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Gratitude, affect balance, and stress buffering: A growth curve examination of cardiovascular responses to a laboratory stress task☆

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ABSTRACT

Previous research has indicated that gratitude and affect-balance play key stress-buffering roles. However, to date there is limited research on the impact of gratitude and affect balance on cardiovascular recovery from acute psychological stress, and whether affect balance moderates the relationship between gratitude and cardiovascular reactions to acute psychological stress. In this study, 68 adults completed measures of state gratitude, positive and negative affect, and completed a laboratory-based cardiovascular stress-testing protocol. This incorporated a 20-minute acclimatization period, a 10-minute baseline, a 6-minute arithmetic stress task, and an 8-minute recovery period. Mixed-effects growth curve models were fit and the results indicated that state gratitude predicted lower systolic blood pressure responses throughout the stress-testing period. Affect balance was found to moderate the association between state gratitude and diastolic blood pressure responses to stress, amplifying the effects of state gratitude. These findings suggest that state gratitude has a unique stress-buffering effect on both reactions to and recovery from acute psychological stress.

Psychological stress refers to situations where an individual perceives that the demands placed upon them exceed their ability to cope (Cohen et al., 2007). While stress cannot be avoided, it can have a negative impact on an individual's health and well-being. Notably, epidemiological data shows that stress predicts increased cardiovascular morbidity and coronary heart disease (Kivimäki and Steptoe, 2018; Steptoe and Kivimäki, 2012). The cardiovascular stress response is a complex and dynamic process; two important aspects of this response are cardiovascular reactivity to stress and cardiovascular recovery from stress (Felt et al., 2017; Llabre et al., 2004; Woody et al., 2018). Where cardiovascular stress reactivity can be defined as the response to challenging conditions, cardiovascular stress recovery refers to the response following cessation of the stressor (Panaite et al., 2015). We propose that state gratitude and affect balance modulate both of these components of the stress response.

Past studies have consistently shown that large-magnitude responses to stress are associated with cardiovascular outcomes such as high blood pressure, hypertension, and cardiovascular disease mortality (Chida and Steptoe, 2010; Treiber et al., 2003). Increased cardiovascular reactivity has been associated with poorer health outcomes such as high blood pressure and hypertension (Carroll et al., 2012; Hocking Schuler and O'Brien, 1997; Yuenyongchaiwat, 2015). Similarly, impaired cardiovascular recovery from stress is associated with serious health problems such as hypertension and even cardiovascular death (Hocking Schuler and O'Brien, 1997; Kivimäki et al., 2006). Taken together, this suggests that the relationship between physiological responses to stress and health has an inverted “U” shape (Whittaker et al., 2021) whereby the ‘steepness' of the upward slope represents cardiovascular reactivity (with greater reactivity representing a greater response or reaction to a stressor) and the downward slope representing how fast or slow the physiological recovery following the reactivity (with slower recovery representing a poorer physiological response).

The stress-buffering hypothesis proposes that positive emotions have the capacity to mitigate negative reactions to stress and thus protect individuals from the potential pathogenic effects of stressful events (Fredrickson et al., 2000; Gellert et al., 2018; Pressman et al., 2019). Positive emotions dampen the autonomic nervous system and hypothalamic-pituitary-adrenal axis responses to stress (Drolet et al., 2001; Okely et al., 2017) and facilitate the utilization of stress coping mechanisms such as the reappraisal of stressful situations (Ashby et al.,

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1999; Pressman et al., 2019). In line with this, past research has demonstrated that positive affect was associated with faster physiological recovery from acute psychological stress (Ong and Allaire, 2005; Papousek et al., 2010). Regardless of which aspect of cardiovascular health is considered (reactivity or recovery), identifying the stress-buffering effects of positive emotions is important to reduce the overall burden of cardiovascular disease, which is already the leading cause of death globally (Mathers and Loncar, 2006).

With regard to affect, previous research has connected both positive and negative affect to health outcomes (Danhauer et al., 2013; Pressman et al., 2019). There is evidence that negative affect is associated with poorer cardiovascular health outcomes (DeSteno et al., 2013). In contrast, increased positive emotions have been associated with positive health outcomes (Dubois et al., 2012; Teoh and Hilmert, 2018) such as reduced sleep problems (Steptoe et al., 2008), positive overall health (Cohen and Pressman, 2006), and reduced mortality risk (Zhang and Han, 2016). Positive affect is also associated with reduced cardiovascular reactions to stress (Brummett et al., 2009), decreased hospital readmission following cardiovascular issues (Middleton and Byrd, 1996), and overall is thought to play an independent, protective role against cardiovascular disease (Boehm and Kubzansky, 2012). Hence, affect is thought to play a critical stress buffering role, both reducing reactions to stress and hastening recovery (Pressman et al., 2019).

Past research has been criticised for a sole focus on either positive or negative affect (Kolanowski et al., 2014). Rather, what is important is the balance of positive to negative emotions (Fredrickson, 2001). This concept is supported by findings that positive and negative affect are associated with separate outcomes (Russell and Carroll, 1999; Schlauch et al., 2013). Thus, rather than examining either positive or negative affect independently, this study examined the balance between them, or affect balance (Diener et al., 2010).

Affect balance has been conceptualised as a key component of well-being insofar as it measures the relative frequency of experiencing positive affect over negative affect (Kolanowski et al., 2014). It is also frequently attached to the “positive ratio” (Garland et al., 2010; Veilleux et al., 2020). When an individual experiences more positive than negative affect, they tend to experience better mental health (Diehl et al., 2011), well-being (Meeks et al., 2012), life satisfaction (du Plessis and Guse, 2017). Affect balance has also been found to negatively predict stress (Veilleux et al., 2020). Furthermore, a specific body of work has demonstrated that greater experience of positive constructs such as social support (Phillips et al., 2009) and positive affect (Pressman and Cohen, 2005) are associated with lowered cardiovascular reactivity and improved recovery.

Gratitude is a specific positive emotion described as the recognition that something good has happened to an individual and which is perceived as costly, altruistic, or valuable (Wood et al., 2010). There is growing evidence that gratitude has a significant impact on individual health. Cross-sectional studies indicate that dispositional gratitude in adults is associated with positive self-reported physical health (O'Connell and Killeen-Byrt, 2018). This link is also seen in numerous studies concerning cardiovascular health (Celano et al., 2017; Jackowska et al., 2016). Importantly, recent research has uncovered evidence regarding gratitude's stress-buffering effects, with state gratitude, as opposed to trait gratitude, being associated with decreased cardiovascular reactivity to acute psychological stress in a laboratory setting (Gallagher et al., 2020; Ginty et al., 2020).

These effects are theoretically consistent with the neurovisceral integration model, which charts the brain-heart link (Park et al., 2013; Thayer et al., 2009). From this perspective, gratitude may play a role in regulating central autonomic nervous system activity (Kyeong et al., 2017), with some studies having found an association between gratitude and increased parasympathetic heart rate variability and cardiac coherence (Rash et al., 2011; Redwine et al., 2016). Importantly, previous research indicates that state gratitude can be manipulated in individuals by simple interventions (Davis et al., 2016; Hussong et al., 2019). As such, gratitude may constitute plausible low-cost health intervention (Wood et al., 2010), with a greater understanding of the stress-buffering effects of gratitude having the potential to improve individual and community health and well-being.

The effects of gratitude and affect balance are consistent with the cognitive model of stress which states that an individual's internal characteristics and resources influence how one copes and manages stress (Folkman and Lazarus, 1988). For example, individuals expressing higher levels of gratitude appear to more successfully cope with stress and adversity (Wood et al., 2010). For example, gratitude expressions are correlated with coping actions such as reappraisal (Bryan et al., 2018), as well as planning and goal-directed strategies which reduce the frequency and intensity of stress (Wood et al., 2007). Similarly, positive affect (Pressman et al., 2019), negative affect (Diehl and Hay, 2010) and the balance between them (Amai and Hojo, 2022) have been found to be associated with stress coping.

In past research investigating the impact of gratitude on cardiovascular reactivity, positive affect has typically been modelled as a control variable in order to establish the independent effect of gratitude on cardiovascular reactivity (Ginty et al., 2020). Ginty et al. (2020) found that including positive affect in the regression model did not change the significance of state gratitude as a predictor. This suggests that gratitude has an impact on the cardiovascular stress response that is relatively independent of positive affect.

However, previous research has also suggested that positive affect may moderate the effects of gratitude on well-being (Rash et al., 2011). This is based on the resistance hypothesis which states that individuals who already experience a high amount of positive emotions are unlikely to be affected by additional positive experiences such as experiencing gratefulness (McCullough et al., 2004; Rash et al., 2011). For example, Froh et al. (2009) conducted a randomised-control study assessing the impact of a gratitude letter on positive and negative affect. They found that pre-test positive affect moderated the effect of the intervention on post-test affect whereby individuals lower in positive affect benefitted more from the intervention. As such, recent research has called for greater investigation into how affect might moderate the effects of gratitude on positive outcomes (Klibert et al., 2019). Based on this idea, it is posit that gratitude and affect interact in buffering the effects of acute stress on cardiovascular reactivity and cardiovascular recovery. It is expected that individuals with poorer affect balance (i.e., those who experience more negative than positive affect on balance) will benefit more from experiencing state gratitude.

In sum, exaggerated cardiovascular stress reactions and delayed cardiovascular recovery are associated with poorer health outcomes. Positive psychological constructs such as gratitude and affect balance appear to have an important cardiovascular stress-buffering effect, including reducing cardiovascular stress reactions and hastening cardiovascular stress recovery. Previous research has uncovered inverse relationships between gratitude and cardiovascular reactions (Cousin et al., 2021). However, previous research has not examined gratitude's effect on cardiovascular recovery. As such, the interactive relationship between gratitude, affect balance, and cardiovascular reactivity is unclear. Therefore, this paper has the following aims: (1) to assess the impact of state gratitude and affect balance on the cardiovascular response to stress, including both reactivity and recovery, and (2) to assess whether affect-balance moderates the relationship between state gratitude and the cardiovascular response to stress.

