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ORIGINAL ARTICLE

Loneliness and cardiovascular reactivity to acute stress in older adults

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Abstract

Loneliness has been linked to cardiovascular health outcomes in older adulthood. One proposed mechanism by which loneliness influences cardiovascular health is through atypical cardiovascular reactivity (CVR) to stress. This study is an examination of loneliness and CVR in older adults, comparing associations across two stressors and two commonly used measures of loneliness, with a particular focus on underlying hemodynamic variables including cardiac output, total peripheral resistance, and ejection time (EJT). Eighty older adults, ranging in age from 55 to 88 years ($M = 68.93$, $SD = 8.28$), completed two versions of the UCLA loneliness scale (a 20-item and a briefer, three-item) and took part in a laboratory stress-testing procedure which included a mental arithmetic challenge and a public speaking task. Cardiovascular activity was monitored continuously throughout. For the 20-item version of the UCLA loneliness scale, loneliness was not significantly related to CVR, and was only significantly associated with lower levels of overall EJT. For the three-item version of the UCLA, no associations withstood adjustment for multiple testing. Loneliness was not reliably associated with CVR. Further, although greater loneliness was related to lower levels of overall EJT, this was only observed for the 20-item scale. The findings do not strongly provide support for reactivity to acute stress as a pathway linking loneliness to disease outcomes, and highlight key methodological issues related to the assessment of loneliness-reactivity associations for future.

KEYWORDS

cardiovascular, loneliness, older adults, reactivity, stress

1 | INTRODUCTION

Loneliness refers to the emotional distress that can accompany the perception of inadequacy in our social relationships (Peplau & Perlman, 1982). It has significant health implications for older adults, with loneliness being linked to an increased risk of mortality (Holt-Lunstad et al., 2015; Luo et al., 2012; Perissinotto et al., 2012; Tilvis et al., 2011) and of cardiovascular disease (CVD) (Bu et al., 2020; Hu et al., 2021; Sorkin et al., 2002). Furthermore, loneliness has been associated with an increased likelihood of suffering from hypertension in older adulthood (Momtaz et al., 2012); as well as higher levels of resting systolic blood pressure (SBP) and increased

age-related changes in the same measure over a 4-year period (Hawkley et al., 2006, 2010). Given the potential risk that loneliness presents for the cardiovascular health of older adults, research has investigated the possible psychobiological mechanisms underlying its impact, particularly in terms of cardiovascular stress reactivity. Our recent systematic review of this area, suggests that loneliness appears to be related to dysregulation in cardiovascular responses to stress (Brown et al., 2018); however, few studies focused on older adult samples, and the available evidence for indices besides blood pressure and heart rate (HR) was very limited. Therefore, the goal of the present study was to examine associations between loneliness and cardiovascular stress reactivity (blood pressure, HR, cardiac output [CO], total peripheral resistance [TPR], *and ejection time [EJT]*) to two standardized laboratory stressors in a sample of older adults.

Cardiovascular reactivity (CVR) refers to the difference in blood pressure or other measures of cardiovascular function observed between periods of rest and during the presentation of an external stressor. Exaggerated blood pressure responses to stress are associated with the development of hypertension (Carroll et al., 2001, 2003; Matthews et al., 2004; Treiber et al., 2003) and a higher risk of CVD (Carroll et al., 2012), while more recent evidence suggests that diminished or blunted CVR is associated with different types of adverse health outcomes, including obesity (Phillips, 2011), depression (Phillips, 2011), and lower cognitive functioning (Ginty et al., 2016). Loneliness has been associated with exaggerated CVR in previous studies; for example, Ong et al. (2012) found that loneliness predicted increased blood pressure reactivity to stress, and compared with young adults, lonely older adults appeared to have the greatest increase in SBP reactivity (Ong et al., 2012). However, loneliness has been associated with blunted CVR in other studies, for example, lonely individuals were reported to have a decreased HR response to acute stress compared to non-lonely individuals (Cacioppo et al., 2000), while Brown et al. (2019) reported that loneliness was associated with diminished TPR reactivity in younger adults (Brown et al., 2019). To date, the direction of these associations between loneliness and CVR appear to be somewhat mixed.

