Accepted refereed manuscript of: Gallagher S, Creaven A, Howard S, Ginty AT & Whittaker AC (2021) Gratitude, social support and cardiovascular reactivity to acute psychological stress. *Biological Psychology*, 162, Art. No.: 108090.
https://doi.org/10.1016/j.biopsycho.2021.108090

Gratitude, social support and cardiovascular reactivity to acute psychological stress

Stephen Gallagher,[1,2]*, Ann-Marie Creaven, [1,2] Siobhán Howard,[1,2] Annie T. Ginty[3] and Anna, C. Whittaker,[4]

[1]Department of Psychology, Centre for Social Issues Research, Study of Anxiety, Stress and Health Laboratory, University of Limerick, Limerick, Ireland

[2]Health Research Institute, University of Limerick, Ireland

[3]Department of Psychology and Neuroscience, Baylor University, Waco, TX, USA

[4]Faculty of Health Sciences and Sport, University of Stirling, Stirling, Scotland, UK.

*Corresponding author Stephen Gallagher

E-mail address: stephen.gallagher@ul.ie

ORCID: https://orcid.org/0000-0002-5471-7774

Twitter @DrSGallagher

Ph: + 353 (0) 61 324899

Fax: +353 (0) 61 233211

Funding: The authors received no funding for this research

Abstract

The pathways linking gratitude to cardiovascular reactivity (CVR) to acute stress are not fully understood. We examine whether this association is mediated by social support. Healthy adults (*N* = 178) completed measures of trait gratitude and perceived social support and participated in a standardised mental arithmetic and speech stress testing protocol. Their CVR (i.e., systolic and diastolic blood pressure [SBP, DBP], heart rate [HR], cardiac output [CO] and total peripheral resistance [TPR]) were monitored throughout. Gratitude was positively associated with SBP, DBP and TPR reactivity, with those reporting higher gratitude showing higher CVR. Social support was positively associated with TPR to the maths task. The association between gratitude and TPR was mediated by social support but this was only evident in response to the maths task and not the speech task. These novel findings suggest that CVR may be a potential mechanism underlying the gratitude-physical health link.

Key Words: Blood pressure; cardiovascular reactivity; gratitude; social support; stress.

Introduction

An estimated 31% of all global deaths annually are due to cardiovascular diseases, with 17.5 million people dying from coronary heart disease (CHD) alone (WHO, 2016). One factor, although often overlooked (Brown et al., 2019), associated with the onset and development of CHD is psychological stress (Dimsdale, 2008; DuPont et al., 2020; Steptoe & Kivimäki, 2013; Turner et al., 2020). Stress has been defined as an interaction between an individual and their environment with stress occurring when people perceive that the demands from external situations are beyond their coping capacity (Lazarus & Folkman, 1984). In terms of health impact, stress, in both childhood and adulthood, has been associated with ~40–60% excess risk of CHD (Steptoe & Kivimäki, 2012). In fact, there is a twofold increased risk of CHD among those reporting three or more childhood adversities compared with those reporting none (Scott et al., 2011). In adults, the impact of chronic stressors such as loneliness and social isolation on CHD mortality is comparable to that of established risk factors such as smoking (Holt-Lunstad et al., 2010). One of the proposed pathways linking stress to CHD is cardiovascular reactivity (CVR) to acute psychological stress.

The reactivity hypothesis (Obrist, 1981; Phillips & Hughes, 2011), proposes that exaggerated or prolonged CVR contributes to the manifestation of CHD in both adults (Brindle et al., 2018; Gianaros et al., 2002; Krantz & Manuck, 1984) and children (Roemmich et al., 2009). This hypothesis has received substantial support over the years (Chida & Steptoe, 2010) with prospective studies finding that exaggerated reactivity to stress is associated with adverse cardiovascular outcomes including hypertension (Carroll, Ginty, Painter, et al., 2012), atherosclerosis (Barnett et al., 1997; Matthews et al., 1998), and mortality (Carroll, Ginty, Der, et al., 2012). However, recent research suggests that relatively low CVR to stress also has adverse health associations including obesity, depression, and addiction (e.g. smoking, alcohol) (Phillips & Hughes, 2011). These are also linked directly and indirectly to CHD through pathophysiological mechanisms (De Hert et al., 2018). Identifying positive psychosocial factors that may mitigate atypical stress reactions has been a focus of considerable research (Bajaj et al., 2019; Fredrickson, 1998; Fredrickson & Levenson, 1998; Kok et al., 2013; Puig-Perez et al., 2017).

One such factor which has attracted a growing level of interest for physical health and biological processes is gratitude (Jans-Beken et al., 2020; Park et al., 2014; Schache et al., 2019). Gratitude is conceptualized as a broad dispositional orientation towards perceiving and appreciating the positive in life (Wood et al., 2010). Dispositional gratitude is usually assessed by the GQ-6 with no specified time limits, whereas state gratitude can be captured by the gratitude adjective checklist (GAC) using a more limited timeframe (Froh et al., 2011; McCullough et al., 2002). In terms of physical health, gratitude has been associated with reduced physical symptoms as indexed by reduced headaches, muscle fatigue, and feelings of nausea (Emmons & McCullough, 2003) as well as better cardiovascular health (Jackowska et al., 2016; Mills et al., 2015). Recent research has begun to examine the direct physiological effects of gratitude as a way of understanding its implications for physical health. For example, heart failure patients who participated in a gratitude intervention had reduced inflammation and increased parasympathetic heart rate variability compared to those in the control group (Redwine et al., 2016). Similarly, in a study of pregnant women, gratitude journaling reduced the stress hormone cortisol (Matvienko-Sikar & Dockray, 2017). In fact, these studies are in line with current theory on positive emotions which are considered to be a buffer against the negative effects of stress (Folkman, 2008; Levenson, 2019; Pressman et al., 2019).

A grateful response to life circumstances is considered a fundamental process by which everyday experiences are positively interpreted (Emmons & McCullough, 2003). As such, gratitude as a positive emotion may facilitate how people deal with, and manage, stress (Folkman, 2008). Research examining gratitude as a buffer of cardiovascular stress reactivity is limited; however, one recent study reported that state, but not trait, gratitude was associated with lower CVR to a mental arithmetic stress task (Ginty et al., 2020). A similar finding was also recently reported, with state-like gratitude proving most predictive of lower CVR (Gallagher et al., 2020), indicating it may be a stress buffer. However, this study had a relatively small sample, and the underlying hemodynamic variables (i.e., cardiac output [CO] and total peripheral resistance [TPR], which are fundamental to obtaining greater insight into the pathophysiology of hypertension) (Pollock et al., 2020), were not examined. Moreover, reduced TPR and increased CO have been associated with emotional and social factors (Brown et al., 2019; Weisbuch et al., 2009) and so may be relevant to the present context. Thus, given the call for researchers to examine the pathways underling the gratitude-health link (Jans-Beken et al., 2020; Schache et al., 2019) and the paucity of research in the area, further research into the influence of gratitude on CVR to acute stress is needed.

Gratitude has also been found to reduce feelings of social isolation (Frinking et al., 2020) and enhance social relationships (O'Connell et al., 2017). Similarly, those expressing gratitude towards others in diaries were found to have increased relationship satisfaction relative to active controls (O’Connell et al., 2016). Other studies have found that gratitude fortifies existing relationships by fostering social bonds and socially inclusive behaviours (Bartlett et al., 2012), and encourages relationship formation and connections (Algoe, 2012). Thus, it might be that gratitude is influencing CVR via social support which has known associations with CVR (Gallagher et al., 2014; Uchino, 2009).

Social support is the processes by which social relationships promote health and well-being (Cohen, 2004). A meta-analysis examining experimental manipulations of social support (e.g., provision of active or passive support compared to no support) on CVR to laboratory stress found that it was associated with reduced hemodynamic reactivity (Thorsteinsson & James, 1999). In line with this notion, perceived social support in real life was associated with lower cardiovascular responses to a stress task (Howard et al., 2017; O'Donovan & Hughes, 2008). Moreover, social support is a multi-dimensional construct including instrumental, tangible and emotional facets, with emotional support viewed as more nurturing than either informational or tangible support (Trobst, 2000). Emotional support also has stronger cardioprotective effects (Horsten et al., 2000). While the stress-buffering effect of manipulated social support on CVR has been extensively researched (Gallagher et al., 2014; Holt-Lunstad et al., 2008; Uchino, 2006; Uchino et al., 1996; Uchino et al., 2011) little research has been conducted on the effects of perceived availability of social support.