The cardiovascular stress response has an inverted u-shape, whereby when an individual experiences a stressful situation, they experience a corresponding cardiovascular reaction (e.g. increase in heart rate or blood pressure) which is typically termed ‘reactivity’. Once the stressor has abated, the individual's cardiovascular response slowly returns to normal but how quickly this occurs varies across individuals. This is termed recovery and, as such, a faster recovery phase (e.g. lowering of heart rate) is better for one's health. Overall, lower responses are considered healthier than higher responses. Thus, using multilevel growth curve models is a useful way of modelling the relationship between state gratitude, affect balance and the cardiovascular response to acute stress (Curran et al., 2010). Multilevel growth curve models allow for the indexing of reactivity and recovery through the analysis of the shape and significance of time course patterns for cardiovascular measures (Hoogerwerf et al., 2018; Woody et al., 2018). This is advantageous over traditional methods of analysing repeated measures data as it permits researchers to examine various patterns of change (e.g. linear, quadratic) and allows for within-person variability (Lehman et al., 2015). In the context of this paper, it is expected that state gratitude and affect balance would predict lower responses throughout the laboratory-testing period (Woody et al., 2018). To our knowledge, this is the first paper to assess the impact of state gratitude and affect balance on the cardiovascular stress response using this method.

Accordingly, this paper has the following hypotheses:

H1. State gratitude will predict lower overall cardiovascular responses to acute psychological stress.

H2. Affect balance will predict lower overall cardiovascular responses to acute psychological stress.

H3. Affect-balance will moderate the relationship between state gratitude and the cardiovascular response to stress, with individuals with lower scores benefitting more from the effects of state gratitude.

1. Method

1.1. Design

This study used a within-subjects experimental design. The experimental design induced stress and measured individuals cardiovascular reactivity and recovery in response to this. The predictor variables (state gratitude and affect balance) were assessed in the lab via a paper-and-pencil survey prior to the stress task. This study focused on state gratitude as previous research has found it to play an important role in stress buffering (Gallagher et al., 2020). Affect can be conceptualised as either a state or a trait depending on the temporal phrasing of survey items (Merz and Roesch, 2011) and state gratitude experienced over the previous 24 h was assessed in this study. Affect balance was measured ‘over the past week’ and as such reflects the general affective state individuals experienced in the week prior to their participation in the study. This ensured that affect was captured as opposed to more momentary emotions. The dependent variables were cardiovascular reactivity and cardiovascular recovery to the induced stress.

1.2. Participants

A convenience sample of 68 undergraduate students studying psychology in an Irish university volunteered to take part. Of these, 24 were male and 44 were female. The ages ranged from 18 to 57 ($M = 22.87$, $SD = 8.07$). The inclusion criteria included individuals who were 18 years old or older and able to consent. Participants were excluded if they (1) consumed alcohol in the 12 h before the study took place, (2) engaged in vigorous exercise in the 12 h before the study took place, (3) consumed caffeine or smoked cigarettes less than 2 h before the study took place, (4) consumed food 1 h before the study, (5) were pregnant, or (6) currently held a diagnosis of cardiovascular disease. These precautions were to control for confounding variables and are in line with previous research (Creaven and Hughes, 2012; Gallagher et al., 2020). Three participants were excluded for violating the exclusion criteria; having eaten less than an hour before the study commenced. This left a sample of 65 individuals.

Studies that utilize repeated measures, as the current study does, usually have higher power than comparable between-subjects studies (Murphy et al., 2014). A priori power analyses were conducted using *G*Power* (Faul et al., 2007). F-test was selected and R^2 increase examined for effect size estimation. Based on studies of the effects of positive emotion on the physiological response and mood response to stress, we estimated that a medium effect size was justified (Fredrickson et al., 2000; Monfort et al., 2015). An alpha level of 0.05, a power of 0.80 and medium effect sizes of 0.15 for two tested predictors and a total of seven predictors overall was set. The suggested sample size was 68. Additionally, as the analysis was run in long format, this yielded a total of 189 observation. This suggests that the study attained sufficient power.

1.3. Measures and materials

1.3.1. Stress task

The study used an adaptation of the serial subtraction task whereby participants were asked to subtract in increments of thirteen from 1222 (al'Absi et al., 1995). If participants made an error, or forgot their place, they were asked to begin the task again. Mental arithmetic tasks, such as the one used in this study, are commonly used to elicit a physiological stress response in the lab (Mathias et al., 2017; Whittaker et al., 2021).

1.3.2. Lab setting

The laboratory added pressure on each participant by: (1) including a fake leader board directly opposite the participant, (2) using a small lab with two researchers present, and (3) switching off the main laboratory light during the task, leaving the room illuminated by a lamp in front of the participant.

1.3.3. Cardiovascular assessment

Systolic blood pressure, diastolic blood pressure and heart rate in beats per minute were measured using a GE Dinamap Pro 400 V2 vital signs monitor (GE Medical Systems, Freiburg, Germany). A stopwatch was used to ensure that measurements were taken at consistent times. A standard blood pressure cuff was placed over the brachial artery on the participant's non-dominant arm. After acclimatization, four baseline measurements were taken over a ten minute period. Three measurements were taken during the six minute stress task. Four measurements were taken immediately after the stress task in the ten minute recovery period.

1.3.4. State gratitude

State gratitude was assessed using the Gratitude adjective checklist (GAC; McCullough et al., 2002). This scale has demonstrated high internal reliability ($\alpha = 0.83$) in prior research (Froh et al., 2010) and this was confirmed in the current study ($\alpha = 0.86$). The scale is the sum of three adjectives: grateful, thankful, and appreciative, assessed using a 5-point Likert scales (1 = not at all to 5 = extremely) with higher scores reflecting higher levels of state gratitude. The stem of this scale assessed gratitude over the past day. However, the measure was completed in the same lab session as the stress test. The scale was summed in line with previous research and scores ranged from 3 to 15 (Gallagher et al., 2020).

1.3.5. Affect balance

Affect balance was assessed using the Positive and Negative Affect Schedule Short Form (PANAS-SF; Watson et al., 1988). This is a 20-item scale where participants rate the extent to which they have felt certain emotions on a 5-point scale from very slightly/not at all (1) to extremely (5) over the past week. The measure was completed in the same lab session as the stress test. The scale demonstrated acceptable reliability for both positive affect ($\alpha = 0.82$) and negative affect ($\alpha = 0.82$). Affect balance was computed by subtracting the negative affect score from the positive affect score (Veilleux et al., 2020).

1.3.6. Stress task measures

Stress task measures were immediately taken after the completion of the stress task with a three-item scale ($\alpha = 0.83$). Participants were asked to rate how stressful they found the task on 7-point Likert scale 0 (Not at all) to 6 (Extremely).

1.4. Procedure

Prior to attending, participants were instructed to refrain from drinking alcohol or exercising in the 12 h prior to the study and to refrain from smoking and consuming caffeine 2 h before, or eating 1 h before the study took place. Upon arrival, the acclimatization period began at the laboratory. During this time, participants were greeted by the primary experimenter and instructed to read study information sheets to confirm eligibility and provide consent. The researcher recorded the participant's height and weight measurements for the computation of BMI. They were then seated and the blood pressure cuff was placed on their upper, non-dominant arm, and they were instructed to place their feet in a box under the table in order to control for movement during the study (Pickering et al., 2005). During this period, acclimatization measures were taken, demographic details were recorded, and psychometric scales were completed. The acclimatization period lasted 20 min. The participant was then asked to refrain from speaking for the rest of the experiment. This was followed by a formal ten minute baseline period where measures were taken every 20 min.

Once the formal baseline was completed, the researcher (first author) turned off the lights, turned on a spotlight and explained to the participant that they would be completing a serial subtraction task. The task lasted for 6 min. Blood pressure measurements were taken throughout at two minute intervals, yielding three measurement points. Prompts to continue were delivered by the researcher if the participant stopped engaging. After the task, the lights were switched back on and participants were asked to rate how stressful they found the task. This was immediately followed by an eight minute recovery period where participants sat quietly and had a blood pressure measurements taken every 2 min, yielding four measurement points. They then filled out a self-report stress and motivation questionnaire, and were debriefed and thanked for their time after study completion.

1.5. Data reduction and data analysis

R (Version 4.2.0; R Core Team, 2022) was used for data analysis. The packages *lme4* (*Version 1.1.30*; Bates et al., 2015) and *lmerTest* (*Version 3.1.3*; Kuznetsova et al., 2017) were used to fit mixed-effects growth models. Four resting baseline measures for each of the cardiovascular parameters were averaged to yield baseline values for each participant. The same was done with the three stress task measures and the four recovery measures, in line with similar approaches taken in previous research (Phillips et al., 2009). Data were screened and checked for normality using the visual inspection of histograms, QQ-plots, and by utilizing the Shapiro test for normality. Outliers were assessed using z-scores with a z score $\geq |3|$ constituting an outlier. One outlier was removed as a result. Repeated measures ANOVAs were used to confirm that the stress task increased cardiovascular responses from baseline, and confirmatory factor analysis was used to confirm that state gratitude, positive affect, and negative affect were best modelled as three distinct constructs. Correlations between study variables were examined prior to moving to hypothesis testing.