Cacioppo and Cacioppo's (2018) evolutionary theory of loneliness provides a framework within which to understand associations between loneliness and CVR. This model suggests that short-term feelings of loneliness motivate us to renew the social connections we need to ensure survival. In this model, the experience of loneliness may have evolved as an aversive state that, like hunger or thirst, promotes behavior change to increase the likelihood of survival (Cacioppo et al., 2014). Empirical studies suggest that lonely (vs. non-lonely) individuals demonstrate hyper-attentiveness to social information, particularly possible social threats, which can contribute to an increased burden on systems that monitor and respond to stressors (Cacioppo & Hawkley, 2009; Hawkley et al., 2010). If these periods of hyper-vigilance are short, the accompanying physiological reactions may be adaptive and inconsequential in terms of the impact on our physiological systems. However, if feelings of loneliness and accompanying hyper-vigilance are persistent, this may result in dysregulation of physiological systems including our cardiovascular stress responses.

To date, the majority of studies examining loneliness and CVR in older adult samples have focused on blood pressure and HR; however, hemodynamic variables (e.g., CO and TPR), are important determinants of cardiovascular functioning including blood pressure levels. Increased vascular resistance is connected to greater blood pressure, which is a key characteristic of hypertension (Berger & Li, 1990; Julius & Nesbitt, 1996; Lund-Johansen, 1989; Schobel & Schmieder, 1997) and increases the risk of CVD (Franklin & Olsen, 2015), and lonely individuals have been observed to have higher levels of TPR compared to non-lonely younger adults (Cacioppo et al., 2002). Likewise, loneliness was related to greater vascular resistance along with lower CO when looking at ambulatory levels during daily life (Hawkley et al., 2003), though it was predictive of lower vascular reactivity to stress in a young adult sample (Brown et al., 2019). Therefore, greater loneliness may lead to decreased vascular responsivity which may be contributing factor to the greater overall levels of TPR observed in lonelier individuals. Additionally, even though loneliness has previously been associated with a shorter pre-ejection period (Cacioppo et al., 2002), how loneliness associates with ventricular EJT has largely gone unexamined. Therefore, how loneliness impacts wider hemodynamics could be particularly important in understanding the loneliness-reactivity relationship.

Another factor of interest here is stressor type. Lonely individuals may become more sensitive to socially relevant threats (Bangee et al., 2014; Cacioppo et al., 2015, 2016; Nowland et al., 2018), implying that the relationship between loneliness and stress reactivity should be stronger for stressors involving a social element. Studies comparing responses across stressors have noted differences, though these are not consistent with the idea that loneliness is particularly relevant to social stressors; Nausheen et al. (2007) reported that greater levels of implicit loneliness predicted higher diastolic blood pressure (DBP) responses to an arithmetic task but not to a speech-based stress task. Brown et al. (2019) reported that greater loneliness was associated with lower TPR reactions to a public speaking task but not to arithmetic challenge, albeit in a sample of younger, not older, adults.

Moreover, while loneliness is commonly measured using the 20-item UCLA loneliness scale (Russell, 1996), shorter versions are also employed in health research including the shortened three-item of UCLA loneliness scale (Hughes et al., 2004). Originally developed for use in older adult surveys, this scale contains items with no explicit reference to "lonely" or "loneliness", to avoid potential stigma associated with loneliness. However, the use of different scales means there is some degree of mismatch between survey research linking loneliness to health outcomes like mortality, for example, and laboratory-based reactivity research using the 20-item scale. Although shorter scales are more convenient for large-scale surveys (e.g., the longitudinal Health and Retirement Study), there may be differences in findings based on these different assessments of loneliness, leading some researchers to advocate for comparing findings using both the three-item and 20-item UCLA measures (Jorgensen, 2018). Naturally, the use of multiple measures also facilitates an assessment of the robustness of findings across these different measures.

In summary, there are clear conceptual and methodological justifications for the examination of associations between loneliness and CVR across different stressor types and different measures of loneliness. The aim of the present study was to conceptually replicate previous research on loneliness and CVR in older adults, and to extend prior work by assessing (1) hemodynamic determinants of blood pressure, including CO and TPR, and (2) associations between these variables and loneliness across different stressor types and measures of loneliness. The existing findings for older adult groups are mixed. However, based on conceptual and empirical work demonstrating that loneliness is associated with hyper-vigilance to social contexts, we hypothesized that associations between loneliness and exaggerated blood pressure and HR reactivity, if observed, would be more pronounced for the speech task, compared to the maths task. Further, we anticipated that associations would be driven by reduced CO and elevated TPR, consistent with the idea that loneliness is linked with perceptions of threat. In light of limited and mixed prior research, we had no priori hypotheses regarding EJT reactivity and the different loneliness measures; these analyses were conducted on an exploratory basis.

