Social Interaction and Sleep as Possible Mechanisms of the Association between Loneliness and Increased Blood Pressure

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Previous research has found that loneliness is associated with increased blood pressure in old adults (Hawkley, Masi, Berry, & Cacioppo, 2006; Hawkley, Thisted, Masi, & Cacioppo, 2010). However, later studies suggested that this association between loneliness and blood pressure may not be replicable. The present study examined whether there was an association between loneliness and blood pressure in a sample of 391 mid-aged and older adults (SHINE: Study of Health and Interactions in the Natural Environment), with loneliness measured by UCLA Loneliness Scale-Revised and blood pressure assessed during a four-day ambulatory monitoring study. Moreover, building on the loneliness model proposed by Hawkley and Cacioppo (2010), the current study examined whether social interaction quality and sleep may explain such a link between loneliness and increased blood pressure in this sample, with social interaction quality measured by ecological momentary assessment and sleep measured objectively by actigraphy and subjectively by the Pittsburgh Sleep Quality Index. Findings showed that loneliness was not associated with blood pressure in mid-aged and older adults after controlling for age, sex, race, and education. Loneliness was also not related to Actigraphy-assessed sleep (total sleep time and sleep efficiency). However, loneliness was significantly related to lower self-reported sleep quality as well as to lower social interaction positivity and higher social interaction negativity among participants in daily life. The results of the current study have implications for current models of loneliness, social interactions, and health.

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Preface

I would like to express my sincere gratitude to the University Honor College and the Psychology Department for giving me the opportunity to complete a Bachelor of Philosophy thesis. To my committee, Dr. Anna Marsland, Dr. Tristen Inagaki, and Dr. Jesse Stewart, thank you for your suggestions and assistance throughout my project. To Kristina Dickman, thank you for supporting me throughout the whole process with professional knowledge and warm encouragement. To the members of Behavioral Medicine Research Group—Dr. Barbara Anderson, Mark Thomas, Erin McPherson, Thomas Wood, Rachel Koffer for helping me overcome different challenges. To all my friends and family—especially to my parents for encouraging, understanding, and supporting me to chase my dream. Most of all, I am extremely grateful for having Dr. Thomas Kamarck as my supervisor and director. From him, I not only learned how to do research in a rigorous manner but also how to behave as a virtuous person. His conscientiousness, wisdom, patience, and enthusiasm guided me through the years and pushed me farther than I thought I could go.

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1.0 Introduction

Increasing evidence suggests that social relationships are important for psychological and physical health across the lifespan. Loneliness, defined as a negative feeling resulting from a discrepancy between desired and actual state of social relationships (Peplau & Perlman, 1982), is associated with increased risk of morbidity and mortality from cancer, cardiovascular disease, and a host of other diseases (Cacioppo & Cacioppo, 2014). However, the pathways between loneliness and negative health outcomes are not yet fully understood.

In industrialized nations, cardiovascular disease is one of the leading causes of morbidity and mortality, and hypertension is a major risk factor for cardiovascular disease (Kannel, 1996). Relatively consistent evidence suggests that loneliness is associated with increased vascular resistance and blood pressure, and this association is significant not only in cross-sectional studies but also in longitudinal studies (Cacioppo, Hawkley, Crawford, et al., 2002; Hawkley, Burleson, Berntson, & Cacioppo, 2003; Hawkley, Masi, Berry, & Cacioppo, 2006; Hawkley, Thisted, Masi, & Cacioppo, 2010; but see Shankar et al., 2011; Das, 2019). Two early studies (Cacioppo, Hawkley, Crawford, et al., 2002; Hawkley, Burleson, Berntson, & Cacioppo, 2003) found that lonely young adults (2002 study: $N = 89$, mean age = 19.3; 2003 study: $N = 135$, mean age = 19.2) had heightened total peripheral resistance (an influential factor of blood pressure) compared to their non-lonely counterparts. Moreover, with a convenience sample of older adults aged between 53 and 78 ($N = 25$, mean age = 65), research found that age was associated with a greater increase in blood pressure in lonely than in nonlonely older adults (Cacioppo, Hawkley, Crawford, et al., 2002). To further investigate the possible linkage between loneliness and cardiovascular markers, Hawkley, Masi, Berry, and Cacioppo (2006) studied the cross-sectional association between

loneliness and blood pressure in 229 middle-aged and older adults (mean age = 57.5, range: 50-68, 52% female) of mixed race. In this study, loneliness was assessed with the UCLA Loneliness Scale-Revised (UCLA-R), and cardiovascular measures, including heart rate and blood pressure were collected in the lab. Cross-sectional analyses revealed that loneliness was significantly associated with increased systolic blood pressure (SBP) even after controlling for demographic and psychosocial risk factors such as age, gender, depressive symptoms, social support, perceived stress, and hostility. Moreover, there was a significant interaction between loneliness and age, which indicated that the association between loneliness and SBP became stronger as people aged.

Longitudinal analyses have provided further support for the link between loneliness and blood pressure. Following the same sample over four years, Hawkley, Thisted, Masi, & Cacioppo (2010) examined the longitudinal association between loneliness and cardiovascular changes over a 4-year period. With a cross-lagged panel analysis, the study found that higher levels of loneliness at study onset predicted greater increases in SBP two, three, and four years later. Individuals who were one standard deviation higher in their loneliness level showed a 2.3 mm greater increase in SBP over four years. This relationship between loneliness and SBP was independent of demographic covariates, chronic health conditions and other psychosocial risk factors.

Even though cross-sectional and longitudinal evidence supports links between loneliness and blood pressure, contradictory findings also exist. One cross-sectional study conducted by Shankar et al. (2011) did not find a significant relationship between loneliness and blood pressure. In a large sample of older adults living in England (ELSA), this study examined how loneliness and social isolation link to health behaviors and biological health indicators. After adjusting for age, sex, depression, chronic illness, wealth, and use of antihypertensive medication, the study found that loneliness was not significantly associated with either systolic or diastolic blood

pressure. Another study (Das, A., 2019), based on two nationally representative longitudinal samples (English ELSA and U.S. HRS), also found that loneliness was not significantly linked to blood pressure. Discrepant findings could be due to cultural differences or variations in measurement. Both studies used a short 3-item version of the UCLA Loneliness Scale-Revised instead of the complete scale that had been used in most previous studies (Cacioppo, Hawkley, Crawford, et al., 2002; Hawkley, Burleson, Berntson, & Cacioppo, 2003; Hawkley, Masi, Berry, & Cacioppo, 2006; Hawkley, Thisted, Masi, & Cacioppo, 2010). One of the aims of the current study was to examine whether there is an association between loneliness and blood pressure using the complete UCLA Loneliness Scale-Revised in a large community sample of middle-aged and older adults.

1.1 The Loneliness Model

Further studies have examined possible mechanisms through which loneliness may predict higher blood pressure. The Loneliness Model, proposed by Hawkley and Cacioppo (2016), serves as a theoretical foundation guiding research to operationalize and examine possible pathways linking loneliness to increased blood pressure. According to the Loneliness Model, feeling lonely produces a maladaptive cognitive bias that heightens individuals' sensitivity to the effects of negative social interactions. These attentional and cognitive effects of loneliness are then thought to lead to inappropriate social behaviors, such as distrust, which further contribute to more negative social interactions. This process activates several neurobiological and behavioral mechanisms (for example, increased HPA axis activation and diminished sleep quality) that are assumed to lead to adverse health outcomes, such as elevated blood pressure. Among these hypothesized

mechanisms, sleep, a prototypic restorative behavior, was proposed by Hawhley and Cacioppo (2016) as an important mechanism that contributes to the influence of loneliness. Consistent with the proposed Loneliness Model, both the quality of daily social interactions and the quality of daily sleep have been shown to be associated with loneliness and blood pressure and therefore could act as plausible mediators, as described below.