A series of mixed-effects growth curve models were used to test the hypotheses and assess the impact of state gratitude and affect balance on the cardiovascular stress response. Growth curve models can help gain insight into the reactivity and recovery periods by the specification of non-linear growth parameters and their interactions with other predictors (Bolger and Laurenceau, 2013; Felt et al., 2017). Mixed-effect growth curves are advantageous as they allow a more parsimonious test of the effects of state gratitude and affect balance over the whole testing session (i.e., baseline, stress task, and recovery) and estimate the effects of the predictor variables on the trajectory of the changes over time (Verkuil et al., 2014). They also more elegantly control for baseline cardiovascular differences by allowing varying intercepts at baseline (by coding mean baseline measures as time 0 and varying slopes for individual participants; Gueorguieva and Krystal, 2004). Mixed-effects models have also been shown to perform well with smaller sample (McNeish, 2017), particularly by making use of restricted maximum likelihood estimation (REML; Snijders, 2005). As such, all models will be fit using REML estimation.

As it was likely that some non-linearity would need to be incorporated into the models, firstly it was formally tested whether a linear or quadratic growth fitted best, using a normal chi-square distribution.

The data were modelled at two levels, with the most detailed level comprising level one (Snijders and Bosker, 2011). As such, the measurement occasion (time) was modelled at level one, which thus represented the within-person, random effects. The intercept was allowed to vary in order to account for different baseline cardiovascular measures. Measurement occasions were nested within people, and so level two represented the between-person, fixed effects or growth parameters. The primary predictor variables were state gratitude and affect balance. The control variables were task stress ratings, age and sex. Both the predictor variables and control variables were person-level variables and so, only possible to model at level 2. To test the hypotheses, the interaction between affect balance, state gratitude and the growth parameters were of main interest (i.e. *Systolic blood pressure* = *Growth* * *State gratitude* + *Growth* * *Affect balance*). For interactions, state gratitude and affect balance scores were standardised as z-scores as recommended by Bauer and Curran (2005). Models were fitted hierarchically, with the growth parameters and control variables entered into the model first, then the cross-level interactions between state gratitude and time and affect balance and time second, and finally adding the interaction between state gratitude, affect balance and time in step 3.

Restricted maximum likelihood estimation were used to analyse the main effects and moderation analyses. Overall model fit is evaluated using the Akaike information criterion on a smaller-is-better basis and the Loglikelihood on a bigger-is-better basis (Woody et al., 2018). Model comparison was also formally tested using likelihood ratio tests for nested models which make use of an ordinary χ^2 distribution, with significant differences indicating that the full model fits better than the nested model (Bliese, 2022). A marginal coefficient of determination R^2 was used to compute an effect size, ΔR^2 (Gueorguieva and Krystal, 2004). This quantifies the variance explained by the fixed effects of the models. An alpha level of 0.05 was selected.

2. Results

2.1. Preliminary analyses

Descriptive statistics and correlations between the study variables

Table 1
Descriptive statistics of all variables.

Name	Mean	SD	Min	Max
Age	22.79	8.23	18.00	57.00
Affect balance	13.11	9.40	−17.00	30.00
Gratitude score	10.98	2.57	3.00	15.00
Task stress rating	2.79	0.89	0.25	4.25
Baseline SBP	117.44	10.09	98.50	142.50
Stress task SBP	126.58	12.11	103.00	148.67
Recovery SBP	115.09	9.68	97.25	132.50
Baseline DBP	65.46	7.60	53.75	83.00
Stress task DBP	71.84	9.58	55.67	94.67
Recovery DBP	65.05	8.25	54.50	87.00
Baseline HR	80.37	13.07	53.50	120.00
Stress task HR	89.03	14.51	57.33	131.00
Recovery HR	77.38	12.53	51.50	112.00

Note. SBP = systolic blood pressure (mmHG), DBP = diastolic blood pressure (mmHG), HR = heart rate (BPM), stress task = average measurement during the study's stress task.

are outlined in Tables 1 and 2. State gratitude had significant correlations with affect balance and systolic blood pressure during the stress task; it did not correlate with other cardiovascular measures. Affect balance did not correlate with any cardiovascular measures. A series of repeated measures ANOVAs were used to check if the stress task increased cardiovascular responses from baseline, to stress, and decrease to recovery (see Fig. 1), for systolic blood pressure $F(2, 128) = 134.05$, $p < 0.001$, $\eta_p^2 = 0.67$, diastolic blood pressure $F(2, 128) = 59.94$, $p < 0.001$, $\eta_p^2 = 0.48$, and heart rate $F(2, 128) = 81.21$, $p < 0.001$, $\eta_p^2 = 0.56$, with results indicating statistically significant changes from baseline, stress, and recovery epochs. The intraclass correlation coefficients (ICC1) for systolic blood pressure, diastolic blood pressure and heart rate were 0.61, 0.65, and 0.67 respectively. This indicates that 61 % of the variation in systolic blood pressure was at level 2 (person level), 65 % for diastolic blood pressure, and 67 % for heart rate.

To ensure that gratitude, positive affect, and negative affect were best captured as three distinct constructs, three confirmatory factor analyses (CFAs) were carried out (see Table 3). The first CFA loaded all the items onto a single factor. The second loaded gratitude and positive affect onto one factor and negative affect onto a second factor. The third loaded gratitude, positive affect, and negative affect onto three distinct factors. As both AIC and BIC are lowest for the three-factor model, this model was accepted (see Table 3).

2.2. Assessing the pattern of growth

The test if a non-linear growth parameter would fit the data better, linear and quadratic growth parameters were fitted to model systolic blood pressure, diastolic blood pressure and heart rate over time. The addition of the quadratic growth pattern yielded significant improvements to model fit for systolic blood pressure ($\chi^2(1) = 140.43$, $p < 0.001$), diastolic blood pressure ($\chi^2(1) = 88.08$, $p < 0.001$) and heart rate ($\chi^2(1) = 97.36$, $p < 0.001$). As such, the quadratic growth parameter was retained for the rest of the analysis. All models were fitted with random intercepts and linear random slopes; linear random slopes were fitted in order to circumvent issues of singularity and create more parsimonious models (Bates et al., 2015; Matuschek et al., 2017). Additionally, for all models, the addition of autocorrelated error terms did not improve model fit and as such were not retained in the final model.

2.3. Hypothesis testing

To test the hypotheses, multilevel growth models were fit to the data in a procedure similar to hierarchical regressions. For step one, the model with the growth parameters and the control variables were entered into the model. For step two, the cross level interactions between state gratitude and growth, and affect balance and growth were entered into the model. Finally, in the third step, the interaction between affect balance, state gratitude and growth was entered into the model.

Hypothesis 1 proposed that state gratitude would predict lower overall cardiovascular responses to acute psychological stress. The cardiovascular response was tested via the growth curves of diastolic blood pressure, systolic blood pressure and heart rate. The relevant results for this can be found in step 2 of Tables 4, 5, and 6, and Fig. 1. State gratitude significantly interacted with linear growth ($B = -1.57$, 95%CI [−2.66, −0.49], $p = 0.005$), and quadratic growth ($B = -0.74$, 95%CI [0.21, 1.26], $p = 0.007$) to predict systolic blood pressure. Visual inspection of the interaction plot revealed that higher levels of state gratitude were associated with a lower systolic blood pressure response to stress. Adding this interaction to the model decreased the AIC and increased the LL fit indices and resulted in a 6 % increase in the variance explained ($\Delta R^2 = 0.06$, $\chi^2(6) = 21.62$, $p = 0.001$). State gratitude did not interact with linear growth to predict either diastolic blood pressure ($B = 1.73$, 95%CI [−0.90, 4.35], $p = 0.195$), or heart rate ($B = -2.80$, 95% CI [−6.63, 1.03], $p = 0.151$) stress responses. Similarly, state gratitude

Table 2
Correlations between study variables.

Variable	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1. Age															
2. Gender	−0.09														
3. Positive affect	0.02	−0.37**													
4. Negative affect	−0.19	0.10	−0.10												
5. Affect balance	0.13	−0.33**	0.77**	−0.71**											
6. State gratitude	−0.18	0.07	0.39**	−0.11	0.35**										
7. Stress task rating	−0.19	0.33**	−0.26*	0.35**	−0.41**	−0.24									
8. Baseline SBP	0.18	−0.24	0.10	−0.06	0.11	−0.23	−0.09								
9. Stress task SBP	0.29*	−0.33**	−0.00	−0.09	0.05	−0.38**	−0.19	0.81**							
10. Recovery SBP	0.19	−0.28*	0.03	−0.08	0.07	−0.28*	−0.12	0.91**	0.83**						
11. Baseline DBP	0.35**	0.19	−0.26*	−0.06	−0.15	−0.20	−0.03	0.63**	0.56**	0.64**					
12. Stress task DBP	0.38**	−0.04	−0.18	−0.11	−0.06	−0.19	−0.03	0.53**	0.60**	0.59**	0.75**				
13. Recovery DBP	0.31*	0.16	−0.26*	−0.06	−0.15	−0.20	−0.09	0.53**	0.46**	0.60**	0.87**	0.79**			
14. Baseline HR	−0.19	0.42**	−0.16	−0.05	−0.08	0.09	0.25*	0.03	−0.20	−0.06	0.16	−0.02	0.09		
15. Stress task HR	−0.02	0.38**	−0.17	−0.09	−0.06	0.01	0.31*	−0.01	−0.04	−0.05	0.19	0.05	0.01	0.80**	
16. Recovery HR	−0.15	0.40**	−0.18	−0.01	−0.12	0.11	0.26*	−0.00	−0.21	−0.05	0.17	0.02	0.12	0.95**	0.77**

Note. SBP = systolic blood pressure (mmHG), DBP = diastolic blood pressure (mmHG), HR = heart rate (BPM), stress task = average measurement during the study's stress task.

* Indicates $p < 0.05$.

