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LONELINESS AND SLEEP DISTURBANCE IN OLDER AMERICANS

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A dissertation submitted in partial fulfillment of requirements for the degree of Doctor of Philosophy in Clinical Psychology at Virginia Commonwealth University

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Abstract

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Loneliness is a risk factor for premature mortality but the mechanics of this relationship remain obscure. A potential mechanism is sleep disturbance. The present study aimed to examine the association between loneliness and sleep disturbance, evaluate loneliness as a risk factor for sleep disturbance and vice-versa, model effects between loneliness and sleep disturbance over time, and evaluate a mediation model of loneliness, sleep disturbance, and health. Data came from the 2006-2012 waves of the Health and Retirement Study, a nationally-representative study of older Americans; participants $\geq$ 65 were included (n=11,400). Analyses included (i) linear regressions accounting for complex sampling and (ii) path analysis (cross-lagged panel and mediation models). Loneliness and sleep disturbance were correlated and were risk factors for one another. Cross-lagged panel models showed reciprocal effects between loneliness and sleep disturbance. Cross-lagged mediation models showed that loneliness predicted subsequent sleep

disturbance, which in turn predicted poor self-reported health. Moreover, there was evidence of a direct and indirect effect of loneliness on sleep disturbance. All associations were weakened—but remained—when accounting for demographics, isolation, and depression. Collectively, these findings are consistent with the theory that sleep disturbance is a mechanism through which loneliness damages health. However, effects between loneliness and sleep are reciprocal, rather than unidirectional. Moreover, longitudinal effects were very small. Further research is necessary to speak to causality, assess daily associations between loneliness and sleep, assess a comprehensive model of the mechanics of loneliness and health, and examine loneliness and sleep in the context of other factors.

Loneliness and Sleep Disturbance in Older Americans

In October of 2017, Dr. Vivek Murthy, the 19th Surgeon General of the United States, identified loneliness as the most common pathology that he had encountered in his three years of service. The statement made headlines, but the identification of social isolation as a health risk dates back decades. In 1988, House, Landis, and Umber synthesized research at the time to argue that social relationships affect health and underlined the need for further work on the social, psychological, and biological processes that mediate this relationship. Subsequent research has bolstered House, Landis, and Umber's (1988) conclusion: multiple meta-analyses indicate that social factors, including isolation, loneliness, and social support, predict morbidity and mortality (Holt-Lunstad, Smith, Baker, Harris, & Stephenson, 2015; Holt-Lunstad, Smith, & Layton, 2010; Manzoli, Villari, Pirone, & Boccia, 2007; Sbarra, Law, & Portley, 2011; Shor, Roelfs, & Yogev, 2013). However, the dearth of research identifying mechanisms underlying the link between social relationships and health remains thirty years later after the relationship was initially identified (Thoits, 2011).

The construct of social relationships is not unidimensional but rather encapsulates a cluster of factors—including social ties, social support, isolation, loneliness—which interact with one another (Berkman, Glass, Brissette, & Seeman, 2000; Cacioppo & Cacioppo, 2014; Thoits, 2011). These factors differ in terms of their level of objectivity versus subjectivity: different factors tap into internal versus external experiences. On either end of this spectrum lie the factors of isolation and loneliness. Isolation is the state of *being* alone; loneliness is the state of *feeling* alone. The two are related yet distinct: studies consistently report a significant yet modest correlation between loneliness and isolation (Gale, Westbury, & Cooper, 2017; Ge, Yap, Ong, &

Heng, 2017; Hughes, Waite, Hawkley, & Cacioppo, 2004; Matthews et al., 2016; Steptoe, Owen, Kunz-Ebrecht, & Brydon, 2004).

Cacioppo and Hawkley (2003; 2009) emphasized the role of loneliness in the connection between social relationships and health. The authors proposed a model of the mechanisms underlying the relationship between loneliness and health that identifies sleep disturbance as a mechanism through which loneliness influences health (see Appendix A for full model). Preliminary evidence for this theory comes from a study led by Cacioppo that showed that lonely persons had lower sleep efficiency and higher levels of wake time after sleep onset than non-lonely participants (2002). Cacioppo and Hawkley argue that this sleep disturbance marks the loss of a fundamentally restorative behavior, thus affecting metabolic, neural, and hormonal processes (2003). The study did not control for isolation nor did it assess for the effects of sleep quality on loneliness.

Two major lines of evidence are necessary to provide support for sleep disturbance as mechanism through which loneliness influences health: (i) loneliness must impair sleep and (ii) sleep disturbance must worsen health. To support the claim that loneliness disrupts sleep, or that loneliness is a causal risk factor for sleep disturbance, it is first necessary to establish that loneliness and sleep disturbance correlate. Next, it is necessary to assess whether the correlation between loneliness and sleep disturbance is due to a third factor. It is not possible to rule out the possibility of a third factor driving both loneliness and sleep disturbance, but it is necessary to identify and test for likely potential confounds. Finally, it is necessary to determine the direction of the effect between loneliness and sleep—i.e., that the correlation is due to loneliness impairing sleep rather than the reverse. This does not preclude the possibility that loneliness and sleep quality both influence one another, but rather requires that the correlation between loneliness and

sleep is not entirely attributable to sleep disturbance eliciting loneliness. As such, it is necessary to both assess loneliness as a risk factor for sleep disturbance and sleep disturbance as a risk factor for loneliness. The same types of evidence are necessary to establish that sleep disturbance worsens health. That is to say, it is necessary to show that sleep disturbance correlates with poor health, that sleep disturbance precedes decline in health, and that there is not a third factor accounting for the relationship.

The current literature on each of these lines of evidence is summarized below. Subsequently, the literature looking specifically at sleep disturbance as a mediator for the relationship between loneliness and health is reviewed.

Cross-sectional Relationship between Loneliness and Sleep

There is strong support for the cross-sectional association between loneliness and sleep disturbance, both in terms of lower subjective sleep quality and higher insomnia symptoms across a wide range of samples (see Appendices B and C) and measures (see Appendix D). All but one study (Kurina et al., 2011) that have examined the association between loneliness and self-reported sleep quality in adults have found a significant bivariate correlation between loneliness and subjectively measured sleep quality. Furthermore, two studies have examined sleep quality objectively (Cacioppo et al., 2002: polysomnography; Kurina et al., 2011: actigraphy) to find a significant bivariate association between loneliness and at least one dimension of sleep quality. Cacioppo, Hawkley, Bernston et al. (2002) found that lonely persons were awake for longer after sleep onset than non-lonely persons, though did not find evidence that loneliness was associated with other dimensions of sleep quality, to include sleep efficiency, sleep onset, and number of awakenings. Kurina et al. (2011) demonstrated that participants who endorsed higher levels of loneliness showed higher levels of sleep fragmentation.

All of the studies examining insomnia severity found that higher loneliness correlated with higher levels of insomnia symptoms (Chu et al., 2016; Hom, Chu, et al., 2017; Hom, Hames, et al., 2017; Stickley et al., 2015). All of the studies that assessed either sleep adequacy (Jaremka et al., 2014; Segrin & Passalacqua, 2010) and sleep satisfaction (Jacobs, Cohen, Hammerman-Rozenberg, & Stessman, 2006) showed a significant bivariate association between these variables and loneliness.

In summary, sleep disturbance—as defined by impaired sleep quality, insomnia symptoms, sleep inadequacy, or sleep dissatisfaction—correlates with loneliness across studies using a wide range of studies, measures, and samples. Further research is necessary to replicate this finding in a sample that is representative of older Americans.

Confounds

The majority of studies that have examined the cross-sectional relationship between loneliness and sleep did not control for potential confounds. Moreover, studies differ in terms of which factors they controlled for. A narrative summary of results on the relationship between loneliness and sleep with adjustments is presented in Appendix E**,** which highlights the wide range of demographics (age, college program and semester, education, gender, income, marital status, occupation/employment, parenthood), health behaviors (alcohol use, BMI, physical exercise, smoking), health factors (blood pressure, cognitive impairment, comorbidity, functional limitations, heart disease, pain, polypharmacy, risk of sleep apnea, stroke), mental health factors (anxiety, negative affect, neuroticism, perceived burdensomeness, quality of life, rumination, stress), and social factors (association membership, household size, isolation, social contacts, social support) accounted for.

The most commonly studied confound was depression, which substantially attenuated the relationship between loneliness and both sleep quality and insomnia symptoms across all studies (Cheng et al., 2015; Hayley et al., 2017; Hom, Hames, et al., 2017; Kurina et al., 2011; Matthews et al., 2017; McHugh, Casey, & Lawlor, 2011; Yu, Steptoe, Niu, Ku, & Chen 2017). An association between loneliness and sleep quality remained after controlling for depression in four out of ten studies: Hayley et al. (2017), Mathews et al. (2017), Segrin & Burke (2015), and Kurina (2011). To conclude, other factors, in particular depression, consistently attenuate the relationship between loneliness and sleep disturbance, sometimes to the point where the association between loneliness and sleep disturbance was no longer significant. These findings underline the importance of accounting for factors that may confound the association between loneliness and sleep disturbance. However, more importantly, it is necessary to understand how depression may interplay with both factors, given that depression is tightly intertwined with loneliness (Erzen & Çikrikci, 2018), sleep disturbance (Becker, Jesus, João, Viseu, & Martins, 2017), and health (Cuijpers & Smit, 2002; Rutledge, Reis, Linke, Greenberg, & Mills, 2006; van Dooren et al., 2013) .

Loneliness as a Risk Factor for Sleep Disturbance

The research on loneliness as a risk factor for sleep disturbance is smaller and less conclusive than the cross-sectional literature. Only eight peer-reviewed studies have evaluated loneliness as a risk factor for sleep disturbance in adults, with differing conclusions (see Appendix F for a summary). These studies differed in terms of their outcome of interest (to include insomnia symptoms, sleep quality, sleep satisfaction, and sleep adequacy), in addition to other key methodological factors to include length of follow-up (3 months to 7 years), measures,

samples, analyses, attrition rates (5.5% - 56.1%), handling of attrition, and potential confounds, making it difficult to draw conclusions across studies.

Four studies have examined sleep quality as an outcome, with inconsistent results across studies (first study from Jaremka et al., 2014; McHugh & Lawlor, 2013; Yu et al., 2017; Zawadzki, Graham, & Gerin, 2013). One of these studies did not speak directly to the association between loneliness and sleep quality but reported that changes in loneliness corresponded with changes in anxiety, which in turn predicted changes in sleep quality (Zawadzki et al., 2013). These findings indicate that there is a path from loneliness to sleep quality, albeit an indirect one. Of the remaining three studies, only one identified loneliness as a risk factor for diminished sleep quality (McHugh & Lawlor, 2013). This study did not control for depressive symptoms, which may account for why it found a significant effect where Yu et al. (2017), who adjusted for depression (among many other factors), did not. The second study that did not detect an effect (Jaremka et al., 2014) did not control for depression or any other potential confounds; however, it is possible that the sample size (n=115) in the latter study was too small to detect an effect.

The four remaining studies examined different outcomes, to include insomnia symptoms (study 6 from Hom, Hames, et al., 2017), sleep satisfaction (Jacobs et al., 2006), sleep adequacy (second study from Jaremka et al., 2014), and sleep problems (study 5 from Hom, Hames, et al., 2017); collectively, these studies provide initial support for the loneliness as a risk factor for sleep difficulties. The study that examined sleep problems (study 5 from Hom, Hames, et al., 2017) used an item from the Beck Depression Inventory—II (BDI-II) asking about change in sleep. This item lacks face validity as a measure of sleep problems: it does not distinguish between sleeping more or less than in the past, and only asks about change in sleep over the past two weeks rather than sleep issues more broadly. As such, the fact that this study did not find

evidence of a longitudinal relationship between loneliness and change in sleep has little bearing on whether sleep disturbance is a mechanism through which loneliness shapes health. Hom, Hames, et al. (2017) found that insomnia symptoms at baseline predict subsequent loneliness and vice versa, but not when controlling for depression. These findings are consistent with the cross-sectional research and point to the importance of examining loneliness and sleep disturbance in the context of depression. Jacobs, Cohen, Hammerman-Rozenberg, & Stessman (2006) found that loneliness predicts subsequent sleep satisfaction when controlling for potential confounds, including depression. Similarly, Jaremka et al. (2014) found that loneliness predicted subsequent sleep inadequacy.

In conclusion, there is preliminary evidence that loneliness predicts subsequent sleep disturbance, but further research is necessary. This research could build upon the existing work by using scales with adequate psychometric properties and examining how depression and other factors relate to the longitudinal relationship between loneliness and sleep disturbance. Moreover, although four studies examined older adult samples (Jacobs et al., 2006; Jaremka et al., 2014; McHugh & Lawlor, 2013; Yu et al., 2017), none of these samples were representative of the United States population of older adults. Additionally, it is important that this work account for attrition bias (Weuve et al., 2012). Lonely participants are at greater mortality risk (Holt-Lunstad et al., 2015); therefore, attrition would likely be selective for lonely individuals, which may increase likelihood of a Type II error. None of the longitudinal work thus far accounted for attrition bias, although Yu and colleagues (2017) examined baseline differences in those retained in the study versus those lost to follow-up.

Sleep Disturbance as a Risk Factor for Loneliness

Three studies have examined sleep problems as a risk factor for loneliness in adults. Two studies led by Hom and Hames (2017) examined sleep problems as a risk factor for loneliness. The first study by Hom, Hames, et al. (2017) used an item from the BDI-II assessing change in sleep which, as mentioned earlier, lacks face validity as a measure of insomnia symptoms and thus cannot speak to whether sleep disturbance predicts subsequent loneliness. The second study by Hom, Hames, et al. (2017) showed that insomnia symptoms predicted loneliness five weeks later, though not when controlling for depression, in a sample of undergraduate students (n=151).

Simon and Walker (2018) examined this relationship more closely via an experiment to conclude that sleep disturbance increased loneliness. All undergraduate student participants (n=18) underwent two conditions: one in which they spent a night in the laboratory, where they were sleep-deprived, and the second in which they spent the night at home and slept naturally. The order of the two conditions was counterbalanced across participants. Participants completed mood and anxiety questionnaires the following morning. Participants reported higher levels of loneliness after the sleep deprivation condition than the natural sleep condition, suggesting that sleep disturbance causes loneliness. However, although the use of an experimental design strengthens this study's ability to infer causality, it also introduces bias. Participants spent the night in a laboratory in the sleep-deprivation condition as opposed to in their homes in the natural-sleep condition. A night in a laboratory might foster loneliness, for example by separating participants from their friends, family, partner, or pets. Moreover, study conclusions are limited given the small sample size (n=18) and the fact that participants were limited to college students, who likely differ from the larger population both in terms of their sleep and their social habits.

Simon and Walker (2018) supplemented this experiment with an online observational study (n=293; analytical n=138) examining daily fluctuations in sleep quality (measured via

sleep survey) and loneliness (measured via a short form of the UCLA-R) over two days. Participants were then dichotomized according to whether they experienced increased versus decreased sleep efficiency over the two nights. Participants with increased sleep efficiency became less lonely whereas participants with decreased sleep efficiency became more lonely the following day.