2 | METHOD

2.1 | Participants

Eighty older adults (n = 50 female) were recruited from the local community with a mean age of 68.93 (SD = 8.28), ranging between 55 and 88 years of age. They had a mean body mass index (BMI) of 28.09 kg/m^2 (SD = 4.76). Participants were recruited in many different ways including during information sessions at a number of community groups for older adults. They were offered reimbursement for travel expenses and were entered into a draw for a €50 voucher. To control for potential confounds, participants refrained from drinking alcohol and vigorously exercising for at least 12 hr beforehand. They also avoided consuming caffeine and ingesting nicotine for at least 2 hr and food for at least 1 hr before participation. Compliance with these restrictions was confirmed by a checklist. Ethical approval for the study was granted by the institution's review board and before commencing participants provided written informed consent. Overall, 81 participants were recruited however, one participant was excluded because of missing cardiovascular data. In terms of health status, 30% reported having a health condition that may affect cardiovascular measures and 3.8% were unsure (1.3% did not provide an answer). Likewise, 38.8% reported taking medication that may affect cardiovascular outcomes and 2.5% were unsure.

2.2 | Apparatus

A Finometer PRO (FMS, Finapres Medical Systems BV) was used to measure cardiovascular parameters: SBP, DBP, mean arterial pressure (MAP), HR, CO, ventricular EJT, and TPR. The Finometer accurately records beat-to-beat cardiovascular activity and its use in cardiovascular measurement has been previously validated for measuring blood pressure (Guelen et al., 2003; Schutte et al., 2004). BeatScope® Easy (a recording software) was used to note the times at which each period began and ended. It is often used in similar CVR research (e.g., Hughes et al., 2011). The Finometer comprises of a finger-cuff and an arm-cuff which are placed on the participants' nondominant hand, secured to their wrist to reduce movement effects. The finger-cuff is then attached to the middle finger and contains an infrared photoplethysmograph allowing detection of changes in the diameter of the arterial wall. In order to correct for hand-to-heart distance, a hydrostatic height correction system is used.

Weight (kg) and height (cm) were measured using an electronic weighing scale and a stadiometer, respectively. These values were then used to calculate BMI.

2.3 | Psychological measures

Loneliness was measured using the UCLA Loneliness Scale (Version 3) (Russell, 1996) which consists of 20 items assessing how often an individual feels a different aspect

of loneliness. Response options are on a four-point Likert scale of 1 = "Never", 2 = "Rarely", 3 = "Sometimes", or 4 = "Often", with scores ranging from 20 to 80, with higher scores indicating higher loneliness. An example of an item is "how often do you feel alone?". In the current study, its internal reliability was good (Cronbach's $\alpha = .82$).

The Three-Item Loneliness Scale (UCLA-3; Hughes et al., 2004) was also included as it has previously been used in larger older adult samples. This shorter version of the UCLA scale was designed for use in large telephone-based surveys of loneliness in older adults; however, there is comparably little laboratory-based research employing this scale. It includes three items measuring loneliness (1 = "Hardly ever" to 3 = 'Often' (3–9), with higher scores indicating higher levels of loneliness. For example, "how often do you feel left out?" and "how often do you feel that you lack companionship?". The internal reliability of the scale was good (Cronbach's $\alpha = .83$).

Participants rated how stressed they felt before and after the tasks (0 = "Not at all" to 6 = "Extremely"). They also rated how stressful they found the individual stress tasks (0 = 'Not at all' to 6 = 'Extremely').

The present study also controlled for levels of negative affect as they have both been previously linked to loneliness (Beutel et al., 2017; Cacioppo et al., 2010) and to stress reactivity (Carroll et al., 2007; Kibler & Ma, 2004). Thus, anxiety and depression were measured using the respective subscale items adapted from the Patient Health Questionnaire-4 (PHQ-4; Kroenke et al., 2009) using a five-item Likert scale (1 = "Never" to 5 = "Very often). For example, "how often do you feel not being able to stop or control worrying?" or "how often do you feel down, depressed, or hopeless?"

2.4 | Stress tasks

The stress tasks were counter-balanced with no rest period between tasks. Visual and audible instructions for the tasks were computerized. They both required speaking aloud and had an evaluative element (i.e., the experimenter was sitting nearby but behind a screen to avoid any unnecessary distractions).