** Indicates $p < 0.01$.

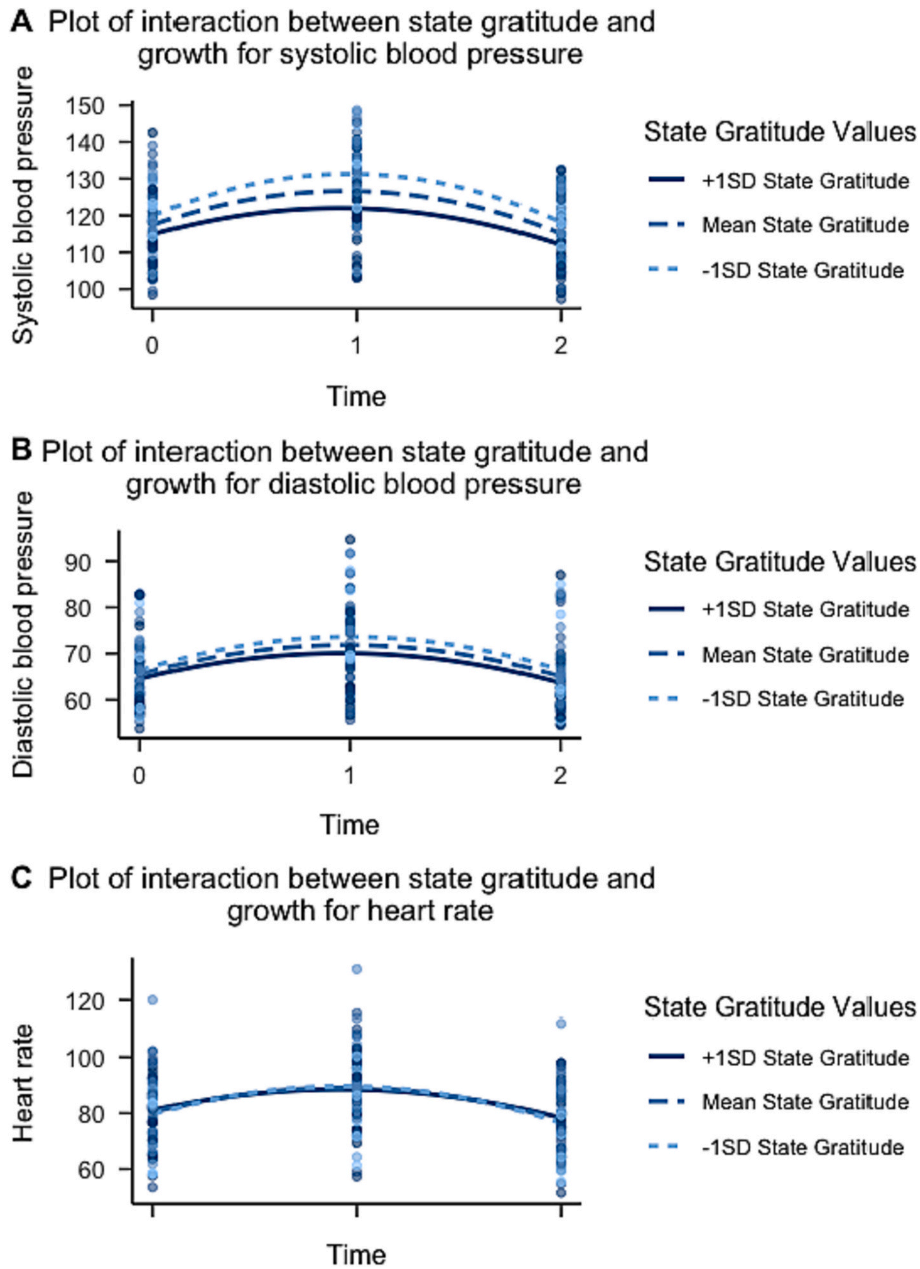

Fig. 1. Interaction plots for low (−1SD), average (mean) and high (+1SD) levels of state gratitude and how the trajectory of growth and decline changes at each level for cardiovascular measures.

Table 3
Confirmatory factor analysis model fit statistics of state gratitude, positive affect and negative affect.

	χ^2	*df*	p	CFI	TLI	RMSEA (90 % CI)	SRMR	AIC	BIC	ssBIC
One-factor model	621.03	230	<0.001	0.318	0.250	0.162 (0.146–0.177)	0.181	4080.393	4230.426	4013.231
Two-factor model	463.85	229	<0.001	0.590	0.548	0.126 (0.109–0.142)	0.131	3925.212	4077.419	3857.077
Three-factor model	389.89	227	<0.001	0.716	0.683	0.105 (0.087–0.123)	0.121	3855.246	4011.802	3785.164

Note: Estimator = MLR; $\chi 2$ = Chi-square Goodness of Fit statistic; *df* = degrees of freedom; p = Statistical significance; CFI = Comparative Fit Index; TLI = Tucker Lewis Index; RMSEA (90 % CI) = Root-Mean-Square Error of Approximation with 90 % confidence intervals; SRMR = Standardized Root-Mean Square Residual; AIC = Akaike Information Criterion; BIC = Bayesian Information Criterion; ssaBIC = sample size adjusted BIC. One-factor model = gratitude adjective checklist, positive and negative affect on one factor. Two-factor model = gratitude adjective checklist and positive affect on one factor and negative affect on a second factor. Three-factor model = gratitude adjective checklist, positive affect and negative affect loaded onto three separate factors.

did not interact with quadratic growth to predict either diastolic blood pressure (B = 0.67, 95%CI [−0.60, 1.95], p = 0.299), or heart rate (B = 1.45, 95%CI [−0.39, 2.39], p = 0.123) responses. Taken together, partial support for Hypothesis 1 was found as higher state gratitude predicted a lower systolic blood pressure response to stress, but did not predict diastolic blood pressure or heart rate responses.

Table 4
Multi-level growth model results looking at the cross-level interactions between state gratitude, affect balance and growth in systolic blood pressure.

Step	1				2				3			
	Est	95 % CI	*t*	*p*	*Est*	95 % CI	*t*	*p*	*Est*	95 % CI	*t*	*p*
Fixed effects												
Intercept	121.58	[108.06, 135.10]	17.80	<0.001**	123.57	[109.78, 137.35]	17.75	<0.001**	126.51	[111.61, 141.41]	16.82	<0.001**
Age	0.26	[−0.05, 0.56]	1.68	0.098	0.17	[−0.13, 0.47]	1.11	0.271	0.12	[−0.19, 0.44]	0.79	0.435
Gender	−5.81	[−11.28, −0.33]	−2.12	0.038*	−4.19	[−9.80, 1.42]	−1.50	0.140	−3.97	[−9.59, 1.65]	−1.41	0.163
Perceived stress	−0.11	[−3.08, 2.85]	−0.08	0.939	−1.04	[−4.12, 2.03]	−0.68	0.499	−1.74	[−5.07, 1.60]	−1.04	0.301
Linear growth	19.46	[16.80, 22.12]	14.48	<0.001**	19.56	[16.94, 22.17]	14.82	<0.001**	19.77	[16.99, 22.55]	14.09	<0.001**
Quadratic growth	−10.32	[−11.59, −9.04]	−15.98	<0.001**	−10.36	[−11.62, −9.11]	−16.34	<0.001**	−10.42	[−11.76, −9.09]	−15.46	<0.001**
Affect balance					0.82	[−2.18, 3.83]	0.55	0.587	0.63	[−2.40, 3.66]	0.42	0.678
State gratitude					−2.58	[−5.47, 0.31]	−1.79	0.079	−2.90	[−5.88, 0.07]	−1.95	0.056
Affect balance × Linear growth					0.63	[−2.19, 3.45]	0.44	0.659	0.58	[−2.26, 3.42]	0.40	0.687
Affect balance × Quadratic growth					−0.37	[−1.73, 0.98]	−0.55	0.584	−0.36	[−1.73, 1.00]	−0.52	0.601
State gratitude × Linear growth					−4.08	[−6.93, −1.24]	−2.84	0.005**	−4.18	[−7.07, −1.29]	−2.86	0.005**
State gratitude × Quadratic growth					1.91	[0.54, 3.28]	2.76	0.007**	1.94	[0.55, 3.33]	2.76	0.007**
Affect balance × State gratitude									−1.01	[−3.69, 1.67]	−0.76	0.452
Affect balance × State gratitude × Linear growth									−0.62	[−3.20, 1.96]	−0.48	0.634
Affect balance × State gratitude × Quadratic growth									0.17	[−1.07, 1.41]	0.27	0.788
Random effects												
Intercept (σ^2)	9.33				9.01				8.99			
Time (σ^2)	0.03				0.04				0.04			
Residual (σ^2)	4.18				4.11				4.13			
Model fit indices												
AIC	1259.36				1249.75				1250.93			
LL	−619.68				−608.87				−606.46			
$\chi^2(df)$					21.61(6); p < 0.001**				4.82(3); *p* = 0.185			
R^2 (ΔR^2)	0.27				0.33(0.06)				0.33 (0.00)			

Note: AIC = Akaike information criterion, LL = log likelihood, R^2 = marginal coefficient of determination representing variance explained by fixed effects, σ^2 = standard deviation.
* p < 0.05.
** p < 0.01.

Hypothesis 2 proposed that affect balance would predict lower overall cardiovascular responses to acute psychological stress. The relevant results for this can be found in step 2 of Tables 4, 5 and 6 and Fig. 2. Across the three models, there was no evidence that affect balance moderated the growth trajectory of the cardiovascular response to stress. Thus, Hypothesis 2 was not supported.

