Loneliness and Health: Potential Mechanisms

JOHN T. CACIOPPO, PHD, LOUISE C. HAWKLEY, MA, L. ELIZABETH CRAWFORD, PHD, JOHN M. ERNST, PHD, MARY H. BURLESON, PHD, RAY B. KOWALEWSKI, MA, WILLIAM B. MALARKEY, MD, EVE VAN CAUTER, PHD, AND GARY G. BERNTSON PHD

Objective: Two studies using cross-sectional designs explored four possible mechanisms by which loneliness may have deleterious effects on health: health behaviors, cardiovascular activation, cortisol levels, and sleep. **Methods:** In Study 1, we assessed autonomic activity, salivary cortisol levels, sleep quality, and health behaviors in 89 undergraduate students selected based on pretests to be among the top or bottom quintile in feelings of loneliness. In Study 2, we assessed blood pressure, heart rate, salivary cortisol levels, sleep quality, and health behaviors in 25 older adults whose loneliness was assessed at the time of testing at their residence. **Results:** Total peripheral resistance was higher in lonely than nonlonely participants, whereas cardiac contractility, heart rate, and cardiac output were higher in nonlonely than lonely participants. Lonely individuals also reported poorer sleep than nonlonely individuals. Study 2 indicated greater age-related increases in blood pressure and poorer sleep quality in lonely than nonlonely older adults. Mean salivary cortisol levels and health behaviors did not differ between groups in either study. **Conclusions:** Results point to two potentially orthogonal predisease mechanisms that warrant special attention: cardiovascular activation and sleep dysfunction. Health behavior and cortisol regulation, however, may require more sensitive measures and large sample sizes to discern their roles in loneliness and health.
Key words: loneliness, cardiovascular activation, blood pressure, cortisol, aging.

DBP = diastolic blood pressure; SBP = systolic blood pressure; HR = heart rate; PEP = preejection period; CO = cardiac output; TPR = total peripheral resistance; RSA = respiratory sinus arrhythmia; ZCG = impedance cardiograph; PSQI = Pittsburgh Sleep Quality Index.

INTRODUCTION

Socially isolated adults, Berkman and Syme (1) reported, suffer higher rates of mortality over the succeeding 9 years even after accounting for self-reports of physical health, socioeconomic status, smoking, alcohol consumption, obesity, race, life satisfaction, physical activity, and use of preventive health services. House, Robbins, and Metzner (2) replicated these findings using physical examinations to assess health status. In a review of prospective studies on social isolation and health, House et al. (3) confirmed that social isolation was a major risk factor for morbidity and mortality from widely varying causes—a risk factor comparable in size to obesity, sedentary lifestyles, and possibly even smoking. These effects were evident even after statistically controlling for known biological risk factors, social status, baseline measures of health, and health behaviors (3, 4), with some of the fastest growing segments of the population, including the elderly, the poor, and minorities such as African Americans, showing the most severe negative health consequences of social isolation.

Social isolation is typically defined in the epidemiological literature in terms of a few simple indexes such as marital status, contact with a close friend, religious member, and member of voluntary groups. The literature on the hypothesized human need to belong, in contrast, has emphasized the psychological impact of social interactions and relationships rather than their presence or absence (eg, 5). Although a measure of marital status, contact with family and friends, church membership, and/or membership in voluntary groups may correlate with feelings of social isolation, the correlation is imperfect for several reasons. Time spent alone can foster restoration or constructive efforts rather than feelings of isolation, for instance, and conflicts with marital partners and friends can create feelings of loneliness as well as elevations in autonomic function and stress hormones over extended periods (6). Even church membership, an index of social integration, can produce feelings of conflict and isolation (7).

In the present study, we focused on the psychological construct of loneliness, which consists of feelings of social isolation due, in part, to the discrepancy between an individual's desired and actual relationships (8). Although the data are more limited, the existing research supports a link between loneliness

From the Department of Psychology, University of Chicago, Chicago, IL (J.T.C., E.C.); the Department of Psychology, Ohio State University, Columbus, OH (L.C.H., R.B.K., G.G.B.); the Department of Psychology, Illinois Wesleyan University, Bloomington, IL (J.M.E.); the Department of Social and Behavioral Sciences, Arizona State University West, Phoenix, AZ (M.H.B.); the Department of Medicine, Ohio State University School of Medicine, Columbus, OH (W.B.M.); and the Department of Medicine, University of Chicago, Chicago, IL (E.V.C.).

Address reprint requests to: John T. Cacioppo, University of Chicago, Department of Psychology, 5848 S. Maryland Avenue, Chicago, IL 60637. Email: cacioppo@uchicago.edu

Received for publication July 12, 2000; revision received June 27, 2001.

0033-3174/0−2000/6403-0407

and mortality as well as between isolation and mortality (4). In the present research, we examined four specific mechanisms by which feelings of loneliness may be associated with broad-based morbidity and mortality. First, given the deleterious effects of tobacco and alcohol consumption, poor nutrition, and sedentary lifestyles, we examined the hypothesis that lonely individuals would engage in poorer health behaviors than nonlonely individuals. Second, given that cardiovascular disease remains the major cause of morbidity and mortality in industrialized nations, we tested the hypothesis that lonely individuals would show altered cardiovascular activation. Third, given the wear and tear on physiological systems produced by chronically elevated levels of hypothalamic pituitary adrenocortical activation (9), we tested the hypothesis that lonely individuals would show higher mean salivary (ie, unbound) cortisol levels over the course of a normal day. Finally, recent research has shown that many Americans suffer from a serious sleep deficit (10) and that sleep debt lowers glucose tolerance, increases sympathetic tonus, and diminishes cortisol regulation—mimicking many of the effects of aging (11). We therefore examined the hypothesis that lonely days invade the nights to produce poorer quality sleep in lonely than in nonlonely participants.

We tested these hypotheses in Study 1 in a sample of college undergraduates (mean age = 19 years) who, developmentally speaking, were selecting partners and establishing lifetime health habits and in Study 2 in a sample of older adults (mean age = 65 years) whose physiological resilience could be expected to be diminished relative to our sample in Study 1.

STUDY 1

Participants and Design

Participants were 45 men and 44 women who were undergraduate students (mean age = 19.26, SEM = 0.12, range 18–24) at Ohio State University, recruited from residence halls, fraternities, sororities, and introductory psychology classes. Students were recruited from those scoring in the upper quintile (lonely group: total score ≥46; 22 men and 22 women) and lower quintile (nonlonely group: total score ≤28, 23 men and 22 women) on the UCLA-R loneliness scale (12).[1] Inclusion criteria included the following: low depressive symptomatology (ie, a total score of 13 or less) as measured by the Beck Depression Inventory at prescreening (13), body mass index (BMI) no greater than 27, enrolled in at least 6 credit hours, were neither first-quarter freshmen nor last-quarter seniors, not speech or needle phobic, not married nor living with a significant other, and a U.S. citizen. Participants were paid for their participation in the study. Cell sizes in the analyses are adjusted for incomplete data from participants.

Hypotheses regarding health behaviors, mean salivary cortisol levels, and sleep quality were tested using a two-group (lonely vs. nonlonely) cross-sectional design. The study design for testing cardiovascular differences was a 2 (loneliness: lonely vs. nonlonely) x 2 (period: baseline, task) mixed-model factorial.