1.2 Quality of Social Interactions as a Possible Mechanism

In line with the predictions of the Loneliness Model, we will first consider the association between loneliness and quality of social interactions. Studies found that loneliness increases individuals' hypervigilance to social threat, their selective attention to negative social interaction, and the possibility of engaging in negative social interaction (Cacioppo & Cacioppo 2014; Hawkley, Preacher & Cacioppo, 2007). In a recent study, Arpin and Mohr (2019) examined the effect of transient loneliness on social interaction using an experimental design in 194 adult females with no current depression. Participants were randomly assigned to a high loneliness or a low loneliness group. The high loneliness group was exposed to a loneliness induction task that asked participants to spend 3 minutes reflecting on statements adopted from the UCLA Loneliness Scale-Revised (e.g. "Think of a time when you were no longer close to anyone. Perhaps you felt like you had no friends"). The low loneliness group was asked to spend 3 minutes reflecting on their close relationships (e.g. "Think of a time when you felt you had someone you could share anything with. Perhaps this was a person who was or who could be your best friend"). The loneliness induction task produced a significant group difference in state loneliness, as expected. After the loneliness induction task or the control task, participants were asked to engage in a

capitalization interaction task, in which they described recent positive events for ten minutes with an interaction partner. The study found that participants in the high loneliness group perceived their social interactions with others as less positive and less enjoyable, and reported their interaction partner as less responsive, relative to participants in the low loneliness group.

This association between loneliness and the quality of social interactions found in this study (Arpin & Mohr, 2019) is important since the quality of social interactions has also been found to be associated with blood pressure (Brondolo et al., 2003; Cornelius, Birk, Edmondson, & Schwartz, 2018). Brondolo et al. (2003) measured 104 healthy adults' ambulatory blood pressure with electronic devices and their reported social interactions within a paper diary every 20 minutes for 1 day. They found that both the intensity of positive social interaction (i.e., mean ratings of three items— "pleasant," "friendly," and "agreeable") and negative social interactions (i.e., mean ratings of five items— "uncomfortable," "tense," "confrontational," "openly angry," or "about something upsetting") was significantly positively associated with the magnitude of the momentary increase in blood pressure (Brondolo et.al, 2003). Another study, which used ecological momentary assessment to measure the quality of social interactions, found that greater average positivity of social interactions also predicts lower average blood pressure in 805 healthy adults (Cornelius et. al, 2018). Moreover, in 135 undergraduate students, Hawkley et al. (2003) found that higher positivity of social interactions as measured by an ambulatory diary was associated with lower total peripheral resistance (TPR) as measured by ambulatory blood pressure and impedance monitor (an ambulatory impedance cardiography unit).

Despite evidence linking loneliness to quality of social interactions and quality of social interactions to blood pressure, from our knowledge, no study to date has directly examined quality of social interaction as a mediator of the association between loneliness and blood pressure.

Therefore, one of the contributions of this study would be its examination of this possible mediation effect.

1.3 Sleep as a Possible Mechanism

A second possible mechanism that might explain the association between loneliness and blood pressure is fragmented sleep. We will now consider the evidence available linking loneliness and sleep. Loneliness has been found to be associated with impaired sleep (Cacioppo, Hawkley, Berntson, et al., 2002; Hawkley, Preacher, & Cacioppo, 2010; Jacobs, Cohen, Hammerman-Rozenberg, & Stessman, 2006; Kurina et al., 2011). For example, Cacioppo, Hawkley, Berntson, et al. (2002) examined the link between loneliness and sleep in 64 healthy college students. Based on their scores on the UCLA Loneliness Scale-Revised, participants were divided into 3 groups: a lonely group (total score≥46), a middling group (33< total score< 39), and a nonlonely group (total score<28). The study used a Nightcap (an electronic device measuring sleep by detecting eye movements and head movements) to assess all participants' sleep efficiency, sleep duration, and wake time after onset in both controlled laboratory conditions and home settings. The study found that the lonely group, compared with the nonlonely group, showed lower sleep efficiency and more time awake after sleep onset. This association was observed in both laboratory conditions and home settings and was independent of sleep duration, depressive symptoms, and other risk factors (Cacioppo, Hawkley, Berntson, et al., 2002). Kurina et al. (2011) further investigated the association between loneliness and sleep in 95 adults (M_{age} = 39.8, range: 19-84, 55% female) who lived in South Dakota. The study used wrist actigraphy to measure participants' sleep duration and sleep fragmentation for seven days. In this study, sleep fragmentation was defined as the sum of

the percentage of the sleep period spent moving and the percentage of the number of one-minute long immobile phases. The Pittsburgh Sleep Quality index (PSQI) was also used to measure the subjective sleep quality of participants. The study found that elevated loneliness was significantly associated with higher levels of sleep fragmentation after adjusting for demographic covariates, psychosocial factors and health conditions. But loneliness was not significantly linked to objective sleep duration or subjective sleep quality.

Findings on the association between loneliness and sleep are important, given that sleep deprivation has also been shown to be associated with elevated blood pressure. Palagini et al. (2013) conducted a systematic review to investigate the relationship between sleep deprivation and blood pressure. Their results indicated that different types of experimental sleep deprivation (first part of the night, second half of the night, full night, for 36 hours, and for 40 hours) predicted acute increase in blood pressure. For example, Lusardi et al. (1996) studied 18 healthy adults' blood pressure in a day of full night sleep and in a day of partial sleep deprivation (first part of the night). They found that participants' blood pressure in the day of partial sleep deprivation was significantly higher compared to their blood pressure in the day of full night sleep. In addition, the review (Palagini et al., 2013) also found strong evidence supporting the longitudinal association between persistent insomnia (defined as difficulties falling asleep and maintaining sleep for more than 1 year) and hypertension. For example, in a longitudinal study, Suka et al. (2003) examined whether persistent insomnia is a predictor of the development of hypertension in Japanese middle-aged male over a 4-year period. They found that participants who reported persistent difficulty initiating sleep (DIS) or difficulty maintaining sleep (DMS) were at higher risk of developing hypertension than participants who had never reported DIS or DMS, even after controlling for risk factors including age, body mass index, smoking, alcohol drinking, and job stress.

Based on these associations, it is reasonable to propose that disturbed sleep might be a possible mechanism linking loneliness and increased blood pressure. Following this line of reasoning, one study examined sleep as a possible mediator between loneliness and cardiovascular impairment (Christiansen, Larsen, & Lasgaard, 2016). This study included a large sample of older adults and used self-reported questionnaires to measure loneliness, sleep, and cardiovascular disease. In the study, cross-sectional multiple mediation analyses were conducted to determine if sleep mediates the association between loneliness and cardiovascular disease. The results showed a significant indirect effect. However, this study measured sleep quality, sleep duration, and even cardiovascular disease with subjective measures. Several studies have shown that subjective assessments of sleep duration and efficiency are not strongly associated with more objective assessments (Sadeh, 2011; Werner, Griffin, & Galovski, 2016). To further investigate whether sleep is a mechanism between loneliness and increased blood pressure, the current study used both objective and subjective measures of sleep duration and sleep efficiency and objective measures of blood pressure as well.