Together these studies provide preliminary support for sleep disturbance as a risk factor for loneliness. However, the first study by Hom, Hames, et al. (2017) is severely limited by its sleep measure and none of the samples are representative of—or even resemble—the United States population. Additionally, it is necessary to assess whether these findings endure over a longer time frame. Examination of the day to day relationship between fluctuations of loneliness and sleep is critical, but it is also important to look at their relationship long-term to understand how effects may accumulate to produce enduring changes in health. Findings that sleep disturbance partially or fully mediates the relationship between loneliness and health would be equally important in understanding these relationships and, for example, would suggest that the target of intervention should be sleep rather than loneliness.

Sleep Disturbance Deteriorates Health

Sleep is integral to health (Medic, Wille, & Hemels, 2017; B. Phillips & Gelula, 2006). Although there are competing theories as to why sleep is necessary, it is well-established that sleep is essential to several biochemical and physiological processes and is connected to immune functioning, hormone production, and cardiovascular functioning (Medic et al., 2017; B. Phillips & Gelula, 2006). As such, it is unsurprising that sleep disturbance has been identified as a risk factor for hypertension (Meng, Zheng, & Hui, 2013), cardiovascular disease (Sofi et al., 2014),

type II diabetes (Cappuccio, D'Elia, Strazzullo, & Miller, 2010), and systemic inflammation (Irwin, Olmstead, & Carroll, 2016) among other health issues.

Sleep Disturbance as a Mechanism through which Loneliness Deteriorates Health

Three studies have examined sleep disturbance as a mediator for the association between loneliness and health. First, Segrin and Passalacqua (2010) examined a convenience sample of 265 adults to show that sleep adequacy, in addition to other health behaviors, mediated the relationship between loneliness and health using the Baron and Kenny (1986) mediation analytical procedure. Second, Segrin and Domschke (2011) used structural equation modeling to examine the relations between social support, loneliness, sleep quality, and health. Loneliness was associated with poorer sleep quality, which in turn was associated with worse health (as measured by health quality of life, health problems, and global health rating). Furthermore, Segrin and Domschke found significant indirect effects of loneliness via sleep quality on both health quality of life and health problems. Third, Christiansen, Larsen, and Lasgaard (2016) showed that poor sleep mediated the relationship between loneliness and both diabetes and migraine in a sample of older adults (>65 years) living in Denmark.

Collectively, these studies suggest that sleep disturbance mediates the relationship between loneliness and health. However, all three studies are cross-sectional, limiting their ability to speak to the inherently longitudinal nature of mediation. Cross-sectional mediation analyses produce biased estimates (Mitchell & Maxwell, 2013). Furthermore, none of the samples is representative of the United States population.

Loneliness, Sleep, and Health in Older Adults

It is important to examine sleep as a mechanism for the association between loneliness and health in older Americans specifically. Older adults represent a growing population in the

United States (Cohen, 2003): the United States Census Bureau estimates that by 2035 the population of older Americans will surge to 78 million (2019). As the number of older adults rises, the impact of their health in terms of human suffering, medical utilization, and medical costs mushrooms, making it increasingly critical to understand—and in turn target—the factors underlying healthy aging.

Furthermore, older adults may be a clearer lens through which to see the interactions between biological, psychological, and social factors (Garroway & Rybarczyk, 2015); it may be possible to detect an effect of a psychosocial factor on health in older adults that would have been obscured by the robust good health enjoyed by a younger adult. Engel (1977) challenged the reductionism pervasive in the medical field, arguing that "the boundaries between health and disease, between well and sick, are far from clear and never will be clear, for they are diffused by cultural, social, and psychological considerations" (p. 132). Engel contended that the biomedical model must be expanded to incorporate the patient, their social context, and health care systems. The resulting biopsychosocial model has since guided research and practice: recent years have marked the proliferation of evidence (i) documenting the interactions between psychological, social, and biological factors, (ii) showing the benefits of improved communication between provider and patient, (iii) identifying the psychosocial factors that drive medical utilization and costs. Garroway & Rybarczyk (2015) argue that this framework is particularly vital in the study of older adults, where phenomena such as cascade iatrogenesis (the spiral of complications following a medical procedure), translocational confusion (the onset of confusion after relocation), late paraphrenia (constellation of paranoid ideation, confabulations, delusions, and alterations to personality, affect, or orientation in older adults), late-life frailty, and late-life resilience highlight the importance of a comprehensive, rather than myopic, conception of health.

Moreover, many Americans lose autonomy as they age, relying more on family members or institutions to meet their social needs. Interventions may therefore be more effective for this population, as their loneliness may be due to structural factors rather than their choices, and therefore more amenable to change on the policy level. Research directed at improving institutional policies that inadvertently foster loneliness may be more effective than efforts to produce behavioral change on the individual level.

The Strength and Vulnerability Integration (SAVI) model outlines ways in which aging may color the associations between loneliness, sleep, and health (Charles, 2010). The SAVI model contends that older adulthood is marked both by increased strengths—via enhanced coping strategies—and increased vulnerabilities—via decreased ability to recover from the sustained arousal accompanying certain situations. Increased strengths in coping include improved emotional regulation (Susan Turk Charles & Carstensen, 2007; Gross et al., 1997; L. H. Phillips, Henry, Hosie, & Milne, 2006), reduced goal discrepancies (the difference between the actual vs idea self (S.T. Cheng, 2004; Ryff, 1991); greater tendency towards downward or lateral social comparisons (Frey & Ruble, 1990; Sheldon, 2004), more complex emotional processing (S.T. Charles, 2005; Magai, Consedine, Krivoshekova, Kudadjie-Gyamfi, & McPherson, 2006; Ong & Bergeman, 2004), greater attention towards positive as opposed to negative stimuli (Carstensen & Mikels, 2005; Isaacowitz, 2006), more expedient disengagement from negative experiences (Birditt & Fingerman, 2003; Diehl, Coyle, & Labouvie-Vief, 1996), and lower perception of the severity of negative events (Lefkowitz & Fingerman, 2003; Story et al., 2007). The SAVI model also incorporates the Socioemotional Selectivity Theory (SST) as part of these age-related strengths (Carstensen, Isaacowitz, & Charles, 1999). The SST argues that humans are constantly aware of time, and that this awareness of time—and its finiteness—

informs social goals. According to SST, there are two broad categories of social goals: knowledge-related and emotional. When humans view time as open-ended, they tend towards knowledge-related goals; when humans view time as limited, they tend towards emotional goals. As humans age, they perceive time as increasingly finite, and thus their preferences shift from knowledge-related to emotional social goals. This shift in turn contributes to greater emotional health enjoyed by older adults.

However, according to the SAVI, older adults are more vulnerable to the sustained physiological arousal accompanying certain situations, such as the loss of social belonging, chronic uncontrollable stressors such as poverty, abuse, or a debilitating health condition, and neurological dysfunction (Charles, 2010). Older adults are more at risk for many of these conditions—as members of their social network die, chronic health conditions rise, and the incidence of cognitive impairment increases—yet are less equipped physiologically to cope with the sustained arousal accompanying these conditions. Aging is associated with changes in cardiovascular functioning and flattened patterns of cortisol (reflecting reduced flexibility in the neuroendocrine system), which may in turn amplify the harms of sustained arousal.

The SAVI and SST would predict increased resilience to loneliness in older adults; according to these models, older adults are more likely to seek out social partners who fulfill their emotional needs, more likely to attend to the positive aspects of these relationships, and less likely to seek out conflict within these relationships. However, older adults are more vulnerable to specific life events that could trigger or exacerbate loneliness—such as deaths of friends, family, and spouses and disability that increases the barriers to spending time with others—and the sustained arousal resulting from this loneliness.

The relationships between loneliness, sleep, and health may also differ in older adults due to the changes that occur in sleep over the lifespan (for a review see Miner & Kryger, 2017). Older adults experience a phase advance in sleep, whereby they feel sleepy earlier in the evening and awake earlier in the morning (Monk, 2005). Moreover, aging is associated with the following changes in sleep architecture: *decreased* total sleep time, sleep efficiency, slow wave sleep, and rapid eye movement sleep and *increased* time awake after sleep onset, arousals, and sleep latency (Miner & Kryger, 2017; Ohayon, Carskadon, Guilleminault, & Vitiello, 2004). Older adults are at increased risk of insomnia symptoms and drowsiness; these symptoms in turn predict worse self-reported health, cognitive decline, depression, disability, institutionalization, cardiovascular disease, and death (Ancoli-Israel & Cooke, 2005; Ayling et al., 2016; Bloom et al., 2009; Dew et al., 2003; Stone, Ensrud, & Ancoli-Israel, 2008; Vaz Fragoso & Gill, 2007). Older adults on average sleep less than younger adults, but this reduction in sleep does not appear to be due to a reduced need for sleep. The National Sleep Foundation recommends that older adults sleep 7-8 hours based on research showing that 6-9 hours of sleep in this population is associated with improved cognitive function, mental health, physical health, and quality of life (Hirshkowitz et al., 2015; Miner & Kryger, 2017). It is therefore of paramount importance to understand factors that may disrupt sleep in older adults, as this population is at increased risk for sleep disruption and this disruption is a risk factor for poor health outcomes.

Conclusion and Present Study

The current literature provides initial support for the theory that sleep disturbance is a mechanism through which loneliness influences health (Cacioppo and Hawkley, 2003): loneliness and sleep disturbance consistently correlate across multiple studies using a range of measures and samples. However, there is as of yet insufficient evidence to say that loneliness

precedes sleep disturbance or vice-versa, and therefore the direction of causality between loneliness and sleep disturbance remains obscure. It is possible that the correlation between sleep disturbance and loneliness is due, at least in part, to the effect of sleep disturbance on loneliness. Moreover, it is unclear how other factors are contributing to the relationship between loneliness and sleep disturbance.

The present study first aims to establish loneliness as a correlate of sleep disturbance using a sample that is representative of older Americans living in the community. Next, it aims to determine whether loneliness predicts sleep disturbance and vice versa over eight years; first, by assessing each as a risk factor for the other, and second, by examining this relationship more closely using a cross-lagged panel design. Finally, the present study aims to assess sleep disturbance as a mediator for the association between loneliness and health longitudinally using a cross-lagged panel mediation model. Each of these aims is outlined in greater detail below.

Objectives

Cross-sectional relationship between loneliness and sleep disturbance.

(1) Assess the bivariate association between loneliness and sleep disturbance in a sample that is representative of older adults in the United States.

Hypothesis. Higher levels of loneliness will be associated with greater sleep disturbance.

(2) Assess the association between loneliness and sleep disturbance in a sample that is representative of older adults in the United States when controlling for demographics, isolation, and depression.

Hypothesis. Controlling for demographics, isolation, and depression will attenuate the relationship between loneliness and sleep disturbance.

Loneliness as a risk factor for sleep disturbance.

(1) Assess loneliness as a predictor of sleep disturbance over four years and eight years in a sample that is representative of older adults in the United States.

Hypothesis. Loneliness will predict subsequent sleep disturbance.

(2) Assess loneliness as a predictor of sleep disturbance over four years and eight years in a sample that is representative of older adults in the United States when controlling for demographics, isolation, and depression.

Hypothesis. Controlling for demographics, isolation, and depression will attenuate the longitudinal relationship between loneliness and sleep disturbance.

Sleep disturbance as a risk factor for loneliness.

(1) Assess sleep disturbance as a predictor of loneliness over four years and eight years in a sample that is representative of older adults in the United States.

Hypothesis. Sleep disturbance will predict subsequent loneliness.

(2) Assess sleep disturbance as a predictor of loneliness over four years and eight years in a sample that is representative of older adults in the United States when controlling for demographics, isolation, and depression.

Hypothesis. Controlling for demographics, isolation, and depression will attenuate the longitudinal relationship between sleep disturbance and loneliness.

Loneliness and sleep disturbance over time.

(1) Examine the bidirectional longitudinal relationship between loneliness and sleep disturbance.

Hypothesis. Loneliness will be a stronger predictor of subsequent sleep disturbance than the reverse.

(2) Examine the bidirectional relationship between loneliness and sleep disturbance when controlling for demographics, isolation, and depression.

Hypothesis. Loneliness will be a stronger predictor of subsequent sleep disturbance than the reverse when controlling for demographics, isolation, and depression.

Sleep disturbance as a mediator for the relationship between loneliness and health.

(1) Examine sleep disturbance as a mediator of the relationship between loneliness and health.

Hypothesis 1. There will be a direct effect of loneliness on sleep disturbance.

Hypothesis 2. There will be a direct effect of sleep disturbance on health.

Hypothesis 3. There will be an indirect effect of loneliness on health.

(2) Examine sleep disturbance as a mediator of the relationship between loneliness and health when controlling for demographics, isolation, and depression.

Hypothesis. Controlling for demographics, isolation, and depression will attenuate the relationships between all variables.

Methods

Overview of the Health and Retirement Study

Data for this study come from the Health and Retirement Study (HRS), a panel study of Americans over the age of 50 and their spouses (Sonnega et al., 2014) with a full sample size exceeding 37,000 persons. Participants are followed from enrollment until death. The study enrolls new generations as they reach the age eligibility threshold, thus following multiple cohorts. Data collection occurs every two years and assessing a wide array of domains, to include income, employment, assets, pension plans, health insurance, physical health, mental health, physical functioning, cognitive functioning, and health care expenditures.

This study used data from 2006, 2008, 2010, 2012, and 2014. Each data collection is referred to as a *wave*. Although the HRS began in 1992, the administration of the Leave-Behind-Questionnaire was only fully implemented in 2006 (piloting began in 2004). The Leave-Behind-Questionnaire contains the Hughes Loneliness Scale and the isolation (Contact with Social Network) scale. As such, only data from 2006 onward was be analyzed for this study. More information on the administration of the Leave-Behind-Questionnaire is provided in the Procedures section. To briefly summarize here, only half the sample received the Leave-Behind-Questionnaire in 2006; the second half received the questionnaire in 2008. Similarly, the sleep disturbance scale was only administered reliably in 2006, 2010, and 2014.

Participants

The HRS's population of interest is community dwelling adults entering retirement age in the United States. The HRS follows a Longitudinal Cohort Sample Design, whereby multiple cohorts are studied over multiple waves (Sonnega et al., 2014). Moreover, beginning in 1998, the

study follows a steady state design, adding a new cohort every six years as it enters retirement age.

The initial response rates (number of respondents/number of persons deemed eligible by screener) range from approximately 70-80%. The follow-up response rates range from approximately 85-93% (not including persons who did not respond at baseline, requested to be removed from the sample, or died (Sonnega et al., 2014). The Participant Lifestyle Questionnaire, also known as the Leave-Behind-Questionnaire, requires participants to complete and mail back a survey: the response rate on the 2004 pilot of the Participant Lifestyle Questionnaire was approximately 78%.