2.4.1 | Mental arithmetic

The mental arithmetic challenge (6 min) used the Paced Auditory Serial Addition Test (PASAT; Gronwall & Sampson, 1974; Ring et al., 2002). Single digit numbers are presented audibly every few seconds and the participant adds these numbers together. This involves remembering the preceding number utilized for the last sum and adding this to the next digit heard. A scoring sheet was used by the experimenter to record performance.

2.4.2 | Public speaking

The structure of the speech task was adapted from the trier social stress test (TSST) (Kirschbaum et al., 1993). There was a public speaking task (7 min) which involved participants preparing and giving an impromptu speech on three good and three bad characteristics about themselves, illustrating each one with a relevant example.

2.5 | Procedure

Following arrival at a health laboratory, participants gave informed consent. Their height and weight were recorded. After being seated, the Finometer cuff was placed on the participants' nondominated hand. Participants were instructed to use their unrestricted hand to complete all tasks. Participants were asked to keep their feet as still as possible so as to avoid excessive movement and to avoid speaking unless necessary. By completing a questionnaire booklet, participants provided sociodemographic information and ratings of loneliness. After a 20-min period of acclimatization, baseline was measured for 10 min. Participants then answered a pre-task questionnaire before the stress tasks started. Following the stress tasks, participants answered a questionnaire providing post-task ratings. Following a recovery period, cardiovascular monitoring ceased and participants were debriefed.

2.6 | Statistical analysis

All statistical analyses were conducted using IBM SPSS version 24. Cardiovascular data were screened and checked for outliers >3 *SD* from the mean. Differences in degrees of freedom reflect outliers excluded list-wise from analyses. Paired-samples *t* tests were employed to confirm the effectiveness of the stress tasks in eliciting a stress response. Multilevel models using maximum likelihood estimation were used to examine the relationship between loneliness and the cardiovascular indices during the different phases while accounting for the hierarchical nature of the data (i.e., repeated cardiovascular measures nested in individual participants). For Level 1, the three phases (baseline, public speaking task, and arithmetic challenge) were the repeated measures for each individual cardiovascular measure. For Level 2, this was the individual participant and loneliness was the predictor. Loneliness was grand-mean centered (see Kreft et al., 1995). Again,

at Level 2, BMI, sex, age, depression, anxiety, and task order were entered as covariates. We compared this basic model to the model with random intercepts, and to the model with random slopes and intercepts, and then tested the covariance between these. The Akaike's information criterion adjusted log likelihood which corrects for model complexity was used to determine goodness of fit of these models. The overall models provide an indication of potentially important predictors, which are followed up with fixed effect estimates of individual parameters.

To examine if loneliness was associated with psychological reactivity, regressions and change scores were used. One participant was missing data for one of the depression items (0.006% of the overall depression data), so the overall mean of this item was used to replace this score for this control variable (Tabachnick & Fidell, 2007). As we assessed two related measures of loneliness, a conservative two-tailed p value of <.025 (= .05/2) was considered statistically significant.

3 | RESULTS

3.1 | Descriptive statistics

The average loneliness score on the 20-item UCLA was 34.20 (SD = 7.79) ranging from 22 to 62. This was comparable to previous reactivity studies using the UCLA with older adults (e.g., Ong et al., 2012). The average loneliness score on the 3-item UCLA was 3.83 (SD = 1.46) ranging from 3 to 9. This is also comparable to previous older adult samples (e.g., Hughes et al., 2004). There was a significant positive correlation between the UCLA-20 item and the UCLA three-item scales (r = .694, p < .001). The stress tasks successfully elicited a significant physiological reaction (see Table 1). There was a significant difference in how stressed participants reported feeling before the stress tasks (M = 0.81, SD = 1.12) and afterwards (M = 3.86, SD = 1.99) (MD = 3.05, SD = 2.00; t [79] = 13.64, p < .001). There was also a significant difference in perceived stressfulness of the arithmetic task (M = 4.81, SD = 1.48) and speech task (M = 4.33, SD = 1.83) with participants reporting the maths as more stressful (MD = 0.49, SD = 1.6; t [79] = 2.73, p = .008). There were no significant differences in reactivity based on order of stressor presentation, with the exception of a marginal difference for DBP to the maths task, such that those who undertook it first had relatively lower reactivity (M = 88.31, SD = 13.22 vs. M = 93.66, SD = 9.49).