1.4 Current Study

The current study aimed at examining whether quality of social interactions explains the link between loneliness and increased blood pressure in a sample of 391 middle-aged and older adults, with both social interaction and ambulatory blood pressure measured by ecological momentary assessment (EMA) over the course of a week. EMA is a data collection method that enables us to assess participants' behaviors, experiences, and moods in real time and in real-world settings. The study also aimed to investigate whether differences in objectively measured total

sleep time, sleep efficiency, and subjectively measured sleep quality may explain the link between loneliness and increased blood pressure. Participants were asked to wear a wrist actigraphy device measuring their sleep patterns over the course of a week and to report their sleep quality using the Pittsburgh Sleep Quality Index. On each of 4 intensive monitoring days, ambulatory blood pressure was collected on an hourly basis, along with an hourly electronic diary assessing recent mood, activities, and social interactions. Data collected in the study were averaged across observations for each participant. Based on the existing evidence, we hypothesized that:

1. Higher loneliness scores, as measured by the UCLA Loneliness Scale-Revised, would be associated with higher average ambulatory blood pressure.
2. Higher loneliness scores and higher average ambulatory blood pressure would be associated with lower average ratings of positive social interactions and higher average ratings of negative social interactions. Negative social interactions were hypothesized to explain any observed links between loneliness and increased blood pressure.
3. Higher loneliness scores and higher average ambulatory blood pressure would be associated with lower average levels of total sleep time and sleep efficiency (as measured objectively by actigraphy), and with lower self-reported sleep quality (as measured subjectively by Pittsburgh Sleep Quality Index). Impaired sleep, in turn, was hypothesized to explain any observed links between loneliness and increased blood pressure.

2.0 Method

2.1 Participants

The data in the present study were obtained from the Study of Health and Interactions in the Natural Environment (SHINE). The sample involves 391 healthy adults between the ages of 40 and 64 years in Pittsburgh, PA. The study excluded a) those diagnosed with chronic physical illness, such as cardiovascular disease, cancer, diabetes, b) those on medications that have an effect on cardiovascular, HPA axis, metabolic system, and immune system, and c) those with resting blood pressure ≥180/110 mmHg. The study also excluded participants with health habits and life conditions that were expected to have an adverse effect on their participation in this study, such as excessive alcohol consumption (≥ 5 portions, ≥ 3 times per week), recent recreational drug use, severe mental health problems (schizophrenia or bipolar disorder), less than 8^{th} grade reading skills, permanent neurological deficit, and current pregnancy. Individuals with shift work were also excluded, because shift work has an impact on ambulatory blood pressure and sleep (Motohashi et al., 1998; Ohira et al., 2000; Yamasaki et al., 1998). Participants were paid $400 for their participation.

2.2 Procedure

Following informed consent, participants attended 4 lab visits. In the first visit, screening procedures, including rest blood pressure, a history interview, and a self-report health behavior

assessment were conducted. In the second visit, participants' social network characteristics were measured. In the third visit, participants were trained to use an ambulatory blood pressure monitor (Accutracker Oscar oscillometric monitor), an electronic diary, and actigraphy. In between the third visit and fourth visit, ambulatory monitoring data were collected over a 7 day-period. Within the period, participants were fully monitored for 4 days. On each of the 4 Full Monitoring Days, ambulatory blood pressure was collected hourly with each assessment followed by an Electronic Diary interview measuring recent mood, activities, and social interactions. During the whole monitoring period, participants were asked to wear a wrist actigraphy device measuring their nightly sleep circumstances, including total sleep time and sleep efficiency. Participants were also asked to wear an arm band (SenseWear multichannel accelerometry device) to measure their physical activity (not reported in this paper). In the fourth visit, participants returned the devices and were debriefed on their participation.

2.3 Measures

2.3.1 Demographic Assessments and Health Behaviors

Participants provided information about their age, sex, race, ethnicity, socioeconomic status (income, education, and occupation), marital status, and household composition (the number of people or pets that the participant lives with).

Participants also indicated their physical activity, alcohol consumption, smoking status and history, and dietary habits. Participants' height, weight, and waist circumference were measured in the lab. For all statistical analyses, we adjusted for age, sex, race (White/non-White), and

education (high school or lower degree, some college, college degree, and advanced degree) (Appendix A).

2.3.2 Ambulatory Blood Pressure (ABP) Assessments

ABP measures were collected on an hourly basis on each of the four Full Monitoring Days. An Accutracker Oscar oscillometric monitor (Goodwin et al., 2007; Jones et al.2004) was used to obtain hourly systolic and diastolic blood pressure readings from the non-dominant arm. ABP data collected in the study was averaged across observations for each participant. To reduce skewness, we applied log transformation to ABP data. One outlier, which had average ambulatory DBP more than 3 standard deviations above the study mean after log transformation, was winsorized (set equal to a value 3 SDs from the mean—4.1).

2.3.3 Loneliness

Loneliness was assessed using the UCLA Loneliness Scale-Revised (UCLA-R) (Russell, 1996) in the fourth visit. Several studies have shown that the UCLA-R possesses good construct validity when used as a measure of trait loneliness (Russell, Peplau, & Cutrona, 1980; Cramer & Barry, 1999). The UCLA-R contains 20 items and each of the items is rated on a scale of 1 (never), 2 (rarely), 3 (sometimes), and 4 (always). Examples of the items are, “I feel alone” and “I feel outgoing and friendly” (Russell, 1996). After reverse scoring corresponding items, loneliness scores were calculated as the sum of all items. Higher scores indicate greater loneliness. To reduce skewness, we applied log transformation to loneliness scores (Appendix B).

2.3.4 Social Interactions

In the hourly Electronic Diary, one item assessed if the participants were in a social interaction at the time of cuff inflation, and another asked when the participants' most recent social interaction had ended. The following items required participants to rate the quality of their most social interaction, with each item rated on a scale from 0 (no) to 10 (yes). Three items described positive social interactions ("Most recent interaction-Pleasant interaction?" "Agreeable interaction?" and "Friendly interaction?"). The mean ratings across these three items were averaged across observations for each participant, serving as the positive social interaction score. Three items described negative social interactions ("Most recent interaction- Someone was insensitive to you?" "Someone made you tense?" "Someone interfered with your efforts?") (Appendix C). The mean ratings across these three items were averaged across observations for each participant, serving as the negative social interaction score. The statistical analyses only included observations pertaining to social interactions which had occurred in the 10 minutes before assessment. Subjects who had fewer than 5 valid observations that met this 10-minute criterion were excluded from relevant analyses. To reduce skewness, we applied log transformation to both positive social interaction scores and negative social interaction scores.