Gratitude is seen as a social emotion (Emmons & McCullough, 2004) and such emotions help us connect with others (Petersen et al., 2019). As such, gratitude might increase perceptions of social support. At least two recent studies are consistent with this idea. First, social support was identified as a mediator of the association between gratitude and depressive symptoms, such that those higher on gratitude reported higher social support and lower depression (McCanlies et al., 2018). Second, lower loneliness and lower perceived stress were found to be sequential mediators of the association between gratitude and physical health symptoms. Those higher on trait gratitude, reported less loneliness, perceived the stress in their lives to be lower, and had better physical health. Based on the above evidence it is plausible that the association between gratitude and CVR may be mediated by social support such that those reporting higher gratitude will also report higher social support and subsequently have lower CVR to acute stress. This fits with calls to examine the links between gratitude (Parks et al, 2014), social support (Uchino et al., 2012), and physical health.

One limitation of previous research investigating the association between gratitude and CVR is the use of a largely asocial stress task by some (Gallagher et al., 2020) and a more social task by others (Ginty et al., 2020). The social context of a stress-task can be an important moderator of the relationship between psychological factors and CVR. For example, socially relevant personality traits such as Type D, show differing associations depending on the social nature of the task (Bibbey et al., 2015; O'Riordan et al., 2019). Loneliness, also a construct that reflects a social dimension, has shown differing associations with CVR depending on whether the stressor was social or asocial (Brown et al., 2019). Therefore, it remains to be established if observed associations between gratitude and CVR generalize across both asocial and social contexts within the same study.

Therefore, our aim is to replicate and extend limited prior research evaluating associations between gratitude and CVR to both social and asocial stressors by evaluating the same association across two different stress tasks; social and asocial. We hypothesized the following: 1) both gratitude and social support are inversely associated with CVR to acute psychological stress and that these effects are more pronounced for the asocial task; and 2) the association between gratitude and CVR is mediated by perceived social support.

Materials and methods

Participants

Data were collected from 178 healthy adults (63.5 % female), recruited from a university setting over an 18-month year period starting in October, 2017. G-power calculations confirmed that a minimum sample size of 146 participants was needed to detect a significant effect (p = .05, f^2=0.06) at 80% power. The present manuscript is part of a larger study observing demographic and psychosocial factors associated with cardiovascular responses to acute psychological stress. Participants were recruited by means of a course credit system, by word of mouth, and the advertisement of the study throughout the campus. Participants ranged in age from 18-40 years (*M* = 21.7, *SD* = 5.38) with a mean body mass index (BMI) of 23.6kg/m^2 (*SD* = 3.73), the majority were White Irish (95.2%) and 64% were single.

Participants were excluded if they were pregnant, currently ill, or had cardiovascular problems. In preparation for the testing session, they were asked to refrain from alcohol intake and vigorous exercise for 12 hours prior to testing, as well as no smoking (17% were current smokers, 7.8% previous smokers) or consuming caffeine for 2 hours before testing. Smoking was coded as, 1= yes, 2= previous, 3= no). Those who did not adhere to these restrictions were rescheduled for another lab visit. They were asked whether there was a history of cardiovascular disease in the family (12.8%). These precautions were to control for confounding and are in line with existing research (Gallagher et al., 2019). All participants provided written informed consent and the study was approved by the university's research ethics committee.

Design

A within-subjects correlational design was used with the main predictor variables being gratitude and social support. The dependent variables were measures of CVR including systolic and diastolic blood pressure (SBP, DBP), heart rate (HR), cardiac output (CO), and total peripheral resistance (TPR). Reactivity scores were computed as the difference between mean baseline and mean task values for each cardiovascular parameter, in line with previous research (Carroll et al., 2005; Gallagher et al., 2014) .

Materials and Apparatus

Demographic and Anthropometric Variables

Standardised weighing scales and portable stadiometer were used to measure height and weight for calculation of BMI. Socio-demographic information such as age, gender, ethnicity, relationship status, smoking status and family history of cardiovascular disease were gathered using an in-house standardised questionnaire. These assessments, as in previous studies in the field (Brown et al., 2019; Carroll, Ginty, Painter, et al., 2012), are collected to control for potential confounding.

Gratitude

Gratitude was assessed using the Gratitude Questionnaire-Six Item Form trait-like measure (GQ-6 (McCullough et al., 2002). This self-report scale examines general thankfulness and gratitude, under four facets of grateful tendencies- intensity, density, span, and frequency. Respondents are asked to indicate how much they agree with six statements, two of which are reverse scored. An item example includes; 'I have so much in life to be thankful for'. Respondents provide their answer on a 7-point scale ranging from '*Strongly disagree'*= 1 to '*Strongly agree'* = 7. In line with prior research using this measure (e.g., (O'Connell & Killeen-Byrt, 2018), items were summed to give a total gratitude score with higher scores indicating higher gratitude. The scale is internally consistent with Cronbach's alpha α = .82 in previous research (McCullough et al., 2002) with a similar alpha coefficient in the present sample, α = 0.78.

Social support

The 16-item NIH Toolbox, social support scale was used (Cyranowski et al., 2013). The scale has two perceived social support subscales: instrumental (e.g., I have someone to help me if I'm sick in bed) and emotional support (e.g., I have someone who understands my problems). These items are rated on a 5-point Likert-type scale; responses from 1= '*Never'*, *2 ='Rarely'*, *3='Sometimes'*, *4 =Usually'*, *and 5 ='Always* and items are scored to give a total score. Excellent internal consistency has been reported at α = .95 (Cyranowski et al., 2013) and similar here, α = .91. The two subscales were positively correlated ($r = .44$, $p < .001$) with a high reliability for both the emotional (α = .90) and instrumental (α = .92) subscales.

Stress Task Measures

Immediately before and after both stress tasks (i.e., PASAT and speech), participants were asked to indicate how stressful and how engaging they expected to find or found the task, using separate single items scored on a 7-point Likert scale 0 (*Not at all*) to 6 (*Extremely*). These were captured to confirm that our stress task was psychologically stressful and engaging and such items have been used in similar studies (e.g., Phillips et al., 2009).

Cardiovascular Assessment

A Finometer Pro hemodynamic cardiovascular monitor (Finapres Medical Systems BV, BT Arnhem, The Netherlands) was used to capture measures of SBP, DBP, HR, CO, and TPR. The Finometer takes beat-to-beat continuous non-invasive measurements from finger arterial pressure attached to the middle finger of the participant's non-dominant hand. Another cuff is attached to the participant's upper arm to calibrate reconstructions of the intra-brachial pressure derived from the finger cuff. This is also accompanied by a hydrostatic height correction system to correct hand height to heart level which accurately assesses absolute blood pressure (Schutte et al., 2004) and meets the validation criteria of the Association for the Advancement of Medical Instrumentation (Brittain et al., 2018).

Stress Task

An adapted version of the Trier Social Stress Task (Kirschbaum et al., 1993) was used as our stressor; here we used the paced auditory serial addition test (PASAT; (Gronwall,

1977) as our math task. This task has been used within laboratory-based studies and has been found to successfully perturb the cardiovascular system (Gallagher et al., 2014; Phillips et al., 2009). During the task, participants listen to a 5-minute audio track where single digit numbers are read aloud via computer. Participants listen and are required to retain the previous number and add it to the subsequent number and say the answer out loud. The numbers were presented at a rate of 2.4 seconds during the first minute with the speed of presentation increasing by .4 seconds for each subsequent minute. In order to make this task less social or socially evaluative, our experimenter, unlike in previous studies (Phillips et al., 2009), was not obtrusively marking the participants. Further, to reduce the social evaluative nature (Bosch et al., 2009), the experimenter was sitting behind a screen while recording the answers. For our socially relevant stressor, participants had to give a 4-minute speech, where they were given two minutes to prepare. For this task, while in the same position and under the same conditions described above for the math task, they were instructed to describe and provide real-life examples of three of their best and worst characteristics (Bosch et al., 2009). These speech tasks have been found to be more socially relevant than mental arithmetic tasks with resulting different CVR consequences. This appears to be the case as articulating personal information about your best and worst characteristics has social implications (Al'Absi et al., 1997). Moreover, speech tasks also have a greater social-evaluative threat aspect (Dickerson & Kemeny, 2004). If participants ceased speaking at any time during the four-minute period, they were immediately prompted by the experimenter to continue. Only the four-minute speaking period was used for calculation of CVR. The order of these tasks was counterbalanced. To heighten the sense of stress, the testing was conducted in reduced light with a spotlight illuminating the candidate and experimenters all wearing white laboratory coats.