Hypothesis 3 proposed that affect balance and state gratitude would interact with growth to predict the cardiovascular stress response. The relevant results for this can be found in step 3 of Tables 4, 5 and 6 and Fig. 3. There was a significant three-way interaction for diastolic blood pressure for linear (B = −2.46, 95%CI [−4.81, −0.10], $p = 0.041$), and quadratic growth (B = 1.31, 95%CI [0.18, 2.45], $p = 0.023$). Adding this interaction to the model decreased the AIC and increased the LL fit indices and resulted in a 7 % increase in the variance explained ($\Delta R^2 = 0.07$, $\chi^2(3) = 14.86$, $p = 0.002$). Inspection of the interaction plots (see Fig. 3B) implies that the more an individual experienced positive emotion over negative emotion, the stronger the effect of state gratitude on the diastolic blood pressure response to stress was. The three way interaction was not significant for systolic blood pressure, although inspection of the interaction plot in Fig. 3a demonstrates a similar (albeit non-significant) pattern of interaction whereby more positive emotion on balance amplified the effects of state gratitude.

The three way interaction with quadratic growth for heart rate was marginally significant (B = 1.70, 95%CI [0.05, 3.34], $p = 0.043$), but the change in R^2 was <0.1 % so this finding was interpreted as non-significant. Thus, there was some support for Hypothesis 3 with regard to diastolic blood pressure but not for systolic blood pressure or heart rate.

3. Discussion

This study aimed to assess the stress buffering functions of state gratitude and affect balance. It found that state gratitude buffered the impact of induced stress on systolic blood pressure, indicated by a 'flatter' curve in systolic blood pressure (lower reactivity and faster recovery) at higher levels of state gratitude compared to moderate and low

Table 5
Multi-level growth model results looking at the cross-level interactions between state gratitude, affect balance and growth in diastolic blood pressure.

Step	1				2				3			
	Est	95 % CI	*t*	*p*	*Est*	95 % CI	*t*	*p*	*Est*	*95 % CI*	*t*	*p*
Fixed effects												
Intercept	52.60	[42.26, 62.94]	10.07	<0.001**	55.22	[44.38, 66.06]	10.09	<0.001**	61.05	[49.95, 72.15]	10.89	<0.001**
Age	0.39	[0.16, 0.62]	3.33	0.001**	0.36	[0.12, 0.60]	3.03	0.004**	0.27	[0.04, 0.51]	2.33	0.023*
Gender	2.65	[−1.53, 6.83]	1.27	0.210	2.77	[−1.63, 7.18]	1.26	0.213	3.20	[−0.98, 7.39]	1.53	0.130
Perceived stress	−0.15	[−2.41, 2.12]	−0.13	0.896	−0.92	[−3.33, 1.50]	−0.76	0.450	−2.25	[−4.74, 0.23]	−1.82	0.074
Linear growth	12.95	[10.53, 15.37]	10.59	<0.001**	12.99	[10.55, 15.42]	10.56	<0.001**	13.85	[11.31, 16.38]	10.81	<0.001**
Quadratic growth	−6.58	[−7.74, −5.42]	−11.20	<0.001**	−6.59	[−7.76, −5.42]	−11.16	<0.001**	−7.05	[−8.27, −5.83]	−11.46	<0.001**
Affect balance					−1.08	[−3.48, 1.33]	−0.90	0.374	−1.47	[−3.78, 0.83]	−1.28	0.206
State gratitude					−0.90	[−3.21, 1.42]	−0.78	0.441	−1.59	[−3.86, 0.68]	−1.41	0.165
Affect balance × Linear growth					1.73	[−0.90, 4.35]	1.30	0.195	1.53	[−1.06, 4.12]	1.17	0.245
Affect balance × Quadratic growth					−0.86	[−2.12, 0.41]	−1.34	0.182	−0.75	[−2.00, 0.50]	−1.19	0.236
State gratitude × Linear growth					−1.59	[−4.24, 1.07]	−1.18	0.239	−1.97	[−4.61, 0.67]	−1.48	0.141
State gratitude × Quadratic growth					0.67	[−0.60, 1.95]	1.04	0.299	0.88	[−0.39, 2.15]	1.37	0.173
Affect balance × State gratitude									−2.35	[−4.39, −0.31]	−2.31	0.025*
Affect balance × State gratitude × Linear growth									−2.46	[−4.81, −0.10]	−2.07	0.041*
Affect balance × State gratitude × Quadratic growth									1.31	[0.18, 2.45]	2.30	0.023*
Random effects												
Intercept (σ^2)	7.02				6.97				6.54			
Time (σ^2)	0.15				0.06				0.16			
Residual (σ^2)	3.81				3.83				3.77			
Model fit indices												
AIC	1203.47				1204.45				1195.58			
LL	−591.74				−586.22				−578.79			
$\chi^2(df)$					11.02 (6); $p = 0.088$				14.86 (3); p = 0.002**			
R^2 (ΔR^2)	0.24				0.27 (0.03)				0.34 (0.07)			

Note: AIC = Akaike information criterion, LL = log likelihood, R^2 = marginal coefficient of determination representing variance explained by fixed effects, σ^2 = standard deviation.
* $p < 0.05$.
** $p < 0.01$.

levels. This study also uncovered evidence of a moderating effect of affect balance on state gratitude's effect on diastolic blood pressure, where the more positive emotion an individual experienced, the greater the effect of higher levels of state gratitude on the diastolic blood pressure response to stress.

However, the study did not find evidence for affect balance's role as a moderator of the relationship between gratitude and the trajectory of systolic blood pressure or heart rate responses to acute stress. Similarly, there was no evidence of a direct buffering effect of affect balance on any cardiovascular outcome.

Overall, this study provides some evidence that state gratitude plays a unique stress-buffering role on systolic blood pressure during an acute stress response, where the response consists of both the reaction to and recovery from the stressor. Moreover, it found that this same response for diastolic blood pressure was moderated by the balance of positive to negative emotion, where more positive than negative emotion amplifies the stress-buffering effects of state gratitude.

State gratitude was found to have a significant interaction with the linear and quadratic growth parameters for systolic blood pressure. This means that individuals higher on state gratitude had lower responses to stress and had lower systolic blood pressure during the recovery period compared to those who reported moderate and low levels of state gratitude. It is worth noting that to our knowledge, no other study has examined how gratitude impacts cardiovascular recovery. While previous research has noted the effects of state gratitude on cardiovascular reactivity to stress (Gallagher et al., 2020, 2021; Ginty et al., 2020), no other study has examined the recovery period. Considered in the light of research indicating that exaggerated responses to stress are associated with negative cardiovascular health outcomes (Chida and Steptoe, 2010; Treiber et al., 2003), this implies that state gratitude has an important stress-buffering function. This is consistent with prior work on gratitude and cardiovascular reactivity where gratitude played a unique role (Gallagher et al., 2020; Ginty et al., 2020). This also coheres with other previous research where positive psychological well-being has been associated with reduced cardiovascular mortality (Chida and Steptoe, 2008) and previous work has also noted how positive emotional states

Table 6
Multi-level growth model results looking at the cross-level interactions between state gratitude, affect balance and growth in heart rate.

Step	1				2				3			
	Est	95 % CI	*t*	*p*	*Est*	*95 % CI*	*t*	*p*	*Est*	95 % CI	*t*	*p*
Fixed effects												
Intercept	58.59	[42.53, 74.65]	7.22	<0.001**	55.61	[38.48, 72.74]	6.43	<0.001**	56.16	[37.46, 74.86]	5.95	<0.001**
Age	−0.06	[−0.42, 0.31]	−0.32	0.753	−0.06	[−0.43, 0.32]	−0.30	0.765	−0.07	[−0.46, 0.33]	−0.34	0.735
Gender	9.83	[3.34, 16.33]	3.03	0.004**	10.44	[3.47, 17.41]	3.00	0.004**	10.49	[3.44, 17.54]	2.98	0.004**
Perceived stress	2.40	[−1.12, 5.92]	1.36	0.178	3.09	[−0.73, 6.91]	1.62	0.110	2.93	[−1.26, 7.11]	1.40	0.167
Linear growth	18.82	[15.32, 22.32]	10.64	<0.001**	18.88	[15.37, 22.40]	10.63	<0.001**	20.04	[16.36, 23.73]	10.77	<0.001**
Quadratic growth	−10.16	[−11.84, −8.47]	−11.96	<0.001**	−10.19	[−11.88, −8.50]	−11.94	<0.001**	−10.78	[−12.55, −9.01]	−12.06	<0.001**
Affect balance					1.54	[−2.22, 5.31]	0.82	0.415	1.53	[−2.29, 5.36]	0.80	0.426
State gratitude					0.74	[−2.88, 4.36]	0.41	0.685	0.72	[−3.03, 4.48]	0.39	0.701
Affect balance × Linear growth					1.53	[−2.27, 5.32]	0.80	0.427	1.26	[−2.51, 5.02]	0.66	0.510
Affect balance × Quadratic growth					−0.90	[−2.72, 0.92]	−0.98	0.330	−0.76	[−2.57, 1.05]	−0.83	0.406
State gratitude × Linear growth					−2.80	[−6.63, 1.03]	−1.45	0.151	−3.32	[−7.16, 0.51]	−1.72	0.089
State gratitude × Quadratic growth					1.45	[−0.39, 3.29]	1.56	0.123	1.71	[−0.13, 3.56]	1.84	0.068
Affect balance × State gratitude									0.17	[−3.21, 3.55]	0.10	0.920
Affect balance × State gratitude × Linear growth									−3.32	[−6.75, 0.10]	−1.92	0.057
Affect balance × State gratitude × Quadratic growth									1.70	[0.05, 3.34]	2.05	0.043*
Random effects												
Intercept (σ^2)	11.02				11.11				11.22			
Time (σ^2)	0.04				0.04				0.04			
Residual (σ^2)	5.50				5.53				5.49			
Model fit indices												
AIC	1346.82				1344.84				1342.01			
LL	−663.41				−656.42				−652.01			
$\chi^2(df)$					13.98(6); $p = 0.030$*				8.82(3); $p = 0.032$*			
R^2 (ΔR^2)	0.27				0.28 (0.01)				0.28 (0.00)			

Note: AIC = Akaike information criterion, LL = log likelihood, R^2 = marginal coefficient of determination representing variance explained by fixed effects, σ^2 = standard deviation.
* $p < 0.05$.
** $p < 0.01$.

are important for the stress process (Folkman, 2008). Importantly, this finding was robust to the adjustment for control variables (Gallagher et al., 2020) and was adequately powered. The findings for diastolic blood pressure, while statistically non-significant, followed a similar pattern to that found for systolic blood pressure, whereby higher levels of state gratitude predicted lower diastolic blood pressure responses to the stress task. This interaction between state gratitude and quadratic growth explained 3 % of the variance in diastolic blood pressure. Similarly, there was no evidence of a buffering effect on heart rate.