Active Coping Tasks

Verbal mental arithmetic. Verbal mental arithmetic consisted of serial subtractions from a large number. Participants began by subtracting aloud from a three-digit number by steps of three. After the first minute, the experimenter measured the participant's performance and assigned the participant a new starting number and subtrahend based on their performance (14). Participants who performed well in the first minute received a more difficult set for minute 2 than did participants who did not perform well. The task continued similarly for an additional 2 minutes with new subtrahends for minutes 3 and 4. This procedure ensures relatively equal effort across varying levels of ability (14). Responses were averaged across minutes to increase the reliability of the autonomic assessments.

Speech tasks. Five speech tasks designed to sample a wide range of situations were employed. The first four speech tasks required that participants "describe the way from your place of residence to your first class of the week," "describe the inanimate objects in the room," "ask someone out for a first date," and "describe why you are a likable person." Participants were given 2 minutes to prepare and 2 minutes to present each of these speeches following the method described by Saab, Matthews, Stoney, and McDonald (15). Participants were told that their speeches were being audio recorded for further evaluation. The order of these speeches and the mental arithmetic task were randomly determined for each participant. The final task was the Saab et al. (15) speech task, in which participants had 2 minutes to prepare and 2 minutes to give a speech in which they imagined they were falsely accused of stealing a belt in a department store. Each participant was told to give a speech defending himself or herself to the store manager. Differences in response across the speeches were inconsequential, so the responses were averaged across the speech tasks to increase the reliability of the autonomic assessments.

Orthostasis Stressor

To examine whether autonomic differences between lonely and nonlonely participants were specific to psychological stressors, orthostasis was used to measure participants' cardiovascular responses to changes in posture. After sitting quietly for 3 minutes, participants stood quietly for 5 minutes. Participants then sat quietly for an additional 3 minutes. Cardiovascular measures described below were collected continuously during the last 2 minutes of the first period, during the last 4 minutes of the second period, and during the last 2 minutes of the final period. Mean responses during sitting and during standing were calculated and submitted to analyses.

Measures

Health behavior and demographic questionnaire. Participants provided information about their living situations (alone, with

[1] Individuals falling in the middle quintile were also tested in Study 1. Because mean responses fell between the other groups, none of the results differed by including this group, and because only lonely and nonlonely Ss were tested in Study 2, data from this group are not reported here. The results including data from this group are available from the authors.

friend/s, with parents), number of coinhabitants, height, weight, gender, age, citizenship, and racial/ethnic origin.[2]

Participants also indicated their average weekly consumption of alcohol (beer or an equivalent amount of other alcoholic beverages), average weekly consumption of caffeine, average weekly consumption of recreational drugs, and average number of packs of cigarettes consumed weekly. Participants' body mass indexes (BMIs) were calculated by dividing weight in kilograms by the square of the height in meters. To assess exercise, participants were asked if they engaged in any activities at least once a week to generate a sweat and, if so, to list how many times and how many hours per week.

Revised UCLA Loneliness Scale. The R-UCLA loneliness scale is a 20-item self-report questionnaire that has been associated with shyness, low self-esteem, insecure attachment, negative affect and reactivity, anxiety, and hostility (12). Participants were asked to rate how often they feel the way described by the items on a four-point Likert scale ranging from one (never) to four (often). Scores for all participants were tabulated by summing the responses for all items and ranged from 20 (low loneliness) to 80 (high loneliness). For scale design and psychometric properties, see Russell, Peplau, and Cutrona (12; see, also 16).

Beck Depression Inventory-Short Form. The Beck Depression Inventory-Short Form (BDI-S) (13) is a 13-item scale that asks participants to respond to one or more of four statements per item that best describe how they have been feeling for the past week. A Beck depression score was tabulated by summing the highest scoring responses to all 13 items, yielding a scale score range of 0 (low depression) to 39 (high depression).

Sleep quality. Sleep quality was measured using the Pittsburgh Sleep Quality Index (PSQI), a 19-question self-report questionnaire that assesses the sleep quality over a 1-month time frame (see 17 for scale design and psychometric properties). Seven component scores, all ranging from zero (no problems in area) to three (high problem area), are calculated using scoring instructions given by Buysse et al. (17). The seven components of the PSQI are subjective sleep quality, sleep latency, sleep duration, habitual sleep efficiency, sleep disturbances, use of sleeping medications, and daytime dysfunction. A global score was calculated for all participants by summing the seven component scores and yielded a scale score with a range of 0 (good sleep quality) to 21 (poor sleep quality). In addition, measures of blinking and movement were secured using a Nightcap model P200B, the results of which will be reported elsewhere.

Salivary cortisol assays. Salivettes (Sarstedt, Inc., Newton, NC) were used to collect saliva samples for cortisol assessment. Salivary cortisol levels were determined by radioimmunoassay following the modifications outlined by the kit manufacturer (Diagnostic Products Corp., Los Angeles, CA). The sensitivity of this method for salivary cortisol is 0.05 pg/ml, with intra- and interassay coefficients of variation of 4.4 and 7.6%, respectively. All participants' saliva samples were processed in a batch.

Cardiovascular activity. Cardiovascular measures were obtained via impedance cardiograph (ZCG; Minnesota Impedance Cardiograph, model 304B), electrocardiograph and blood pressure (BP) equipment (Colin Vital Signs Monitor, model BP-508; Vital Signs, Minster, OH). ZCG was obtained using the standard tetrapolar aluminum/mylar tape electrode system (18) and procedures described elsewhere (14). Electrocardiography was recorded using the standard lead II configuration with Ag/AgCl disposable electrodes (Protrace 9113). The Colin Monitor records a pulse wave tonometrically by partial occlusion of the radial artery against the radius at the wrist, allowing for beat-to-beat measurement of blood pressure. It was calibrated against an initial BP reading obtained using an oscillometric cuff and was periodically recalibrated either automatically or on experimenter initiation.

We assessed heart rate (HR), cardiac contractility as measured by preejection period (PEP; 19, 20), and respiratory sinus arrhythmia as measured by high-frequency heart period variability (RSA; 21). We also measured respiration as derived from the impedance signal (22) to insure any effects on RSA were not secondary to differences in respiration. Stroke volume was derived using the Kubicek equation applied to the impedance (*Zo* and dZ/dt) waveforms. Cardiac output (CO; liter/min) was defined as HR $\times$ stroke volume, and total peripheral resistance (TPR; dyne-sec/cm^5) was defined as MAP/CO $\times$ 80.

Procedure

In preparation for the study, participants were asked a) not to donate blood for 3 weeks before testing, b) to fast from 1 PM until 4 PM the day of testing, and c) to eat lunch between 11:30 and 12:30. All participants were tested at approximately the same time in the late afternoon, beginning between 4 and 5 PM and ending between 6:30 and 7 PM. On arriving at the General Clinical Research Center, all participants were provided with a small snack and informed consent was obtained. Experimenters were kept blind to the loneliness group of the participant.

After the attachment of sensors and preparation of the participant, the experimenter ensured signal quality and a 15-minute adaptation period followed, during which time participants filled out several questionnaires. Cardiovascular responses were measured continuously throughout the remainder of the experiment during all task and resting periods.