Procedure

Participants were sent a study information sheet prior to arrival at the laboratory. Those who agreed to take part and were deemed eligible were asked to attend a 45-minute testing session at our health and psychophysiology laboratory. On arrival, participants were asked to confirm they had adhered to the health behaviour protocol described above, those not adhering were rescheduled. Once consented, they completed a demographic questionnaire, and were heighted and weighted for calculation of BMI. Participants were then seated at a desk by the spotlight and were requested to place their feet in a box to control for unnecessary movements that may affect cardiovascular measures (Hayes & Rockwood, 2017; Pickering et al., 2005). Following a 20-minute acclimatization period where the upcoming task was explained, participants sat quietly reading magazines and cardiovascular acclimatization measuring took place. The psychometric scales (e.g., gratitude) were completed during the acclimatization phase. Formal baseline cardiovascular measures were then recorded for 10 minutes. Following the formal baseline, and 1-minute before the stress task began, the researcher asked the participant to complete the pre-stress task rating questionnaire for both PASAT and speech. After the stress task, the participant completed the post-task stress questionnaire, had the blood pressure cuff removed, and were thanked for their participation and debriefed.

Data analyses

Prior to analyses, data were screened for normality and assumptions of fit. While our data for all CVR indices were normally distributed, i.e., all *p*'s for Kolmogorov-Smirnov and Shapiro- tests were >. 18, several of the baseline values were high (e.g., SBP, DBP, HR and TPR) with Z scores $\geq$ 3 SD. Thus, we ran our analyses with and without these outliers (9 in total) and our results became stronger without them. When included, gratitude was the most consistent variable to be associated with several of the CVR indices, with support only associated with TPR reactivity: when excluded, both gratitude and social support were predictive across several CVR indices. Therefore, we ran our analyses with outliers removed on a final sample of 169 (105 females). In our initial analyses were tests of difference and correlations checking for gender, lifestyle, BMI and socio-demographic differences/associations with our CVR outcome variables. Next repeated-measures analysis of variance (ANOVA) confirmed whether our task perturbed the cardiovascular system and if it was psychologically stressful. This was then followed by a series of hierarchical linear regressions to test our main hypotheses in which we analysed the CVR (change scores; task minus baseline) to the pooled tasks and each predictor (gratitude and social support) separately. In these, confounding variables which were associated with cardiovascular indices (age, gender, BMI, smoking, task order, and baseline cardiovascular indices) were entered at Step 1, followed by the predictor variables separately at Step 2. We then repeated the same analyses for speech and PASAT separately. In sensitivity analysis for social support, the same analyses were performed for emotional and instrumental support separately. Mediation analysis was conducted using Model 4 in PROCESS (Hayes, 2017). Partial eta-squared and R-squared are reported throughout as effect sizes.

Results

Descriptive Statistics

Descriptive statistics for psychological and cardiovascular variables are reported in Table 1. Trait gratitude scores are similar to other studies in young adults (O’Connell et al., 2016) and our social support mean score is higher than found elsewhere (Cyranowski et al., 2013). The correlation between support and gratitude was r = .23, p =.003, with higher levels of social support associated with higher gratitude. While there was no difference in gratitude score between men and women, men tended to report slightly lower gratitude scores (34.21 (5.93) versus 35.85 (4.66); $F(1, 164) = 3.88$, $p = .05$, $\eta_p^2 = .02$) compared to women. Women had higher social support (65.35 (9.26) versus 61.61 (10.33); $F(1, 164) = 5.81$, $p = .017$, $\eta_p^2 = .03$) compared to men.

[Insert Table 1 about here]

Manipulation check

A series of repeated-measures (baseline, task) ANOVAs confirmed that the pooled stress task increased cardiovascular responses for: SBP, $F(1, 167) = 400.79$, $p < .001$, $\eta_p^2 = .71$; DBP, $F(1, 167) = 471.17$, $p < .001$, $\eta_p^2 = .74$; HR, $F(1,167) = 111.19$, $p < .001$, $\eta_p^2 = .40$; CO, $F(1,167) = 34.83$, $p < .001$, $\eta_p^2 = .17$; and TPR, $F(1,167) = 40.91$, $p < .001$, $\eta_p^2 = .20$. Further, repeated-measures ANOVAs also revealed a significant increase from pre- to post-task rating of pooled self-reported stress, $F(1, 164) = 96.84$, $p < .001$, $\eta_p^2 = .37$.

There were no differences in CVR across stress tasks, however, participants rated the PASAT as more stressful than the speech task; mean (*SD*), 4.57 (1.26) vs 4.13 (1.46), $F(1, 168) = 12.38$, $p < .001$, $\eta_p^2 = .07$, with no significant differences in terms of how engaging they found the task.

Age, family history of CVD, relationship status, smoking status, and ethnicity were not correlated with our baseline cardiovascular indices. However, BMI was associated with lower HR and TPR as well as higher CO (all *p*s < .05). Men had lower HR, TPR, and higher CO (all *p*'s <.05) In terms of CVR, age was negatively associated with DBP; BMI was positively associated with SBP and CO; and smoking was positively associated with HR (all *p*'s <.05). Thus, given the associations of age, gender, smoking, and BMI with our cardiovascular indices, these confounding factors, along with task order, were controlled for in relevant analyses.

Associations between gratitude, social support and cardiovascular reactivity to the pooled stress task.

A series of hierarchical linear regressions, with confounders added at Step 1 and each predictor variable (gratitude, social support) individually at Step 2, were conducted on the pooled stress task reactivity. There were no associations between gratitude and either HR or CO reactivity. There were significant positive associations between gratitude and SBP, β = .16, 95% CI [0.02, .72], $t = 2.17$, $p = .03$; DBP, β = .17, 95% CI [0.02, .42], $t = 2.17$, $p = .03$ and TPR, β = .18, 95% CI [0.001, .013], $t = 2.29$, $p = .02$, such that those expressing higher levels of trait gratitude had higher reactivity to the pooled stress task. These added an additional 2%, 3% and 3% variance in explaining SBP, DBP and TPR reactivity, respectively. In the social support models, there were no associations between support and SBP, DBP, HR and CO. However, support was positively associated with TPR reactivity, β = .18, 95% CI [.001, .007], $t = 2.38$, $p = .02$, such that those with higher social support had higher TPR reactivity, contrary to our hypotheses. Social support explained an additional 3% above and beyond the confounding factors. In sensitivity analysis of the social support subscales, where each one was entered separately, emotional support was the key driver of these associations with TPR reactivity (β = .17, 95% CI [.001, .013], $t = 2.13$, $p = .02$), whereas instrumental support was not statistically significant (β = .15, 95% CI [.00, .010], $t = 1.89$, $p = .06$).

Associations between gratitude, social support and cardiovascular reactivity to speech and PASAT.

A similar set of hierarchical linear regressions were conducted with confounders added at Step 1 and each predictor variable individually at Step 2, for speech and PASAT separately. In these models, there were no associations between gratitude or social support and any of the CVR indices to the speech task. However, for gratitude, although there were no associations with HR, CO and TPR to the PASAT, it was associated with both SBP, β = .17, 95% CI [0.03, .75], t = 2.12, p = .03 and DBP, β = .20, 95% CI [0.06, .50], t = 2.50, p = .01, such that those who reported higher levels of gratitude had higher reactivity to the PASAT. These added an additional 3% and 4% each to the variance in explaining SBP and DBP reactivity to the PASAT. Further, support was positively associated with TPR reactivity to the PASAT, β = .17, 95% CI [.001, -.012], t = 2.18, p = .03, such that those with higher social support had higher TPR reactivity to the PASAT.

In addition, emotional support, β = .20, 95% CI [.003, .026], t = 2.58, p = .01, but not instrumental support, was responsible for the association between social support and TPR reactivity. Given these observations, we checked to see if the scores on the PASAT were associated with reactivity. PASAT scores were positively associated with DBP, β = .16, 95% CI [0.00, .09], t = 1.98, p = .04, but not with TPR reactivity. There was a positive trend for SBP, β = .13, 95% CI [-0.012, .14], t = 1.66, p = .09. We re-analysed our SBP and DBP findings and entered PASAT scores at Step 3, and our gratitude results were attenuated but still withstood adjustment; SBP, β = .11, 95% CI [0.04, .49], t = 2.06, p = .04; and DBP, β = .18, 95% CI [0.03, .47], t = 2.27, p = .02. PASAT scores remained significant in the DBP model. In the social support model, we entered emotional support due to its stronger association with TPR, and again this withstood adjustment, β = .20, 95% CI [0.004, .26], t = 2.60, p = .01. The associations for gratitude are illustrated in Figure 1a and 1b.

[Insert Figure 1 About Here]

Mediation Analyses for CVR to the PASAT

Given that only SBP, DBP, and TPR were significantly related to either gratitude or emotional social support in the above analyses, we focused on these indices in mediation analyses. There was no evidence of mediation for emotional social support on SBP or DBP. However, for TPR there was an indirect relationship through emotional social support (see Figure 2). Specifically, the findings for TPR suggest that emotional social support is a pathway from which gratitude influences TPR reactivity to an asocial task. These findings withstood adjustment for confounding. Given the cross-sectional nature of the data, we also checked the alternative model (i.e., would gratitude mediate the association between emotional social support and TPR reactivity). This model was not supported (indirect effect: B = .001 [-.002, .004]).