Sampling procedure. The HRS follows a multi-stage area probability sample design to select participants (Heeringa & Connor, 1995), selecting in order: (1) Metropolitan Statistical Areas and non-Metropolitan Statistical Areas (2) area segments within these primary stage units (3) housing units within the selected area segment (taken from a complete enumeration of housing units in the bounds of each selected area segment) (4) one age-eligible person within the housing unit. There are oversamples of Americans who are black, Hispanic, or living in Florida to power subgroup analyses. See Heeringa and Connor's report on the HRS survey sample design for more information on this sampling procedure (1995).

Eligibility. The above procedure generates sampled housing units. To assess eligibility, a screening interview was then provided to each housing unit; adults in the household gave their age and relationship status. A primary respondent was randomly selected from all household members who are eligible for the HRS (i.e. 50+). That person's partner was also included in the sample (Heeringa & Connor, 1995).

Only community dwelling adults are recruited into the HRS. However, subjects are followed for the remainder of their lives, including if they enter retirement homes. Only respondents (i.e. the individual selected to take part in the study, not his or her spouse) who were community-dwelling in 2006 were included in this project.

Weighting. The HRS uses sample weights to align the data with that of the US population as determined by the American Community Survey (2004 to present; Sonnega et al., 2014). There are separate weights for community dwelling and nursing home respondents to generate a representative sample of each. This study used the 2006 weighting for community-dwelling respondents for all analyses accounting for complex sampling.

Present sample. Only participants aged 65 and older were included in this study. Sample characteristics for the present sample are summarized in Table 1. There were 11,400 participants at baseline (2006). Table 1 also provides the characteristics of the participants who completed a measure of sleep disturbance (n=6357; either the scale or the CES-D) in 2014 versus those who did not (n=5043; deemed lost to follow-up).

Of these participants, 5,067 returned the Participant Lifestyle Questionnaire in 2006, 2010, or 2014. All of these participants completed the sleep disturbance scale, though only 4,624 of these participants completed the Hughes Loneliness Scale, in 2006. In 2010, these numbers dropped to 4,111 completing the sleep disturbance scale and 3,424 completing the Hughes Loneliness Scale. In 2014, 3,121 participants completed the sleep disturbance scale and 2,608 participants completed the Hughes Loneliness Scale.

Table 1

Characteristics of the Sample in 2006, Overall and Stratified by Follow-up Status.

		Overall N (%)	Retained N (%)	Lost to Follow-up N (%)
M baseline age (SD)		74.90 (7.62)	72.40 (5.90)	78.06 (8.34)
M loneliness (SD)		-0.53 (0.53)	-0.57 (0.51)	-0.46 (0.56)
M sleep disturbance (SD)		1.64 (0.52)	1.62 (0.51)	1.65 (0.53)
M self-reported health (SD)		3.01 (1.12)	2.74 (1.04)	3.34 (1.12)
Gender				
	Male	4865 (42.68%)	2585 (40.66)	2280 (45.21)
	Female	6535 (57.32%)	3772 (59.34)	2763 (54.79)
Education				
	Less than high school	3103 (27.22)	1439 (22.64)	1664 (33.00)
	GED	497 (4.36)	277 (4.36)	220 (4.36)
	High-school graduate	3707 (32.52)	2119 (33.34)	1588 (31.49)
	Some college	2108 (18.49)	1251 (19.68)	857 (16.99)
	College and above	1984 (17.41)	1270 (19.98)	714 (14.16)
Race				
	White/Caucasian	9523 (83.54)	5321 (83.70)	4202 (83.32)
	Black/African American	1510 (13.25)	819 (12.88)	691 (13.70)
	Other	367 (3.22)	217 (3.41)	150 (2.97)
Ethnicity				
	Not Hispanic	10489 (92.01)	5822 (91.58)	4667 (92.54)
	Hispanic	911 (7.99)	535 (8.42)	376 (7.46)
Socioeconomic status				
	Lower	2280 (20.00)	954 (15.01)	1326 (26.29)
	Lower Middle	2295 (20.13)	1174 (18.47)	1121 (22.23)
	Middle	2271 (19.92)	1353 (21.28)	918 (18.20)
	Upper Middle	2274 (19.95)	1379 (21.69)	895 (17.75)
	Upper	2280 (20.00)	1497 (23.55)	783 (15.53)
Marital Status				
	Married	6422 (56.33)	3959 (62.28)	2463 (48.84)
	Partnered	227 (1.99)	133 (2.09)	94 (1.86)
	Separated/divorced	1030 (9.04)	606 (9.53)	424 (8.41)
	Widowed	3422 (30.02)	1494 (23.50)	1928 (38.23)
	Never married	299 (2.62)	165 (2.60)	134 (2.66)

Notes. Lost to Follow-up defined as missing a sleep disturbance outcome (scale or CESD-R item) in 2014. *M* = mean, SD = standard deviation.

These rates constitute significant attrition. Moreover, examination of the baseline characteristics of participants who completed a sleep disturbance scale in 2014 versus those who did not (see Table 1) suggests that this attrition is not missing completely at random (MCAR). There appear to be differences in participants retained versus lost to follow-up. The threat of attrition bias was handled in two ways. First, for the analyses examining the association between loneliness and sleep disturbance, loneliness as a risk factor for sleep disturbance, and sleep disturbance as a risk factor for loneliness, sensitivity analyses were run using multiple imputation. Second, expectation maximization (EM) was used for the path analyses.

Procedures

The HRS conducts interviews every two years, either by phone or face-to-face. The majority of baseline interviews were administered face-to-face (Sonnega et al., 2014). Follow-up interviews were initially conducted primarily by phone, but in 2004 the numbers of face-to-face follow-ups rose. In 2006, the HRS began a mixed-mode follow-up. Fifty percent of the sample was randomly assigned to face-to-face follow-ups while the remaining 50% was phone follow-ups. The assignment then rotates every two years, ensuring that both halves of the sample receive face-to-face interviews every four years. The face-to-face interviews allow for the collection of physical measures (e.g., grip strength), biological measures (e.g., saliva sample), and the Participant Lifestyle Questionnaire. The Participant Lifestyle Questionnaire is a survey that is given to the participant following the interview to be completed independently and mailed back (Smith et al., 2013). The HRS seeks to identify a proxy respondent when a participant is unable or unwilling to answer interview questions; the rate of proxies per wave is around 9% but rises to 18% for participants over 80.

Measures

Loneliness. The primary loneliness measures used in this study was the Hughes Loneliness Scale. The Hughes Loneliness Scale consists of the questions: (1) "How often do you feel that you lack companionship?," (2) "How often do you feel left out?," (3) "How often do you feel isolated from others?" (Clarke, Fisher, House, Smith, & Weir, 2008). Responses consisted of: "1=Often," "2=Some of the time," and "3=Hardly ever or never." Beginning in 2008 the format of these questions changed slightly but the response options remained the same. To be more specific, beginning in 2008 the questionnaire had the prompt of "How much of the time do you feel…" then the options "You lack companionship?", "Left out?", and "Isolated from others" instead of imbedding the "How often" prompt into each question as described above. Items were reverse coded and averaged to create a scale score of loneliness. If more than one item was missing the scale score was set to missing (Clarke et al., 2008). Hughes, Waite, Hawkley, & Cacioppo (2004) have demonstrated that the Hughes Loneliness Scale has satisfactory concurrent validity, discriminant validity, and reliability. The Hughes Loneliness Scale was administered to alternating halves of the full sample beginning in 2006.

Additionally, the loneliness item on the Center for Epidemiologic Studies Depression Scale Revised (CESD-R), whereby participants provided a yes/no answer as to whether they have "felt lonely" in the past week, was used for some sensitivity analyses. The CESD-R loneliness item was reliably administered across all waves, allowing for the examination of relationships every two years as opposed to every four years.

Sleep disturbance. The primary sleep disturbance measure used for this study was a scale created using four items in the HRS. These items consist of three questions regarding sleep specifically: (1) "How often do you have trouble falling asleep?," (2) "How often do you have trouble with waking up during the night?," (3) "How often do you have trouble with waking up

too early and not being able to fall asleep again?." Additionally, one item assesses rest: "How often do you feel really rested when you wake up in the morning?". Responses across all four items included "rarely or never," "sometimes," and "most of the time." The sleep items were reverse coded and then all four items were averaged to create a sleep dysfunction scale. Sleep items were reliably administered in the 2006, 2010, and 2014 waves.

Two additional sleep disturbance measures were used in sensitivity analyses. First, the sleep disturbance scale was modified to exclude the feeling rested item. Second, the CESD-R sleep item—a yes/no question as to whether sleep was restless over the past week (Chien et al., 2013)—was used to examine relationships every two years because this item was reliably administered across all waves.

Health. Health was assessed via self-reported health. Self-reported health was measured using the question: "Would you say your health is excellent, very good, good, fair, or poor?" Higher values reflected worse self-reported health. Although a single-item measure, self-reported health is a strong predictor of mortality even after accounting for covariates (DeSalvo, Bloser, Reynolds, He, & Muntner, 2006).

Demographics. Demographics included age, gender (male, female), education (less than high school, GED, high school graduate, some college, college and above), race (white/Caucasian, black/African American, and other), ethnicity (Hispanic, not Hispanic), marital status (married, single, separated/divorced, widowed) and socioeconomic status (SES). SES was gauged using the net worth variable (Chien et al., 2013) or the sum of all wealth components (e.g., salary, house, automobile) minus total debt. This variable was converted into an ordinal scale whereby participants were divided into quintiles according to net worth representing lower, lower middle, middle, upper middle, and upper SES. Categorical variables

were dummy coded, with the following reference categories: white/Caucasian for race, married for marital status, middle net worth quintile for SES, high school graduate for education, not Hispanic for ethnicity, and male for gender.

Isolation. Isolation was defined as the frequency of contact with social network. Participants reported how often they "Meet up (includes both arranged and chance meetings)," "Speak on the phone," and "Write or email" their children, other family members, and friends. Responses consisted of: "1=Three or more times a week," "2=Once or twice a week," "3=Once or twice a month," "4=Every few months," "5=Once or twice a year," and "6=Less than once a year or never." Values were reverse coded and averaged across all items to create an overall measure of isolation; if more than one item is missing the total score was set to missing (Smith, Fisher, Ryan, Clarke, House, & Weir, 2013). Isolation was administered to alternating halves of the full sample beginning in 2006.

Depression. Depression was measured using the CESD-R minus the sleep and loneliness items. Participants were asked if (yes/no) they had experienced the following over the past week: "I felt depressed," "I felt that everything I did was an effort," "My sleep was restless," "I was happy," "I felt lonely," "I enjoyed life," "I felt sad," "I could not get going." The items "My sleep was restless" and "I felt lonely" were excluded from the total scale score for this study as they tap into sleep and loneliness respectively. A composite score of the remaining items was created by subtracting the items "I was happy" and "I enjoyed life" from the sum of the other items (Chien et al., 2013). These items were subtracted because they are in the opposite direction of the other items, i.e., endorsement of these items is indicative of lower levels of depression.

Analyses

Raw materials for this study are available on the Open Science Framework (https://osf.io/72djr/?view_only=70996fcf5d634fa2b5857095ef547906).

Association between loneliness and sleep disturbance. The cross-sectional relationship between loneliness and sleep disturbance was assessed using linear regression, first examining their bivariate relationship and then examining their relationship when controlling for demographics (i.e. age, race, ethnicity, gender, education, and SES), depression, and isolation. Analyses accounted for complex sampling using sample weights from 2006. Analyses were run in SAS 9.4.

Loneliness as a risk factor for sleep disturbance. Linear regressions were used to evaluate loneliness as a risk factor for sleep disturbance both four and eight years later. Regressions were first run just controlling for baseline sleep disturbance, then run when controlling for demographics, depression, and isolation. Analyses accounted for complex sampling using sample weights from 2006. Analyses were run in SAS 9.4.

Sleep disturbance as a risk factor for loneliness. Linear regressions were used to evaluate sleep disturbance as a risk factor for loneliness both four and eight years later. Regressions were first run just controlling for baseline loneliness, then run when controlling for demographics, depression, and isolation. Analyses accounted for complex sampling using sample weights from 2006. Analyses were run in SAS 9.4.

Sensitivity analyses. First, sensitivity analyses were run to examine the association between loneliness and sleep disturbance, loneliness as a risk factor for sleep disturbance, and sleep disturbance as a risk factor for loneliness when using a scale for sleep disturbance without the feeling rested item. Typically, the item on feeling rested has been included in the composite sleep disturbance measure (Dong, Agnew, Mojtabai, Surkan, & Spira, 2017; Hunter et al., 2018;

Lee, 2017; Leggett, Sonnega, & Lohman, 2018; Stephan, Sutin, Bayard, & Terracciano, 2018), but it differs from the other items conceptually in that it does not directly assess sleep quality. This set of analyses accounted for complex sampling (2006 sample weights).

Next, analyses were run using multiple imputation (using multivariate normal distribution) to mitigate potential attrition bias. Forty-four imputed datasets were created because 44% of data for the Hughes Loneliness Scale in 2014 was missing (there were fewer cases of missing data for the sleep disturbance scale in 2014 so I opted for the higher, or more conservative, number). The following variables were used in the imputation model: sleep disturbance scale (2006, 2010, 2014), Hughes Loneliness Scale (2006, 2010, 2014), isolation (2006, 2010, 2014), depression (2006, 2008, 2010, 2012, 2014), CESD-R sleep and loneliness items (2006, 2008, 2010, 2012, 2014), baseline age, gender, race, ethnicity, education, baseline SES, baseline marital status. This list includes all the variables in the final adjusted model for both sleep disturbance as a risk factor for loneliness and vice-versa in addition to the auxiliary variables of the CESD-R sleep and loneliness items. The same imputed dataset was used for all analyses with the rationale that variables that were part of the model should serve as auxiliary variables in the other analyses. This set of analyses did not account for complex sampling because the multiple imputation procedure implemented does not allow for this option. Both sets of sensitivity analyses were run in SAS 9.4.

Path analyses. The longitudinal relationship between loneliness and sleep disturbance was further examined by running a cross-lagged panel model examining the relationship between loneliness and sleep disturbance in 2006, 2010, and 2014 (measures: Hughes Loneliness Scale, sleep disturbance scale). A second cross-lagged panel model was then run controlling for demographics, depression, and isolation.

A cross-lagged mediation model (time points: 2006, 2010, 2014) was run to examine sleep disturbance as a mediator for the relationship between loneliness and health (measures: Hughes Loneliness Scale, sleep disturbance scale, self-reported health). A second cross-lagged mediation model was then run controlling for demographics, depression, and isolation. Expectation maximization (EM) was used for the path analyses, due to evidence that data were not missing completely at random (MCAR) from examination of the data and significant findings on Little's MCAR test (*p*s <.001). Bootstrapping (2,000 bootstrap samples) was used to calculate indirect effects and confidence intervals. EM was conducted in IBM SPSS Statistics 25 and path analysis was conducted in IBM SPSS AMOS 25.

Sensitivity analyses. A cross-lagged panel model (measures: CESD-R loneliness item, CESD-R restless sleep item) and a cross-lagged mediation model (measures: CESD-R loneliness item, CESD-R restless sleep item, self-reported health) were run examining relationships across 2006, 2008, 2010, 2012, and 2014 time points. Single item measures of loneliness and sleep disturbance were used because the full scales were only administered every other wave.