Participants completed four speeches and the verbal mental arithmetic task. These five tasks were randomly ordered for each participant. The verbal mental arithmetic task was preceded by a 4-minute sitting rest period; the four speeches were preceded by a 2-minute sitting rest period. These tasks were followed by orthostasis and concluded with the Saab et al. (15) speech task, which was always preceded by a 4-minute sitting rest period. Participants were then given dinner. Afterward, participants completed psychological surveys and spent the night in the Clinical Research Center at Ohio State University.

On the second day after the laboratory component of the study in the General Clinical Research Center, participants were given Salivettes to collect saliva samples at nine random times during the day. Calendar wrist watches (Casio, No. 642, Dover, NJ) were programmed to signal participants between 10 AM and 11 PM under the constraint that signals be no less than 45 minutes apart. Participants were instructed to collect the saliva sample by chewing on a cotton wad that they removed from the appropriately labeled salivary collection tube. Saliva samples were returned to the General Clinical Research Center by noon the following day, where they were centrifuged and the working saliva sample frozen at -70°C until assayed.

RESULTS

Preliminary Analyses

Lonely and nonlonely participants were selected based on pretests to differ in terms of their levels of

[2] Participants completed additional surveys as part of a larger study, the results of which are to be reported elsewhere.

loneliness.[3] Analyses of their scores at follow-up on the R-UCLA loneliness scale confirmed that the groups differed in loneliness (M_{lonely} =44.01, $M_{nonlonely}$ = 26.76, $F(1,87) = 124.78$, $p < .001$). Also consistent with the selection criteria, analyses confirmed that lonely and nonlonely participants did not differ in age (M = 19.25 and 19.28, respectively) or any sociodemographic variable. For instance, all participants were single, the number of roommates did not differ by loneliness ($F < 1$), residence did not differ by loneliness ($\chi^2 = 1.22$, $p > .5$), and whether participants lived alone, with friends, or with parents did not differ by loneliness ($\chi^2 = 2.92$, $p > .2$).

Health Behaviors

Lonely and nonlonely individuals did not differ significantly on body mass index ($F(1,87) = 2.01$, $p < .17$); alcohol consumption ($F < 1$); tobacco consumption ($F < 1$); caffeine consumption, either in the form of coffee and tea ($F < 1$) or soda ($F(1,85) = 1.26$, $p < .27$); frequency of weekly exercise ($F < 1$); or number of hours of weekly exercise ($F < 1$). The only effect to emerge was reported recreational drug use, which was generally low but higher among the lonely than the nonlonely ($F(1,85) = 4.97$, $p < .05$) (Table 1).

Cardiovascular Activity

Repeated measures analyses of variance (ANOVAs) were performed on the responses to mental arithmetic and to the speech stressors.[4] Cell means are summarized in Table 2. Analyses of SBP revealed the expected main effect of period for the math stressor ($F(1,77) = 74.35$, $p < .01$) and speech stressors ($F(2,160) = 137.94$, $p < .001$), and these effects that were observed for DBP as well (math stressors, $F(1,77) = 81.59$, $p < .01$; speech stressors, $F(2,160) = 218.66$, $p < .001$). No main effect of loneliness and no interaction between loneliness and period were observed for SBP or DBP during the speech stressors. During the math stressor, a significant loneliness by period interaction was observed for both SBP ($F(1,77) = 7.03$, $p < .05$) and DBP ($F(1,77) = 7.53$, $p < .05$). These effects are primarily due to higher blood pressure at baseline for lonely compared with nonlonely participants in the math task.

Blood pressure is a regulated endpoint that reflects two component processes, TPR (controlled by alpha-adrenergic activation) and CO (controlled by a combination of beta-adrenergic and vagal activation). The repeated measures analysis of TPR revealed a significant main effect of period for the math stressor ($F(1,71) = 29.11$, $p < .01$) and the speech stressors ($F(2,152) = 34.79$, $p < .001$). As expected, TPR was higher during the task than during baseline. Analyses also revealed a significant main effect of loneliness for the math stressor ($F(1,71) = 4.54$, $p < .05$) and the speech stressors ($F(1,76) = 5.41$, $p < .05$). As can be seen in Table 1, lonely participants showed consistently higher TPR than nonlonely participants at baseline and during the psychological stressors.

Analysis of CO revealed a main effect of period for the math stressor ($F(1,79) = 20.641$, $p < .01$) and speech stressors ($F(2,160) = 19.84$, $p < .001$), with CO higher during the tasks than baselines. Given comparable BP and higher TPR in lonely participants, CO should be lower in lonely participants. This was indeed the case. Analyses revealed a significant main effect of loneliness for the math stressor ($F(1,79) = 4.43$, $p < .05$) and speech stressors ($F(1,80) = 5.28$, $p < .05$) and significant interactions between period and loneliness for the math stressor ($F(1,79) = 6.55$, $p < .05$) and speech stressors ($F(2,160) = 7.83$, $p < .01$). Pairwise comparisons indicated that nonlonely participants showed larger increases in CO in response to the laboratory tasks than lonely participants (see Table 2).

To further examine cardiac effects, we examined HR, PEP, and RSA separately. Cell means are summarized in Table 2. Repeated measures ANOVAs of HR revealed a main effect of period for the math stressor ($F(1,80) = 262.76$, $p < .01$) and speech stressors ($F(2,164) = 302.24$, $p < .001$), a significant interaction between period and loneliness for the speech stressor ($F(2,164) = 3.57$, $p < .05$), and a nonsignificant interaction for the math stressor ($F(1,80) = 3.42$, $p < .07$). Analyses of PEP revealed a significant main effect of period for the math stressor ($F(1,81) = 70.00$, $p < .01$) and speech stressors ($F(2,164) = 124.66$, $p < .01$) and significant interactions between period and loneliness for the math stressor ($F(1,81) = 7.04$, $p < .05$) and speech stressors ($F(2,164) = 14.21$, $p < .01$). Finally, analyses of RSA showed a significant effect of period

[3] The results of analyses of variance are reported in the text for ease of exposition. Comparable outcomes were found when a regression approach was used. In addition, analyses correcting for baseline levels of cardiovascular activity produced comparable results, as did analyses correcting for recreational drug use.

[4] No interactions between loneliness and type of speech stressor were significant. To increase generalizability, therefore, responses were averaged across the speech stressors. Although some main effects of gender were observed (eg, men had higher blood pressure than women, ($F(1,78) = 25.654$, $p < .001$), there were no significant gender × loneliness interactions. Readers may contact the authors for information about the main effects of task or gender.

TABLE 1. Study 1: Loneliness Group Means (*N*, SEMs) in Sleep Efficacy, Health Behaviors, and Psychological Measures

	Nonlonely	Lonely
Health behaviors		
Body mass index (kg/height in m^2)	22.02 (45, 0.3)	22.7 (44, 0.3)
Alcohol (no. drinks/wk)	1.2 (43, 0.2)	1.0 (43, 0.2)
Tobacco (no. packs/wk)	0.4 (43, 0.2)	0.3 (44, 0.2)
Coffee/tea (no. cups/wk)	0.9 (43, 0.2)	0.9 (43, 0.2)
Soda (no. sodas containing caffeine/wk)	1.8 (43, 0.2)	1.5 (44, 0.2)
Recreational drug use (no. pills/wk)	0.02 (43, 0.02)	0.2 (44, 0.06)
Frequency of weekly exercise (no. sessions/wk)	4.0 (41, 0.3)	3.9 (37, 0.4)
Hours of weekly exercise	5.8 (41, 0.7)	6.1 (36, 1.2)
Subjective sleep measures (PSQI)[a]		
Subjective quality	1.0 (44, 0.1)	1.3 (44, 0.1)
Sleep latency	1.2 (44, 0.1)	1.6 (44, 0.1)
Sleep duration	0.7 (44, 0.1)	1.2 (44, 0.1)
Sleep disturbances	1.0 (44, 0.1)	1.0 (44, 0.1)
Sleep medication	0.2 (44, 0.1)	0.1 (44, 0.1)
Daytime dysfunction	0.8 (44, 0.1)	1.5 (44, 0.1)
Sleep efficiency	0.3 (44, 0.1)	0.4 (44, 0.1)
Global PSQI	5.2 (44, 0.4)	7.1 (44, 0.3)

[a] The PSQI response scale ranges from zero ("no problems in this area") to three ("severe problems in this area").

