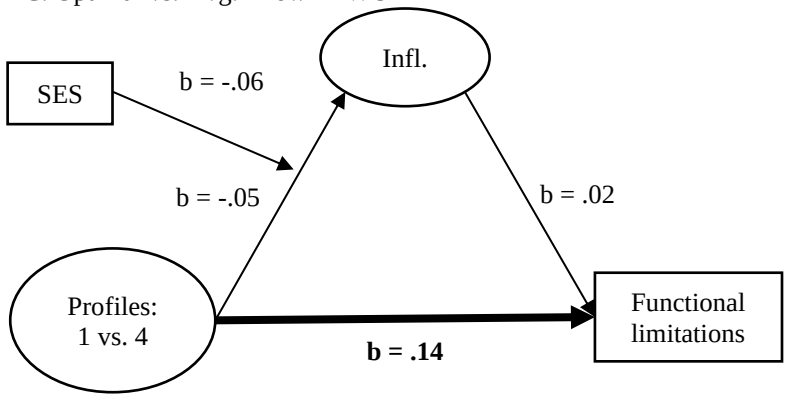
Simple indirect = -.008, p = .42
Total (direct + mediated interaction) = .19, p = .001
Moderated indirect = -.13, p = .096

B. Optimal vs. Avg. + low support



Simple indirect = -.006, p = .61
Total (direct + mediated interaction) = .01, p = .85
Moderated indirect = .03, p = .76

C. Optimal vs. Avg. + low PRWO

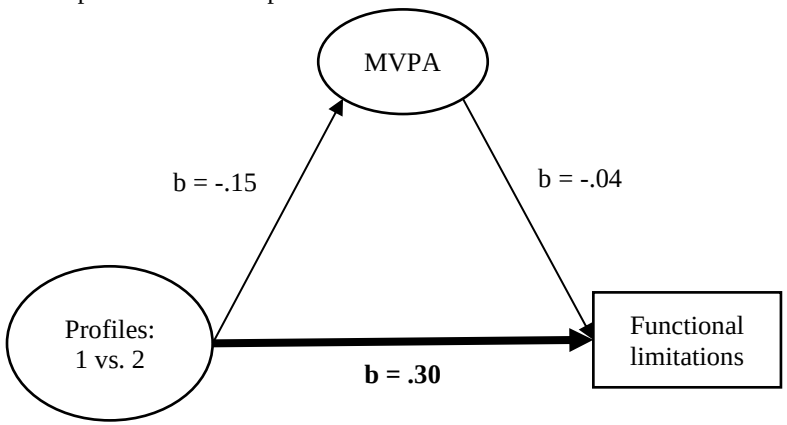


Simple indirect = -.005, p = .52
Total (direct + mediated interaction) = .16, p = .001
Moderated indirect = -.06, p = .45

Note. All significant pathways/effects are bolded. Infl. = inflammation (latent variable of CRP, IL-6, and fibrinogen). Covariates: age, sex, race, marital status, NSAID use, & self-rated health.

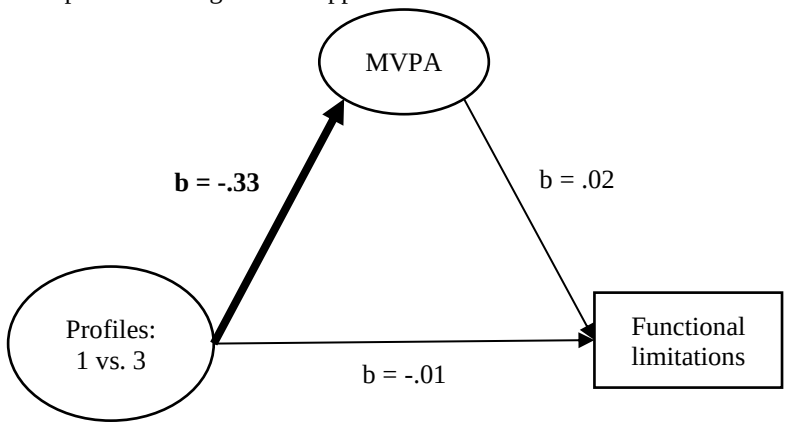
Figure B.5. Mediation Results for Model 1 in Biomarker Subsample (*n* = 1225)

A. Optimal vs. Least optimal



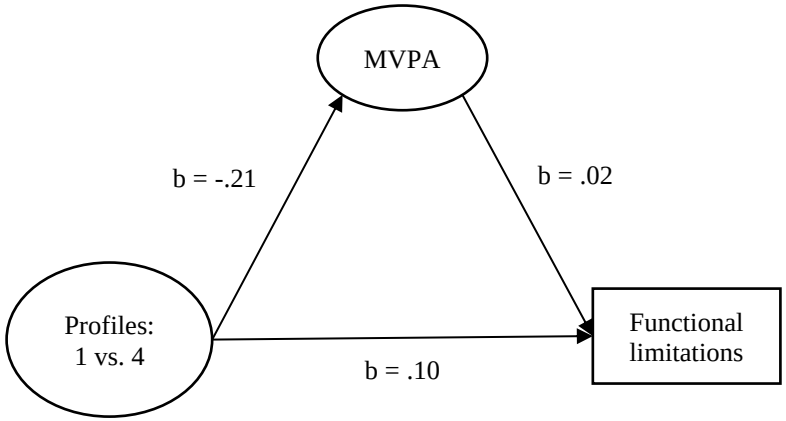
Simple indirect = .009, p = .29
Total (direct + mediated interaction) = .21, p < .001