3.2 | The 20-item UCLA loneliness scale

3.2.1 | Cardiovascular activity

To examine the relationship between loneliness (20-item UCLA) and cardiovascular parameters during the various phases while taking the hierarchical nature of the data into account, a series of two-level linear mixed models were carried out.

For SBP, the model with only the intercept varied was the best fit (VAR (u_{0j}) = 286.301, χ^2 (1) = 123.76, p < .001), indicating variability in the intercept but no significant variability in the slope over time across participants. While there was a significant main effect of phase (F [2, 97.20] = 151.81, p < .001), indicating the tasks were physiologically stressful, there was no significant main effect of loneliness on SBP (F [1, 76.82] = 1.55, p = .22), indicating that loneliness did not significantly predict differences in overall SBP. The interaction between phase and loneliness was also not significant (F [1, 97.20] = 2.93, p = .058), indicating loneliness did not significantly predict differences in SBP during any of phases.

For DBP, the model with only the intercept varied was the best fit (VAR (u_{0j}) = 98.33, χ^2 (1) = 201.20, p < .001). There was a significant main effect of phase

TABLE 1 Results of manipulation checks for stress tasks

	Baseline *M* (*SD*)	Speech task *M* (*SD*)	Speech difference from baseline	Maths task *M* (*SD*)	Maths difference from baseline
SBP	149.36 (17.57)	174.82 (20.79)	t (78) = 16.33 p < .001	171.99 (19.58)	t (78) = 14.31 p < .001
DBP	80.99 (9.89)	92.78 (12.31)	t (78) = 15.35 p < .001	90.88 (11.81)	t (78) = 13.67 p < .001
MAP	106.47 (11.44)	124.30 (15.01)	t (78) = 16.93 p < .001	122.07(14.23)	t (78) = 15.00 p < .001
HR	70.26(11.65)	75.39 (13.13)	t (79) = 7.30 p < .001	73.82(12.78)	t (77) = 5.64 p < .001
CO	3.71 (1.20)	3.92 (1.37)	t (78) = 3.74 p < .001	3.96(1.38)	t (77) = 3.97 p < .001
EJT	0.30 (0.02)	0.30 (0.03)	t (79) = 2.13 p = .04	0.31 (0.02)	t (76) = 5.06 p < .001
TPR	1.95 (0.81)	2.17 (0.93)	t (77) =7.15 p < .001	2.06 (0.84)	t (76) = 4.27 p < .001

Abbreviations: CO, cardiac output (liters per minute); DBP, diastolic blood pressure (mmHg); EJT, ejection time; HR, heart rate (bpm); MAP, mean arterial pressure; SBP, systolic blood pressure (mmHg); TPR, total peripheral resistance (peripheral resistance units).

(F [2, 95.46] = 140.54, $p < .001$) and although a significant main effect of loneliness on DBP was indicated in the overall model (F [1, 76.78] = 5.55, $p = .021$), the fixed effect parameter estimates confirmed that the relationship between loneliness and DBP was not significant ($b = 1.94$, t [87.70] = .39, $p = .056$). The interaction between phase and loneliness was also not significant (F [2, 95.46] = 1.15, $p = .322$), indicating no significant variability in the associations between loneliness and DBP across phases.

For MAP, the model with only the intercept varied was the best fit (VAR (u_{0j}) = 139.50, χ^2 (1) = 156.55, $p < .001$). There was a significant main effect of phase (F [2, 98.12] = 174.53, $p < .001$), however there was no significant main effect of loneliness on MAP (F [1, 73.69] = 3.54, $p = .064$). The interaction between phase and loneliness was also not significant (F [2, 98.12] = 1.67, $p = .19$).

For HR, the model with only the intercept varied was the best fit (VAR (u_{0j}) = 139.50, χ^2 (1) = 156.55, $p < .001$). There was a significant main effect of phase (F [2, 91.03] = 29.97, $p < .001$), however, there was no significant main effect of loneliness on HR (F [1, 80.903] = 0.63, $p = .43$), The interaction between phase and loneliness was also not significant (F [2, 91.03] = 1.03, $p = .36$).

For CO, the model with only the intercept varied was the best fit (VAR (u_{0j}) = 0.65, χ^2 (1) = 251.45, $p < .001$). There was a significant main effect of phase (F [2, 81.91] = 8.76, $p < .001$). The main effect of loneliness on CO was not significant (F [1, 78.96] = 3.78, $p = .055$). The interaction between phase and loneliness was also not significant (F [2, 81.91] = 1.13, $p = .33$), indicating loneliness did not significantly predict differences in CO during any of phases.