($F(2,164) = 8.67$, $p < .01$) for the speech task only and no effect of group.[5]

Analyses of the cardiovascular data from the orthostatic stressor revealed a main effect of loneliness ($F(1,72) = 5.56$, $p < .05$), with lonely participants showing significantly higher TPR than nonlonely participants in both postures (see Table 2). Also replicating the results from the psychological stressors, we found no significant effect of loneliness on blood pressure, but a significant effect on CO was again found ($F(1,77) = 5.05$, $p < .05$), with lower CO in lonely than nonlonely participants regardless of posture.

Mean Cortisol Levels

Mean levels of cortisol were computed by participant for each of three time intervals, morning (samples taken from 9 AM to noon.), afternoon (samples taken from noon to 6 PM), and evening (samples taken from 6 PM to midnight). Repeated measures ANOVAs of salivary cortisol (nmol/liter) as a function of loneliness and time of day (morning, afternoon, evening) revealed the expected decline across the day ($M_{morning} = 8.83$, $M_{afternoon} = 5.52$, $M_{evening} = 3.86$, $F(2,92) = 33.78$, $p < .01$). No significant main effect of loneliness and no interaction between loneliness and time of day were observed ($M_{nonlonely} = 5.52$, $M_{lonely} = 5.52$), however. No group differences were found when diurnal slopes were examined either.

Reported Sleep Quality

Analyses of the total score on the PSQI, which combines various measures of poor sleep, revealed that lonely participants scored higher on this scale than nonlonely participants ($F(1,86) = 17.3$ $p < .001$; Table 1). Analyses of the seven subscales further revealed that lonely, relative to nonlonely, participants were characterized by significantly poorer subjective sleep quality ($F(1,86) = 7.35$, $p < .01$), marginally longer sleep latency ($F(1,86) = 5.64$, $p < .06$), shorter sleep duration ($F(1,86) = 5.00$, $p < .05$), and greater daytime dysfunction ($F(1,86) = 19.31$, $p < .001$). Lonely and nonlonely participants did not differ significantly in subjective sleep efficiency, sleep disturbances, or use of sleeping medications ($F < 1$).

Ancillary Analysis

Although we have considered the four potential mechanisms of cardiovascular activation, sleep dysfunction, circulating cortisol levels, and health behaviors separately, they may not be orthogonal either because of a direct link (eg, the effects of exercise on cardiovascular activation) or a common third factor (eg, individual differences in hostility mediating sleep and cardiovascular activation). To explore this issue, correlations were calculated among the major dependent measures (eg, TPR, PSQI, drug use, mean cortisol). Results revealed no significant correlation among the measures. Moreover, the effects of loneliness on these measures were not eliminated when controlling statistically for depression.

DISCUSSION

Lonely individuals did not report poorer health behaviors than nonlonely individuals. Although the use of self-report measures is a limitation in this study, this finding is similar to that of Eccles et al. (23) in their study of over 1300 high school students in Detroit. It is conceivable that health behaviors affect broad-based morbidity and mortality but do not contribute to differences in health outcomes for lonely and nonlonely individuals, at least in young adults. The same might be said of quotidian cortisol levels, which were also comparable for lonely and nonlonely young adults.

[5] Analyses correcting for respiration rate produced comparable results.

TABLE 2. Study 1: Means (SEM) of Cardiovascular Responses to Mental Arithmetic and Speech Stressors by Period

Psychological Stressors		Nonlonely (N = 45)			Lonely (N = 44)		
		Baseline	Prep	Delivery	Baseline	Prep	Delivery
Systolic blood pressure (SBP, mm Hg)	math	114.6 (2.7)		133.0 (2.9)	123.0 (2.8)		132.8 (3.0)
	speech	118.3 (2.2)	125.1 (2.5)	132.5 (2.5)	119.6 (2.0)	125.2 (2.1)	132.2 (2.2)
Diastolic blood pressure (DBP, mm Hg)	math	61.0 (1.4)		75.5 (1.8)	65.0 (1.7)		72.7 (1.9)
	speech	63.3 (1.2)	67.9 (1.3)	74.3 (1.3)	62.9 (1.2)	67.4 (1.1)	73.6 (1.2)
Total peripheral resistance (TPR, dyne-sec/cm^5)	math	889.3 (33.7)		988.9 (36.9)	1014.5 (40.4)		1094.2 (46.1)
	speech	920.9 (31.2)	965.7 (37.1)	1003.5 (39.0)	1023.1 (40.6)	1106.3 (44.1)	1140.7 (42.5)
Cardiac output (CO, liters/min)	math	7.4 (.3)		7.9 (.3)	6.8 (.2)		7 (.3)
	speech	7.3 (.2)	7.4 (.3)	7.8 (.3)	6.7 (.2)	6.6 (.2)	6.8 (.2)
Heart rate (HR, beats/min)	math	70.5 (1.4)		84.8 (2.0)	68.8 (1.2)		80.3 (1.6)
	speech	70.0 (1.6)	76.0 (1.6)	83.6 (1.8)	68.6 (1.2)	73.7 (1.4)	79.5 (1.5)
Preejection period (PEP, msec)	math	127.1 (2.4)		116.4 (3.1)	124.8 (2.0)		119.2 (2.3)
	speech	127.4 (2.6)	123.1 (2.7)	116.6 (2.8)	125.6 (1.9)	123.3 (2.0)	120.3 (2.3)
Respiratory sinus arrhythmia (RSA, log units)	math	6.6 (.1)		6.3 (.2)	6.6 (.1)		6.5 (.1)
	speech	6.5 (.1)	6.3 (.1)	6.5 (.1)	6.6 (.1)	6.3 (.1)	6.4 (.1)

Orthostatic Stressors	Nonlonely (N = 45)		Lonely (N = 44)	
	Sitting	Standing	Sitting	Standing
Systolic blood pressure (SBP, mm Hg)	115.9 (2.1)	123.3 (2.6)	118.1 (2.2)	127.1 (2.3)
Diastolic blood pressure (DBP, mm Hg)	64.4 (1.3)	70.7 (1.3)	64.3 (1.5)	73.7 (2.0)
Total peripheral resistance (TPR, dyne-sec/cm^5)	940.3 (32.7)	1191.0 (36.1)	1052.3 (43.0)	1341.1 (53.0)
Cardiac output (CO, liters/min)	7.1 (.3)	6.0 (.2)	6.3 (.2)	5.4 (.2)
Heart rate (HR, beats/min)	68.4 (1.4)	83.4 (1.6)	67.4 (1.3)	80.5 (1.5)
Preejection period (PEP, msec)	130.4 (2.6)	136.1 (2.3)	126.9 (2.2)	134.3 (2.1)
Respiratory sinus arrhythmia (RSA, log units)	6.5 (.1)	5.4 (.2)	6.6 (.1)	5.6 (.1)

The pattern of cardiovascular activation differed profoundly for lonely and nonlonely individuals. Lonely individuals were found to be characterized by higher TPR, whereas nonlonely individuals were characterized by higher CO throughout the study. Previous research has shown that passive coping is associated with elevated BP due to increases in vascular resistance, whereas active coping is associated with elevated BP due to increases in CO (24). The parallels between these findings are suggestive in light of recent evidence that lonely individuals are less likely throughout the day to actively cope and more likely to feel anxious and threatened than nonlonely individuals (15).