2.3.5 Sleep Measured by Actigraphy

The study measured sleep objectively using Actigraphy. Participants were asked to wear an Actiwatch (Philips Respironics, Eindhoven, The Netherlands) on the wrist 24-hours a day across the 7 day-period. Data collected by the Actiwatch was scored with Actiware software (v.5.59) using automated algorithms. The data were stored in 1-minute epochs. Wake threshold

was set at 40 activity counts per epoch. Sleep onset was defined as a period lasting at least 10 consecutive minutes with activity counts < 40 per epoch. Wake onset was defined as a period of at least 10 consecutive minutes of ≥ 40 activity counts per epoch. Total sleep time (TST) was the total number of minutes scored as sleep by the algorithms between sleep onset and wake onset (i.e., excluding minutes that meet the wake threshold). Sleep efficiency (SE) was the percentage of total sleep time from the beginning of sleep onset until wake onset. Actigraphy-assessed sleep data were cleaned according to the following procedures: a) we checked the Actigraphy report for every observation with Total Sleep Time ≥ 600 mints, Total Sleep Time ≤ 180 mints, or Sleep Efficiency ≥ 97%; b) based on these Actiprahy reports, we excluded all observations during which it was apparent that participants took off their Actiwatch at night; c) we excluded subjects who had fewer than 5 nights of sleep observations. Cleaned Actigraphy data were averaged across available nights for each participant.

2.3.6 Sleep Measured by Pittsburgh Sleep Quality Index

Participants' self-reported sleep quality was also measured by the Pittsburgh Sleep Quality Index (PSQI; Buysse, Reynolds, Monk, Berman, & Kupfer, 1989) in the second visit. General sleep quality was based on the total PSQI score (ranges from 0 to 21), which captures sleep duration, disturbance, latency, efficiency, quality, daytime dysfunction and the use of sleep medications. A total PSQI score ≤ 5 indicates good sleep quality. Higher PSQI scores are associated with poor sleep quality (Appendix D). Studies have shown that the PSQI processes good construct validity, test-retest reliability (r = .85), and high internal consistency (α = .83) when used as a measure of sleep quality and disturbance over the past month (Carpenter & Andrykowski, 1998; Backhaus, Junghanns, Broocks, Riemann, & Hohagen).

2.4 Data Analyses

In order to test our hypotheses, multiple linear regressions were performed in SAS (SAS Institute Inc., 2013), with adjustments for age, sex, race, and education. We tested mediation in this sample using a product of coefficients method, where the indirect effect of loneliness through the quality of social interactions (or sleep) was expressed as the cross-product of 2 coefficients, one linking the explanatory variable and the mediator ("a" path), and the other linking the mediator and the dependent variable ("b" path), and this cross-product term was tested for significance using bootstrapping methods. Tests of indirect effects were only performed for variables in which the a-path and b-path were both significant or marginally significant. The bootstrapping methods are resampling methods with replacement. We used the methods to generate a sampling distribution of the indirect effect of loneliness through the quality of social interactions (or sleep) and derive confidence intervals from the distribution. The reiteration rate of sampling was set to 10,000 times (see Figure 1 and Figure 2).

Please note that due to the current circumstance of COVID-19, I did not have access to the data to perform some exploratory analyses to which I will make reference below.

3.0 Results

3.1 Sample Characteristics

Of the total sample of 391 participants, one individual was excluded for having fewer than five ambulatory blood pressure observations. As a result, the total sample used for data analyses here contained 390 participants. The average age for the total sample was 52.63 years (*SD* = 7.12). Participants were mostly female (61.3%), White (77.4%) and post-bachelors (63.6%). For relevant analyses, we removed 2 subjects who had fewer than 5 observations of social interactions, 4 subjects who had missing UCLA-R data, 29 subjects who had fewer than 5 nights of sleep monitoring or invalid sleep data, and 10 subjects with missing PSQI data. As a result, different sample sizes were available for different analyses. (see Table 1).

The Mean UCLA-R score of the current sample is 35.55 (*SD* =9.92, *N* = 386), which is comparable to the mean and standard deviations of the Chicago Health, Aging, and Social Relations Study (CHASRS) (*M* = 36.0 (*SD* = 9.8), *N* = 299, 52.4% Female, *Mage* = 57.5 (*SD* = 4.4)) (Hawkley, Masi, Berry, & Cacioppo, 2006). A meta-analysis on the UCLA Loneliness Scale has found that, in older adults, women are more likely to report loneliness compared to men (Pinquart, M., & Sörensen, S., 2001). An independent-samples t-test was conducted to compare loneliness scores across genders with the current sample. Contrary to previous findings, loneliness scores for male subjects (*M* = 37.91, *SD* = 10.79) were significantly greater than that for female subjects (*M* = 34.05, *SD* = 9.04; *t* (276.65) = 3.64, $p < .001$). The average ABP of participants was 138.21 mmHg (*SD* = 17.32) for systolic BP and 82.00 mmHg (*SD* = 10.56) for diastolic BP. As mentioned earlier, the current study excluded individuals diagnosed with chronic physical illness,

individuals on medications that have an effect on cardiovascular system, and individuals with resting blood pressure ≥180/110 mmHg. The mean positive social interaction score was 7.40 (*SD* = 1.12, range: 0-10, *N* = 388) and the mean negative social interaction score was 1.09 (*SD* = 1.05, range: 0-10, *N* = 388).

The mean total sleep time of participants in this sample, as measured by Actigraphy, was 374.13 (*SD* = 52.48, *N* = 361), which was similar to the finding of a previous study (AHAB-II) using the same method measuring total sleep time in older adults (*M* = 356.8 (*SD* = 52.85), *N* = 480, 53.6% Female, mean age = 42.8 (*SD* = 7.3)) (Peterson et al., 2017). The mean sleep efficiency of participants measured by Actiwatch was 85.03% (*SD* = 4.94, *N* = 361), which was similar to the finding of a previous study (*M* = 84.11% (*SD* = 8.72), *N* = 26, 57% Female, mean age = 71.42 (*SD* = 2.0)) (Cochrane, A., Robertson, I. H., & Coogan, A. N., 2012). The mean PSQI score of the current sample was 4.87 (*SD* = 2.60, *N* = 380), which was similar to the mean PSQI score of older adults in the AHAB-II study (*M* = 5.0, *SD* = 2.68) (Peterson et al., 2017).

3.2 Loneliness and Blood Pressure

Both average ambulatory SBP and average ambulatory DBP were significantly associated with age, sex, race and education, with older individuals, men, nonwhites, and less educated individuals having higher average SBP and DBP. Contrary to our prediction, regression analyses showed that loneliness was not a significant predictor of either average ambulatory SBP (*b* = -0.00051, *F* = 0.00, *p* = .982) or average ambulatory DBP (*b* = 0.01493, *F* = 0.43, *p* = .513), in the models adjusting for age, sex, race, and education.

3.3 Potential Mediators between Loneliness and Blood Pressure

Even though there were no significant associations between loneliness and blood pressure, we examined associations between loneliness and our hypothesized mediators.

3.3.1 Social Interactions

As predicted, in the model controlling for age, sex, race and education, higher loneliness scores were associated with lower average ratings of positive social interactions (b = -0.13854, F = 27.53, p < .001) and higher average ratings of negative social interactions (b = 0.38390, F = 21.37, p < .001). Moreover, after adjusting for age, sex, race, education, and loneliness, lower average ratings of positive social interactions showed a marginally significant association with higher average ambulatory SBP as predicted (b = -0.078519, F = 3.35, p = .068), but not with average ambulatory DBP (b = -0.07092, F = 2.53, p = .112). Tests of indirect effects showed no significant indirect effects of loneliness on average ambulatory SBP through positive social interactions (ab = 0.01088, *95% CI*: -0.00135, 0.02310, p = .081). A reverse pattern was found with negative social interactions. In the adjusted model, higher average ratings of negative social interactions showed a marginally significant association with higher ambulatory DBP (b = 0.02599, F = 3.37, p = .067), but not with average ambulatory SBP (b = 0.02038, F = 2.23, p = .137). There was no evidence for significant indirect effects of loneliness on average ambulatory DBP through negative social interactions (ab = 0.00998, *95% CI*: -0.00137, 0.02133, p = .085).