The purpose of these sensitivity analyses was to address potential issues due to lag, i.e., the time elapsed between measurements, that can occur in cross-lagged models. A lag could be too short, whereby measurement occurs too early to detect an effect, or too long, whereby measurement occurs after an effect has faded.

Results

Cross-sectional Relationship Between Loneliness and Sleep Disturbance

Higher loneliness was associated with higher sleep disturbance at baseline, β = .21, *B* = 0.20, SE=.02, 95% CI [0.17, 0.24], $p < .0001$. This association was attenuated by controlling for age, gender, education, race, ethnicity, isolation, depression, marital status, and SES, β = .08, *B* = 0.08, SE=.02, 95% CI [0.03, 0.13], $p = .0008$.

Sensitivity analyses. Analyses using a sleep disturbance scale without the feeling rested item showed similar results (bivariate: β = .17, *B* = 0.18, SE=.02, 95% CI [0.14, 0.22], $p < .0001$, adjusted: β = .07, *B* = 0.07, SE=.03, 95% CI [0.02, 0.12], $p = .0064$), though effects were slightly smaller. Using multiple imputation without accounting for complex sampling did not appreciably change results (bivariate: *B* = 0.21, SE=.01, 95% CI [0.18, 0.24], $p < .0001$, adjusted: *B* = 0.08, SE=.01, 95% CI [0.05, 0.11], $p < .0001$).

Loneliness as a Risk Factor for Sleep Disturbance

Higher loneliness predicted higher sleep disturbance both four (β = .09, *B* = 0.08, SE=.01, 95% CI [.05, .11], $p < .0001$) and eight (β = .08, *B* = 0.08, SE=.02, 95% CI [.03, .12], $p = .0022$) years later when controlling for baseline sleep disturbance. These effects were attenuated when additionally controlling for age, gender, education, race, ethnicity, isolation, depression, marital status, and SES, (2006 to 2010, four year follow-up: β = .07, *B* = 0.07, SE=.02, 95% CI [.03, .11], $p = .0009$; 2010 to 2014, eight year follow-up: β = .07, *B* = 0.08, SE=.03, 95% CI [.02, .13], $p = .0068$).

Sensitivity analyses. Analyses using a sleep disturbance scale without the feeling rested item showed similar results for both the four year follow-up (controlling for baseline sleep disturbance: β = .08, *B* = 0.08, SE=.02, 95% CI [0.05, 0.12], $p < .0001$; fully adjusted: β = .07, *B*

= 0.07, SE=.02, 95% CI [0.02, 0.12], p = .0039) and the unadjusted eight year follow-up (β = .05, B = 0.06, SE=.03, 95% CI [0.00, 0.12], p = .0465), though again effects were smaller. Loneliness was no longer a significant risk factor in the adjusted eight year model, β = .05, B = 0.06, SE=.03, 95% CI [-0.01, 0.12], p = .0908). Analyses using multiple imputation (without complex sampling) for the eight year model showed similar findings to the main analyses, (controlling for baseline sleep disturbance: B = 0.08, SE=.02, 95% CI [0.05, 0.11], p < .0001, fully adjusted: B = 0.07, SE=.02, 95% CI [0.04, 0.11], p < .0001).

Sleep Disturbance as a Risk Factor for Loneliness

Higher sleep disturbance predicted higher loneliness both four (β = .05, B = 0.05, SE=.02, 95% CI [.01, .09], p =.0104) and eight (β = .11, B = 0.12, SE=.02, 95% CI [.08, .16], p < .0001) years later when controlling for baseline sleep disturbance. These effects were attenuated when additionally controlling for age, gender, education, race, ethnicity, isolation, depression, marital status, and SES, (2006 to 2010, four year follow-up: β = -.00, B = -0.00, SE=.02, 95% CI [-0.04, 0.04], p = .9023; 2010 to 2014, eight year follow-up: β = .09, B = 0.09, SE=.03, 95% CI [.04, .15], p = .0006).

Sensitivity analyses. Analyses using a sleep disturbance scale without the feeling rested item showed similar results for both the unadjusted (β = .04, B = 0.03, SE=.02, 95% CI [0.00, 0.01], p = .0342) and the adjusted (β = -.01, B = -0.01, SE=.02, 95% CI [-0.04, 0.03], p = .6742) four year model, as well as both the unadjusted (β = .10, B = 0.10, SE=.02, 95% CI [0.06, 0.13], p < .0001) and adjusted (β = .08, B = 0.07, SE=.02, 95% CI [0.03, 0.12], p = .0012) eight year models. Analyses using multiple imputation (without complex sampling) for the eight year model showed similar findings to the main analyses, (bivariate: B = 0.12, SE=.02, 95% CI [0.08, 0.15], p < .0001, adjusted: B = 0.08, SE=.02, 95% CI [0.04, 0.12], p = .0002).

Loneliness and Sleep Disturbance over Time

See Figure 1 for the cross-lagged panel model fit using time points 2006, 2010, and 2014 with standardized estimates (loneliness measured via the Hughes Loneliness Scale, sleep measured via the sleep disturbance scale). The chi-square (χ^2) goodness-of-fit test was significant, which typically indicates poor model fit, $\chi^2(4) = 1017.00$, $p < .001$. However, χ^2 statistics are sensitive to large sample size, rendering this test uninformative in the present study. The root mean square of approximation (RMSEA) was .22, comparative fit index (CFI) was .92, Tucker-Lewis index (TLI) was .70, goodness-of-fit index (GFI) was .94. Only the goodness-of-fit index met fit criteria (≥.90).

All paths were significant (*p*s <.001). The paths from loneliness to sleep disturbance (2006 to 2010: β = .10, *B* = .09, standard error (SE)=.01; 2010 to 2014: β = .07, *B* = 0.07, SE=.01) and sleep disturbance to loneliness (2006 to 2010: β = .05, *B* = 0.05, SE=.01; 2010 to 2014: β = .14, *B* = 0.14, SE=.01) were small. The model accounted for 49% of the variance in loneliness and 43% of the variance in sleep disturbance in 2014.

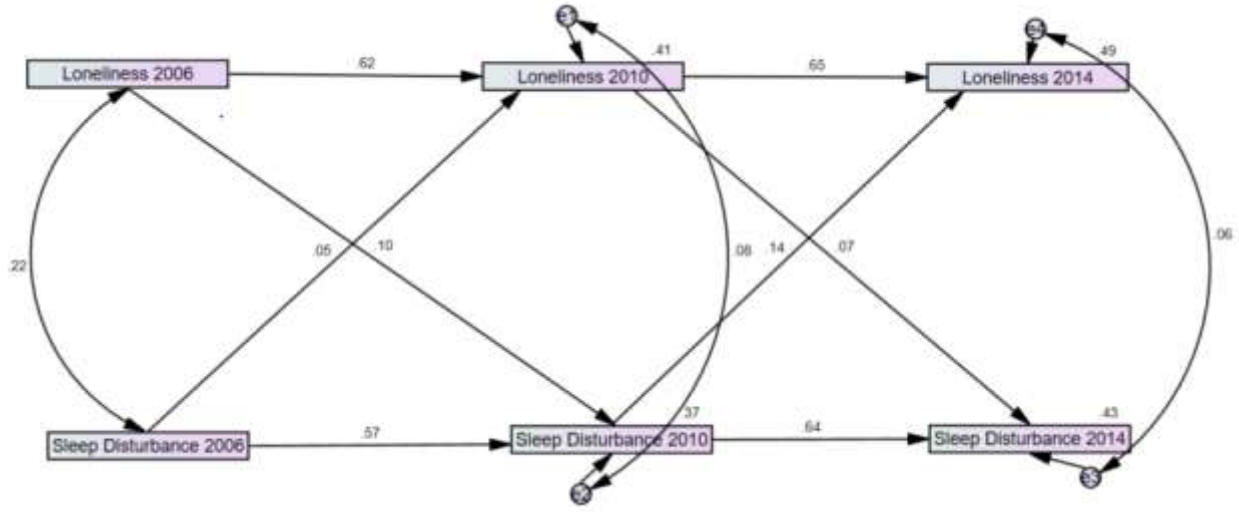

Figure 1. Cross-lagged panel model (2006, 2010, 2014), with standardized regression weights.

See Figure 2 for the cross-lagged panel model (2006, 2010, 2014; standardized regression weights) with adjustments for age, gender, education, race, ethnicity, isolation, depression, marital status, and SES. The chi-square (χ^2) goodness-of-fit test was significant, $\chi^2(509) = 65333.27$, $p < .001$. The root mean square of approximation (RMSEA) was .16, comparative fit index (CFI) was .16, Tucker-Lewis index (TLI) was .02, goodness-of-fit index (GFI) was .62. None of these indices met fit criteria.

The paths from loneliness to sleep disturbance (2006 to 2010: β = .07, *B* = .06, SE=.01, *p* <.001; 2010 to 2014: β = .06, *B* = 0.06, SE=.01, *p* <.001) and sleep disturbance to loneliness (2006 to 2010: β = .01, *B* = 0.01, SE=.01, *p*=.61; 2010 to 2014: β = .11, *B* = 0.10, SE=.01, *p* <.001) were attenuated by the inclusion of adjustments in the model. The model accounted for 46% of the variance in loneliness and 42% of the variance in sleep disturbance in 2014.

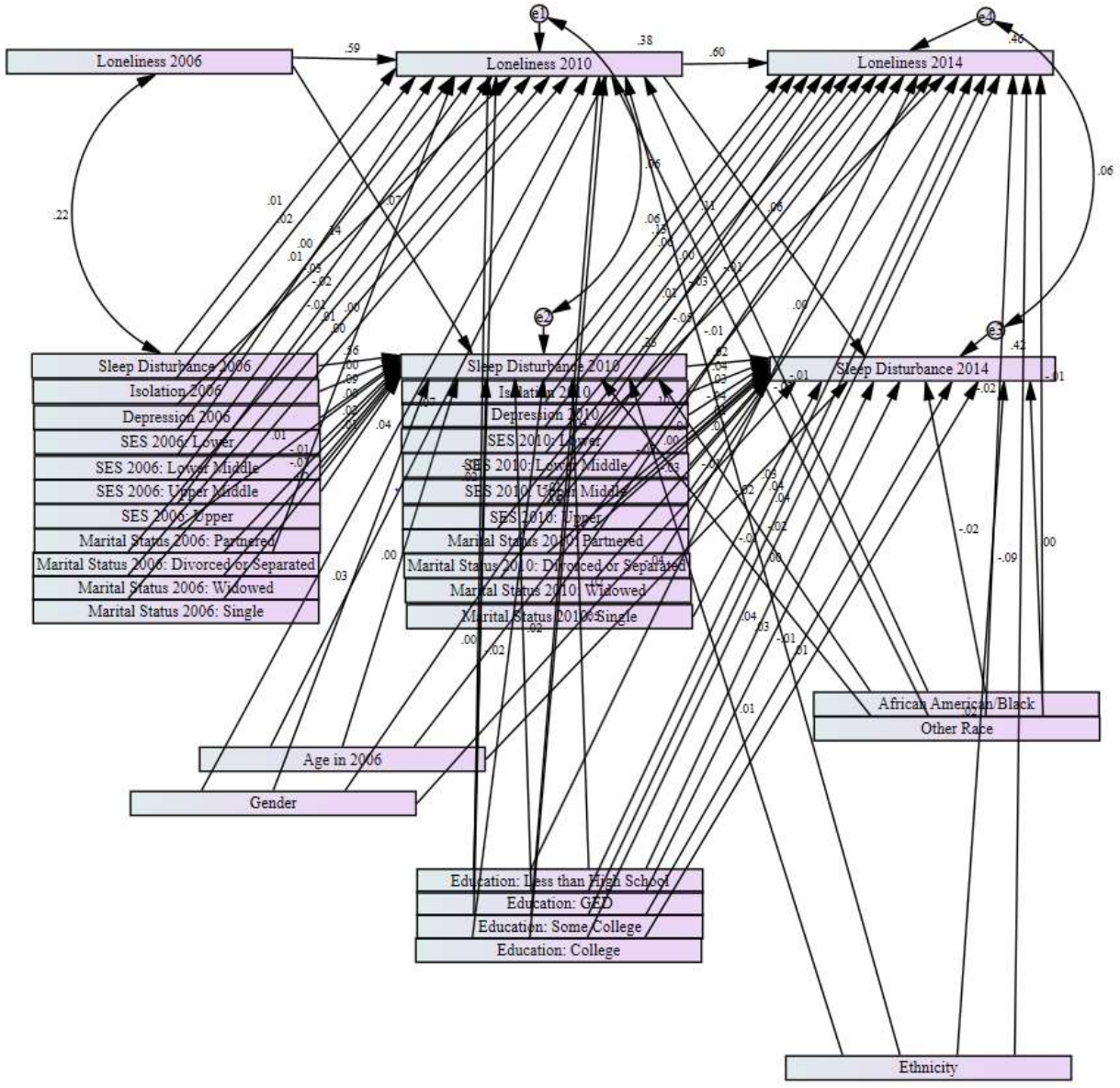

Figure 2. Adjusted cross-lagged panel model (2006, 2010, 2014), with standardized regression weights.

Sensitivity analysis. See Figure 3 for the cross-lagged panel model fit using time points 2006, 2008, 2010, 2012, and 2014 (loneliness measured via CESD-R loneliness item, sleep disturbance measured via the CESD-R sleep restlessness item). The chi-square (χ^2) goodness-of-fit test was significant, $\chi^2(24) = 7638.36$, $p < .001$. The root mean square of approximation

(RMSEA) was .17, comparative fit index (CFI) was .79, Tucker-Lewis index (TLI) was .61, goodness-of-fit index (GFI) was .90. None of these indices met fit criteria.

All paths were significant (*p*s <.001). The standardized regression weights from loneliness to sleep disturbance and vice versa were all indicative of small effect sizes; loneliness to sleep paths ranged from .09 to.12 and sleep to loneliness paths ranged from .09 to .12. The model accounted for 34% of the variance in loneliness and 28% of the variance in sleep disturbance in 2014.

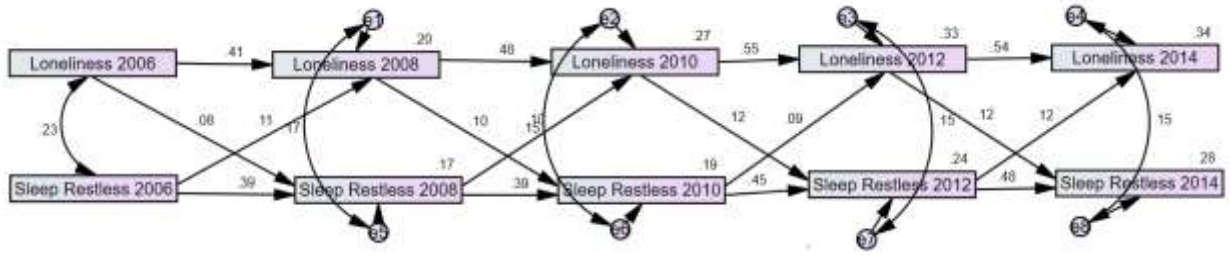

Figure 3. Cross-lagged panel model (2006, 2008, 2010, 2012, 2014), with standardized regression weights.