Affect balance did not moderate the growth trajectory for systolic blood pressure, diastolic blood pressure, or heart rate. This may reflect the fact that the stem of the affect-balance measures referred to positive and negative affect over the past week and as such was not as proximally relevant as state gratitude, leading to smaller effects. For example, there is some research describing the different effects of state and trait affect on outcomes such as cardiovascular stress responses (Määttänen et al., 2021; Papousek et al., 2010). Future research should examine more proximal measures of affect-balance in order to further explore this relationship.

However, there was evidence that affect balance moderated the effects of state gratitude on diastolic blood pressure, but not systolic blood pressure or heart rate. The results indicate that a balance of more positive emotions to negative emotions amplified the effects of higher gratitude for diastolic blood pressure. A similar pattern is observable for systolic blood pressure and, although it did not reach statistical significance, it suggests that in a larger sample, this effect would be significant. Similarly, while the interaction for heart rate was significant, as the effect was <0.01, we cautiously interpret this as non-significant. This interaction may indicate that affect-balance does not directly impact the cardiovascular response to stress, but instead works to amplify the effects of gratitude on the stress response.

Interestingly, this result is the opposite of what was expected. It was expected that individuals who experienced more positive than negative emotion would not benefit as much from experiences of gratefulness, in line with the resistance hypothesis (McCullough et al., 2004). For example, previous research found that low baseline positive affect

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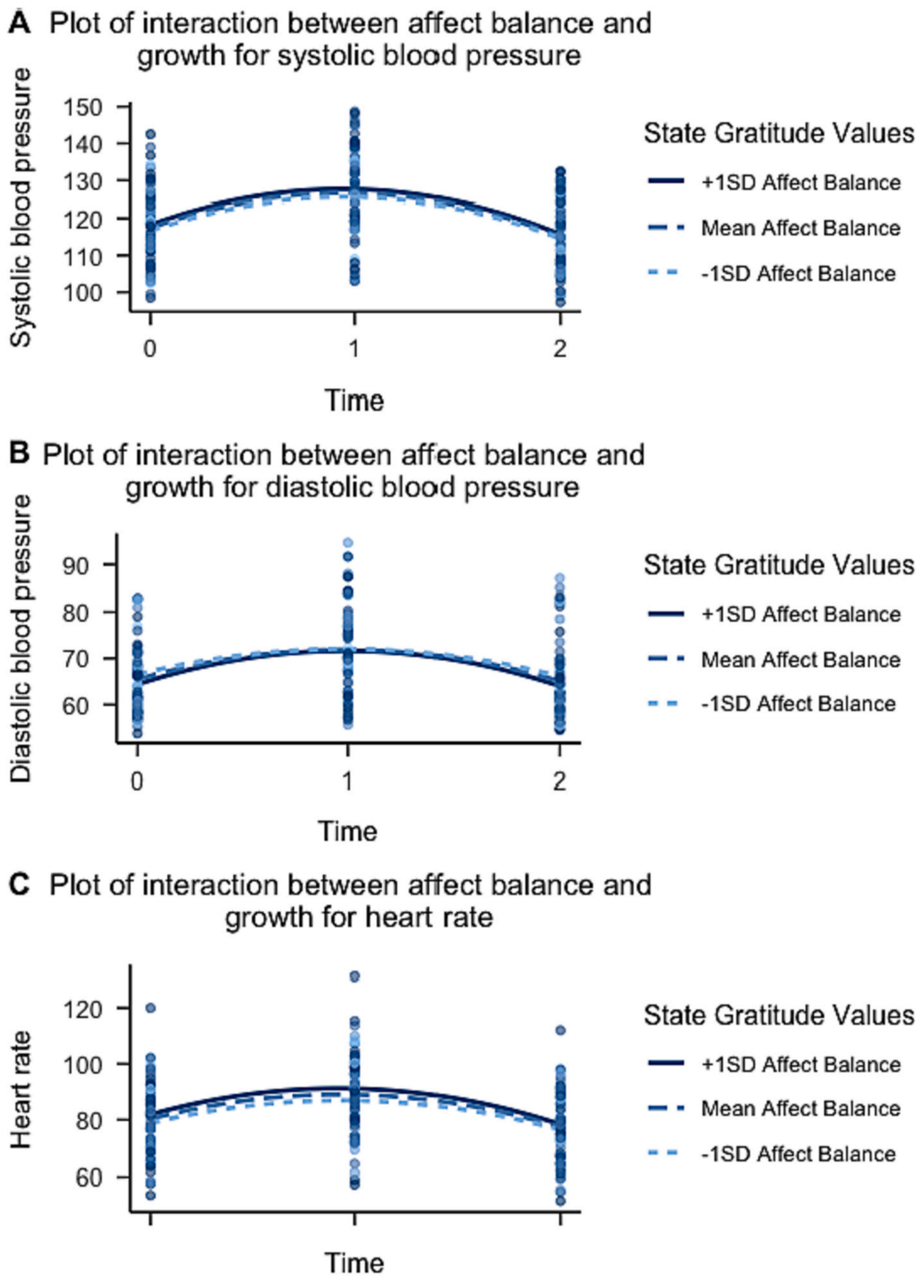

Fig. 2. Interaction plots for low (−1SD), average (mean) and high (+1SD) levels of affect-balance and how the trajectory of growth and decline changes at each level for cardiovascular measures.

amplified the relationship between a gratitude intervention on positive affect two weeks later (Froh et al., 2009). However, the results show that a balance of *more* positive to negative emotion amplifies the effects of state gratitude. Thus, the findings are more consistent with the broaden-and-build theory (Fredrickson, 2004) which posits that positive emotions can beget upward spirals which lead to optimal functioning (Garland et al., 2010; O'Connell et al., 2016). Additionally, and in line with past research suggesting the importance of considering positive and negative affect (Fredrickson, 2001; Kolanowski et al., 2014), this research tentatively suggests a role for considering affect balance when looking at the effect of state gratitude on cardiovascular stress responses.

A notable outcome of these results is that there are differing outcomes for systolic blood pressure, diastolic blood pressure and heart rate. This discrepancy may reflect differences in the cardiovascular and autonomic profiles of positive emotions (Shiota et al., 2011; Sinha et al., 1992), or differences in the cardiovascular profile of different emotional regulation strategies in response to stress (Griffin and Howard, 2022). For example, the discrepancy in the results may reflect differences in how gratitude and affect balance impact cardiac output, which is a determinant of systolic blood pressure, and total peripheral resistance, which is a determinant of diastolic blood pressure (Chaudhry et al., 2022; Magder, 2018; Tortora and Derrickson, 2019). Similarly, there are multiple determinants of heart rate, such as through parasympathetic nervous system activity or through the release of hormones like epinephrine and norepinephrine (Tortora and Derrickson, 2019). Research has found that positive emotions are differentially associated with cardiac output and total peripheral resistance (Kreibig, 2010), as well as parasympathetic nervous system activity (Levenson, 2014). Similarly, emotional regulation strategies in response to stress are differentially associated with cardiovascular outcomes (Griffin and Howard, 2022). For example, one study shows that using a reappraisal emotional regulation strategy is associated with decreased total