HR was elevated and PEP was shortened during the laboratory stressors, effects that were stronger in the nonlonely than lonely. These results would be expected if the hemodynamic response in lonely individuals resulted in compensatory reductions (eg, via the baroreceptor reflex) in the sympathetic activation of the heart. The sympathetic activation of the vasculature need not be related simply to the sympathetic activation of the heart, in part due to local factors and in part due to variations in the sympathetic activation of the heart vs. vasculature (24). Indeed, although blood pressure was comparable for lonely and nonlonely young adults, a relative emphasis by lonely individuals on vascular over cardiac activation to regulate BP across the lifespan may contribute to elevated BP in older adults.

Finally, analyses of the participants' responses to the PSQI suggested that the subjective quality of sleep was impaired in lonely participants. In light of findings that link sleep deprivation to poor health (11), this result suggests that, in the long-term, sleep debt may be an important mechanism through which loneliness undermines health.

STUDY 2

Participants and Design

Twenty-five adult participants (6 men, 19 women) were recruited by mail from a condominium in Chicago. They were between the ages of 53 and 78 (M = 65, SEM = 1.4) and reported that they were generally healthy, were not suffering from diabetes or cancer, and were not taking beta blockers or antidepressants. The hypotheses regarding health behaviors, cardiovascular function, salivary cortisol levels, and sleep quality were tested using a two-group (lonely vs. nonlonely) cross-sectional design. The study design for testing the hypotheses was a 2 (loneliness: lonely, nonlonely) × 2 (age: young, old) × gender (male, female) factorial in which participants

were divided into lonely and nonlonely subgroups by a median split on R-UCLA loneliness (median = 34) and into young and old subgroups by a median split on age (median = 65). Preliminary analyses revealed no effects of gender, so the data were collapsed across this factor.

Measures

As in Study 1, participants completed the R-UCLA loneliness scale and the PSQI, and Salivettes (Sarstedt, Inc.) were used to collect saliva samples for cortisol assessment. (All participants' saliva samples were processed in a single batch.) In addition, HR, BP, height, weight, waist, and hips were measured, and participants completed the following scales.

Health behavior survey. This survey asked participants to indicate their average daily consumption of alcohol for each day of the week, frequency of seatbelt use for the past 10 car trips, average consumption of caffeine for each day of the week, and average number of cigarettes consumed each day of the week. It also asked them to rate how healthy their diet was on a five-point Likert scale that ranges from one (extremely unhealthy) to five (extremely healthy). In addition, participants rated how well they met the medication schedule set by their doctor on a five-point scale from one (I rarely take medications when I'm supposed to) to five (I almost always meet the medication schedule set by my doctor).

Exercise measure. The scale for activity in older adults (25) is a 15-item scale used in prior health interview studies. Participants were asked whether (yes/no) they had performed activities such as walking for exercise, jogging, hiking, dancing, golfing, playing tennis, etc., in the past 14 days. For activities they had performed, participants were asked how many times they had performed each activity and on average how many minutes they had spent performing that activity. Activities were categorized as light (eg, walking, golfing, dancing), moderate (hiking, swimming, bicycling), and heavy (jogging, aerobic dancing, playing handball) based on intensity codes established by the Minnesota Heart Survey (25).

Procedure

After informed consent procedures, each participant's height, weight, waist, and hip measurements were taken. The experimenter then administered the psychological measures in written format, except for the demographic and exercise questionnaires, which were administered verbally. For each measure, the experimenter read the instructions aloud as the participant read along. Questionnaires were then completed independently, although the experimenter was available to clarify questions as needed. Because major cardiovascular differences were apparent in basal values in Study 1 and because of constraints with the older population, we focused attention on baseline measures in the present study. Three times during the session, blood pressure and heart rate were measured using a blood pressure monitor manufactured by Omron (model HEM-739AC; Omron Healthcare Inc., Vernon Hills, IL). The first measurement was taken after the participant had been seated for approximately 10 minutes, and the others followed at approximately 10-minute intervals.

On the day after the interview, participants used Salivettes to take nine saliva samples, once every hour starting at 8:00 AM and continuing until 4:00 PM. Participants were instructed to place the cotton wad inside the cheek for about 30 seconds or until they could feel it was saturated with saliva and were asked to store the samples in the refrigerator. Samples were collected at the end of the day, refrigerated for 1 to 3 days, centrifuged for 2 minutes at 2000 rpm, and then frozen at −80°.

RESULTS

Health Behaviors

Lonely and nonlonely individuals did not differ significantly on body mass index ($F < 1$), reported alcohol consumption ($F(1,23) = 1.01$, NS), tobacco consumption ($F < 1$), caffeine consumption ($F < 1$), diet quality ($F < 1$), or medical compliance ($F < 1$). There were also no significant differences in amount of light ($F(1,23) = 1.32$, $p < .26$), moderate ($F(1,23) = 1.76$, $p < .20$), heavy ($F(1,23) = 2.23$, $p < .15$), or total exercise ($F(1,23) = 1.79$, $p < .19$) participants reported doing in the previous 2 weeks. Cell means are summarized in Table 3.[6]

Cardiovascular Activity

Medical guidelines were changed recently to recommend that SBP rather than DBP be used to define hypertension in adults above 35 years of age (26). We, therefore, first examined whether lonely individuals 53 to 78 years of age would be characterized by higher SBP overall and larger age-related increases in SBP than nonlonely individuals. Cell means are summarized in Figure 1. The ANOVA revealed a significant main effect of age ($F(1,21) = 6.52$, $p < .05$) and an interaction between age and loneliness ($F(1,22) = 5.88$, $p = .05$). Pairwise comparisons confirmed that, within lonely participants, SBP was higher in 65 to 78 year olds than in 53 to 64 year olds (Tukey-Kramer test statistic = 4.79, $p < .05$), whereas no such age-related elevation in SBP was found to characterize nonlonely participants. No differences in DBP were observed, possibly due to the greater measurement error for DBP. Comparable analyses of HR revealed a main effect of age ($F(1,21) = 5.48$, $p < .05$) and a significant interaction between age and loneliness ($F(1,21) = 4.56$, $p < .05$) (Figure 1). Pairwise contrasts revealed only that HR was higher in older than younger nonlonely participants (Tukey-Kramer test statistic = 4.76, $p < .05$).

To specifically address age-related increases in BP, we also examined the correlation between age and SBP within groups. The correlation within the lonely group was 0.78 ($p < .05$) and within the nonlonely group was −0.01 (NS).