Sleep Disturbance as a Mediator for the Relationship between Loneliness and Health

See Figure 4 for the cross-lagged panel model fit using time points 2006, 2010, and 2014 with standardized estimates. The chi-square (χ^2) goodness-of-fit test was significant, $\chi^2(16) = 2236.97$, $p < .001$. The root mean square of approximation (RMSEA) was .17, comparative fit index (CFI) was .89, Tucker-Lewis index (TLI) was .76, goodness-of-fit index (GFI) was .92. Only the goodness-of-fit index met fit criteria (≥.90).

All paths were significant (*p*s <.001). The paths from loneliness to sleep disturbance (2006 to 2010: β = .09, *B* = .08, SE=.01; 2010 to 2014: β = .07, *B* = 0.07, SE=.01) were small, as were the paths from sleep disturbance to self-reported health (2006 to 2010: β = .08, *B* = 0.16, SE=.02; 2010 to 2014: β = .06, *B* = 0.12, SE=.02). The direct effect of 2006 loneliness on 2014

self-reported health was similarly small (β = .06, *B* = 0.11, SE=.02). There was an indirect effect of loneliness in 2006 on self-reported health in 2014 (β = .01, 95% CI [.00, .01], *p* <.001). The model accounted for 46% of the loneliness, 42% of the sleep disturbance, and 48% of the self-reported health in 2014.

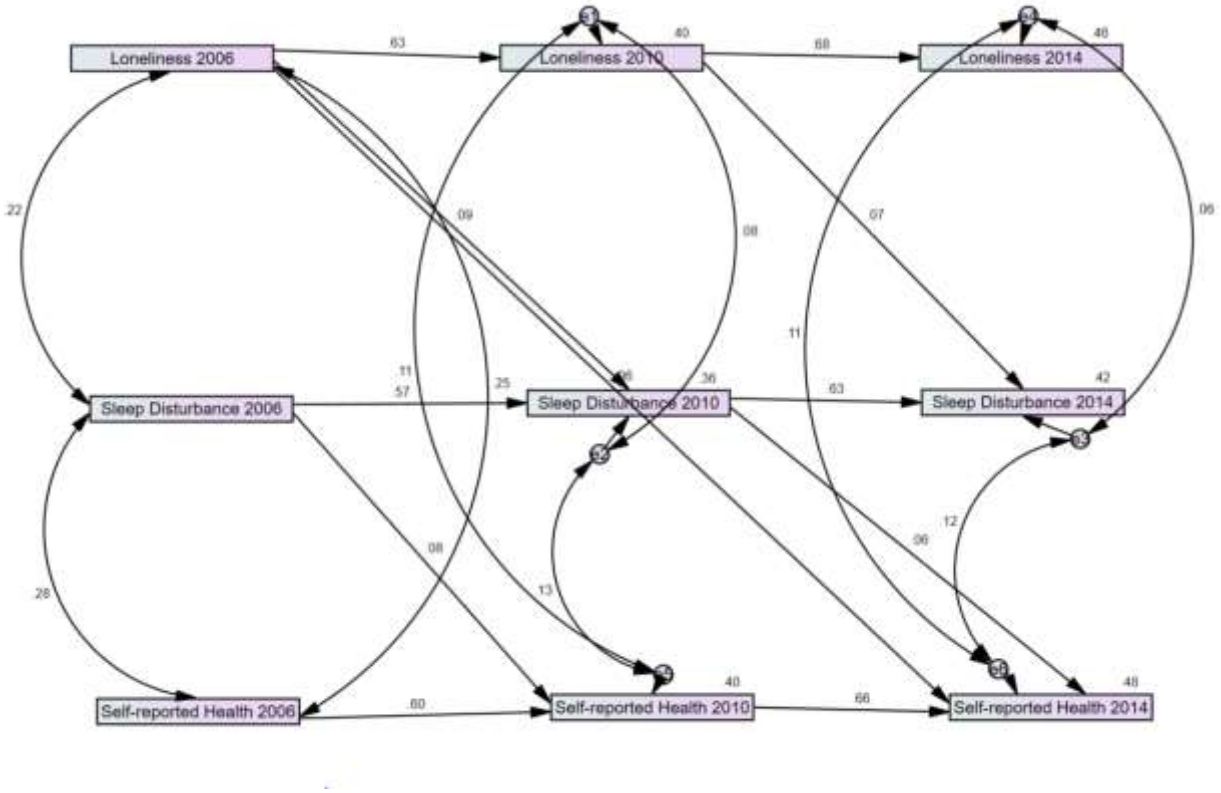

Figure 4. Cross-lagged mediation model (2006, 2010, 2014), with standardized regression weights.

See Figure 5 for the cross-lagged mediation model (2006, 2010, 2014; standardized regression weights) with adjustments for age, gender, education, race, ethnicity, isolation, depression, marital status, and SES. The chi-square (χ^2) goodness-of-fit test was significant, $\chi^2(569) = 67380.04$, $p < .001$. The root mean square of approximation (RMSEA) was .15, comparative fit index (CFI) was .23, Tucker-Lewis index (TLI) was .00, goodness-of-fit index (GFI) was .61. None of these indices met fit criteria.

The paths from loneliness to sleep disturbance (2006 to 2010: β = .06, *B* = .05, SE=.01, *p* <.001; 2010 to 2014: β = .06, *B* = 0.06, SE=.01, *p* <.001) and the paths from sleep disturbance to self-reported health (2006 to 2010: β = .06, *B* = 0.12, SE=.02, *p* <.001; 2010 to 2014: β = .05, *B* = 0.10, SE=.02, *p* <.001) were attenuated by adding adjustments to the model. The direct (β = .03, *B* = 0.04, standard error (SE)=.02, *p* = .014) and indirect effect (β = .00, 95% CI [.00, .01], *p* <.001) of loneliness in 2006 on self-reported health in 2014 were similarly attenuated. The model accounted for 44% of the loneliness, 41% of the sleep disturbance, and 44% of the self-reported health in 2014.

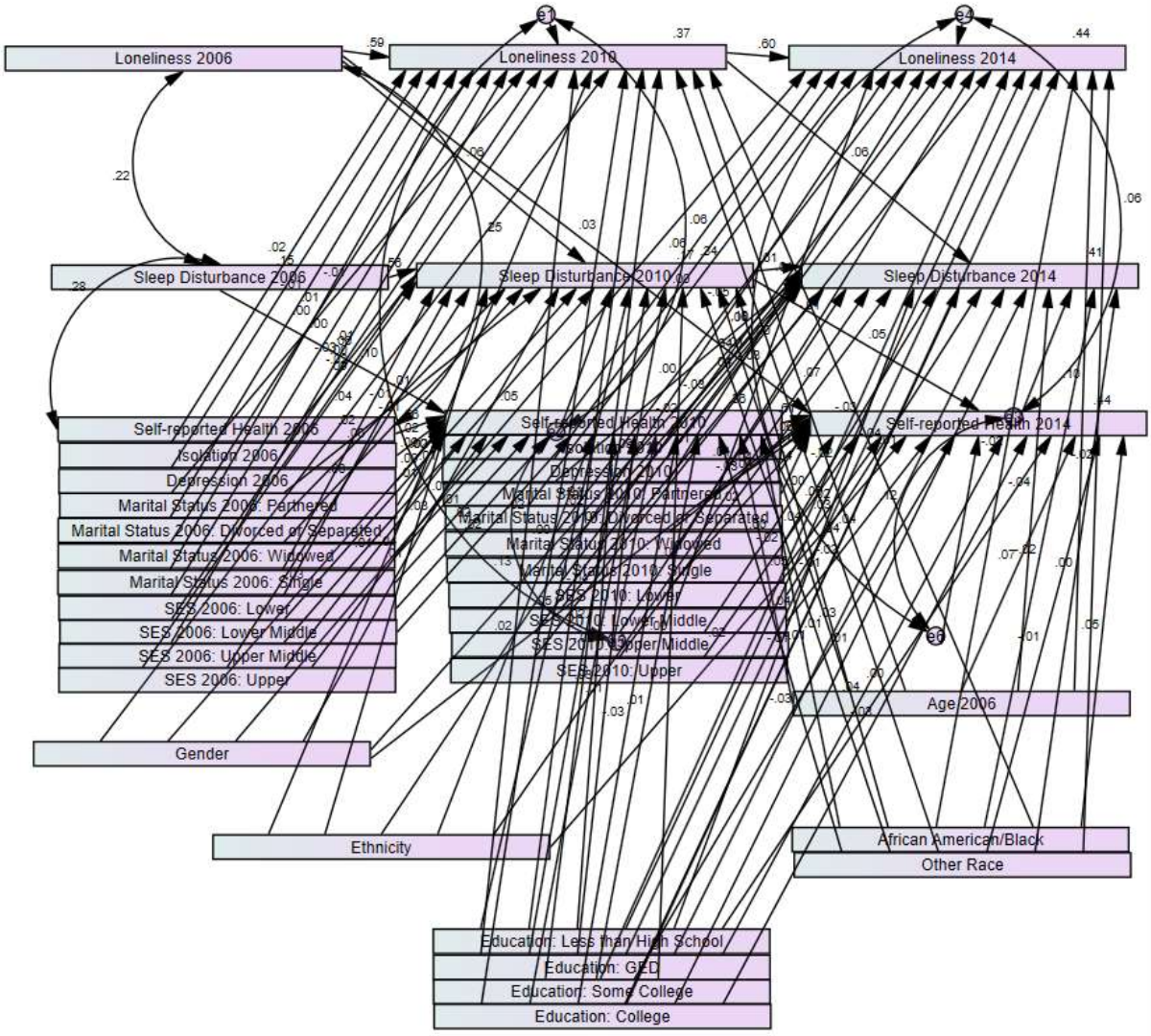

Figure 5. Adjusted cross-lagged mediation model (2006, 2010, 2014), with standardized regression weights.

Sensitivity analysis. See Figure 6 for the cross-lagged mediation model using time points 2006, 2010, and 2014 with standardized estimates. The chi-square (χ^2) goodness-of-fit test was significant, $\chi^2(67) = 15701.06$, $p < .001$. The root mean square of approximation (RMSEA) was .14, comparative fit index (CFI) was .80, Tucker-Lewis index (TLI) was .69, goodness-of-fit index (GFI) was .87. None of these indices met fit criteria.

All paths were significant (*p*s <.001). Direct effects (standardized) from loneliness to sleep disturbance ranged from .08 to .12; direct effects from sleep disturbance to self-reported health ranged from .05 to .06. There were direct effects of loneliness on self-reported health four years later ranged from .04, to .06. There were also indirect effects of loneliness on self-reported health (2006 to 2010: β =.01, 95% CI [.00,.01], p = .005; 2008 to 2012: β =.01, 95% CI [.00,.01], p = .007; 2010 to 2014: β =.01, 95% CI [.00,.01], p = .007). The model accounted for 33% of the loneliness, 26% of the sleep disturbance, and 54% of the self-reported health in 2014.

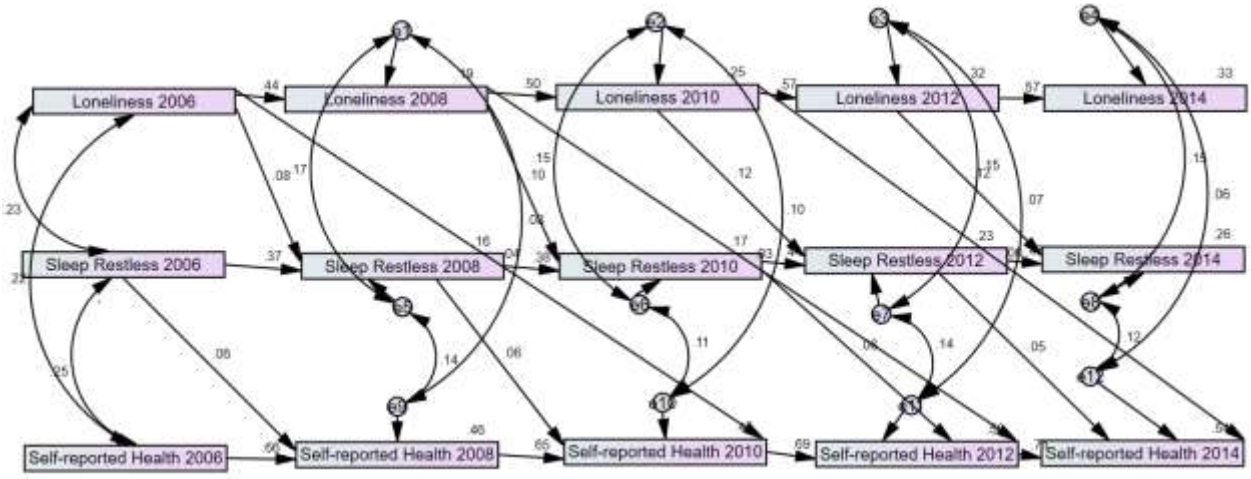

Figure 6. Cross-lagged mediation model (2006, 2008, 2010, 2012, 2014), with standardized regression weights.

Discussion

Association between Loneliness and Sleep Disturbance

Loneliness was associated with higher sleep disturbance at baseline. This association was attenuated, yet remained, when controlling for demographics, isolation, and depression. Using a modified scale of sleep disturbance that excluded the item on feeling rested did not change study conclusions, though it appeared to weaken the association between loneliness and sleep disturbance. Using multiple imputation (without complex sampling) did not appreciably change results.

The detection of a bivariate association between loneliness and sleep disturbance is consistent with the prior literature, which has demonstrated a correlation between loneliness and sleep problems across a wide array of measures and samples. The effect size of this association in this study, r =.21, is consistent with the mean correlation coefficient of r = .27 found across past studies examining loneliness and sleep disturbance (Griffin, Williams, Ravyts, & Rybarczyk, n.d.). The attenuation of this association when adjusting for potential confounds, to include demographics, isolation, and depression, is also consistent with past studies (P. Cheng et al., 2015; Hayley et al., 2017; Hom, Hames, et al., 2017; Kurina et al., 2011; T. Matthews et al., 2017b; McHugh et al., 2011; Segrin & Burke, 2015b; S. S. Smith, Kozak, & Sullivan, 2010; Steptoe et al., 2004; Stickley et al., 2015; Yu et al., 2017; Zawadzki et al., 2013). The association remained significant in the present study, whereas in some previous studies accounting for other factors attenuated the association between loneliness and sleep disturbance to the point of non-significance. This difference is likely due to the high statistical power of the present study, enabling the detection of very small effects.

This study is the first to address the association between loneliness and sleep disturbance in older Americans. Previous samples were either from other countries or not representative of the American population (e.g., college students, residents of a Chicago condominium complex; see Appendices B and C). These findings indicate that loneliness is associated with sleep disturbance in older Americans and that this association is not entirely attributable to the influence of isolation, depression, or the demographics of age, race, ethnicity, gender, education, and SES.