3.3.2 Sleep Measured by Actigraphy

Loneliness scores were not associated with total sleep time (b = 1.79562, F = 0.03, p = .863) or sleep efficiency (b = -0.48592, F = 0.26, p = .614). Moreover, total sleep time was not associated with either average ambulatory SBP (b = -0.00013, F = 1.25, p = .264) or average ambulatory DBP (b = -0.00009, F = 0.61, p = .436). Sleep efficiency was also not related to either average ambulatory SBP (b = -0.00013, F = 0.49, p = .482) or average ambulatory DBP (b = -0.00072, F = 0.40, p = .577).

3.3.3 Sleep Measured by PSQI

As predicted, higher loneliness scores were significantly associated with higher total PSQI scores (b = 2.11213, F = 18.37, p < .001), where lonely individuals had poorer self-reported sleep quality. However, total PSQI scores were not associated with either average ambulatory SBP (b = -0.00089, F = 1.60, p = .482) or average ambulatory DBP (b = 0.00144, F = 0.34, p = .558).

4.0 Discussion

As outlined previously, the current study aimed at examining whether the quality of social interactions and sleep account for the association between loneliness and increased blood pressure. The current study did not find an association between loneliness and averaged ambulatory blood pressure (ABP). The results of the current study, however, did show that higher loneliness was significantly associated with lower social interaction positivity and with higher social interaction negativity, as expected. The current study found a marginally significant association between social interaction positivity and ambulatory systolic blood pressure, with lower social interaction positivity being associated with higher ambulatory systolic blood pressure. The results also suggested a marginally significant association between social interaction negativity and ambulatory diastolic blood pressure, with higher social interaction negativity being associated with higher ambulatory diastolic blood pressure. As suggested by the results, there was no evidence for an indirect effect of loneliness on ABP through either social interaction positivity or social interaction negativity. As for sleep, the results showed that higher loneliness was associated with lower self-reported sleep quality. However, self-reported sleep quality was not related was not related to ABP in this sample, and neither loneliness nor ABP were related to Actigraphy-assessed sleep.

The current study involved a relatively large sample of middle-aged and older adults. The distribution of age, sex, ABP, loneliness, social interaction quality, objective sleep measurements, and subjective sleep quality were all within the expected range compared to previous studies. As the descriptive statistics suggested, however, the sample was not representative of the local population with respect to race (most were White) and education (most had a bachelor's degree).

Moreover, as mentioned earlier, in this sample, males had higher loneliness scores than females, a finding that is in contrast with results from a previous meta-analysis on this subject (Pinquart, M., & Sörensen, S., 2001). This difference in sample characteristics may suggest some biases with respect to the types of participants that were enrolled in this study; it is possible that among males, those who were more lonely were more likely to participate whereas, among females, this may not have been the case.

4.1 Loneliness and Blood Pressure

Our hypothesized association between loneliness and blood pressure was based on the findings of previous studies that loneliness was linked to both heightened total peripheral resistance in young adults and increased blood pressure in older adults (Cacioppo, Hawkley, Crawford, et al., 2002; Hawkley, Burleson, Berntson, & Cacioppo, 2003; Hawkley, Masi, Berry, & Cacioppo, 2006; Hawkley, Thisted, Masi, & Cacioppo, 2010). As mentioned earlier, two of these studies provided cross-sectional and longitudinal evidence for the association between loneliness and increased blood pressure respectively (Hawkley, Masi, Berry, & Cacioppo, 2006; Hawkley, Thisted, Masi, & Cacioppo, 2010). Both of these previous analyses utilized the Chicago Health, Aging, and Social Relations Study (CHASRS)—a sample of 229 middle-aged and older adults from Cook County, Illinois. (Hawkley, Masi, Berry, & Cacioppo, 2006; Hawkley, Thisted, Masi, & Cacioppo, 2010). The findings of this one sample have been cited by a number of reviews (e.g., Cacioppo & Cacioppo, 2014; Colonnello et al., 2017; Valtorta et al., 2016) and have been used as the foundation for studies aimed at explaining this association (Christiansen, Larsen, & Lasgaard, 2016; Hawkley and Capitanio, 2015).

However, our study was not the first study that was not able to replicate the association between loneliness and blood pressure. Contradictory results have also been found in other studies (Shankar et al., 2011; Das, A., 2019). Two studies, based on data from the U.S. HRS and the English ELSA (two nationally representative longitudinal studies with more than 3000 older adults), found no significant association between loneliness and blood pressure. However, methodological concerns can also be raised about these two studies, since both HRS and ELSA used a Three-Item Loneliness Scale instead of the standard UCLA Loneliness Scale-Revised. As one study suggested (Hughes, Waite, Hawkley, & Cacioppo, 2004), the alpha coefficient of reliability for the Three-Item Loneliness Scale was 0.72, which was lower than the alpha coefficient of reliability for the standard UCLA Loneliness Scale-Revised ($\alpha = 0.91$). Therefore, even though the two studies included large representative samples, they might still have reduced power to detect this effect.

The current study, which was based on a large community sample, used the complete UCLA Loneliness Scale-Revised, and measured blood pressure in ambulatory settings. The findings here aligned with Das and Shankar et al to suggest that loneliness may not be reliably linked with blood pressure in middle aged and older adults. These consistent null results repeated across the different populations in diverse contexts and with more valid assessment tools cast doubt on the apparent consensus linking loneliness with blood pressure from the previous literature.

While the current study calls previous results into question, it is also possible that the failure to replicate here may be due to the unusual characteristics of this sample. In particular, gender differences involving loneliness were reversed relative to other studies. In addition, participants in the current study were mostly White and post-bachelor, while participants in the CHASRS sample had more diverse racial and educational backgrounds. Therefore, we cannot rule out the possibility

that loneliness may be associated with blood pressure in samples that are more similar to the wider population.

Moreover, as mentioned earlier, previous studies (Cacioppo, Hawkley, Crawford, et al., 2002; Hawkley, Masi, Berry, & Cacioppo, 2006) found that age significantly moderated loneliness's association with blood pressure, which suggested that the link between loneliness and blood pressure was more pronounced as people got older. Participants in the current study (mean age = 52.63, *SE* = 7.1, range: 40-64) were relatively younger than participants in the CHASRS (mean age = 57.5, *SE* = 4.4, range: 50-68). Having middle-aged adults in our sample may have reduced our power to detect the association between loneliness and blood pressure.

4.2 Loneliness and Social Interaction Quality

According to the loneliness model proposed by Hawkley and Cacioppo (2016), lonely individuals tend to be more attentive to negative social interactions, having more negative social expectations and holding more negative social memory than nonlonely individuals. Following the loneliness model, we hypothesized that these maladaptive social interactions would explain links between loneliness and increased blood pressure. The current study provides evidence to support this loneliness model, even though blood pressure findings were not in line with our hypotheses. Data from our sample suggest that lonely individuals rate their social interactions less positively and more negatively than their less lonely counterparts. Despite the present findings, the loneliness model warrants further investigation and clarification. For example, one study (Gardner, Pickett, Jefferis, & Knowles, 2005) found that lonely individuals remembered both more positive and more negative social events than their nonlonely peers. This finding suggested that loneliness is related

to heightened attention and memory, not only to negative social events but to positive social events as well. Why do lonely individuals have both more positive and negative social memory while rating their recent social interactions as less positive and more negative? This is a question that should be further investigated.