For EJT, the model with only the intercept varied was the best fit (VAR (u_{0j}) = .0005, χ^2 (1) = 253.309, $p < .001$). There was a significant main effect of phase (F [2, 95.48] = 15.39, $p < .001$). The main effect of loneliness on EJT was significant (F [1, 80.21] = 3.78, $p = .013$), with the fixed effect estimates confirming that higher loneliness predicted lower *EJT* ($b = -.001$, t [88.33] = −2.41, $p = .018$). The interaction between phase and loneliness was not significant (F [2, 95.48] = 0.04, $p = .96$), indicating no significant variability in associations between loneliness and EJT across phases.

For TPR, the model with only intercepts varied was significant (VAR (u_{0j}) = .29, χ^2 (1) = 245.68, $p < .001$) as was the model with both intercepts and slopes varied, suggesting that the slopes also varied across participants, VAR (u_{1j}) = 0.004, χ^2 (1) = 7.81, $p < .05$), but intercepts and slopes did not significantly covary, Cov (u_{0j}, u_{ij}) = .009, χ^2 (1) = 1.28, $p > .05$). There was a significant main effect of phase (F [2, 86.26] = 35.89, $p < .001$), however, the main effect of loneliness on TPR was not significant (F [1, 58.63] = 2.43, $p = .13$). The interaction between phase and loneliness was also not significant (F [2, 86.26] = 0.43, $p = .66$), indicating no significant variability in associations between loneliness and TPR across phases.

3.2.2 | Psychological reactivity

Loneliness did not significantly predict psychological stress reactivity ($\beta = .16$, t [79] = 1.46, $p = .15$). Additionally, there was no significant association between loneliness and stressfulness appraisals of the mental arithmetic task ($\beta = .17$, $p = .13$) or the public speaking task ($\beta = .16$, $p = .19$).

3.3 | The three-item UCLA loneliness scale

To test if these findings would be replicated when using a shorter version of the same scale, the same analysis was rerun but using the loneliness score from the three-item UCLA loneliness scale.

3.3.1 | Cardiovascular activity

For SBP, there was significant variance in intercepts (VAR (u_{0j}) = 291.42, χ^2 (1) = 157.01, $p < .001$) suggesting that the relationship between loneliness and SBP varied across participants. This model showed the best fit. There was significant main effect of phase (F [2, 97.13] = 155.64, $p < .001$) but there was no main effect of loneliness on SBP (F [1, 76.64] = 0.41, $p = .52$), and the overall interaction between loneliness and phase, (F [2, 97.13] = 3.68, $p = .029$) ((indicative of lower SBP during the speech task relative to the maths task ($b = -1.92$, t [62.64] = −2.38, $p = .020$) but not relative to baseline ($b = -2.20$, t [84.57] = −2.14, $p = .036$)), did not withstand adjustment for multiple testing.

For DBP, there was significant variance in intercepts (VAR (u_{0j}) = 104.89, χ^2 (1) = 210.50, $p < .001$) suggesting that relationship between loneliness and DBP varied across participants. This model showed the best fit. There was significant main effect of phase (F [2, 95.03] = 140.09, $p < .001$) but there was no main effect of loneliness on DBP (F [1, 77/18] = 0.83, $p = .36$). The interaction between phase and loneliness was also not significant (F [2, 95.03] = 1.51, $p = .225$).

For MAP, there was significant variance in intercepts (VAR (u_{0j}) = 146.49, χ^2 (1) = 161.67, $p < .001$) suggesting that relationship between loneliness and MAP varied across participants. This model showed the best fit. There was significant main effect of phase (F [2, 97.96] = 175.26, $p < .001$) but there was no main effect of loneliness on MAP (F [1, 74.58] = 0.32, $p = .58$). The interaction

between phase and loneliness was also not significant (F [2, 97.96] = 2.37, p = .099).

For HR, there was significant variance in intercepts (VAR (u_{0j}) = 139.69, χ^2 (1) = 327.63, p < .001) suggesting that relationship between loneliness and HR varied across participants. This model showed the best fit. There was significant main effect of phase (F [2, 90.84] = 29.49, p < .001) but there was no main effect of loneliness on HR (F [1, 81.39] = 0.15, p = .696). The interaction between phase and loneliness was also not significant (F [2, 90.84] = 0.21, p = .813).