[Insert Figure 2 about here]

Discussion

Our aims were to build on previous research on gratitude and its associations with CVR to acute stressors, testing to see if perceived support was as a mediator of this relationship. Although we found that both gratitude and perceived support were associated with some aspects of CVR, these associations were not observed across all measured indices. Contrary to our hypotheses, both constructs were positively, rather than negatively, associated with CVR; those reporting higher gratitude had higher SBP and DBP reactivity. Similarly, those reporting higher levels of perceived social support, in particular emotional support, had higher TPR reactivity to the asocial mental arithmetic task.

Previous studies have found state gratitude (Gallagher et al., 2020; Ginty et al., 2020) and perceived social support (e.g., Howard et al., 2017) to be associated with lower CVR to acute stress in contrast to this study. Unexpectedly, however, the present effects were not consistent with the stress-buffering hypothesis, as those with higher gratitude and social support had higher CVR. We also found evidence of mediation through which gratitude influences social support and TPR reactivity. While not in the expected direction, this is the first study to show that trait gratitude influences TPR responses to acute psychological stress and identifies social support as a mediator of this relationship. In terms of social support dimensions, it is consistent with other studies showing that emotional support has strong effects on cardiovascular reactivity (Phillips et al., 2009). It is also in line with other psychophysiological studies where emotional support, but not instrumental support, was found to be associated with higher immune responses (Gallagher et al., 2008).

While our findings are not in the expected direction, the circumplex model of emotion (Pressman & Cohen, 2005) is one explanation for increased CVR in response to positive psychological constructs. According to this model, activated emotions (e.g., excitement, joy) are associated with increases in HR and BP, whereas low-activation emotions like pleasantness are associated with a dampening of the cardiovascular response. Our measure of gratitude was a trait-like measure, unlike the activated emotions in the circumplex model. However, studies have found that trait gratitude predicts feelings of joy (Watkins et al., 2018), which is one of the activated emotions associated with increases in BP. Moreover, the two recent studies examining the gratitude-CVR link (Gallagher et al., 2020; Ginty et al., 2020) found that it was state gratitude that was associated with lower CVR responding. We are unsure as to why there would be different CVR responses associated with state and trait gratitude but perhaps there are other unmeasured emotional consequences which may influence the stress appraisal and CVR. Although we did not measure other emotion constructs in our study, future research including more detailed profiles of emotion, in addition to gratitude, may clarify the associations between gratitude and CVR.

Even though higher CVR has been found to be cardio-toxic, it is worth noting that lower CVR reactions also have adverse health correlates (Phillips & Hughes, 2011). It may be the case that what we are evidencing here is a moderate, or healthy, response to stress

(Lovallo, 2011). As such, our findings may be in line with studies showing the cardio-protective effects of positive psychological factors. In line with this, it could be that gratitude is an active emotion; recent research has found gratitude to be a motivating emotion where an individual specifically focuses on positive behaviours that lead to self-improvement (Armenta et al., 2017). In fact, research from motivational intensity theory, which is a conceptual framework for examining the impact of effort (Richter et al., 2016), may be helpful here. Such studies have found that when primed with positive emotions such as happiness, participants completing challenging achievement-type tasks (such as our mental arithmetic task) exhibit increased CVR (Framorando & Gendolla, 2019). These authors suggest that such challenges require mobilisation of effort and positive emotions may facilitate this. In a related study, happiness primes led to increased CVR to a more difficult task when compared to an easy task (Gendolla, 2012). These studies suggest that gratitude, which is a positive emotional trait, may increase engagement and lead to higher CVR. However, given our findings were restricted to the maths task, and no significant differences in task engagement were observed between maths and speech tasks, further research on why maths tasks appear to be more strongly influenced by gratitude (Gallagher et al., 2020; Ginty et al., 2020) compared to speech tasks is needed. Further, with performance on the PASAT also linked to higher CVR, the notion above of greater engagement in the presence of positive emotions leading to increased CVR may still be relevant.

Similarly, not all studies find a buffering effect of social support on CVR, rather, some find that support can be associated with higher CVR (Lee et al., 2015; Roy et al., 1998). Roy and colleagues suggest that social support may also facilitate engagement with stressors and assist with active coping, which may be the case here (Roy et al., 1998). Active stressors (e.g., speech/maths) are those where you can influence an outcome whereas with passive (e.g., cold pressor) stressors, you must merely endure (Obrist, 1981). This may also be relevant to gratitude and why our TPR mediation model was also associated with increased, rather than lower, CVR.

In terms of study limitations, the observational design means causation cannot be inferred (Christenfeld et al., 2004). In fact, despite our mediation model inferring a causal process, we cannot infer causality using this cross-sectional design. Importantly, this study relied on self-report measures of both dispositional gratitude and perceived social support. Although gratitude can be captured in several ways (e.g., diaries, expression of gratitude), the scales we chose are used extensively in this type of research. However, the limitations of self-report measures, including issues of social desirability bias, are acknowledged. Further, while we found that the maths task was a key driver of our CVR, and we speculate that the effort involved in this stressor sheds some light on why we found higher CVR, there may be alternative interpretations or unmeasured variable that better explain this association. Moreover, while the math task was reported as more stressful, there may be other aspects to the tasks such as perceived challenge and threat (Trotman et al., 2018) which have distinct patterns of cardiovascular responding (Meijen et al., 2020). Thus, it might be that our math and speech tasks could have been appraised differently with varying levels of high and low threat and challenge. Future research could specifically target the impact of varying levels of high and low threat and challenge, and the nature of active and passive stress tasks by employing the hemodynamic profile-compensation deficit (HP-CD) model using CO and TPR (James et al., 2012; Why & Chen, 2013). This may be particularly relevant for a psychological construct such as gratitude. Further, including assessment of constructs like depression, which has been associated with blunted reactivity in previous studies(Carroll et al., 2007), is important given depression may be associated both with lower gratitude and social support.

In conclusion, the present study adds to emerging evidence linking gratitude to health outcomes as well as to research on perceived social support and CVR to acute stress. Further, studies that also include assessment of related constructs such as trait personality, emotions, and depression, may help clarify associations between CVR and both gratitude, and perceived social support. Moreover, our gratitude and CVR findings provides evidence for an indirect pathway behind gratitude-health links (Schache et al., 2019). Finally, given the health promoting effects of keeping gratitude diaries for health (Jans-Beken et al., 2020), this concept aligns well with a recent call by some cardiologists for harnessing low-cost mind-body medicine to improve cardiovascular health (Prasad, 2016).

Declaration of interest: The authors report no competing interests

References

Al'Absi, M., Bongard, S., Buchanan, T., Pincomb, G. A., Licinio, J., & Lovallo, W. R. (1997). Cardiovascular and neuroendocrine adjustment to public speaking and mental arithmetic stressors [https://doi.org/10.1111/j.1469-8986.1997.tb02397.x]. *Psychophysiology*, *34*(3), 266-275. https://doi.org/https://doi.org/10.1111/j.1469-8986.1997.tb02397.x

Algoe, S. B. (2012). Find, Remind, and Bind: The Functions of Gratitude in Everyday Relationships [https://doi.org/10.1111/j.1751-9004.2012.00439.x]. *Social and Personality Psychology Compass*, *6*(6), 455-469. https://doi.org/https://doi.org/10.1111/j.1751-9004.2012.00439.x

Armenta, C. N., Fritz, M. M., & Lyubomirsky, S. (2017). Functions of Positive Emotions: Gratitude as a Motivator of Self-Improvement and Positive Change. *Emotion Review*, *9*(3), 183-190. https://doi.org/10.1177/1754073916669596

Bajaj, A., Bronson, C. A., Habel, M., Rahman, S., Weisberg, H. R., & Contrada, R. J. (2019). Dispositional Optimism and Cardiovascular Reactivity Accompanying Anger and Sadness in Young Adults. *Ann Behav Med*, *53*(5), 466-475. https://doi.org/10.1093/abm/kay058

Barnett, P. A., Spence, J. D., Manuck, S. B., & Jennings, J. R. (1997). Psychological stress and the progression of carotid artery disease. *J Hypertens*, *15*(1), 49-55. https://doi.org/10.1097/00004872-199715010-00004

Bartlett, M. Y., Condon, P., Cruz, J., Baumann, J., & Desteno, D. (2012). Gratitude: Prompting behaviours that build relationships. *Cognition and Emotion*, *26*(1), 2-13. https://doi.org/10.1080/02699931.2011.561297