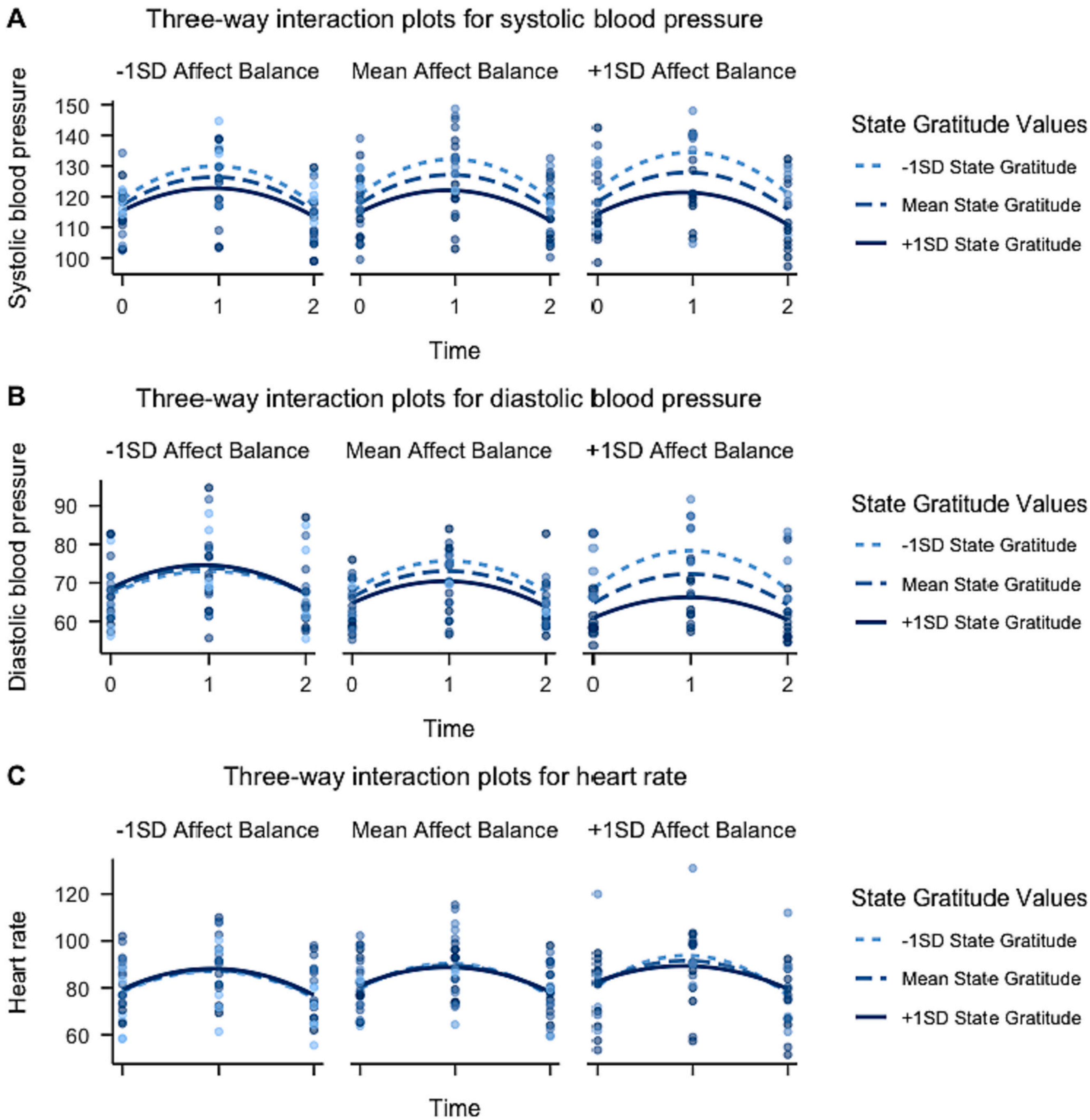

Fig. 3. Interaction plots for low (−1SD), average (mean) and high (+1SD) levels of affect balance and how the trajectory of growth and decline changes at each level for cardiovascular measures.

peripheral resistance (Mauss et al., 2007), and another shows that emotional suppression is associated with greater total peripheral resistance (Peters et al., 2014). As such, the differences in this study's findings may reflect the differences in the autonomic and cardiovascular profiles state gratitude and affect balance.

It is also worth noting that a recent review found that the kind of physiological measure utilized determined the strength of the effect for positive emotions on the cardiovascular response to stress (Behnke et al., 2022). Composite indices of the cardiovascular response to stress are constructed from multiple measurements such as finger pulse amplitude, blood pressure, and heart period are associate with larger effect sizes (Fredrickson et al., 2000; Fredrickson and Levenson, 1998). The reasoning behind their utilization is that they provide a better measure of sympathetic activation than any single measure alone (Behnke et al., 2022; Fredrickson and Levenson, 1998). This is in contrast to the use of studies which focus on heart rate and blood pressure, which index a combination of sympathetic and parasympathetic nervous system activity (Shiota and Danvers, 2014). This indexing of sympathetic and parasympathetic nervous system activity may also explain the differentiated findings in the current study (Shiota et al., 2011).

However, it is also possible that the moderating effect of affect balance and the buffering effects of state gratitude would emerge in a larger sample. Buffering effects have been detected for systolic and diastolic blood pressure and heart rate in larger samples (e.g. Ginty et al., 2020). Moreover, the effects of positive and negative affect on systolic and diastolic blood pressure, and heart rate are similarly undifferentiated

(Brummett et al., 2009; Hilmert et al., 2014). Indeed, it is possible that the effects are much smaller than anticipated, with one meta-analysis indicating that the undoing effects of positive emotions on cardiovascular responses to stress were small (Behnke et al., 2022). Nonetheless, this finding suggests that further research into gratitude, affect balance and the cardiovascular determinants of blood pressure and heart rate is warranted such as cardiac output and total peripheral resistance, as well as through the use of composite measures.

These results can be viewed as a stepping-stone to extend to clinical utility. There are a number of low-cost gratitude interventions which can contribute to well-being (Wood et al., 2010). For example, gratitude lists whereby individuals write down three to five things for which they are grateful have been shown to have a number of beneficial effects (Kerr et al., 2015; Manthey et al., 2016). Previous research has shown how cardiac patients who make use of gratitude journals have better cardiovascular outcomes than those who do not (Redwine et al., 2016). Combined with the results of this study and previous work, gratitude may constitute a useful point of intervention for the improvement of cardiovascular health.

3.1. Limitations

There are some limitations of this study. First, it made use of self-report measures. These have several generic criticisms attached to them (e.g. Chan, 2009). However, self-report measures are frequently used in research and the measures of gratitude and positive and negative affect were psychometrically robust instruments. Additionally, their usage allows the comparison with other research (i.e. Gallagher et al., 2020). Second, this study did not make use of a gratitude induction; however, it did induce stress in a laboratory setting. It would be beneficial to induce gratitude in a randomised control trial context to assess its impact on cardiovascular responses to stress. Third, only blood pressure and heart rate were measured in this study. A fuller range of cardiovascular outcomes might prove instructive, for example, cardiac output and total peripheral resistance. However, the study was well-controlled and followed a standardised stress-testing protocol design. It also uncovered effects consistent with previous research.

3.2. Future directions

Future research to replicate and extend the findings with a larger, more diverse sample of participants would be useful to provide further investigate the interaction between affect balance and gratitude in modulating cardiovascular responses to stress. According to previous stress-buffering models (Pressman et al., 2019), one way by which gratitude may buffer the effects of stress is by interacting with how stressful the task is perceived as. It would be useful to assess this relationship in a stress-testing protocol context. It is also recommended that future research investigate the impact of gratitude in the context of a randomised control trial using a gratitude induction. This will aid in untangling the causal direction at work and explicate the pathways by which gratitude may buffer the deleterious impact of stress.

4. Conclusion

This study found that state gratitude decreases the trajectory of the systolic blood pressure stress responses in terms of reactivity to stress and recovery from stress. Participants with higher state gratitude had lower systolic blood pressure responses to stress during the task and during the recovery period. This implies that gratitude is reducing reactivity and hastening recovery. This provides support for gratitude's stress-buffering role, as these effects withstood adjustment for age, gender and baseline measures. Additionally this research detected a three-way interaction between gratitude, affect-balance and the growth trajectory for diastolic blood pressure. These novel findings suggest that state gratitude can act as a buffer against the negative cardiovascular effects of acute stress and a higher balance of positive to negative emotions amplifies this effect (at least for diastolic blood pressure). This contributes to our overall understanding of how gratitude impacts physical health.

Declaration of competing interest

None.

Data availability

Data will be made available on request.

References

al'Absi, M., Everson, S.A., Lovallo, W.R., 1995. Hypertension risk factors and cardiovascular reactivity to mental stress in young men. Int. J. Psychophysiol. 20 (3), 155–160. https://doi.org/10.1016/0167-8760(95)00029-1.

Amai, K., Hojo, D., 2022. Early adolescent psychological adaptation differences by stress-coping profiles: a latent transition analysis. Anxiety Stress Coping 35 (5), 574–591. https://doi.org/10.1080/10615806.2021.1980782.

Ashby, F.G., Isen, A.M., Turken, A.U., 1999. A neuropsychological theory of positive affect and its influence on cognition. Psychol. Rev. 106 (3), 529–550. https://doi.org/10.1037/0033-295x.106.3.529.

Bates, D., Kliegl, R., Vasishth, S., Baayen, H., 2015. In: Parsimonious Mixed Models. ArXiv, p. 1506.

Bauer, D.J., Curran, P.J., 2005. Probing interactions in fixed and multilevel regression: inferential and graphical techniques. Multivar. Behav. Res. 40 (3), 373–400. https://doi.org/10.1207/s15327906mbr4003_5.

Behnke, M., Pietruch, M., Chwiłkowska, P., Wessel, E., Kaczmarek, L.D., Assink, M., Gross, J.J., 2022. The undoing effect of positive emotions: a meta-analytic review. Emot. Rev. 17540739221104456 https://doi.org/10.1177/17540739221104457.

Bliese, P., 2022. Multilevel Modeling in R (2.7).

Boehm, J.K., Kubzansky, L.D., 2012. The heart's content: the association between positive psychological well-being and cardiovascular health. Psychol. Bull. 138 (4), 655–691. https://doi.org/10.1037/a0027448.

Bolger, N., Laurenceau, J.-P., 2013. Intensive Longitudinal Methods: An Introduction to Diary and Experience Sampling Research. Guilford Press.

Brummett, B.H., Boyle, S.H., Kuhn, C.M., Siegler, I.C., Williams, R.B., 2009a. Positive affect is associated with cardiovascular reactivity, norepinephrine level, and morning rise in salivary cortisol. Psychophysiology 46 (4), 862–869. https://doi.org/10.1111/j.1469-8986.2009.00829.x.

Bryan, J.L., Young, C.M., Lucas, S., Quist, M.C., 2018. Should I say thank you? Gratitude encourages cognitive reappraisal and buffers the negative impact of ambivalence over emotional expression on depression. Personal. Individ. Differ. 120, 253–258. https://doi.org/10.1016/j.paid.2016.12.013.

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.

Celano, C.M., Beale, E.E., Beach, S.R., Belcher, A.M., Suarez, L., Motiwala, S.R., Gandhi, P.U., Gaggin, H., Januzzi Jr., J.L., Healy, B.C., Huffman, J.C., 2017. Associations between psychological constructs and cardiac biomarkers after acute coronary syndrome. Psychosom. Med. 79 (3), 318–326. https://doi.org/10.1097/PSY.0000000000000404. In press.

Chan, D., 2009. In: So Why Ask Me? Are Self-report Data Really That Bad. Statistical and Methodological Myths and Urban Legends: Doctrine, Verity and Fable in the Organizational and Social Sciences, pp. 309–336.