For CO, there was significant variance in intercepts (VAR (u_{0j}) = 0.67, χ^2 (1) = 258.23, p < .001) suggesting that relationship between loneliness and CO varied across participants. This model showed the best fit. There was significant main effect of phase (F [2, 81.57] = 9.04, p < .001) but there was no main effect of loneliness on HR (F [1, 79.27] = 1.24, p = .27). The interaction between phase and loneliness was also not significant (F [2, 81.57] = 2.28, p = .11).

For EJT, there was significant variance in intercepts (VAR (u_{0j}) = 0.0005, χ^2 (1) = 262.33, p < .001) suggesting that relationship between loneliness and EJT varied across participants. This model showed the best fit. There was significant main effect of phase (F [2, 94.84] = 15.41, p < .001) however, unlike for the 20-item UCLA, there was no main effect of loneliness on EJT (F [1, 80.48] = 2.03, p = .158). The interaction between phase and loneliness was also not significant (F (2, 94.84 = 0.55, p = .58).

For TPR, there was significant variance in intercepts (VAR (u_{0j}) = 0.0005, χ^2 (1) = 262.33, p < .001) suggesting that relationship between loneliness and TPR varied across participants. This model showed the best fit. There was significant main effect of phase (F [2, 85.38] = 26.21, p < .001). However, the main effect of loneliness on TPR was not significant at our conservative alpha level (F [1, 74.76] = 4.19, p = .044); this was confirmed with reference to the fixed effects (b = .110, t [80.16] = −2.08, p = .040). The interaction between phase and loneliness was also not significant (F [2, 85.38] = 0.39, p = .68), indicating no significant variability in associations between loneliness and TPR across phases.

3.3.2 | Psychological reactivity

As with the 20-item UCLA scale, loneliness as measured by UCLA three-item did not significantly predict psychological stress reactivity or stress appraisals of both tasks (p >. 05).

3.3.3 | Moderation by age

The analyses for both the UCLA 20-item and UCLA three-item was repeated with the interactions between age, loneliness, and phase included. Age did not moderate the relationship between loneliness and CVR (ps > .025).

4 | DISCUSSION

Loneliness has previously been associated with CVR in older adults; however, these findings are mixed. Here, we add to this literature by demonstrating null findings; loneliness was not significantly associated with CVR in older adults. This study advanced upon previous research by evaluating the underlying hemodynamic determinants of blood pressure and by comparing responses to different stressors and using two different versions of the UCLA loneliness scale commonly used to assess loneliness. The only effect to withstand adjustment for multiple testing was an association between loneliness and overall EJT; however, this was contingent on the version of the measure used to assess loneliness. Based on these results it is difficult to draw solid conclusions about the role of loneliness in CVR to acute stress; however, it is clear that greater consideration of the conceptual associations between loneliness and stress reactivity is needed, and that including multiple stressors and measures where possible, will highlight the extent to which loneliness-CVR findings are robust in older adult samples.

The initial analysis with the 20-item UCLA did not provide support for an association between increased feelings of loneliness and cardiovascular responses to stress in older adults. There were no significant differences in the magnitude of cardiovascular changes based on loneliness. This is not consistent with past research which has reported that loneliness predicts exaggerated SBP responses to stress in older adults (Ong et al., 2012); and we echo here the caution of Das (2018) who notes that often inconsistent findings in this area can be attributed too easily to variations in methods, when there currently remains insufficient evidence to strongly support that a significant effect might exist in the first place. With that being said, there are some methodology differences between the studies worth noting. For instance, Ong et al. (2012) used a more overt form of social evaluation, with the experimenter acting in such a way as to signal to the participant they were performing poorly. Previous studies have demonstrated that differences in the type of social evaluation can have a meaningful impact on physiological stress responses (Bosch et al., 2009; Dickerson et al., 2008). For instance, Bosch et al. (2009) found that having a larger audience elicited a greater change in HR. Therefore, associations between loneliness and CVR may be restricted to stressors involving explicit and/or intentionally negative forms of social evaluation. However, while this interpretation is consistent with conceptual literature on loneliness

and bias toward social threat (e.g., Bangee et al., 2014), it is inconsistent with some limited empirical data demonstrating associations for asocial but not social tasks (e.g., Nausheen et al., 2007).