Bibbey, A., Carroll, D., Ginty, A. T., & Phillips, A. C. (2015). Cardiovascular and Cortisol Reactions to Acute Psychological Stress Under Conditions of High Versus Low Social Evaluative Threat: Associations With the Type D Personality Construct. *Psychosomatic Medicine*, *77*(5). https://journals.lww.com/psychosomaticmedicine/Fulltext/2015/06000/Cardiovascular_and_Cortisol_Reactions_to_Acute.14.aspx

Bosch, J. A., de Geus, E. J. C., Carroll, D., Goedhart, A. D., Anane, L. A., Veldhuizen van Zanten, J. J., Helmerhorst, E. J., & Edwards, K. M. (2009). A General Enhancement of Autonomic and Cortisol Responses During Social Evaluative Threat. *Psychosomatic Medicine*, *71*(8). https://journals.lww.com/psychosomaticmedicine/Fulltext/2009/10000/A_General_Enhancement_of_Autonomic_and_Cortisol.10.aspx

Brindle, R. C., Duggan, K. A., Cribbet, M. R., Kline, C. E., Krafty, R. T., Thayer, J. F., Mulukutla, S. R., & Hall, M. H. (2018). Cardiovascular Stress Reactivity and Carotid Intima-Media Thickness: The Buffering Role of Slow-Wave Sleep. *Psychosomatic Medicine*, *80*(3), 301-306. https://doi.org/10.1097/PSY.0000000000000560

Brittain, J. M., Busk, T. M., & Møller, S. (2018). Validation of non-invasive haemodynamic methods in patients with liver disease: the Finometer and the Task Force Monitor [https://doi.org/10.1111/cpf.12425]. *Clinical Physiology and Functional Imaging*, *38*(3), 384-389. https://doi.org/https://doi.org/10.1111/cpf.12425

Brown, E. G., Creaven, A. M., & Gallagher, S. (2019). Loneliness and cardiovascular reactivity to acute stress in younger adults. *Int J Psychophysiol*, *135*, 121-125. https://doi.org/10.1016/j.ijpsycho.2018.07.471

Carroll, D., Ginty, A. T., Der, G., Hunt, K., Benzeval, M., & Phillips, A. C. (2012). Increased blood pressure reactions to acute mental stress are associated with 16-year

cardiovascular disease mortality. *Psychophysiology, 49*(10), 1444-1448. https://doi.org/10.1111/j.1469-8986.2012.01463.x
Carroll, D., Ginty, A. T., Painter, R. C., Roseboom, T. J., Phillips, A. C., & de Rooij, S. R. (2012). Systolic blood pressure reactions to acute stress are associated with future hypertension status in the Dutch Famine Birth Cohort Study. *Int J Psychophysiol, 85*(2), 270-273. https://doi.org/10.1016/j.ijpsycho.2012.04.001
Carroll, D., Phillips, A. C., Hunt, K., & Der, G. (2007). Symptoms of depression and cardiovascular reactions to acute psychological stress: Evidence from a population study. *Biological Psychology, 75*(1), 68-74. https://doi.org/https://doi.org/10.1016/j.biopsycho.2006.12.002
Carroll, D., Phillips, A. C., Ring, C., Der, G., & Hunt, K. (2005). Life events and hemodynamic stress reactivity in the middle-aged and elderly [https://doi.org/10.1111/j.1469-8986.2005.00282.x]. *Psychophysiology, 42*(3), 269-276. https://doi.org/https://doi.org/10.1111/j.1469-8986.2005.00282.x
Chida, Y., & Steptoe, A. (2010). Greater cardiovascular responses to laboratory mental stress are associated with poor subsequent cardiovascular risk status: a meta-analysis of prospective evidence. *Hypertension, 55*(4), 1026-1032. https://doi.org/10.1161/HYPERTENSIONAHA.109.146621
Christenfeld, N. J. S., Sloan, R. P., Carroll, D., & Greenland, S. (2004). Risk Factors, Confounding, and the Illusion of Statistical Control. *Psychosomatic Medicine, 66*(6). https://journals.lww.com/psychosomaticmedicine/Fulltext/2004/11000/Risk_Factors,_Confounding,_and_the_Illusion_of.11.aspx
Cohen, S. (2004). Social relationships and health. *Am Psychol, 59*(8), 676-684. https://doi.org/10.1037/0003-066X.59.8.676
Cyranowski, J. M., Zill, N., Bode, R., Butt, Z., Kelly, M. A. R., Pilkonis, P. A., Salsman, J. M., & Cella, D. (2013). Assessing social support, companionship, and distress: National Institute of Health (NIH) Toolbox Adult Social Relationship Scales. *Health psychology : official journal of the Division of Health Psychology, American Psychological Association, 32*(3), 293-301. https://doi.org/10.1037/a0028586
De Hert, M., Detraux, J., & Vancampfort, D. (2018). The intriguing relationship between coronary heart disease and mental disorders. *Dialogues Clin Neurosci, 20*(1), 31-40. https://www.ncbi.nlm.nih.gov/pubmed/29946209
Dickerson, S. S., & Kemeny, M. E. (2004). Acute stressors and cortisol responses: a theoretical integration and synthesis of laboratory research. *Psychol Bull, 130*(3), 355-391. https://doi.org/10.1037/0033-2909.130.3.355
Dimsdale, J. E. (2008). Psychological stress and cardiovascular disease. *Journal of the American College of Cardiology, 51*(13), 1237-1246. https://doi.org/10.1016/j.jacc.2007.12.024
DuPont, C. M., Wright, A. G. C., Manuck, S. B., Muldoon, M. F., Jennings, J. R., & Gianaros, P. J. (2020). Is stressor-evoked cardiovascular reactivity a pathway linking positive and negative emotionality to preclinical cardiovascular disease risk? [https://doi.org/10.1111/psyp.13741]. *Psychophysiology, n/a*(n/a), e13741. https://doi.org/https://doi.org/10.1111/psyp.13741
Emmons, R., & McCullough, M. (2004). The Psychology of Gratitude. New York, NY: Oxford University Press.
Emmons, R. A., & McCullough, M. E. (2003). Counting blessings versus burdens: an experimental investigation of gratitude and subjective well-being in daily life. *J Pers Soc Psychol, 84*(2), 377-389. https://doi.org/10.1037//0022-3514.84.2.377
Folkman, S. (2008). The case for positive emotions in the stress process. *Anxiety, Stress, & Coping, 21*(1), 3-14. https://doi.org/10.1080/10615800701740457

Framorando, D., & Gendolla, G. H. E. (2019). It's about effort: Impact of implicit affect on cardiovascular response is context dependent [https://doi.org/10.1111/psyp.13436]. *Psychophysiology*, *56*(11), e13436. https://doi.org/https://doi.org/10.1111/psyp.13436
Fredrickson, B. L. (1998). What Good Are Positive Emotions? *Rev Gen Psychol*, *2*(3), 300-319. https://doi.org/10.1037/1089-2680.2.3.300
Fredrickson, B. L., & Levenson, R. W. (1998). Positive Emotions Speed Recovery from the Cardiovascular Sequelae of Negative Emotions. *Cogn Emot*, *12*(2), 191-220. https://doi.org/10.1080/026999398379718
Frinking, E., Jans-Beken, L., Janssens, M., Peeters, S., Lataster, J., Jacobs, N., & Reijnders, J. (2020). Gratitude and loneliness in adults over 40 years: examining the role of psychological flexibility and engaged living. *Aging & Mental Health*, *24*(12), 2117-2124. https://doi.org/10.1080/13607863.2019.1673309
Froh, J. J., Fan, J., Emmons, R. A., Bono, G., Huebner, E. S., & Watkins, P. (2011). Measuring gratitude in youth: assessing the psychometric properties of adult gratitude scales in children and adolescents. *Psychol Assess*, *23*(2), 311-324. https://doi.org/10.1037/a0021590
Gallagher, S., Meaney, S., & Muldoon, O. (2014). Social identity influences stress appraisals and cardiovascular reactions to acute stress exposure.