Loneliness as a Risk Factor for Sleep Disturbance

Loneliness is a risk factor for sleep disturbance both four and eight years later. This relationship remains, though is weakened, when controlling for demographics, isolation, and depression. Using a modified scale of sleep disturbance changed results: loneliness no longer predicted sleep disturbance eight years later in the adjusted model when using a scale of sleep disturbance that excluded an item on feeling rested. Using multiple imputation did not appreciably change findings.

The literature on loneliness as a sleep disturbance as a risk factor for sleep disturbance is variable, both in terms of findings and methodologies (Hom, Hames, et al., 2017; Jacobs et al., 2006; Jaremka et al., 2014; McHugh & Lawlor, 2013; Yu et al., 2017; Zawadzki et al., 2013). The present study provides evidence that loneliness is a risk factor for sleep disturbance, and identifies three methodological factors that may underlie the inconsistency in the previous literature. First, controlling for potential confounds dampens the effect of loneliness on subsequent sleep disturbance. Second, measures matter. The inclusion or exclusion of an item on feeling rested changed results. Some sleep measures—perhaps those that tap into feeling tired in addition to sleep patterns—may relate more strongly to loneliness. Third, the length of follow-up

influences results. It is likely that one—or a combination—of these factors, in conjunction with a smaller sample size, are driving differences in findings across studies.

The present study is the first to identify loneliness as a risk factor for sleep disturbance in a nationally-representative sample of older Americans. Moreover, this study elucidates potential methodological factors underlying the differences in findings in earlier longitudinal studies. Loneliness predicts subsequent sleep disturbance, but the effect is very small and further diminished by controlling for potential confounds, measures of sleep disturbance, and length of follow-up. As such, the effect is likely to surface in some studies but not others depending on these three factors in conjunction with statistical power and therefore the ability to detect very small effects.

Sleep Disturbance as a Risk Factor for Loneliness

Sleep disturbance is a risk factor for loneliness both four and eight years later. Controlling for demographics, isolation, and depression attenuated this relationship; sleep disturbance no longer predicted loneliness four years later in the adjusted model. Using a modified scale of sleep disturbance (i.e. without the feeling rested item) and using multiple imputation did not change findings.

The finding that sleep disturbance predicts subsequent loneliness is consistent with previous studies. Controlling for demographics, isolation, and depression attenuated this relationship, consistent with the second study from Hom, Hames et al. (2017). The sample size for this study was significantly larger than their sample size (n=151), explaining why the present study found a significant effect even when controlling for potential confounds where the previous study did not. Notably, the follow-up period was much longer for the present study as compared to past studies—eight years as compared to a follow-up ranging from two days (Simon

& Walker, 2018) to five weeks (Hom, Hames, et al., 2017)—yet results were consistent. Collectively, these findings suggest that sleep disturbance predicts both day to day and year to year fluctuations in loneliness.

This is the first study to identify sleep disturbance as a risk factor for loneliness in a sample that is representative—or even resembling—the population of older, community-dwelling adults in the United States. Moreover, it is the first study to establish this relationship over the course of years as opposed to weeks.

Loneliness and Sleep Disturbance over Time

Cross-lagged models of loneliness and sleep disturbance revealed reciprocal effects between the two across time points. This pattern was visible when examining variations in loneliness and sleep disturbance every two and every four years. Controlling for potential confounds—namely demographics, isolation, and depression—weakened the size of effects, yet findings remained with the exception of 2006 sleep disturbance no longer predicting 2010 loneliness.

This is the first study to examine the reciprocal effects of loneliness and sleep disturbance in this manner. These findings are consistent with previous findings in the literature—in addition to the findings in the present paper—identifying loneliness as a risk factor for sleep disturbance and vice-versa (Hom, Hames, et al., 2017; Jacobs et al., 2006; Jaremka et al., 2014; McHugh & Lawlor, 2013; Simon & Walker, 2018; Zawadzki et al., 2013). The reciprocal nature of this relationship requires revision to the Cacioppo and Hawkley (2003; 2009) model, which posited that loneliness disrupts sleep but not the reverse. Although loneliness may shape health via sleep disturbance, this relationship is not unidirectional; as such, the model must be revised to account for bidirectional effects between loneliness and sleep disturbance. Importantly, cross-lagged

panel modeling cannot establish causality, just direction of effects. Therefore, although the current study indicates that the direction of effects is reciprocal, it remains unclear whether these reciprocal effects are causal. It is possible that an outside factor is driving the fluctuations in both loneliness and sleep disturbance.

There was evidence of poor fit across all of the cross-lagged panel models. The focus of the present paper was to assess the relationships between variables over time, rather than to identify or provide support for a model of loneliness and sleep disturbance. However, the poor fit of these models conveys two important points. First, these models do not account for the full story. Second, the effects detected in these models, though statistically significant, are very small. However, these models are examining the reciprocal relationships between two variables over the course of years. As such, it would be very surprising to detect large effects, given that loneliness and sleep disturbance both fluctuate over time, so that a person who is lonely at baseline could no longer be lonely four years later. The detection of very small reciprocal effects across the span of years likely reflects larger reciprocal effects that are occurring day to day between loneliness and sleep disturbance.

Sleep Disturbance as a Mediator for the Relationship Between Loneliness and Health

Cross-lagged mediation models found that loneliness predicted subsequent sleep disturbance, which in turn predicted subsequent self-reported health. Moreover, there was evidence of both a direct and an indirect effect of loneliness on self-reported health. Controlling for demographics, isolation, and depression attenuated the effect sizes of these relationships but not to the point of non-significance. These findings suggest that sleep disturbance partially mediates the relationship between loneliness and health.

This is the first study using a longitudinal mediation model of loneliness, sleep disturbance, and health. Longitudinal mediational models are better equipped to speak to sleep disturbance as a mechanism underlying the relationship between loneliness and health because they can speak to direction of effects (Selig & Preacher, 2009). The detection of a partial mediation is consistent with previous cross-sectional work (Christiansen et al., 2016; Segrin & Domschke, 2011; Segrin & Passalacqua, 2010) and with the model proposed by Cacioppo and Hawkley (2003; 2009).

There was evidence of poor model fit across all of the cross-lagged mediation models. As was the case with the cross-lagged panel models, the aim of the present study was to assess effects rather than identify the best model to represent the relationship between loneliness, sleep-disturbance, and health. However, the poor model fit is indicative of an incomplete account of how loneliness, sleep-disturbance, and health relate in the context of other factors. Additionally, the model fit reflects small effect sizes. As in the case of the cross-lagged panel models, it would be surprising to find large effect sizes even if sleep disturbance were a major mechanism underlying the relationship between loneliness and health because of the assessment of these variables over the course of years.

However, it is clear that the current model for how loneliness shapes health is incomplete. Findings from the cross-lagged panel models identifies one facet of this incompleteness: the incorporation of reciprocal effects between loneliness and sleep disturbance. The full model proposed by Cacioppo and Hawkley (2003; 2009) additionally identifies other factors that may underly the relationship between loneliness and health. Further research is necessary to assess Cacioppo and Hawkley's full model, taking into account reciprocal effects between loneliness and sleep disturbance, as well as other potential reciprocal effects, such as health problems

disrupting sleep or exacerbating loneliness. This line of research should also assess for other factors that may be involved. Through testing various models (and comparing fit indices), this line of research could identify the model that best represents the mechanics of the relationship between loneliness and sleep.

Strengths and Limitations

The present study must be interpreted in light of its strengths and limitations. A strength of the present study is the sample size, which allows for the detection of very small effects. It could be argued that the detection of very small effects is not a strength, as these effects may be too small to be of real-world significance. However, methodological decisions can diminish or strengthen effect sizes. For example, the lag between variables likely affects the size of their association. As such, the large sample size of this study allows for the detection of effects that may be important, yet diminished by the methodology of the current study.

A second strength of the present study is the use of sensitivity analyses. Sensitivity analyses enable the examination of how methodological decisions influence results. A major issue in interpreting the literature is reconciling disparate findings across studies. It is often unclear why conclusions differ. Sensitivity analyses test the robustness of findings, and if there are discrepancies in findings indicate why. The overall consistency of results across sensitivity analyses suggest that these findings are not dependent on any of the decisions altered via sensitivity analyses. Moreover, the discrepancies detected between analyses identifies potential reasons for discrepancies in the literature, to include controlling for potential confounds, measurement, and length of follow-up.

A third strength of the study is that it controlled for potential confounds, to include demographics, isolation, and depression. Controlling for these variables allowed for comparison

to other studies that used adjustments and ruled out the possibility that findings were completely attributable to any of the factors included in the model. A fourth strength is the use of a longitudinal design, which allowed this study to speak to direction of effects.

However, the study also suffers from several key limitations. The first limitation is measurement. Although the main analyses used scales rather than single items to measure loneliness and sleep disturbance—a strength relative to much of the literature on this subject thus far—these scales were not the best measurement of loneliness and sleep disturbance available: the Hughes Loneliness Scale is an abbreviated version of the UCLA loneliness scale and the psychometric properties of the sleep scale have not been formally assessed. Similarly, further research is necessary to replicate these findings using other measures of health and a more comprehensive measure of depression.

The second limitation is the length of the lag between assessment. The lag time between assessment can change results—for example, through assessing variables before an effect has occurred or after an effect has disappeared. The present study sought to mitigate the potential bias due to lag time through conducting sensitivity analyses modeling the relationships between loneliness, sleep disturbance, and health every two years, in addition to the main analyses with examining these relationships every four years. However, even two-year analyses cannot capture effects occurring on a day to day basis.

A third limitation is the high rate of attrition in the present study. By 2014, there were data on the Hughes Loneliness Scale for only 64% of the original sample. Moreover, this attrition did not appear to be missing completely at random, but rather selective whereby certain participants were more likely to be lost to follow-up than others. This selective attrition raises the possibility of attrition bias. However, the current study sought to mitigate the potential of

attrition bias through conducting sensitivity analyses using multiple imputation for the analyses conducted in SAS and using expectation maximization for the path analyses conducted in AMOS.

A fourth limitation of the present study is that it did not examine the interplay between potential confounds and the variables of interest. Controlling for other factors is important, but it does not shed light on how these factors are involved. Loneliness, sleep disturbance, and health do not occur in a vacuum, but rather are facets of a broader human experience. Further research is necessary to understand how other factors are involved in the relationship between loneliness, sleep, and health. Moreover, additional research is necessary to examine other components of the Cacioppo and Hawkley (2003; 2009) model, as well as to assess other models seeking to explain how loneliness damages health.

Future Directions

Four lines of observational research are particularly important moving forward. First, research examining loneliness and sleep disturbance in the context of other factors—such as demographics, isolation, and depression—is necessary to understand how these factors come together to shape health. It is possible that the relationships examined in the present paper are stronger in subpopulations of the United States, which would be useful in understanding which populations are at greatest health risk. Furthermore, it is important to understand how isolation relates to loneliness and its health risks. The correlation between loneliness and isolation is modest yet their effects on mortality are comparable (Holt-Lunstad et al., 2015). As such, loneliness and isolation likely influence health through different, though potentially overlapping, mechanisms. This paper speaks to one potential pathway through which isolation could affect health: isolation leads to loneliness, which in turn influences sleep disturbance. Additional

research is necessary to pinpoint other pathways. Finally, depression is strongly tied to both loneliness and sleep disturbance. Further research is necessary to not just control for depression, but clarify its role in the link between loneliness and sleep disturbance, and how these factors connect to health.

Second, research is needed to evaluate the full Cacioppo and Hawkley (2003; 2009) model. The present study speaks to one aspect of this model, yet it is clear that this only a part of the relationship between loneliness and health. Research could assess the full model using path analysis, in addition to testing whether paring down or adding additional factors improves the model.

Third, research is needed that delves deeper into the pathophysiological relationship between loneliness and sleep. The seminal work on sleep disturbance as a mechanism for the relationship between loneliness and health did not speculate as to how loneliness would disrupt sleep (Cacioppo, Hawkley, Bernston, et al., 2002; Cacioppo, Hawkley, Crawford, et al., 2002). One potential way in which loneliness could affect sleep is through increased physiological arousal, whereby a person who feels lonely constantly feels more vulnerable than others. Cacioppo and Hawkley (2003; 2009) identified hypothalamic-pituitary-adrenal (HPA) axis activation as a separate mechanism underlying loneliness and health. However, it is likely that increased arousal is entangled with the relationship between loneliness and sleep. The HPA axis controls the output of glucocorticoids, which are integral to the sleep-wake cycle in humans (Oster et al., 2016). Moreover, experimental research indicates that sleep deprivation and restriction impair HPA functioning (van Dalfsen & Markus, 2018). Collectively, these findings suggest HPA axis involvement in the reciprocal effects between loneliness and sleep disturbance, but research is necessary to more closely examine this possibility.

Finally, research is necessary to examine patterns in daily fluctuations between loneliness and sleep disturbance in older adults. The present study allows for the assessment of long-term effects, but due to the time lag cannot accurately gauge the size of effects that may be occurring on a smaller scale. Moreover, this type of research would allow for a closer examination of the pathophysiological factors at play. A study examining fluctuations in loneliness, sleep disturbance, and arousal would provide vital insight on the relationship between loneliness and sleep.

Conclusion

This is the first study to identify an association between loneliness and sleep disturbance, identify loneliness as a risk factor for subsequent sleep disturbance, and identify sleep disturbance as risk factor for subsequent loneliness in a sample that is representative of older, community-dwelling adults living in the United States. Moreover, this is the first study examining the cross-lagged associations between loneliness and sleep disturbance, finding evidence for reciprocal effects between loneliness and sleep disturbance over time. Finally, this is the first longitudinal study identifying sleep disturbance as a partial mediator for the relationship between loneliness and health. Collectively, these findings support—but do not prove—Cacioppo and Hawley's (2003) theory that sleep disturbance is a mediator for the relationship between loneliness and health, yet also identify limitations of their model.

Although the findings from the present study are consistent with the theory that sleep disturbance mediates the relationship between loneliness and health, the study is observational and thus cannot establish causality. This study's longitudinal design and use of path analysis allows for the careful study of direction of effects, but it remains possible that an outside factor not accounted for in this study underlies the reciprocal effects between loneliness and sleep

disturbance. Experimental research is necessary to establish causality and thus speak to sleep disturbance as a mechanism underlying the association between loneliness and health. Furthermore, sleep disturbance predicts subsequent loneliness. As such, it is necessary to revise Cacioppo and Hawkley's (2003; 2009) model to incorporate the reciprocal effects between sleep disturbance and loneliness.

Moreover, longitudinal effect sizes were very small across the board. It is possible that the size of effects is due to the length of lag between assessments. Both loneliness and sleep disturbance are subject to change over time, and these changes may be especially prominent in older adulthood. As such, examining the reciprocal relationship between loneliness and sleep disturbance over the course of years rather than days may weaken effect sizes. Longitudinal research examining the reciprocal effects between loneliness and sleep disturbance more closely is necessary to better understand how these factors relate. However, it is also possible that the reciprocal effects between loneliness and sleep disturbance are small, indicating that other mechanisms are more integral to the association between loneliness and health.