4.3 Social Interaction Quality and Blood Pressure

The current study found a marginally significant effect of social interaction negativity on increased diastolic blood pressure, which was consistent with the findings of Brondolo et al. (2003) that the intensity of negative social interactions was significantly positively associated with blood pressure. Moreover, the current study also found a marginally significant effect of social interaction positivity on decreased systolic blood pressure, which was consistent with the findings of Cornelius et al. (2018) and Hawkley et al. (2003) but contradictory to the findings of Brondolo et al. (2003). Brondolo et al. (2003) found that the intensity of positive social interactions was significantly positively associated with blood pressure. Inconsistent conceptualizations and measurements of social interaction quality in different studies may be the reason for these inconsistent results. In Cornelius et al. (2018), the quality of social interaction was measured using a single item—pleasantness. In Hawkley et al. (2003), the positivity of social interaction was conceptualized as the mean ratings of 8 positive adjectives (comfortable, intimate, involved, sharing, uninhibited, supported, affectionate, understood), and negativity of social interaction was conceptualized as the mean ratings of 8 negative adjectives (cautious, disconnected, conflicted, closed off, distant, phony, dishonest, distrustful). In the paper of Brondolo et al. (2003), the intensity of positive social interaction was measured as mean ratings of three items (pleasant,

friendly, and agreeable) and the intensity of negative social interactions was measured as mean ratings of five items (uncomfortable, tense, confrontational, openly angry, and about something upsetting). To better study the relationship between social interaction quality and blood pressure, studies in this area should develop a consensus on measurement of social interaction quality, as different facets of social interaction quality may be related to blood pressure in different ways.

4.4 Loneliness and Sleep

The current study was the first to examine the relationship between loneliness and sleep in a population of middle-aged and older adults. The findings of the current study suggested that loneliness is only associated with subjective sleep quality (measured by PSQI), but not with objective total sleep time or sleep efficiency (measured by actigraphy) in middle-aged and older adults. These findings are inconsistent with the findings of previous studies. As mentioned earlier, a previous study in a sample of young adults (Cacioppo, Hawkley, Bernston, et al., 2002) found that lonely participants showed lower sleep efficiency (measured by Nightcap—a devise measuring eyelid and body movement) than nonlonely participants. Differences in methods may be a reason the present study fails to replicate previous findings. For instance, the previous study (Cacioppo, Hawkley, Bernston, et al., 2002) (a) used a sample of undergraduate students (b) recruited participants from the upper, middle, or lower quintile on the UCLA-R Loneliness Scale and divided them into 3 groups (c) used Nightcap to assess sleep. Different findings on self-reported sleep quality may also be attributed to methodological differences. The study of Kurina et al. (2011), which did not find a significant association between loneliness and subjective sleep quality, had a smaller sample size (N = 95) and younger participants (M = 39.8).

4.5 Limitations and Future Directions

Although we included participants from diverse racial groups and educational backgrounds, the majority of the participants in the SHINE sample were White (77.4%) and well-educated (63.6% bachelors or above). Therefore, the findings of the current study may not apply to the general population. Future studies should study loneliness, social interaction, sleep, and blood pressure in more diverse samples. For example, future studies can recruit people from different age/racial/socioeconomic groups and examine loneliness's effect on blood pressure, social interaction quality, and sleep across different groups. As mentioned earlier, one demographical variable—age was found to moderate the association between loneliness and blood pressure in previous literature (Cacioppo, Hawkley, Crawford, et al., 2002; Hawkley, Masi, Berry, & Cacioppo, 2006). It is possible that the association between loneliness and blood pressure is strong only among some demographical groups, such as older adults, minorities, and less educated individuals. Due to the special situation of COVID-19, we did not have access to data to perform relevant moderation analyses. Future analyses and studies should look at this possible moderation effect of demographical factors, such as age, gender, race, and education, on the relationship between loneliness and blood pressure.

In further analyses, we should also look at whether differences in the circumstances associated with measurement were responsible for different results. Previous studies (Hawkley, Masi, Berry, & Cacioppo, 2006; Hawkley, Thisted, Masi, & Cacioppo, 2010), which found significant associations between loneliness and blood pressure, measured clinical blood pressure in laboratory settings. In comparison, the current study was focused on ambulatory blood pressure. When the data are available, additional analyses should be performed to investigate whether loneliness is associated with increased clinic blood pressure in SHINE.

Furthermore, it is important to be aware that the current study was cross-sectional. Therefore, we cannot make any causal inference with our current findings. Future studies should investigate the relationship between loneliness, social interaction, sleep, and blood pressure with longitudinal and experimental designs.

As mentioned before, the previous study, which found a negative association between loneliness and objectively measured sleep efficiency, recruited participants from upper, middle, and lower quintile on the UCLA-R Loneliness Scale (Cacioppo, Hawkley, Berntson, et al., 2002). It is possible that the association between loneliness and sleep efficiency is quadratic instead of linear, with highly lonely individuals having extremely low sleep efficiency. Additional analyses should be performed to test this possibility by including quadratic terms into the statistical model.

4.6 Conclusion

In general, results from the current study suggested that loneliness was not associated with blood pressure in mid-aged and older adults. Likewise, loneliness was not related to Actigraphy-assessed sleep (total sleep time and sleep efficiency). However, loneliness was significantly related to a number of subjective measurements (quality of social interactions and sleep quality). Loneliness predicted lower social interaction positivity, higher social interaction negativity, and lower self-reported sleep quality among participants in daily life. Moreover, we also found a pattern in which lower social interaction positivity and higher social interaction negativity were linked to higher average ambulatory blood pressure, albeit in a manner that was not statistically significant. The current study fails to replicate the association between loneliness and blood pressure found by previous research, but this null finding may be attributed to the limited sampling

distribution of the current study. To figure out whether discrepant findings in the literature may be due to sample characteristics, future work in this area should explore moderating influences of demographic features, and recruit participants from diverse age, ethnic and socioeconomic groups. This literature could be strengthened in the future with the use of prospective study designs as well.

5.0 Figures

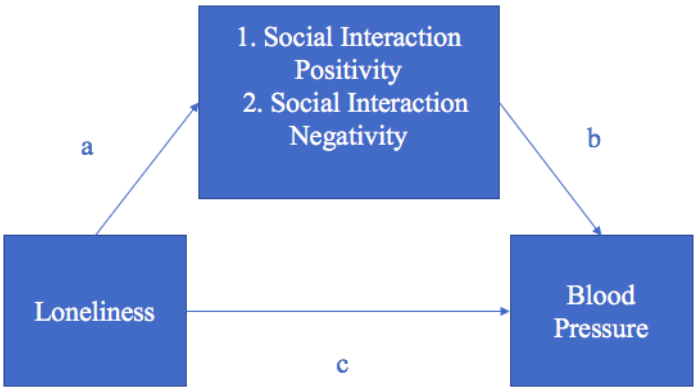

Figure 1

Model 1: In path a, loneliness is the independent variable, and social interaction positivity (or negativity) is the dependent variable. Regression analysis is performed to test their relationship, with adjustments for age, sex, race, and education. In path b, social interaction positivity (or negativity) is the independent variable, and blood pressure is the dependent variable. Regression analysis is performed to test their relationship with adjustments for age, sex, race, education, and loneliness. The indirect effect of loneliness through social interaction positivity (or negativity) is expressed as the cross-product of path a coefficient and path b coefficient. This cross-product term is tested for significance using bootstrapping methods.