B. Optimal vs. Avg. + low support



Simple indirect = .02, p = .08
Total (direct + mediated interaction) = .04, p = .54

C. Optimal vs. Avg. + low PRWO

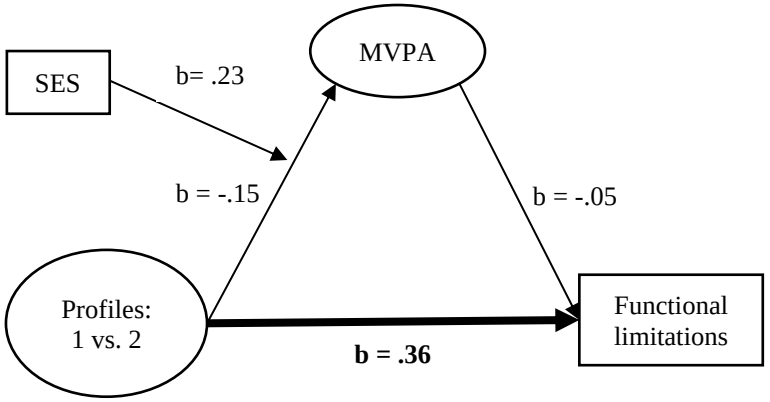


Simple indirect = .01, p = .095
Total (direct + mediated interaction) = .16, p < .001

Note. All significant pathways/effects are bolded. MVPA = moderate-to-vigorous physical activity. Covariates: age, sex, race, & marital status.

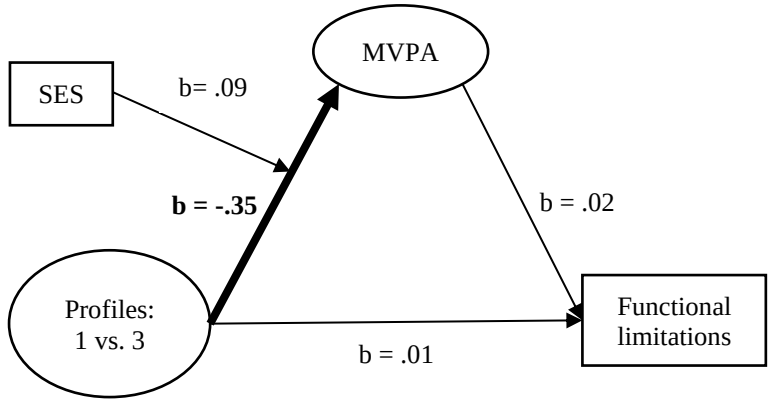
Figure B.6. Moderated Mediation Results for Model 1 in Biomarker Subsample (*n* = 1225)

A. Optimal vs. Least optimal



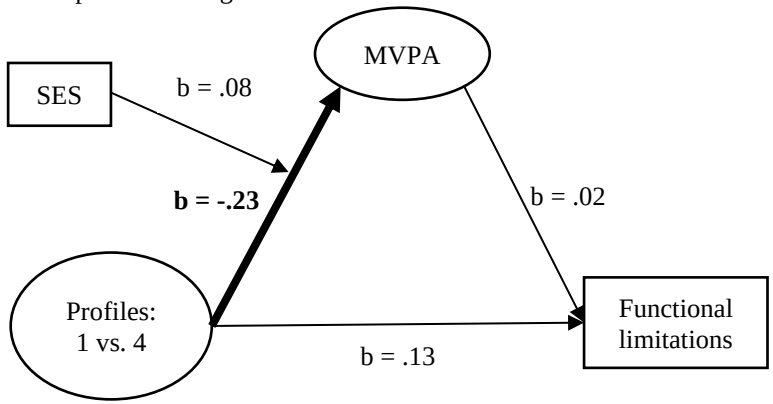
Simple indirect = .01, p = .28
Total (direct + mediated interaction) = .24, p < .001
Moderated indirect = .55, p = .07

B. Optimal vs. Avg. + low support



Simple indirect = .03, p = .07
Total (direct + mediated interaction) = .04, p = .51
Moderated indirect = .22, p = .52

C. Optimal vs. Avg. + low PRWO



Simple indirect = .02, p = .06
Total (direct + mediated interaction) = .17, p < .001
Moderated indirect = .21, p = .46

Note. All significant pathways/effects are bolded. MVPA = moderate-to-vigorous physical activity. Covariates: age, sex, race, & marital status.

APPENDIX C. PAPER 3 SUPPLEMENTAL TABLES & FIGURES

Table C.1. Comparison of MZ Twins to Main MIDUS Sample on Key Variables

	MZ Twins	Main sample
Age (years; MIDUS 2)	53.82 (11.48)**	55.63 (12.69)
Female, %	55.1%	52.4%
White, %	92.2%***	78.3%
Married at baseline, %	73.4%***	61.2%
MVPA	2.45 (1.01)	2.39 (.99)
SES	.07 (.94)	.05 (.99)
Functional limitations	1.56 (.75)***	1.80 (.89)

Note. Main sample excluded all twins. Mean (SD) listed unless otherwise indicated. Significant differences between groups noted in the MZ twins column: ***p<.001; **p<.01. MVPA = moderate-to-vigorous physical activity; SES = socioeconomic status.