Mean Cortisol Levels

Mean levels of cortisol were computed by participant for each of three time intervals, morning (samples

[6] The results of analyses of variance are reported in the text for ease of exposition. Similar outcomes were found when a regression approach was used.

TABLE 3. Study 2: Loneliness Group Means (*N*, SEMs) in Sleep Efficacy, Health Behaviors

	Nonlonely (*N* = 12)	Lonely (*N* = 13)
Health behaviors		
Body mass index (kg/height in m^2)	27.25 (1.5)	27.25 (1.0)
Alcohol (no. drinks/wk)	0.77 (0.31)	0.43 (0.16)
Tobacco (no. packs/wk)	2.5 (2.5)	1.07 (0.76)
Caffeinated drinks (no. cups/wk)	2.73 (0.57)	1.97 (0.63)
Seatbelt use (frequency in past 10 trips)	8.92 (0.82)	9.38 (0.62)
Healthful diet (1 = extremely unhealthy, 5 = extremely healthy)	3.37 (0.36)	3.46 (0.31)
Medication compliance (1 = rarely, 5 = always)	4.92 (0.08)	5.00 (0.0)
Light exercise (hours/wk)	4.69 (1.19)	2.96 (0.95)
Moderate exercise (hours/wk)	2.76 (1.35)	0.96 (0.40)
Heavy exercise (hours/wk)	0 (0)	0.53 (0.34)
Subjective sleep measures (PSQI)[a]		
Subjective quality	0.3 (0.1)	1.0 (0.1)
Sleep latency	0.5 (0.2)	0.5 (0.2)
Sleep duration	0.3 (0.1)	0.8 (0.2)
Sleep disturbances	0.8 (0.1)	1.3 (0.2)
Sleep medication	0.3 (0.3)	0.8 (0.3)
Daytime dysfunction	0.7 (1.2)	1.2 (0.3)
Sleep efficiency	0.1 (0.1)	0.9 (0.3)
Global PSQI	3.0 (0.8)	6.6 (0.7)

[a] The PSQI response scale ranges from zero ("no problems in this area") to three ("severe problems in this area").

taken from 8 AM to 10 PM), midday (samples taken from 11 AM to 1 PM), and afternoon (samples taken from 2 PM to 4 PM). Repeated measures ANOVAs of salivary cortisol as a function of loneliness and time of day (morning, midday, afternoon) revealed the expected decline across the day (M_{morning} = 9.73 nmol/liter, M_{midday} = 6.60 nmol/liter, $M_{\text{afternoon}}$ = 5.83 nmol/liter, $F(2,34) = 28.66$, $p < .001$). As in Study 1, no significant main effect of loneliness and no interaction between loneliness and time of day were observed ($M_{\text{nonlonely}} = 7.77$, $M_{\text{lonely}} = 7.09$).

Reported Sleep Quality

Analyses of participants' responses to the PSQI confirmed that lonely participants scored higher on the total scale ($F(1,23) = 13.39$, $p < .01$), indicating greater sleep dysfunction than nonlonely participants (Table 3). Analyses of the seven subscales further revealed that lonely, relative to nonlonely, participants were characterized by significantly lower subjective sleep quality ($F(1,23) = 13.67$, $p < .01$), lower sleep efficiency ($F(1,23) = 7.31$, $p < .05$), and greater sleep disturbances ($F(1,23) = 5.02$, $p < .05$). Lonely and nonlonely participants did not differ significantly in daytime dysfunction ($F(1,23) = 1.58$, $p < .22$), sleep latency ($F(1,23) = 0.08$, $p < .8$), sleep duration ($F(1\ 23) = 3.64$, $p < .07$), or sleep medications ($F(1,23) = 1.72$, $p < .2$). The effect of age was not significant.

Ancillary Analysis

As in Study 1, we calculated correlations among the major dependent measures (eg, BP, PSQI, mean cortisol). Results again revealed no significant correlation among the measures.

DISCUSSION

Loneliness may be a relatively stable individual trait. In a review of measures of loneliness, Shaver and Brennan (27) note that the 2-month test-retest reliability of the original R-UCLA loneliness scale in a college sample is 0.73 (cited in Russell et al. 28), the 7-month test-retest reliability of this scale in a college sample is 0.62, and the 1-year test-retest reliability of the most recent version of the UCLA scale in an elderly sample is 0.73 (cited in 27). McGuire and Clifford (29) found significant heritability and nonshared environmental influences for children's loneliness, and behavioral observation and laboratory studies implicate social skills deficits and self-defeating interactional styles in the maintenance of loneliness (30), which suggests loneliness could be somewhat stable across time (see also 31, 32). Although the current studies were cross-sectional, note that the mean score on the R-UCLA loneliness scale was 37.80 (SD = 14.0) in sample of young adults (Study 1) and a statistically equivalent 35.1 (SD = 12.1) in our sample of older adults (Study 2).

We tested the hypothesis that lonely individuals, in

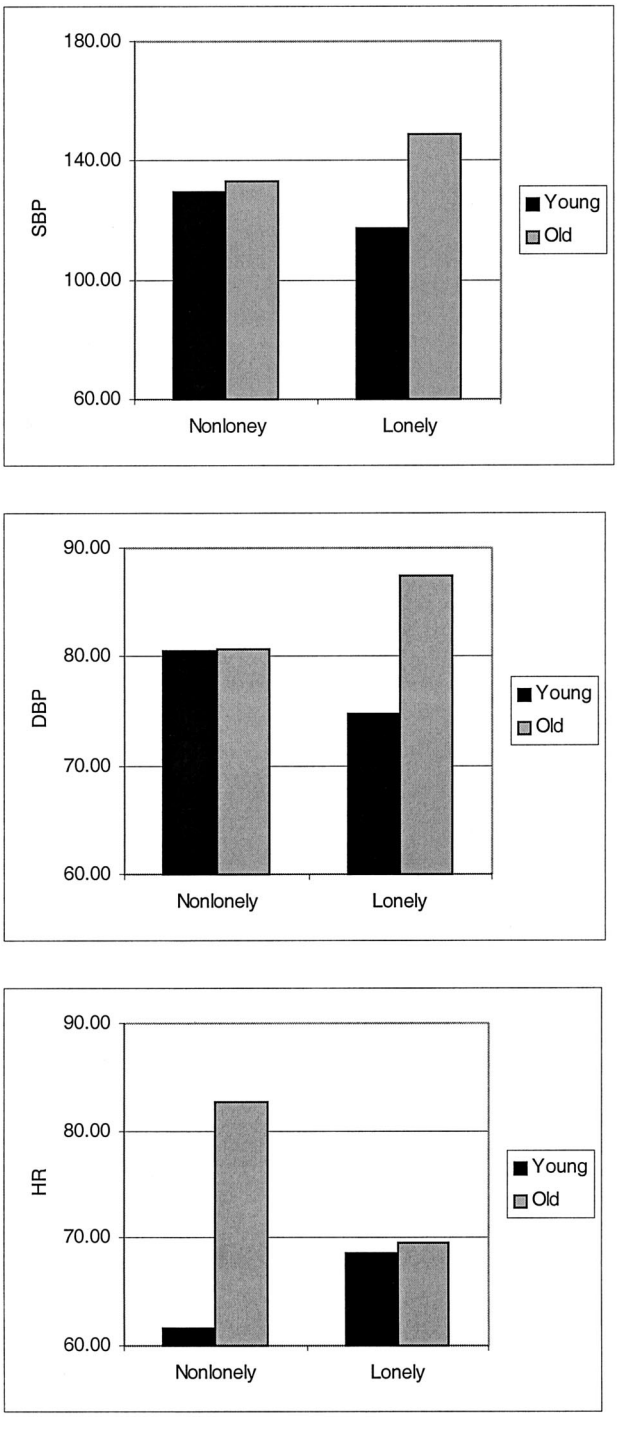

Fig. 1. Mean systolic blood pressure (*top panel*), diastolic blood pressure (*middle panel*), and heart rate (*bottom panel*) as a function of loneliness and age.