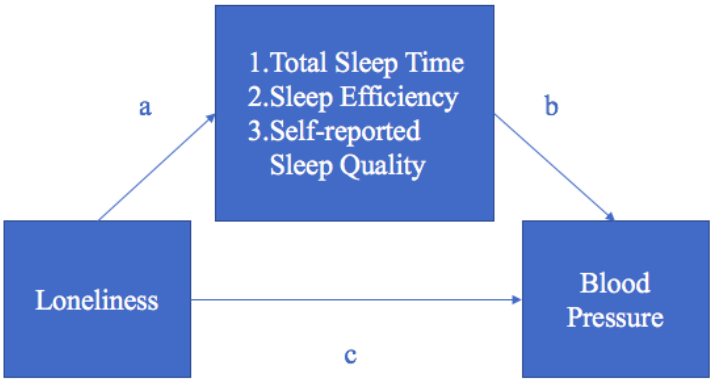

Figure 2

Model 2: In path a, loneliness is the independent variable, and sleep (total sleep time, sleep efficiency, or self-reported sleep quality) is the dependent variable. Regression analysis is performed to test their relationship, with adjustments for age, sex, race, and education. In path b, sleep (total sleep time, sleep efficiency, or self-reported sleep quality) is the independent variable, and blood pressure is the dependent variable. Regression analysis is performed to test their relationship with adjustments for age, sex, race, education, and loneliness. The indirect effect of loneliness through sleep (total sleep time, sleep efficiency, or self-reported sleep quality) is expressed as the cross-product of path a coefficient and path b coefficient. This cross-product term is tested for significance using bootstrapping methods.

6.0 Tables

Table 1 Descriptive Statistics

Characteristic	*M*	*SD*	%
Age (years)	52.63	7.12	
Sex			
Women			61.3%
Race			
White			77.4%
Education			
HS diploma or below			6.4%
Some college, no degree			30.0%
College degree			32.3%
Graduate degree			31.3%
Average Ambulatory SBP, mm Hg	138.21	17.32	
Average Ambulatory DBP, mm Hg	78.50	7.04	
Loneliness (UCLA-R; 20–80) [a]	35.55	9.92	
Positive Social Interactions Score (0-10) [b]	7.40	1.12	
Negative Social Interactions Score (0-10) [b]	1.09	1.05	
Sleep Monitor-measured: Actiwatch			
Total Sleep Time, min. [c]	374.13	52.48	
Sleep Efficiency [c]	85.03%	4.94	
Sleep self-report: PSQI (0-21) [d]	4.87	2.60	

Note. Final Sample (N = 390); SBP = systolic blood pressure; DBP = diastolic blood pressure; UCLA-R= UCLA Loneliness Scale-Revised; PSQI = Pittsburgh Sleep Quality Index.

a N = 386; b N = 388; c N = 361; d N = 380.

Table 2 Ambulatory SBP and Ambulatory DBP Regressed on Loneliness

	Ambulatory SBP			Ambulatory DBP		
Variable	B	SE	*p*	B	SE	*p*
Intercept	4.88517	0.09655	<.001***	4.39409	0.10032	<.001***
Age	0.00345	0.00082	<.001***	0.00179	0.00085	.037*
Sex	-0.07057	0.01207	<.001***	-0.07281	0.01255	<.001***
Race	0.05209	0.01419	<.001***	0.07054	0.01475	<.001***
Education	-0.01431	0.00632	<.001***	-0.01379	0.00657	.036*
Loneliness	-0.00051	0.02192	.982	0.01493	0.02278	.513
***F* (Loneliness)**		**.00**			**.43**	
Multiple R^2		**.15**			**.15**	

Note. An † indicates p < .10, an * indicates p < 0.05, an ** indicates p < .01, and an *** indicates p < .001.

Table 3 Social Interaction and Sleep Regression Results (Ambulatory SBP)

Model	B	*SE*	*p*
Positive Social Interaction			
Loneliness → PSI (a)	-0.13854	0.02640	<.001***
PSI → Ambulatory SBP (b)	-.078519	0.04289	.068†
Negative Social Interaction			
Loneliness → NSI (a)	0.38390	0.08304	<.001***
NSI → Ambulatory SBP (b)	0.02038	0.01366	0.137
Total Sleep Time			
Loneliness → TST (a)	1.79562	10.38016	.863
TST → Ambulatory SBP (b)	-0.00013	0.00011	.264
Sleep Efficiency			
Loneliness → SE (a)	-0.48592	0.96129	.614
SE → Ambulatory SBP (b)	-0.00089	0.00127	.482
Sleep Quality (PSQI)			
Loneliness → Sleep Quality (a)	2.11213	0.49278	<.001***
Sleep Quality → Ambulatory SBP (b)	0.00299	0.00236	.206

Note: Analyses included age, sex, race, and education as covariates. SBP = Systolic Blood Pressure; PSI = Positive Social Interaction Score; NSI= Negative Social Interaction Score; TST = Total Sleep Time; SE = Sleep Efficiency; PSQI = Pittsburgh Sleep Quality Index. An † indicates $p < .10$, an * indicates $p < 0.05$, an ** indicates $p < .01$, and an *** indicates $p < .001$.

Table 4 Social Interaction and Sleep Regression Results (Ambulatory DBP)

Model	*B*	*SE*	*p*
Positive Social Interaction			
Loneliness → PSI (a)	-0.13854	0.02640	<.001***
PSI → Ambulatory DBP (b)	-0.07092	0.04456	0.112
Negative Social Interaction			
Loneliness → NSI (a)	0.38390	0.08304	<.001***
NSI → Ambulatory DBP (b)	0.02599	0.01415	0.067†
Total Sleep Time			
Loneliness → TST (a)	1.79562	10.38016	.863
TST → Ambulatory DBP (b)	-0.00009	0.00012	.436
Sleep Efficiency			
Loneliness → SE (a)	-0.48592	0.96129	.614
SE → Ambulatory DBP (b)	-0.00072	0.00113	.577
Sleep Quality (PSQI)			
Loneliness → Sleep Quality (a)	2.11213	0.49278	<.001***
Sleep Quality → Ambulatory DBP (b)	0.00144	0.00246	0.558

Note: Analyses included age, sex, race, and education as covariates. DBP = Diastolic Blood Pressure; PSI = Positive Social Interaction Score; NSI= Negative Social Interaction Score; TST = Total Sleep Time; SE = Sleep Efficiency; PSQI = Pittsburgh Sleep Quality Index. An † indicates $p < .10$, an * indicates $p < 0.05$, an ** indicates $p < .01$, and an *** indicates $p < .001$.