The present study represents an early step in uncovering the mechanics underlying the association between loneliness and health in older Americans. Understanding the biopsychosocial interactions shaping the health and well-being of older Americans enables the development of prevention and intervention strategies, which in turn promise to improve quality of life, health outcomes, and longevity for this rapidly growing population. Older adults possess both strengths and vulnerabilities for weathering loneliness (Charles, 2010). On the one hand, older adults enjoy improved emotion regulation, present awareness, and positivity bias, in conjunction with a preference for emotionally fulfilling relationships (Carstensen et al., 1999), all of which could protect against loneliness. On the other, older adults are at greater risk for

certain events that may trigger loneliness (Charles, 2010). First, older adults are at greater risk for health conditions that may hinder their ability to spend time with others. Second, older adults are at increased risk of sustaining major changes to their social network, as friends, siblings, and partners die. These changes in social network may be particularly destructive in older adults, who per the Socioemotional Selectivity Theory (SST) have trimmed their social networks to prioritize meaningful relationships. As members of this smaller inner circle die, the potential for subsequent loneliness thus may be higher. Moreover, if chronic loneliness occurs, ensuing arousal is likely to precipitate greater health consequences due to age-related changes in cardiovascular functioning, neuroendocrine functioning and sleep architecture.

This heightened vulnerability makes research examining interactions across biological, psychological, and social factors particularly vital for prevention and intervention. The present study identified sleep as a risk factor for loneliness, suggesting that improving sleep could have cascading benefits on loneliness. This finding is promising in light of the success of behavioral sleep medicine interventions for insomnia (Dzierzewski, Griffin, Ravyts, Rybarczyk, & Griffin, 2018; Qaseem, Kansagara, Forciea, Cooke, & Denberg, 2016). Furthermore, this study illustrates how the heightened level of influence between biological, psychological, and social factors in older adults (Garroway & Rybarczyk, 2015) is not unidirectional but rather reciprocal, whereby changes on the biological level may limit contact with friends and family, thus inducing loneliness. Further research to understanding these interactions is critical to improve the health and quality of life for the rising number of older Americans.

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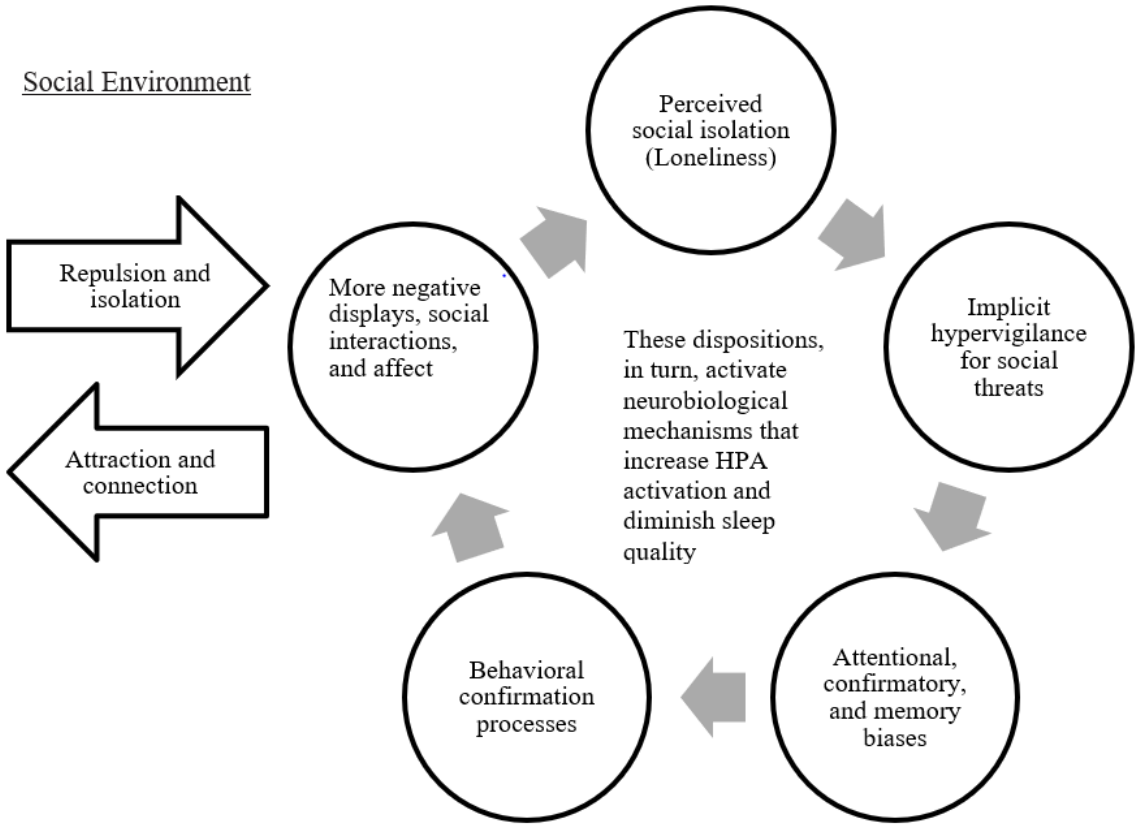
Appendix A

Cacioppo and Hawkley (2009) Model



Notes: Figure taken from Cacioppo and Hawkley (2009). Social isolation causes loneliness, which in turn fosters hypervigilance, triggering attentional, confirmatory, and memory biases, resulting in behavioral confirmation, which in turn modifies behavior to hinder connection with others, thus furthering isolation and loneliness. This cycle causes sleep disturbance and activates the HPA Axis, thereby harming health.

Appendix B

Sample Characteristics of Past Studies Examining the Relationship between Loneliness and Sleep

Author (Year)	Population	Sample Size (Analytic)	Mean Age	Age range	%Male	%Female	Country
Aanes (2011)	Two cohorts residing in Hordaland County, Norway	7,074	Not reported	Approximately 46-50 or 70-75 (born: 1925-1927, 1950-1951; data collection: 1997-2000)	Estimate: 48.2	Estimate 51.8	Norway
Cacioppo, Hawkley, Bernston (2002)	College students	64 (54 with sleep data from lab visit; 37 with sleep data at home)	Not reported	Not reported	61.1 lab; 62.1 home	38.9 lab; 37.8 home	USA
Cacioppo, Hawkley, Crawford (2002) - Study 1	College students	89	19.26	18-24	50.56	49.44	USA
Cacioppo, Hawkley, Crawford (2002) - Study 2	Chicago condominium	25	65.00	53-78	24.00	76.00	USA
Cheng (2015)	Older adults living in rural villages in Chizhou, China	730	69.07	60-86	44.52	55.48	China
Christiansen (2016)	Older adults in Denmark	8593	73.00	65-103	49.00	51.00	Denmark
Chu (2016)	College students	552 (538)	21.53	18-34	25.50	74.50	South Korea
Davis (2000)	Homeless women	50	29.90	18-44	0.00	100.00	USA
Hawkley (2010)	Residents of Cook County, Illinois (Chicago)	229 (215)	57.40	50-68[a]	47.60	52.40	USA

Hayley (2017)	Higher education students in Norway	12,043	Not reported	18-34	33.50	66.50	Norway
Hays (1987)	College students	199	21.00	17-48	38.20	61.80	USA
Hom, Chu (2017) - Study 1	Military services members and veterans	937	38.20	18-88	82.10	17.90	USA
Hom, Chu (2017) - Study 2	Army recruiters	3,386	29.91	20-57	91.50	8.50	USA
Hom, Chu (2017) - Study 3	Military veterans	417	50.73	20-98	67.80	32.20	USA
Hom, Hames (2017) - Study 1	Undergraduate students	747 (666)	18.90	18-33	63.00	37.00	USA
Hom, Hames (2017) - Study 2	Army recruiters	2785	29.90	20-57	91.90	8.10	USA
Hom, Hames (2017) - Study 3	Adults with a history of suicidality/depression	208	19.38	18-36	19.70	80.30	USA
Hom, Hames (2017) - Study 4	Adult psychiatric outpatients	343	26.78	18-71	39.50	60.50	USA
Hom, Hames (2017) - Study 5	Young adults at elevated suicide risk	326	22.17	18-37	82.20	17.80	USA
Hom, Hames (2017) - Study 6	College students	183[b] (151)	19.00	17-29	45.90	54.10	USA
Jacobs (2006)	West Jerusalem residents born between June 1920 - May 1921	452 (290)	70.00	Single cohort	51.72	48.28	Jerusalem
Jaremka (2014) - Study 1	Cancer clinics at the Ohio State University - cancer patients and noncancer controls	115	56.77	30-88	17.00	83.00	USA
Jaremka (2014) - Study 2	(1) Older adults caring for a spouse with Alzheimer's disease or related dementia (2) Non-caregiver controls	229	69.68	35-91	28.00	72.00	USA
Kurina (2011)	Hutterite adults living on two colonies in South Dakota	130 (95)	39.80	19-84	45.00	55.00	USA

Matthews (2017)	Birth Cohort of British Twins	2232	18.40	Not applicable (single cohort)	Not reported but appears to be approximately even		UK
McHugh (2011)	Irish community-dwelling adults over 60	505	73.33	Not reported (over age 60)	31.70	68.30	UK
McHugh (2013)	Irish community-dwelling adults over 60	624 (447)	73.32	Not reported	31.00	69.00	UK
O'Connell (2016)	Online - Irish, American, European, Canadian, Australian	118	30.60	18-59	32.20	67.80	92.4% Irish
Segrin (2010)	College students, acquaintances of college students, parents of high school athletes	265	41.45	19-85	47.55	52.45	USA
Segrin (2011)	College students, acquaintances of college students	224	41.22	18-81	34.82	65.18	USA[c]
Segrin (2015)	College students	510	45.55	Not reported	50.00	50.00	USA
Smith (2010)	University community	97	21.6	Not reported	28.87	71.13	Australia
Steptoe (2004)	London based civil servants aged 35-55 in 1985-1988	240	Not reported	47-59	53.75	46.25	UK
Stickley (2015)	Moscow residents	1190	Not reported	Not reported (over age 18)	42.86	57.14	Russia
Yu (2017)	Taiwanese adults aged 60 and older	1023 (639)	66.14	54 - 80	57.67	42.33	Taiwan
Zawadzki (2013) - Study 3	College students	218	20.30	Not reported	24.31	75.69	USA
Zawadzki (2013) - Study 4	College students	360 (334)	21.20	Not reported	22.75	77.25	USA

Notes: (1) Overlapping samples are highlighted the same shade of gray. (2) Sample size estimates are at baseline for longitudinal studies. (3) Mean ages and age ranges are at baseline. (4) Superscripts denote the following: [a] From (Hawkley et al., 2008). [b] Sample with data at both time points; list-wise deletion used for longitudinal analyses (yielding sample size of 151), but not specified if cross-sectional analyses used the larger dataset. [c] Not reported but authors are from the United States.

Appendix C

Ethnicity for Past Studies on Loneliness and Sleep Conducted in the United States

Author (Year)	%White	%Black	%Hispanic	%Asian/Pacific Islander	%Native American/Alaskan Native	%Other
Cacioppo, Hawkley, Bernston (2002)	Not reported					
Cacioppo, Hawkley, Crawford (2002) – Studies 1 & 2	Not reported					
Davis (2000)	10	64	26	0	0	0
Hawkley (2010)	35.8	35.4	28.8	0	0	0
Hays (1987)	54.6	15.7	14.7	10	0	5
Hom, Chu (2017) - Study 1	67.9	15.2	0	1.8	1.7	13.4
Hom, Chu (2017) - Study 2	66.2	14.8	13.5	4.3	1.1	
Hom, Chu (2017) - Study 3[a]	86.4	1.7	0	0	0.2	9.5
Hom, Hames (2017) - Study 1	75	21	<1	<1	<1	2
Hom, Hames (2017) - Study 2	65.2	15	13.5	4.3	1.1	0.9
Hom, Hames (2017) - Study 3	79.8	10.1	0	4.8	1	4.3

Hom, Hames (2017) - Study 4[b]	75.6	9.1	1.2	2.1	0.3	1.8
Hom, Hames (2017) - Study 5	61	24.8	10.5	1.2	1.2	1.2
Hom, Hames (2017) - Study 6	68	5	8	19	0	0
Jaremka (2014) - Study 1	85	Not reported				
Jaremka (2014) - Study 2	86	Not reported				
Kurina (2011)	100	0	0	0	0	0
Segrin (2010)	78	4	12	4	1	1
Segrin (2011)	77	1	12	6	1	2
Segrin (2015)	81.5	2	11	3	1	1.5
Zawadzki (2013) – Studies 3 & 4	Not reported					

Note: Superscripts denote the following: [a] Percentages add up to 97.8%. [b] Percentages add up to 90.1%.