After adjustment for multiple testing, loneliness did not significantly predict differences in TPR in older adults, including at baseline and during the stressors. This finding is inconsistent with our previous study (Brown et al., 2019) where increased loneliness predicted diminished TPR reactivity to the same speech task in younger adults or with other studies that found relationships between loneliness and greater TPR again in young adult samples (Cacioppo et al., 2002; Hawkley et al., 2003). Similarly, in contrast to previous studies (e.g., Hawkley et al., 2006, 2010; Ong et al., 2012), loneliness was not significantly related to overall resting blood pressure levels (i.e., SBP and DBP). While loneliness was significantly associated with lower overall EJT, in line with previous findings (Cacioppo et al., 2002), this was specific to the 20-item UCLA scale.

In addition, loneliness was not significantly associated with psychological measures of stress reactivity and this is in line with the findings of other previous studies (e.g., Steptoe et al., 2004). While lonely individuals have been previously reported to perceive events as more stressful compared to non-lonely individuals (Hawkley et al., 2003), the results of the current study suggest that level of loneliness do not significantly predict changes in these feelings of subjective stress in response to acute stressors.

The fact that the significant association with EJT was dependent on the form of the UCLA scale used highlights a potentially important issue surrounding the measurement of loneliness. While conceptualized as a unidimensional construct, a number of factor analyses of the 20-item UCLA loneliness scale have suggested the possibility that it consists of two or more different dimensions (e.g., Ong et al., 2016; Shevlin et al., 2014), and there is currently no consensus on the optimal number of factors. This problem is further complicated by the potential for acquiescent responding (the tendency to consistently disagree or agree with questionnaire items, despite their content); the R-UCLA contains nine positively worded, an 11 negatively worded items and so is reasonably well-balanced, but subscales may reflect patterns of acquiescent responding rather than conceptual differences. For example, according to the three-dimensional approach (isolation, relational connectedness and collective connectedness, by Hawkley et al. (2005), all three items included in UCLA three-item loneliness scale (Hughes et al., 2004) are a part of the same "perceived isolation" factor which focuses on feelings of aloneness.

As such, this specific dimension of loneliness that we assessed here may be particularly relevant for understanding any connections to atypical stress reactivity, while the other aspects may be more strongly related to other indirect pathways such as negative health behaviors (e.g., Dyal & Valente, 2015). Moreover, this suggests that while advantageous in terms of being less demanding and time consuming, the UCLA three-item may not be equivalent to the longer 20-item UCLA loneliness scale for use in lab-based studies with older adults (and may also be vulnerable to the acquiescent responding issue noted above). As the UCLA scale is frequently adopted as a unidimensional measure and as we did not have a priori hypotheses about different potential sub-domains of the UCLA scale, we did not test multiple versions or subscales beyond the three-item and 20-item in this study. Nonetheless, due consideration should be given to the choice of loneliness measure as well as the examination of subscales, when designing future studies.

4.1 | Limitations

Another methodological feature worth considering is the presentation of the stress tasks (counter-balanced, with no rest period in between). Although there was no clear rationale to include an inter-task rest period for our study, it is possible that without a rest period, participants may have to some degree habituated over time to the stressors, resulting in marginally lower reactivity overall than would have been the case for stressors with a rest period in between. However, given the tasks were counter-balanced, it seems unlikely that this has meaningful implications for the study findings exploring associations for the individual maths and speech tasks.

Another limitation of the current study is that it was cross-sectional in nature meaning any inferences about causality are impeded. Further, with multiple testing, caution is warranted when interpreting our results. This study also included participants in a relatively wide age range. However, the study is strengthened by the measurement of a greater range of cardiovascular variables than most prior research. Additionally, it also compared the relationship between loneliness and CVR across two different stress types and two different ways of measuring loneliness.

4.2 | Conclusion

Loneliness remains a potentially serious public health issue for older adults. This study, however, did not find any reliable association between loneliness on CVR to acute stress, a potential pathway behind any suggested loneliness and CVD associations. In light of mixed prior findings, this study highlights important methodological issues for future research, including the measurement of loneliness, the potential role of stressor types and a need for caution when interpreting loneliness-reactivity associations.

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AUTHOR CONTRIBUTIONS

Eoin G Brown: Conceptualization; data curation; formal analysis; funding acquisition; investigation; methodology; project administration; software; supervision; writing – original draft; writing – review and editing. **Ann-Marie Creaven:** Conceptualization; data curation; funding acquisition; investigation; methodology; supervision; writing – original draft; writing – review and editing. **Stephen Gallagher:** Conceptualization; data curation; funding acquisition; investigation; methodology; project administration; supervision; writing – original draft; writing – review and editing.

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