Appendix A Demographics and Health Behavior Form

DEMOGRAPHICS AND HEALTH BEHAVIOR FORM

Please check or fill in the following items:

DEMOGRAPHICS:

1. Date of birth? (M/D/YY)

_____/_____/_____

a. Current age? _____years

2. Which best describes your race? (if bi- or multi-racial, please select more than one)

1 ( ) American Indian/Alaska Native
2 ( ) Asian
3 ( ) Native Hawaiian or Other Pacific Islander
4 ( ) Black or African American
5 ( ) White or Caucasian
6 ( ) Other, please specify _____

3. Are you of Hispanic or Latino descent?

1 ( ) Yes
2 ( ) No

4. Sex

1 ( ) Male
2 ( ) Female
3 ( ) Other (e.g., intersex, transgender, please specify _____

Appendix Figure 1 Demographics and Health Behavior Form

Appendix B UCLA Loneliness Scale-Revised

Statement	Never	Rarely	Sometimes	Often
*1. How often do you feel that you are "in tune" with the people around you?	1	2	3	4
2. How often do you feel that you lack companionship?	1	2	3	4
3. How often do you feel that there is no one you can turn to?	1	2	3	4
4 How often do you feel alone?	1	2	3	4
*5. How often do you feel part of a group of friends?	1	2	3	4
*6. How often do you feel that you have a lot in common with the people around you?	1	2	3	4
7. How often do you feel that you are no longer close to anyone?	1	2	3	4
8. How often do you feel that your interests and ideas are not shared by those around you?	1	2	3	4
*9. How often do you feel outgoing and friendly?	1	2	3	4
*10. How often do you feel close to people?	1	2	3	4
11. How often do you feel left out?	1	2	3	4
12. How often do you feel that your relationships with others are not meaningful?	1	2	3	4
13. How often do you feel that no one really knows you we11?	1	2	3	4
14. How often do you feel isolated from others?	1	2	3	4
*15. How often do you fee1 you can find companionship when you want it?	1	2	3	4
*16. How often do you feel that there are people who really understand you?	1	2	3	4
17, How often do you feel shy?	1	2	3	4
18. How often do you feel that people are around you but not with you?	1	2	3	4
*19. How often do you feel that there are people you can talk to?	1	2	3	4
*20. How often do you feel that there are people you can turn to?	1	2	3	4

Appendix Figure 2 UCLA Loneliness Scale-Revised

Appendix C Electronic Diary

CSI *At time of BP – Were you currently in a social interaction?*

- o Yes (1)
- o No (0)

(If Yes, skip to "Think about this most recent interaction…" prompt)

MRSI *When did your most recent social interaction end?*

- o 0 – 10 minutes before BP (0)
- o 11 – 60 minutes before BP (1)
- o 1-3 hours before BP (2)
- o 3+ hours before BP (3)

Appendix Figure 3 Electronic Diary Part 1

Positive Interaction

PI1 *Most recent interaction – Pleasant interaction?* *Range 0-10*

- o NO (0)
- o YES (10)

PI2 *Most recent interaction – Agreeable Interaction?* *Range 0-10*

- o NO (0)
- o YES (10)

PI3 *Most recent interaction – Friendly interaction?* *Range 0-10*

- o NO (0)
- o YES (10)

Appendix Figure 4 Electronic Diary Part 2

Social Conflict

SC1 *Most recent interaction- Someone was insensitive to you?* *Range 0-10*

- o NO (0)
- o YES (10)

SC2 *Most recent interaction- Someone made you tense?* *Range 0-10*

- o NO (0)
- o YES (10)

SC3 *Most recent interaction- Someone interfered with your efforts?* *Range 0-10*

- o NO (0)
- o YES (10)

Appendix Figure 5 Electronic Diary Part 3

Appendix D Pittsburgh Sleep Quality Index

Subject's Initials_____ID#_____Date_____Time_____AM PM

PITTSBURGH SLEEP QUALITY INDEX

INSTRUCTIONS:
The following questions relate to your usual sleep habits during the past month only. Your answers should indicate the most accurate reply for the majority of days and nights in the past month. Please answer all questions.

1. During the past month, what time have you usually gone to bed at night?

   BED TIME _____

2. During the past month, how long (in minutes) has it usually taken you to fall asleep each night?

   NUMBER OF MINUTES _____

3. During the past month, what time have you usually gotten up in the morning?

   GETTING UP TIME _____

4. During the past month, how many hours of actual sleep did you get at night? (This may be different than the number of hours you spent in bed.)

   HOURS OF SLEEP PER NIGHT _____

For each of the remaining questions, check the one best response. Please answer all questions.

5. During the past month, how often have you had trouble sleeping because you . . .

a) Cannot get to sleep within 30 minutes

Not during the past month_____	Less than once a week_____	Once or twice a week_____	Three or more times a week_____

b) Wake up in the middle of the night or early morning

Not during the past month_____	Less than once a week_____	Once or twice a week_____	Three or more times a week_____

c) Have to get up to use the bathroom

Not during the past month_____	Less than once a week_____	Once or twice a week_____	Three or more times a week_____

Appendix Figure 6 Pittsburgh Sleep Quality Index Page 1

d) Cannot breathe comfortably

Not during the past month_____ Less than once a week_____ Once or twice a week_____ Three or more times a week_____

e) Cough or snore loudly

Not during the past month_____ Less than once a week_____ Once or twice a week_____ Three or more times a week_____

f) Feel too cold

Not during the past month_____ Less than once a week_____ Once or twice a week_____ Three or more times a week_____

g) Feel too hot

Not during the past month_____ Less than once a week_____ Once or twice a week_____ Three or more times a week_____

h) Had bad dreams

Not during the past month_____ Less than once a week_____ Once or twice a week_____ Three or more times a week_____

i) Have pain

Not during the past month_____ Less than once a week_____ Once or twice a week_____ Three or more times a week_____

j) Other reason(s), please describe_____

_____

How often during the past month have you had trouble sleeping because of this?

Not during the past month_____ Less than once a week_____ Once or twice a week_____ Three or more times a week_____

6. During the past month, how would you rate your sleep quality overall?

Very good _____

Fairly good _____

Fairly bad _____

Very bad _____

Appendix Figure 7 Pittsburgh Sleep Quality Index Page 2

7. During the past month, how often have you taken medicine to help you sleep (prescribed or "over the counter")?

Not during the past month_____	Less than once a week_____	Once or twice a week_____	Three or more times a week_____

8. During the past month, how often have you had trouble staying awake while driving, eating meals, or engaging in social activity?

Not during the past month_____	Less than once a week_____	Once or twice a week_____	Three or more times a week_____

9. During the past month, how much of a problem has it been for you to keep up enough enthusiasm to get things done?

No problem at all _____

Only a very slight problem _____

Somewhat of a problem _____

A very big problem _____

10. Do you have a bed partner or room mate?

No bed partner or room mate _____

Partner/room mate in other room _____

Partner in same room, but not same bed _____

Partner in same bed _____

If you have a room mate or bed partner, ask him/her how often in the past month you have had . . .

a) Loud snoring

Not during the past month_____	Less than once a week_____	Once or twice a week_____	Three or more times a week_____

b) Long pauses between breaths while asleep

Not during the past month_____	Less than once a week_____	Once or twice a week_____	Three or more times a week_____

c) Legs twitching or jerking while you sleep

Not during the past month_____	Less than once a week_____	Once or twice a week_____	Three or more times a week_____

Appendix Figure 8 Pittsburgh Sleep Quality Index Page 3

d) Episodes of disorientation or confusion during sleep

Not during the past month_____ Less than once a week_____ Once or twice a week_____ Three or more times a week_____

e) Other restlessness while you sleep; please describe_____

_____

Not during the past month_____ Less than once a week_____ Once or twice a week_____ Three or more times a week_____

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Appendix Figure 9 Pittsburgh Sleep Quality Index Page 4

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