. *British Journal of Health Psychology*, *19*(3), 566-579. doi: 510.1111/bjhp.12056. Epub 12013 Jun 12018.
Gallagher, S., O'Riordan, A., McMahon , G., & Creaven, A. (2019). Evaluating personality as a moderator of the association between life events stress and cardiovascular reactivity to acute stress. *International Journal of Psychophysiology*, *126*(52-59. doi: 10.1016/j.ijpsycho).
Gallagher, S., Phillips, A. C., Ferraro, A. J., Drayson, M. T., & Carroll, D. (2008). Social support is positively associated with the immunoglobulin M response to vaccination with pneumococcal polysaccharides. *Biological Psychology*, *78*(2), 211-215. https://doi.org/https://doi.org/10.1016/j.biopsycho.2008.01.001
Gallagher, S., Solano, A. C., & Liporace, M. F. (2020). State, but not trait gratitude is associated with cardiovascular responses to acute psychological stress. *Physiol Behav*, *221*, 112896. https://doi.org/10.1016/j.physbeh.2020.112896
Gendolla, G. H. E. (2012). Implicit affect primes effort: A theory and research on cardiovascular response. *International Journal of Psychophysiology*, *86*(2), 123-135. https://doi.org/https://doi.org/10.1016/j.ijpsycho.2012.05.003
Gianaros, P. J., Bleil, M. E., Muldoon, M. F., Jennings, J. R., Sutton-Tyrrell, K., McCaffery, J. M., & Manuck, S. B. (2002). Is cardiovascular reactivity associated with atherosclerosis among hypertensives? *Hypertension (Dallas, Tex. : 1979)*, *40*(5), 742-747. https://doi.org/10.1161/01.hyp.0000035707.57492.eb
Ginty, A. T., Tyra, A. T., Young, D. A., John-Henderson, N. A., Gallagher, S., & Tsang, J. C. (2020). State gratitude is associated with lower cardiovascular responses to acute psychological stress: A replication and extension. *Int J Psychophysiol*, *158*, 238-247. https://doi.org/10.1016/j.ijpsycho.2020.10.005
Gronwall, D. M. A. (1977). Paced Auditory Serial-Addition Task: A Measure of Recovery from Concussion. *Perceptual and Motor Skills*, *44*(2), 367-373. https://doi.org/10.2466/pms.1977.44.2.367
Hayes, A. F. (2017). *Introduction to mediation, moderation, and conditional process analysis: A regression-based approach*. Guilford Publications.
Hayes, A. F., & Rockwood, N. J. (2017). Regression-based statistical mediation and moderation analysis in clinical research: Observations, recommendations, and

implementation. *Behaviour Research and Therapy*, *98*, 39-57. https://doi.org/https://doi.org/10.1016/j.brat.2016.11.001

Holt-Lunstad, J., Smith, T. B., & Layton, J. B. (2010). Social relationships and mortality risk: a meta-analytic review. *PLoS Med, 7*(7), e1000316. https://doi.org/10.1371/journal.pmed.1000316

Holt-Lunstad, J., Smith, T. W., & Uchino, B. N. (2008). Can hostility interfere with the health benefits of giving and receiving social support? The impact of cynical hostility on cardiovascular reactivity during social support interactions among friends. *Ann Behav Med*, *35*(3), 319-330. https://doi.org/10.1007/s12160-008-9041-z

Horsten, M., Mittleman, M. A., Wamala, S. P., Schenck-Gustafsson, K., & Orth-Gomér, K. (2000). Depressive symptoms and lack of social integration in relation to prognosis of CHD in middle-aged women. The Stockholm Female Coronary Risk Study. *European Heart Journal*, *21*(13), 1072-1080. https://doi.org/10.1053/euhj.1999.2012

Howard, S., Creaven, A. M., Hughes, B. M., O'Leary, E. D., & James, J. E. (2017). Perceived social support predicts lower cardiovascular reactivity to stress in older adults. *Biol Psychol*, *125*, 70-75. https://doi.org/10.1016/j.biopsycho.2017.02.006

Jackowska, M., Brown, J., Ronaldson, A., & Steptoe, A. (2016). The impact of a brief gratitude intervention on subjective well-being, biology and sleep. *J Health Psychol*, *21*(10), 2207-2217. https://doi.org/10.1177/1359105315572455

James, J. E., Gregg, M. E. D., Matyas, T. A., Hughes, B. M., & Howard, S. (2012). Stress reactivity and the Hemodynamic Profile–Compensation Deficit (HP–CD) Model of blood pressure regulation. *Biological Psychology*, *90*(2), 161-170. https://doi.org/https://doi.org/10.1016/j.biopsycho.2012.02.021

Jans-Beken, L., Jacobs, N., Janssens, M., Peeters, S., Reijnders, J., Lechner, L., & Lataster, J. (2020). Gratitude and health: An updated review. *The Journal of Positive Psychology*, *15*(6), 743-782. https://doi.org/10.1080/17439760.2019.1651888

Kirschbaum, C., Pirke, K. M., & Hellhammer, D. H. (1993). The 'Trier Social Stress Test'--a tool for investigating psychobiological stress responses in a laboratory setting. *Neuropsychobiology*, *28*(1-2), 76-81. https://doi.org/10.1159/000119004

Kok, B., Coffey, K., Cohn, M., Catalino, L., Vacharkulksemsuk, T., Algoe, S., Brantley, M., & Fredrickson, B. (2013). How positive emotions build physical health: perceived positive social connections account for the upward spiral between positive emotions and vagal tone. *Psychological Science*, *24*(7), 1123-1132. doi: 1110.1177/0956797612470827.

Krantz, D. S., & Manuck, S. B. (1984). Acute psychophysiologic reactivity and risk of cardiovascular disease: a review and methodologic critique. *Psychol Bull*, *96*(3), 435-464. https://www.ncbi.nlm.nih.gov/pubmed/6393178

Lazarus, R. S., & Folkman, S. (1984). Stress, appraisal, and coping. New York: Springer.

Lee, Y. S. C., Suchday, S., & Wylie-Rosett, J. (2015). Social support and networks: cardiovascular responses following recall on immigration stress among Chinese Americans. *Journal of immigrant and minority health*, *17*(2), 543-552. https://doi.org/10.1007/s10903-013-9955-9

Levenson, R. W. (2019). Stress and Illness: A Role for Specific Emotions. *Psychosomatic Medicine*, *81*(8), 720-730. https://doi.org/10.1097/PSY.0000000000000736

Lovallo, W. R. (2011). Do low levels of stress reactivity signal poor states of health? *Biol Psychol*, *86*(2), 121-128. https://doi.org/10.1016/j.biopsycho.2010.01.006

Matthews, K. A., Owens, J. F., Kuller, L. H., Sutton-Tyrrell, K., Lassila, H. C., & Wolfson, S. K. (1998). Stress-induced pulse pressure change predicts women's carotid atherosclerosis. *Stroke*, *29*(8), 1525-1530. https://doi.org/10.1161/01.str.29.8.1525

Matvienko-Sikar, K., & Dockray, S. (2017). Effects of a novel positive psychological intervention on prenatal stress and well-being: A pilot randomised controlled trial. *Women Birth, 30*(2), e111-e118. https://doi.org/10.1016/j.wombi.2016.10.003

McCanlies, E. C., Gu, J. K., Andrew, M. E., & Violanti, J. M. (2018). The effect of social support, gratitude, resilience and satisfaction with life on depressive symptoms among police officers following Hurricane Katrina. *International Journal of Social Psychiatry, 64*(1), 63-72. https://doi.org/10.1177/0020764017746197

McCullough, M. E., Emmons, R. A., & Tsang, J. A. (2002). The grateful disposition: a conceptual and empirical topography. *J Pers Soc Psychol, 82*(1), 112-127. https://doi.org/10.1037//0022-3514.82.1.112

Meijen, C., Turner, M., Jones, M. V., Sheffield, D., & McCarthy, P. (2020). A Theory of Challenge and Threat States in Athletes: A Revised Conceptualization [Review]. *Frontiers in Psychology, 11*(126). https://doi.org/10.3389/fpsyg.2020.00126

Mills, P. J., Redwine, L., Wilson, K., Pung, M. A., Chinh, K., Greenberg, B. H., Lunde, O., Maisel, A., Raisinghani, A., Wood, A., & Chopra, D. (2015). The Role of Gratitude in Spiritual Well-being in Asymptomatic Heart Failure Patients. *Spiritual Clin Pract (Wash D C), 2*(1), 5-17. https://doi.org/10.1037/scp0000050

O'Connell, B., & Killeen-Byrt, M. (2018). Psychosocial health mediates the gratitude-physical health link. *Psychology Health & Medicine, 23*(9), 1145-1150. doi: 1110.1080/13548506.13542018.11469782. .

O'Connell, B. H., O'Shea, D., & Gallagher, S. (2017). Feeling Thanks and Saying Thanks: A Randomized Controlled Trial Examining If and How Socially Oriented Gratitude Journals Work. *J Clin Psychol, 73*(10), 1280-1300. https://doi.org/10.1002/jclp.22469

O'Donovan, A., & Hughes, B. M. (2008). Access to social support in life and in the laboratory: combined impact on cardiovascular reactivity to stress and state anxiety. *J Health Psychol, 13*(8), 1147-1156. https://doi.org/10.1177/1359105308095968

O'Riordan, A., Howard, S., & Gallagher, S. (2019). Social Context and Sex Moderate the Association Between Type D Personality and Cardiovascular Reactivity. *Applied Psychophysiology and Biofeedback, 44*(4), 321-330. https://doi.org/10.1007/s10484-019-09447-x

O'Connell, B. H., O'Shea, D., & Gallagher, S. (2016). Enhancing social relationships through positive psychology activities: a randomised controlled trial. *The Journal of Positive Psychology, 11*(2), 149-162. https://doi.org/10.1080/17439760.2015.1037860

Obrist, P. (1981). Cardiovascular Psychophysiology: A Perspective. New York: Plenum. DOI 10.1017/S0033291700043671.