contrast with nonlonely individuals, are at risk for poorer health because they are less active, drink more alcohol, eat poorly, disregard seatbelt usage, and generally engage in poor health behaviors. Our samples of young and older adults showed trivial differences between the health behaviors of lonely and nonlonely individuals, suggesting that health behaviors may not be a major cause of differences in morbidity and mortality between lonely and nonlonely individuals. It is possible that verifiable measures of health behaviors and larger sample sizes would have revealed differences that were not discernible in the current research, but the present results suggest that such differences may be modest.

Cardiovascular function, in contrast, was found to differ as a function of loneliness in both studies. BP levels were generally comparable in Study 1 for lonely and nonlonely participants, but the means by which BP was modulated differed. Lonely, compared with nonlonely, young adults in Study 1, eg, had higher levels of TPR and lower CO and they showed smaller changes in HR, cardiac contractility, and CO in response to the laboratory stressors. Similar cardiovascular response profiles have been found in studies of active vs. passive coping tasks (eg, 24) and in studies of threat vs. challenge appraisals (eg, 33) but were observed not in response to stressors but as a main effect at baseline and during acute psychological and orthostatic stressors. Future studies will need to address whether the pattern of cardiovascular activation that differentiated lonely and nonlonely participants reflects generalized feelings of threat, freezing, or passive coping tendencies in lonely individuals. It is interesting in this context, though, that lonely individuals tend to perceive their social world to be less reinforcing and more threatening generally than nonlonely individuals (15).

Contributing to the potential importance of these early differences in cardiovascular functioning, age-related increases in SBP were found in lonely but not nonlonely older adults in Study 2. The correlation between age and SBP was also statistically larger in the lonely than the nonlonely group. Given the similarities in health behaviors between these groups, the possibility is raised that differences in the hemodynamic function observed throughout the session in younger adults may contribute to elevated blood pressure across time in lonely adults. The greater tendency for lonely young adults to show heightened TPR and lonely older adults to show higher blood pressure, eg, draw attention to possible differences in central mechanisms (eg, threat appraisals or passive coping styles) and in peripheral adrenergic function in lonely and nonlonely individuals. Vascular resistance is regulated by neurogenic, hormonal, myogenic, and local metabolic mechanisms, with the relative contribution of each varying across vascular beds (34). Whether loneliness operates at peripheral or central substrates

and whether this varies across the lifespan are important questions for future research.

The hypothalamic pituitary adrenocortical axis, with its effects on fat mobilization, amino acid transport to liver cells, reduced inflammation, and inhibition of allergic reactions, provides critical metabolic support for daily life (35). Prolonged exposure to stressors has been linked to elevated levels of glucocorticoids (ACTH, cortisol), adrenal enlargement, and various disorders (eg, see 9). Research on nonhuman primates has shown that male baboons who experience less social contact have elevated basal plasma cortisol levels compared with those who are more socially connected (36). The link between loneliness and activation of the hypothalamic pituitary adrenocortical axis in humans is more tenuous, however. Based on work by Seeman and McEwen (9) on chronic stress and allostatic load, we hypothesized that lonely individuals would show either elevated tonic activation of the hypothalamic pituitary adrenocortical axis or a muted diurnal pattern. Results revealed the expected diurnal pattern, but no differences in concentrations were found between lonely and nonlonely participants (although the effect approached significance at morning levels).[7]

A review of the literature on the relationship between social support and neuroendocrine activity also revealed the association to be small (37). Assessing the rise in cortisol on awakening may provide a more sensitive procedure for examining cortisol regulation. Whether lonely individuals would show a larger rise in cortisol than nonlonely individuals warrants study.

Finally, we tested the hypothesis that feelings of loneliness disrupt sleep. Animal research offers evidence that social situations, such as social defeat in rats, lead to alterations in sleep regulation and circadian rhythms (38). Sleep problems are known to cooccur with depression, which is also associated with social withdrawal. Analyses of the PSQI in Study 1 revealed differences as a function of loneliness that could not be explained in terms of differences in depression. Participants in Study 1 were selected to be nondepressed, however. Although these results suggest depression is not a necessary mediator, it remains the case that depression may have contributed to the group differences in PSQI observed among older adults in Study 2.

Recently, investigators have begun to appreciate the effects of sleep deficits on metabolic (eg, glucose tolerance), neural (eg, sympathetic tonus), and hormonal (eg, cortisol) regulation as well. Spiegel, Leproult, and Van Cauter (11), eg, tested 11 young men restricted to 4 hours sleep per night for 6 nights. Results revealed the limited sleep lowered glucose tolerance, elevated evening cortisol concentrations, and increased sympathetic tonus. These effects mirror what is seen in normal aging, leading the authors to conclude that sleep debt may increase the severity of age-related chronic disorders (11). Assessments of sleep using the PSQI provided evidence that lonely participants both young (Study 1) and old (Study 2) suffered lower quality sleep on multiple dimensions. If individuals are lonely chronically, it is conceivable that the effects of impaired sleep diminish nightly restorative processes and the overall resilience of lonely individuals. The results for sleep in Studies 1 and 2, therefore, point to a heretofore unrecognized mechanism by which feeling loneliness may, over time, lead to diminished health and well being. The finding that autonomic activation and sleep dysfunction were statistically unrelated raises the additional possibility that they represent separable mechanisms by which loneliness may affect health.

This work was supported by the John D. and Catherine T. MacArthur Foundation and National Institute of Health Grant M01-RR00034 to the General Clinical Research Center. We wish to thank David Lozano and Dan Litvack of the Ohio State University Social Neuroscience Laboratory for their technical assistance; Marsha Greaves of the Institute for Mind and Biology at the University of Chicago, Robert Stickgold from the Harvard University Neurophysiology Lab, the staff of the Ohio State University Residence Halls directed by Steve Kramer for their help; Carolyn Cheney of The Ohio State University Medical Labs for her contributions; and the General Clinical Research Center, including Dana Ciccone, Bob Rice, and the nursing staff headed by Teresa Sampsel, for their assistance and cooperation.

REFERENCES

1. Berkman LF, Syme SL. Social networks, host resistance, and mortality: a nine-year follow-up study of Alameda County residents. Am J Epidemiol 1979;109:186–204.
2. House JS, Robbins C, Metzner HL. The association of social relationships and activities with mortality: prospective evidence from the Tecumseh Community Health Study. Am J Epidemiol 1982;116:123–40.
3. House JS, Landis KR, Umberson D. Social relationships and health. Science 1988;241:540–5.
4. Seeman TE. Health promoting effects of friends and family on health outcomes in older adults. Am J Health Promotion 2000; 14:362–70.