Appendix D

Measures of Past Studies Examining the Relationship between Loneliness and Sleep

Author (Year)	Sleep measure	Sleep Construct	Note on quality	Loneliness Measure	Direct /Indirect	Note on quality
Aanes (2011)	"How is your sleep in general?" on a 5-item Likert scale	Quality	Single item; Not assessed for psychometric properties	Six-item scale modified from scale developed for population-based research in Western Norway	Both	Modified scale; Acceptable internal consistency in this study (alpha=.77)
Cacioppo, Hawkley, Bernston (2002) - sleep efficiency	Blinking and movement during sleep via a Nightcap model P200B1	Both	Objective; Assessed for psychometric properties	UCLA Loneliness Scale (Revised)	Indirect	Scale; Assessed for psychometric properties
Cacioppo, Hawkley, Crawford, et al., (2002) - Study 1	Pittsburgh Sleep Quality Index (PSQI)	Quality	Scale; Assessed for psychometric properties	UCLA Loneliness Scale (Revised)	Indirect	Scale; Assessed for psychometric properties
Cacioppo, Hawkley, Crawford (2002) - Study 2	PSQI	Quality	Scale; Assessed for psychometric properties	UCLA Loneliness Scale (Revised)	Indirect	Scale; Assessed for psychometric properties
Cheng (2015)	PSQI (Chinese version)	Quality	Scale; Assessed for psychometric properties (in English and Chinese)	UCLA Loneliness Scale (Revised; Chinese Version)	Indirect	Scale; English version has been assessed for psychometric properties; Unclear if Chinese version has been assessed for psychometric properties but

Author (Year)	Sleep measure	Sleep Construct	Note on quality	Loneliness Measure	Direct /Indirect	Note on quality
						does demonstrate excellent internal consistency (alpha=0.94)
Christiansen (2016)	Single Item ratings for (1) general sleep quality on a 4-item Likert scale and (2) duration (how many hours and minutes do you approximately sleep on a weekday)	Both	Single item; Not assessed for psychometric properties	Hughes Loneliness Scale (Danish Version)	Indirect	Abbreviated (3-item) version of the UCLA Loneliness Scale English version has been assessed for psychometric properties; Acceptable internal consistency in this study (.72)
Chu (2016)	Insomnia Severity Index (ISI) translated into Korean	Insomnia	Scale; Assessed for psychometric properties in English, though it is unclear how translation might affect these properties	Thwarted Belonginess Subscale of the Interpersonal Needs Questionnaire (Korean Version)	Indirect	Scale; English version has been assessed for psychometric properties; Unclear if Korean version has been assessed for psychometric properties
Davis (2000)	7 questions on sleep from a larger questionnaire	Quality (but both measured)	Minimal information on the scale provided in the article. The cited article on the scale did not give any information on the scale or its psychometric properties.	Part of larger questionnaire; Appears to be a single-item on loneliness but not clearly specified	Not specified, but likely direct	Minimal information on the scale provided in the article; Appears to be a single question that has not been assessed for psychometric properties
Hawkley (2010)	Sleep Diary: Self-reported sleep duration and time in bed awake	Both	Administered daily, thus reducing retrospective reporting bias; Psychometric properties not reported	Six questions form the UCLA Loneliness Scale + one additional item (I feel lonely)	Both	Modified scale; UCLA Loneliness Scale assessed for psychometric properties but the modified scale has not been assessed for psychometric properties

Author (Year)	Sleep measure	Sleep Construct	Note on quality	Loneliness Measure	Direct /Indirect	Note on quality
Hayley (2017)	Single item from the depression subscale of the Hopkins Symptoms Checklist asking about difficulty initiating and maintaining sleep	Quality	Single item; Not assessed for psychometric properties	Social and Emotional Loneliness Scale	Indirect	Poor face validity: appears to be tapping into social support and isolation rather than loneliness; Scale; Assessed for psychometric properties
Hays (1987)	Hours of sleep obtained on the average night	Quantity	Single item; Not assessed for psychometric properties	Three versions of the UCLA Loneliness Scale (ULS-20, ULS-8, ULS-4)	Indirect	assessed for psychometric properties; indirect
Hom, Chu (2017) - Study 1	5-item version of the ISI	Insomnia	Abbreviated scale; Full ISI has been assessed for psychometric properties; Abbreviated scale demonstrated good internal consistency in this study (alpha=.82)	5 questions from the Thwarted Belongingness Subscale of the Interpersonal Needs Questionnaire	Indirect	Abbreviated scale; Full scale assessed for psychometric properties; Abbreviated scale demonstrated good internal consistency in this study (alpha=.89)
Hom, Chu (2017) - Study 2	5-item version of the ISI	Insomnia	Abbreviated scale; Full ISI has been assessed for psychometric properties; Abbreviated scale demonstrated good internal consistency in this study (alpha=.87)	4 questions from the Thwarted Belongingness Subscale of the Interpersonal Needs Questionnaire	Indirect	Abbreviated scale; Full scale assessed for psychometric properties; Abbreviated scale demonstrated excellent internal consistency in this study (alpha=.91)
Hom, Chu (2017) - Study 3	ISI	Insomnia	Scale; Assessed for psychometric properties	Thwarted Belonginess Subscale of the Interpersonal Needs Questionnaire	Indirect	Scale; Assessed for psychometric properties

Author (Year)	Sleep measure	Sleep Construct	Note on quality	Loneliness Measure	Direct /Indirect	Note on quality
Hom, Hames (2017) - Study 1	ISI	Insomnia	Scale; Assessed for psychometric properties	Study-specific loneliness index created with items from CESD, PTSD checklist, Interpersonal Needs Questionnaire, and State Loss of Interest and Pleasure Scale	Both	Scale; Not assessed for psychometric properties; Demonstrated good internal consistency in this study (alpha=0.85)
Hom, Hames (2017) - Study 2	5-item version of the ISI	Insomnia	Abbreviated scale; Full ISI has been assessed for psychometric properties; Abbreviated scale demonstrated good internal consistency in this study (alpha=.87)	4 questions from the Thwarted Belongingness Subscale of the Interpersonal Needs Questionnaire	Indirect	Abbreviated scale; Full scale assessed for psychometric properties; Abbreviated scale demonstrated excellent internal consistency in this study (alpha=.90)
Hom, Hames (2017) - Study 3	ISI	Insomnia	Scale; Assessed for psychometric properties	Thwarted Belonginess Subscale of the Interpersonal Needs Questionnaire	Indirect	Scale; Assessed for psychometric properties
Hom, Hames (2017) - Study 4	ISI	Insomnia	Scale; Assessed for psychometric properties	Thwarted Belonginess Subscale of the Interpersonal Needs Questionnaire	Indirect	Scale; Assessed for psychometric properties
Hom, Hames (2017) - Study 5	Single item from the BDI-II	Change in sleep	Single item; Not assessed for psychometric properties;	9 questions from the Suicide Probability	Both	Scale; Not assessed for psychometric properties; Scale demonstrated adequate

Author (Year)	Sleep measure	Sleep Construct	Note on quality	Loneliness Measure	Direct /Indirect	Note on quality
			Does not indicate direction of change (sleeping more or less)	Scale used to form a loneliness subscale		to good internal consistency in this study across time points (alpha=0.69-0.83)
Hom, Hames (2017) - Study 6	4-items from the Sleep Hopelessness Depression Symptom Questionnaire	Insomnia	Modified scale; Demonstrated adequate to good internal consistency (alpha=.79-.87)	UCLA Loneliness Scale (Revised)	Indirect	Scale; Assessed for psychometric properties
Jacobs (2006)	Yes/No question "Are you satisfied with your sleep in the last month?"	Sleep satisfaction	Single item; Not assessed for psychometric properties	Not specified in article but likely an item from the Brief Symptoms Inventory	Not specified, but likely direct	Minimal information on the scale provided in the article; Appears to be a single question that has not been assessed for psychometric properties
Jaremka (2014) - Study 1	PSQI	Quality	Scale; Assessed for psychometric properties	New York University (NYU) Loneliness Scale	Direct	Scale; Assessed for psychometric properties
Jaremka (2014) - Study 2	Not clearly specified but appears to be a single question asking participants to compare the amount of sleep over the past three days to optimal amount	Adequacy	Single item; Not assessed for psychometric properties	3 questions from the NYU Loneliness Scale	Direct	Abbreviated scale; Full scale assessed for psychometric properties; No evidence that subscale has been assessed for psychometric properties
Kurina (2011)	(1) Wrist actigraphy: sleep duration and sleep fragmentation (2) PSQI	Both	(1) Objective; Assessed for psychometric properties (convergent validity with polysomnography for sleep duration and sleep fragmentation) (2) Scale;	Hughes Loneliness Scale	Indirect	Abbreviated (3-item) version of the UCLA Loneliness Scale; Assessed for psychometric properties

Author (Year)	Sleep measure	Sleep Construct	Note on quality	Loneliness Measure	Direct /Indirect	Note on quality
			Assessed for psychometric properties			
Matthews (2017)	PSQI	Quality	Scale; Assessed for psychometric properties	4 questions from the UCLA Loneliness Scale (Version 3)	Indirect	Abbreviated scale; Full scale assessed for psychometric properties and abbreviated scale includes all three Hughes Loneliness Scale Items; Abbreviated scale demonstrated good internal consistency in this study (alpha=0.83)
McHugh (2011)	PSQI	Quality	Scale; Assessed for psychometric properties	De Jong Gierveld Loneliness Scale (6-Item)	Indirect	Scale; Assessed for psychometric properties
McHugh (2013)	PSQI	Quality	Scale; Assessed for psychometric properties	De Jong Gierveld Loneliness Scale (6-Item)	Indirect	Scale; Assessed for psychometric properties
O'Connell (2016)	4 items on sleep disturbance taken from the 14-item Physical Health Questionnaire	Quality	Abbreviated scale; Full health scale has been assessed for psychometric properties but the properties of the abbreviated scale are not clear	National Institute of Health Toolbox of Adult Social Relationships Loneliness Scale	Both	Scale; Assessed for psychometric properties
Segrin (2010)	Sleep subscale from the Health Practices Scale	Adequacy	Subscale; Full Health Practices Scale only assessed for internal consistency in cited article (Jackson, 2006); Subscale demonstrated good internal	UCLA Loneliness Scale (Version 3)	Indirect	Scale; Assessed for psychometric properties

Author (Year)	Sleep measure	Sleep Construct	Note on quality	Loneliness Measure	Direct /Indirect	Note on quality
			consistency in this study (alpha=.83)			
Segrin (2011)	PSQI	Quality	Scale; Assessed for psychometric properties	UCLA Loneliness Scale (Version 3)	Indirect	Scale; Assessed for psychometric properties
Segrin (2015)	PSQI	Quality	Scale; Assessed for psychometric properties	UCLA Loneliness Scale (Version 3)	Indirect	Scale; Assessed for psychometric properties
Smith (2010)	PSQI	Quality	Scale; Assessed for psychometric properties	UCLA Loneliness Scale (Revised)	Indirect	Scale; Assessed for psychometric properties
Steptoe (2004)	Jenkins et al. (1988) Scale	Quality	Scale; Assessed for psychometric properties	UCLA Loneliness Scale (Revised)	Indirect	Scale; Assessed for psychometric properties
Stickley (2015)	Not clearly specified but appears to be single yes/no question on experience of insomnia in the past year	Insomnia	Single item; Not assessed for psychometric properties	"How often do you feel lonely?" on a 4-item Likert scale	Direct	Single item; Not assessed for psychometric properties
Yu (2017)	(1 – in 2000) Sleep item from the Center for Epidemiologic Studies Depression Scale (CES-D) (2 – in 2006) PSQI (Chinese version)	Quality	(1) Single item; Not assessed for psychometric properties (2) Scale; Assessed for psychometric properties (in English and Chinese)	Loneliness item from the CES-D	Direct	Single item; Not assessed for psychometric properties
Zawadzki (2013) - Study 3	PSQI	Quality	Scale; Assessed for psychometric properties	UCLA Loneliness Scale (Version 3)	Indirect	Scale; Assessed for psychometric properties

Author (Year)	Sleep measure	Sleep Construct	Note on quality	Loneliness Measure	Direct /Indirect	Note on quality
Zawadzki (2013) - Study 4	PSQI	Quality	Scale; Assessed for psychometric properties	UCLA Loneliness Scale (Version 3)	Indirect	Scale; Assessed for psychometric properties

Note: The leading author(s) and year is underlined for longitudinal research.

Appendix E

Narrative Summary of Results of Studies that Accounted for Other Factors

First author (Year)	Narrative Summary of Result
Cheng (2015)	No significant association between sleep quality and loneliness when controlling for age, gender, education, occupation, income, marital status, depression, social support, and quality of life.
Hayley (2017)	Association attenuated when controlling for age, gender, income, physical exercise, smoking, BMI, alcohol use, program, semester, social factors, anxiety, and depression.
Hom, Hames (2017) - Study 1	No significant association between insomnia and loneliness when controlling for depression.
Hom, Hames (2017) - Study 2	Association between insomnia and loneliness attenuated but still significant when controlling for perceived burdensomeness.
Hom, Hames (2017) - Study 3	No significant association between insomnia and loneliness when controlling for depression.
Hom, Hames (2017) - Study 4	No significant association between insomnia and loneliness when controlling for depression.
Kurina (2011)	Association between sleep fragmentation and loneliness attenuated when controlling for age, sex, BMI, risk of sleep apnea, and negative affect.
Matthews (2017)	Association between sleep quality and loneliness attenuated when controlling for social isolation, depression, anxiety, alcohol use, ADHD, PTSD, not being in employment, education, or training, and being the parent of an infant.
McHugh (2011)	Loneliness not a significant predictor of poor *v* good sleep quality when controlling for neuroticism, anxiety, depression, stress, age, polypharmacy, pain, gender, and age-adjusted comorbidity.
Segrin (2015)	Significant association between sleep quality and loneliness when controlling for depression (bivariate relationship not reported).
Smith (2010)	No significant association between sleep quality and loneliness over and above depression, anxiety, and stress.
Steptoe (2004)	Significant association between sleep quality and loneliness when controlling for age, sex, marital status, and grade of employment (bivariate relationship not reported).
Stickley (2015)	Association between insomnia and loneliness attenuated when controlling for sex, age, marital status, education, household size, economic situation, social contacts, association membership, and social support.
Yu (2017)	No significant difference on adjusted sleep quality score (age, sex, education, smoking, alcohol use, exercise, blood pressure, heart disease, stroke, ADLs/IADLs, cognitive impairment, depressive symptoms) in persons with high *v* low loneliness.
Zawadzki (2013) - Study 3	The direct path between loneliness and poor sleep quality was no longer significant when rumination and anxiety were included as mediators.

Appendix F

Narrative Summary of Longitudinal Studies

First Author (Year)	Narrative Summary of Findings	% Lost to Follow-up	Handling of Attrition
Hom, Hames (2017) - Study 5	Baseline loneliness did not significantly predict endorsement of a change in sleep at 1 month or 6 months when controlling for baseline endorsement of a change in sleep; Endorsement of a change in sleep at baseline did not predict loneliness at 1 month or 6 months when controlling for baseline loneliness.	56.13	Not specified (data after 6 months not included).
Hom, Hames (2017) - Study 6	Baseline loneliness predicted insomnia five weeks later when controlling for baseline insomnia symptoms and anxiety; baseline insomnia predicted loneliness five weeks later when controlling for baseline loneliness and anxiety. However, neither loneliness nor insomnia predicted the other when controlling for baseline depression.	17.49[a]	Analyses conducted only with participants who completed both data points.
Jacobs (2006)	Baseline loneliness predicted sleep satisfaction seven years later when controlling for baseline sleep satisfaction, depression, self-rated health, economic problems, obesity, and back pain; Baseline sleep satisfaction predicted loneliness seven years later but not when controlling for depression, health, fatigue, medical conditions, sleeping medications, activity, and gender.	35.84	Not specified.
Jaremka (2014) - Study 1	Loneliness did not predict change in sleep quality over one year.	13.91[b]	Not specified.
Jaremka (2014) - Study 2	Loneliness predicted decline in sleep adequacy over time (3-year follow-up).	12.23[b]	Used analysis (GEE) that enabled the inclusion of participants with partially missing data.
McHugh (2013)	Baseline loneliness predicted sleep quality approximately two years later when controlling for sleep quality at baseline, age, gender, and comorbidities.	28.37	Applied an attrition weight to apply to longitudinal data.
Yu (2017)	Baseline loneliness did not predict change in sleep quality over six years when controlling for age, sex, education, smoking, alcohol use, exercise, blood pressure, heart disease, stroke, baseline sleep quality, ADLs/IADLs, cognitive impairment, isolation, and depression.	37.54	Examined differences in those lost *v* not lost to follow-up.

Zawadzki (2013) - Study 4	Change in loneliness predicted change in anxiety, which in turn predicted change in sleep over three months.	5.56	Analyses conducted only with participants who completed both data points.

Note: Superscripts denote the following: [a] Estimate – attrition rate not specified; calculation made using percentage of missing data at either baseline or follow-up. [b] Estimate – attrition rate not specified; calculation made using the degrees of freedom for longitudinal analyses to estimate n at follow-up.