Park, N., Peterson, C., Szvarca, D., Vander Molen, R. J., Kim, E. S., & Collon, K. (2014). Positive Psychology and Physical Health: Research and Applications. *American Journal of Lifestyle Medicine, 10*(3), 200-206. https://doi.org/10.1177/1559827614550277

Petersen, E., Fiske, A. P., & Schubert, T. W. (2019). The Role of Social Relational Emotions for Human-Nature Connectedness. *Front Psychol, 10*, 2759. https://doi.org/10.3389/fpsyg.2019.02759

Phillips, A. C., Gallagher, S., & Carroll, D. (2009). Social support, social intimacy, and cardiovascular reactions to acute psychological stress. *Ann Behav Med, 37*(1), 38-45. https://doi.org/10.1007/s12160-008-9077-0

Phillips, A. C., & Hughes, B. M. (2011). Introductory paper: Cardiovascular reactivity at a crossroads: where are we now? *Biol Psychol, 86*(2), 95-97. https://doi.org/10.1016/j.biopsycho.2010.03.003

Pickering, T. G., Hall, J. E., Appel, L. J., Falkner, B. E., Graves, J., Hill, M. N., Jones, D. W., Kurtz, T., Sheps, S. G., Roccella, E. J., Subcommittee of, P., & Public Education of the American Heart Association Council on High Blood Pressure, R. (2005). Recommendations for blood pressure measurement in humans and experimental animals: Part 1: blood pressure measurement in humans: a statement for professionals from the Subcommittee of Professional and Public Education of the American Heart Association Council on High Blood Pressure Research. *Hypertension, 45*(1), 142-161. https://doi.org/10.1161/01.HYP.0000150859.47929.8e

Pollock, J. D., Murray, I., Bordes, S., & Makaryus, A. N. (2020). Physiology, Cardiovascular Hemodynamics. In *StatPearls*. https://www.ncbi.nlm.nih.gov/pubmed/29261894

Prasad, K. (2016). Viewpoint: Role of Mind-body Therapies in the Management of Cardiovascular Disorders. *European cardiology, 11*(2), 111-113. https://doi.org/10.15420/ecr.2016:17:2

Pressman, S. D., Jenkins, B. N., & Moskowitz, J. T. (2019). Positive Affect and Health: What Do We Know and Where Next Should We Go? *Annual Review of Psychology, 70*(1), 627-650. https://doi.org/10.1146/annurev-psych-010418-102955

Puig-Perez, S., Hackett, R. A., Salvador, A., & Steptoe, A. (2017). Optimism moderates psychophysiological responses to stress in older people with Type 2 diabetes. *Psychophysiology, 54*(4), 536-543. https://doi.org/10.1111/psyp.12806

Redwine, L. S., Henry, B. L., Pung, M. A., Wilson, K., Chinh, K., Knight, B., Jain, S., Rutledge, T., Greenberg, B., Maisel, A., & Mills, P. J. (2016). Pilot Randomized Study of a Gratitude Journaling Intervention on Heart Rate Variability and Inflammatory Biomarkers in Patients With Stage B Heart Failure. *Psychosom Med, 78*(6), 667-676. https://doi.org/10.1097/PSY.0000000000000316

Richter, M., Gendolla, G. H. E., & Wright, R. A. (2016). Three decades of research on motivational intensity theory: What we have learned about effort and what we still don't know. . *In A. J. Elliot (Ed.), Advances in motivation science: Vol. 3. Advances in motivation science (p. 149–186). Elsevier Academic Press.*

Roemmich, J. N., Lobarinas, C. L., Joseph, P. N., Lambiase, M. J., Archer, I. I. I. F. D., & Dorn, J. (2009). Cardiovascular reactivity to psychological stress and carotid intima-media thickness in children [https://doi.org/10.1111/j.1469-8986.2008.00776.x]. *Psychophysiology, 46*(2), 293-299. https://doi.org/https://doi.org/10.1111/j.1469-8986.2008.00776.x

Roy, M. P., Steptoe, A., & Kirschbaum, C. (1998). Life events and social support as moderators of individual differences in cardiovascular and cortisol reactivity. *J Pers Soc Psychol, 75*(5), 1273-1281. https://doi.org/10.1037//0022-3514.75.5.1273

Schache, K., Consedine, N., Hofman, P., & Serlachius, A. (2019). Gratitude – more than just a platitude? The science behind gratitude and health [https://doi.org/10.1111/bjhp.12348]. *British Journal of Health Psychology, 24*(1), 1-9. https://doi.org/https://doi.org/10.1111/bjhp.12348

Schutte, A. E., Huisman, H. W., van Rooyen, J. M., Malan, N. T., & Schutte, R. (2004). Validation of the Finometer device for measurement of blood pressure in black women. *Journal of Human Hypertension, 18*(2), 79-84. https://doi.org/10.1038/sj.jhh.1001639

Scott, K. M., Von Korff, M., Angermeyer, M. C., Benjet, C., Bruffaerts, R., de Girolamo, G., Haro, J. M., Lépine, J.-P., Ormel, J., Posada-Villa, J., Tachimori, H., & Kessler, R. C. (2011). Association of Childhood Adversities and Early-Onset Mental Disorders With Adult-Onset Chronic Physical Conditions. *Archives of General Psychiatry, 68*(8), 838-844. https://doi.org/10.1001/archgenpsychiatry.2011.77

Steptoe, A., & Kivimäki, M. (2012). Stress and cardiovascular disease. *Nature Reviews Cardiology, 9*(6), 360-370. https://doi.org/10.1038/nrcardio.2012.45

Steptoe, A., & Kivimäki, M. (2013). Stress and Cardiovascular Disease: An Update on Current Knowledge. *Annual Review of Public Health, 34*(1), 337-354. https://doi.org/10.1146/annurev-publhealth-031912-114452

Thorsteinsson, E. B., & James, J. E. (1999). A Meta-analysis of the effects of experimental manipulations of social support during laboratory stress. *Psychology & Health, 14*(5), 869-886. https://doi.org/10.1080/08870449908407353

Trobst, K. K. (2000). An Interpersonal Conceptualization and Quantification of Social Support Transactions. *Personality and Social Psychology Bulletin, 26*(8), 971-986. https://doi.org/10.1177/01461672002610007

Trotman, G. P., Williams, S. E., Quinton, M. L., & Veldhuijzen van Zanten, J. J. C. S. (2018). Challenge and threat states: examining cardiovascular, cognitive and affective responses to two distinct laboratory stress tasks. *International Journal of Psychophysiology, 126*, 42-51. https://doi.org/https://doi.org/10.1016/j.ijpsycho.2018.02.004

Turner, A. I., Smyth, N., Hall, S. J., Torres, S. J., Hussein, M., Jayasinghe, S. U., Ball, K., & Clow, A. J. (2020). Psychological stress reactivity and future health and disease outcomes: A systematic review of prospective evidence. *Psychoneuroendocrinology, 114*, 104599. https://doi.org/https://doi.org/10.1016/j.psyneuen.2020.104599

Uchino, B. N. (2006). Social support and health: a review of physiological processes potentially underlying links to disease outcomes. *J Behav Med, 29*(4), 377-387. https://doi.org/10.1007/s10865-006-9056-5

Uchino, B. N. (2009). Understanding the Links Between Social Support and Physical Health: A Life-Span Perspective With Emphasis on the Separability of Perceived and Received Support. *Perspect Psychol Sci, 4*(3), 236-255. https://doi.org/10.1111/j.1745-6924.2009.01122.x

Uchino, B. N., Bowen, K., Carlisle, M., & Birmingham, W. (2012). Psychological pathways linking social support to health outcomes: a visit with the "ghosts" of research past, present, and future. *Soc Sci Med, 74*(7), 949-957. https://doi.org/10.1016/j.socscimed.2011.11.023

Uchino, B. N., Cacioppo, J. T., & Kiecolt-Glaser, J. K. (1996). The relationship between social support and physiological processes: a review with emphasis on underlying mechanisms and implications for health. *Psychol Bull, 119*(3), 488-531. https://doi.org/10.1037/0033-2909.119.3.488

Uchino, B. N., Carlisle, M., Birmingham, W., & Vaughn, A. A. (2011). Social support and the reactivity hypothesis: conceptual issues in examining the efficacy of received support during acute psychological stress. *Biol Psychol, 86*(2), 137-142. https://doi.org/10.1016/j.biopsycho.2010.04.003

Watkins, P. C., Emmons, R. A., Greaves, M. R., & Bell, J. (2018). Joy is a distinct positive emotion: Assessment of joy and relationship to gratitude and well-being. *The Journal of Positive Psychology, 13*(5), 522-539. https://doi.org/10.1080/17439760.2017.1414298

Weisbuch, M., Seery, M. D., Ambady, N., & Blascovich, J. (2009). On the Correspondence Between Physiological and Nonverbal Responses: Nonverbal Behavior Accompanying Challenge and Threat. *Journal of Nonverbal Behavior, 33*(2), 141-148. https://doi.org/10.1007/s10919-008-0064-8

WHO. (2016). Fact sheet 317: Cardiovascular diseases. Retrieved from http://www.who.int/mediacentre/factsheets/fs317/en/.