[7] We also examined whether differences existed in diurnal gradients in cortisol concentrations. No significant differences were found.

5. Gardner WL, Gabriel S, Diekman AB. Interpersonal processes. In: Cacioppo JT, Tassinary LG, Berntson GG, editors. Handbook of psychophysiology. New York: Cambridge University Press; 2000. p. 643–64.
6. Kiecolt-Glaser JK, Glaser R, Cacioppo JT, Malarkey WB. Marital stress: immunologic, neuroendocrine, and autonomic correlates. Ann NY Acad Sci 1998;840:656–63.
7. Exline JJ. Stumbling blocks on the religious road: fractured relationships, nagging vices, and the inner struggle to believe. Psych Inquiry. In press.
8. Peplau LA, Perlman D. Loneliness. A sourcebook of current theory, research, and therapy. New York: Wiley Interscience; 2000.
9. Seeman TE, McEwen BS. Impact of social environment characteristics on neuroendocrine regulation. Psychosom Med 1996; 58:459–71.
10. National Sleep Foundation. Less fun, less sleep, more work: an American portrait. 2001. Available from: http://www.sleepfoundation.org/NSAW/execsum3.8.ppt.
11. Spiegel K, Leproult R, Van Cauter E. Impact of a sleep debt on metabolic and endocrine function. Lancet 1999;354:1435–9.
12. Russell D, Peplau LA, Cutrona CE. The Revised UCLA Loneliness Scale: concurrent and discriminant validity evidence. J Pers Soc Psychol 1980;39:472–80.
13. Beck AT, Beck RW. Screening depressed patients in family practice: a rapid technique. Postgrad Med 1972;52:81–5.
14. Cacioppo JT, Malarkey WB, Kiecolt-Glaser JK, Uchino BN, Sgoutas-Emch SA, Sheridan JF, Berntson GG, Glaser R. Cardiac autonomic substrates as a novel approach to explore heterogeneity in neuroendocrine and immune responses to brief psychological stressors. Psychosom Med 1995;57:154–64.
15. Saab PG, Matthews KA, Stoney CM, McDonald RH. Premenopausal and postmenopausal women differ in their cardiovascular and neuroendocrine responses to behavioral stressors. Psychophysiology 1989;26:270–80.
16. Cacioppo JT, Ernst JM, Burleson MH, McClintock MK, Malarkey WB, Hawkley LC, Kowalewski RB, Paulsen A, Hobson JA, Hugdahl K, Spiegel D, Berntson GG. Lonely traits and concomitant physiological processes: the MacArthur social neuroscience studies. Int J Psychophysiol 2000;35:143–54.
17. Buysse DJ, Reynolds CF, Monk TH, Berman SR, Kupfer DJ. The Pittsburgh Sleep Quality Index: a new instrument for psychiatric practice and research. Psychiatry Res 1989;28:193–213.
18. Sherwood A, Allen MT, Fahrenberg J, Kelsey RM, Lovallo WR, van Doornen LJ. Methodological guidelines for impedance cardiography. Psychophysiology 1990;27:1–23.
19. Berntson GG, Cacioppo JT, Binkley PF, Uchino BN, Quigley KS, Fieldstone A. Autonomic cardiac control. III. Psychological stress and cardiac response in autonomic space as revealed by pharmacological blockades. Psychophysiology 1994;31: 599–608.
20. Cacioppo JT, Berntson GG, Binkley PF, Quigley KS, Uchino BN, Fieldstone A. Autonomic cardiac control. II. Noninvasive indices and baseline response as revealed by autonomic blockades. Psychophysiology 1994;31:586–98.
21. Berntson GG, Bigger JT, Eckberg DL, Grossman P, Kaufmann PG, Malik M, Nagaraja HN, Porges SW, Saul JP, Stone PH, van der Molen MW. Heart rate variability: origins, methods, and interpretive caveats. Psychophysiology 1997;34:623–48.
22. Ernst JM, Litvack DL, Lozano D, Cacioppo JT, Berntson GG. Impedance pneumography: noise as signal in impedance cardiography. Psychophysiology 1999;36:333–8.
23. Eccles JS, Lord SE, Roeser RW, Barber BL. The association of school transitions in early adolescence with developmental trajectories through high school. In: Schulenberg J, Maggs JL, Hurrelmann K, editors. Health risks and developmental transitions during adolescence. New York: Cambridge University Press; 1997. p. 283–320.
24. Sherwood A, Dolan CA, Light KC. Hemodynamics of blood pressure responses during active and passive coping. Psychophysiology 1990;27:656–68.
25. McPhillips JB, Pellettera KM, Barrett-Connor E, Wingard DL, Criqui MH. Exercise patterns in a population of older adults. Am J Prev Med 1989;2:65–72.
26. Lloyd-Jones DM, Evans JC, Larson MG, O'Donnell CJ, Levy D. Differential impact of systolic and diastolic blood pressure level on JNC-VI staging. Joint National Committee on Prevention, Detection, Evaluation, and Treatment of High Blood Pressure. Hypertension 1999;34:381–5.
27. Shaver PR, Brennan KA. Measures of depression and loneliness. In: Robinson JP, Shaver PR, Wrightsman LS, editors. Measures of personality and social psychological attitudes. Vol. 1. San Diego: Academic Press; 1991. p. 195–290.
28. Russell D, Peplau LA, Ferguson ML. Developing a measure of loneliness. J Pers Assess 1978;42:290–4.
29. McGuire S, Clifford J. Genetic and environmental contributions to loneliness in children. Psych Sci 2000;11:487–91.
30. Jones WH, Hobbs SA, Hockenbury D. Loneliness and social skill deficits. J Pers Soc Psychol 1982;42:682–9.
31. Marangoni C, Ickes W. Loneliness. A theoretical review with implications for measurement. J Soc Pers Relations 1989;6: 93–128.
32. Shaver P, Furman W, Buhrmester D. Transition to college: network changes, social skills, and loneliness. In: Duck S, Perlman D, editors. Understanding personal relationships: an interdisciplinary approach. London: Sage Publications; 1985. p. 193–219.
33. Blascovich J, Kelsey RM, Leitten CL, Tomaka J. Subjective, physiological, and behavioral effects of threat and challenge appraisal. J Pers Soc Psychol 1993;65:248–60.
34. Brownley KA, Hurwitz BE, Schneiderman N. Cardiovascular psychophysiology In: Cacioppo JT, Tassinary LG, Berntson GG, editors. Handbook of psychophysiology. New York: Cambridge University Press; 2000. p. 224–64.
35. Lovallo WR, Thomas TL. Stress hormones in psychophysiological research. In: Cacioppo JT, Tassinary LG, Berntson GG, editors. Handbook of psychophysiology. New York: Cambridge University Press; 2000. p. 342–67.
36. Sapolsky RM, Alberts SC, Altmann J. Hypercortisolism associated with social subordinance or social isolation among wild baboons. Arch Gen Psych 1997;54:1137–43.
37. Uchino BN, Cacioppo JT, Kiecolt-Glaser JK. The relationship between social support and physiological process: a review with emphasis on underlying mechanisms and implications for health. Psych Bull 1996;119:488–531.
38. Meerlo P, Pragt BJ, Daan S. Social stress induces high intensity sleep in rats. Neurosci Lett 1997;225:41–4.