Why, Y. P., & Chen, M. R. (2013). Self-enhancement and cardiovascular reactivity: Limitations of the hemodynamic profile–compensation deficit (HP–CD) model of blood pressure regulation. *Biological Psychology, 92*(2), 205-211. https://doi.org/https://doi.org/10.1016/j.biopsycho.2012.08.010

Wood, A. M., Froh, J. J., & Geraghty, A. W. (2010). Gratitude and well-being: a review and theoretical integration. *Clin Psychol Rev, 30*(7), 890-905. https://doi.org/10.1016/j.cpr.2010.03.005

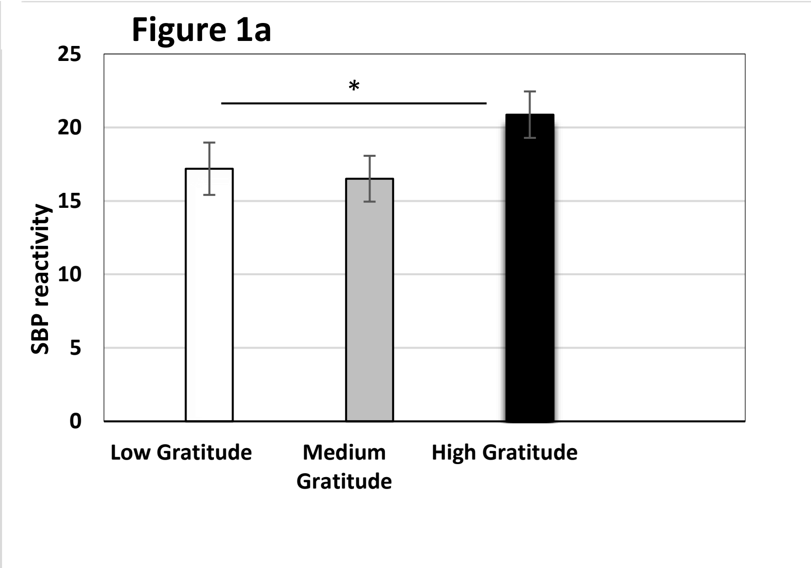
Table 1

Descriptive statistics of gratitude, social support, CVR variables, and task stress rating

Variables	Range	Mean	Standard Deviation
Trait Gratitude	14.00 – 40.00	33.25	5.02
Social Support	37.00- 80.00	63.94	9.78
Baseline SBP	82.89 – 148.48	123.87	11.03
Baseline DBP	65.69 - 115.69	75.40	9.09
Baseline HR	58.03 – 110.64	78.42	10.63
Baseline CO	1.03- 10.31	5.94	1.46
Baseline TPR	.51 – 5.80	1.05	.50
Pooled Task SBP	101.78 – 192.65	142.59	16.99
Pooled Task DBP	61.01 – 135.52	87.47	11.66
Pooled Task HR	57.82 – 111.88	83.21	11.01
Pooled Task CO	1.33 - 12.03	6.36	1.83
Pooled Task TPR	.58 - 5.31	1.19	.58
Pooled CVR SBP	--6.55 - 49.63	18.73	11.63
Pooled CVR DBP	-3.30 – 31.68	11.67	6.68
Pooled CVR HR	-8.26 – 21.02	4.97	5.22
Pooled CVR CO	-1.87 – 2.71	0.36	0.74
Pooled CVR TPR	-.56 – 0.96	0.11	0.19
Speech CVR SBP	-27.89 - 60.27	18.70	15.43
Speech CVR DBP	-14.82 -39.82	12.03	9.83
Speech CVR HR	-27.50 - 38.69	4.16	11.94
Speech CVR CO	-4.38 -5.06	0.30	1.46
Speech CVR TPR	-0.99 – 1.10	0.11	0.33
PASAT CVR SBP	-9.24 – 53.24	17.97	12.10
PASAT CVR DBP	-2.11 – 34.40	11.63	7.36
PASAT CVR HR	-29.92 – 41.01	5.06	11.34
PASAT CVR CO	-3.75- 5.22	0.37	1.46
PASAT CVR TPR	-0.91 – 2.05	0.14	0.37
Pooled Pre Task Stress	0.0 - 6.0	3.22	1.39
Pooled Post Task Stress	1.0 - 6.0	4.35	1.03

Pre Speech Task Stress	0.00- 6.00	2.82	1.35
Post Speech Task Stress	0.00 -6.00	4.13	1.46
Pre Maths Task Stress	0.00 -6.00	3.68	1.58
Post Maths Stress	1.00 -6.00	4.57	1.26

Figure 1. Associations between trait gratitude and SBP reactivity (1a) and DBP reactivity(1b) to the maths task, controlling for confounding including PASAT scores. Error bars are standard error bars and reactivity mean scores for low, medium and high gratitude respectively. The high and low gratitude scores reflect the upper (top 25%) and lower quartile (bottom 25%) scores on the gratitude scale and medium represents the remaining middle 50% of the distribution.



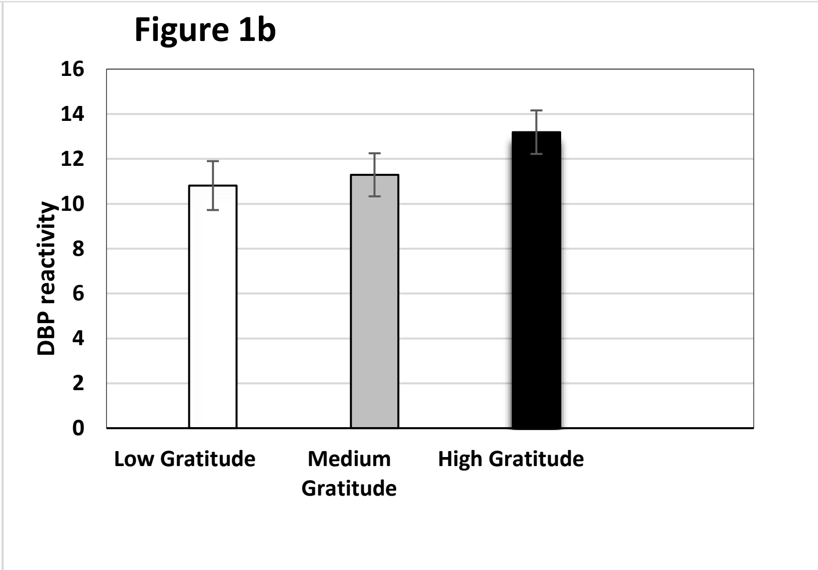
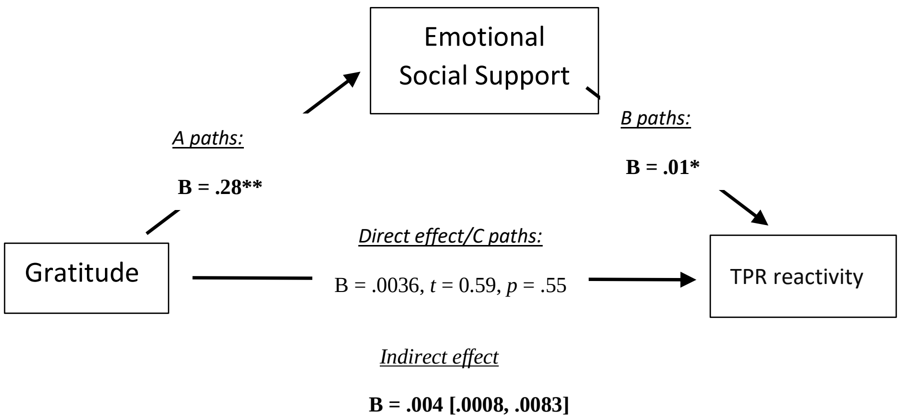


Figure 2. Mediation analysis of the relationship between gratitude, emotional social support and TPR reactivity.



Significant effect are highlighted in bold.

*** $p < 0.01$ level.* $p < 0.05$ level.*

Note: Statistics refer to unstandardized betas (B) and 95% confidence intervals at the lower and upper limit for indirect effects.