Chaudhry, R., Miao, J.H., Rehman, A., 2022. Physiology, cardiovascular. In: StatPearls. StatPearls Publishing. http://www.ncbi.nlm.nih.gov/books/NBK493197/.

Chida, Y., Steptoe, A., 2008. Positive psychological well-being and mortality: a quantitative review of prospective observational studies. Psychosom. Med. 70 (7), 741–756. https://doi.org/10.1097/PSY.0b013e31818105ba.

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 (Dallas, Tex.: 1979) 55 (4), 1026–1032. https://doi.org/10.1161/HYPERTENSIONAHA.109.146621.

Cohen, S., Pressman, S.D., 2006. Positive affect and health. Curr. Dir. Psychol. Sci. 15 (3), 122–125. https://doi.org/10.1111/j.0963-7214.2006.00420.x.

Cohen, S., Janicki-Deverts, D., Miller, G.E., 2007. Psychological stress and disease. JAMA 298 (14), 1685–1687. https://doi.org/10.1001/jama.298.14.1685.

Cousin, L., Redwine, L., Bricker, C., Kip, K., Buck, H., 2021. Effect of gratitude on cardiovascular health outcomes: a state-of-the-science review. J. Posit. Psychol. 16 (3), 348–355. https://doi.org/10.1080/17439760.2020.1716054.

Creaven, A.-M., Hughes, B.M., 2012. Cardiovascular responses to mental activation of social support schemas. Int. J. Psychophysiol. 84 (2), 113–119. https://doi.org/10.1016/j.ijpsycho.2012.01.018.

Curran, P.J., Obeidat, K., Losardo, D., 2010. Twelve frequently asked questions about growth curve modeling. J. Cogn. Dev. 11 (2), 121–136. https://doi.org/10.1080/15248371003699969.

Danhauer, S.C., Legault, C., Bandos, H., Kidwell, K., Costantino, J., Vaughan, L., Avis, N. E., Rapp, S., Coker, L.H., Naughton, M., Naylor, C., Terracciano, A., Shumaker, S.,

2013. Positive and negative affect, depression, and cognitive processes in the Cognition in the Study of Tamoxifen and Raloxifene (Co-STAR) Trial. Neuropsychol. Dev. Cogn. B Aging Neuropsychol. Cogn. 20 (5) https://doi.org/10.1080/13825585.2012.747671 doi:10.1080/13825585.2012.747671.
Davis, D.E., Choe, E., Meyers, J., Wade, N., Varjas, K., Gifford, A., Quinn, A., Hook, J.N., Van Tongeren, D.R., Griffin, B.J., Worthington, E.L., 2016. Thankful for the little things: a meta-analysis of gratitude interventions. J. Couns. Psychol. 63 (1), 20–31. https://doi.org/10.1037/cou0000107.
DeSteno, D., Gross, J.J., Kubzansky, L., 2013. Affective science and health: the importance of emotion and emotion regulation. Health Psychol. 32 (5), 474–486. https://doi.org/10.1037/a0030259.
Diehl, M., Hay, E.L., 2010. Risk and resilience factors in coping with daily stress in adulthood: the role of age, self-concept incoherence, and personal control. Dev. Psychol. 46 (5), 1132–1146. https://doi.org/10.1037/a0019937.
Diehl, M., Hay, E.L., Berg, K.M., 2011. The ratio between positive and negative affect and flourishing mental health across adulthood. Aging Ment. Health 15 (7), 882–893. https://doi.org/10.1080/13607863.2011.569488.
Diener, E., Wirtz, D., Tov, W., Kim-Prieto, C., Choi, D., Oishi, S., Biswas-Diener, R., 2010. New well-being measures: short scales to assess flourishing and positive and negative feelings. Soc. Indic. Res. 97 (2), 143–156. https://doi.org/10.1007/s11205-009-9493-y.
Drolet, G., Dumont, E.C., Gosselin, I., Kinkead, R., Laforest, S., Trottier, J.F., 2001. Role of endogenous opioid system in the regulation of the stress response. Prog. Neuro-Psychopharmacol. Biol. Psychiatry 25 (4), 729–741. https://doi.org/10.1016/s0278-5846(01)00161-0.
du Plessis, G.A., Guse, T., 2017. Validation of the scale of positive and negative experience in a south African student sample. S. Afr. J. Psychol. 47 (2), 184–197. https://doi.org/10.1177/0081246316654328.
Dubois, C.M., Beach, S.R., Kashdan, T.B., Nyer, M.B., Park, E.R., Celano, C.M., Huffman, J.C., 2012. Positive psychological attributes and cardiac outcomes: associations, mechanisms, and interventions. Psychosomatics 53 (4), 303–318. https://doi.org/10.1016/j.psym.2012.04.004.
Faul, F., Erdfelder, E., Lang, A.-G., Buchner, A., 2007. G*Power 3: a flexible statistical power analysis program for the social, behavioral, and biomedical sciences. Behav. Res. Methods 39 (2), 175–191. https://doi.org/10.3758/BF03193146.
Felt, J.M., Depaoli, S., Tiemensma, J., 2017. Latent growth curve models for biomarkers of the stress response. Front. Neurosci. 11. https://www.frontiersin.org/articles/10.3389/fnins.2017.00315.
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.
Folkman, S., Lazarus, R.S., 1988. Coping as a mediator of emotion. J. Pers. Soc. Psychol. 54 (3), 466–475. https://doi.org/10.1037/0022-3514.54.3.466.
Fredrickson, B.L., 2001. The role of positive emotions in positive psychology: the broaden-and-build theory of positive emotions. Am. Psychol. 56 (3), 218–226. https://doi.org/10.1037/0003-066X.56.3.218.
Fredrickson, B.L., 2004. The broaden-and-build theory of positive emotions. Philos. Trans. R. Soc., B 359 (1449), 1367–1378. https://doi.org/10.1098/rstb.2004.1512.
Fredrickson, B.L., Levenson, R.W., 1998. Positive emotions speed recovery from the cardiovascular sequelae of negative emotions. Cognit. Emot. 12 (2), 191–220. https://doi.org/10.1080/026999398379718.
Fredrickson, B.L., Mancuso, R.A., Branigan, C., Tugade, M.M., 2000. The undoing effect of positive emotions. Motiv. Emot. 24 (4), 237–258.
Froh, J.J., Bono, G., Emmons, R., 2010. Being grateful is beyond good manners: Gratitude and motivation to contribute to society among early adolescents. Motiv. Emot. 34 (2), 144–157. https://doi.org/10.1007/s11031-010-9163-z.
Froh, J.J., Kashdan, T.B., Ozimkowski, K.M., Miller, N., 2009. Who benefits the most from a gratitude intervention in children and adolescents? Examining positive affect as a moderator. J. Posit. Psychol. 4 (5), 408–422. https://doi.org/10.1080/17439760902992464.
Gallagher, S., Solano, A.C., Liporace, M.F., 2020a. 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.
Gallagher, S., Creaven, A.-M., Howard, S., Ginty, A.T., Whittaker, A.C., 2021. Gratitude, social support and cardiovascular reactivity to acute psychological stress. Biol. Psychol. 162 https://doi.org/10.1016/j.biopsycho.2021.108090.
Garland, E.L., Fredrickson, B., Kring, A.M., Johnson, D.P., Meyer, P.S., Penn, D.L., 2010. Upward spirals of positive emotions counter downward spirals of negativity: insights from the broaden-and-build theory and affective neuroscience on the treatment of emotion dysfunctions and deficits in psychopathology. Clin. Psychol. Rev. 30 (7), 849–864. https://doi.org/10.1016/j.cpr.2010.03.002.
Gellert, P., Häusler, A., Suhr, R., Gholami, M., Rapp, M., Kuhlmey, A., Nordheim, J., 2018. Testing the stress-buffering hypothesis of social support in couples coping with early-stage dementia. PLoS ONE 13 (1), e0189849. https://doi.org/10.1371/journal.pone.0189849.
Ginty, A.T., Tyra, A.T., Young, D.A., John-Henderson, N.A., Gallagher, S., Tsang, J.-A.C., 2020a. 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.
Griffin, S.M., Howard, S., 2022. Individual differences in emotion regulation and cardiovascular responding to stress. Emotion (Washington, D.C.) 22 (2), 331–345. https://doi.org/10.1037/emo0001037.
Gueorguieva, R., Krystal, J.H., 2004. Move over ANOVA: progress in analyzing repeated-measures data and its reflection in papers published in the archives of general psychiatry. Arch. Gen. Psychiatry 61 (3), 310–317. https://doi.org/10.1001/archpsyc.61.3.310.
Hilmert, C.J., Teoh, A.N., Roy, M.M., 2014. Effort and negative affect interact to predict cardiovascular responses to stress. Psychol. Health 29 (1), 64–80. https://doi.org/10.1080/08870446.2013.825917.
Hocking Schuler, J.L., O'Brien, W.H., 1997. Cardiovascular recovery from stress and hypertension risk factors: a meta-analytic review. Psychophysiology 34 (6), 649–659. https://doi.org/10.1111/j.1469-8986.1997.tb02141.x.
Hoogerwerf, M.D., Veldhuizen, I.J.T., Tarvainen, M.P., Merz, E.-M., Huis in 't Veld, E.M. J., de Kort, W.L.A.M., Sluiter, J.K., Frings-Dresen, M.H.W., 2018. Physiological stress response patterns during a blood donation. Vox Sang. 113 (4), 357–367. https://doi.org/10.1111/vox.12646.
Hussong, A.M., Langley, H.A., Rothenberg, W.A., Coffman, J.L., Halberstadt, A.G., Costanzo, P.R., Mokrova, I., 2019. Raising grateful children one day at a time. Appl. Dev. Sci. 23 (4), 371–384. https://doi.org/10.1080/10888691.2018.1441713.
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.
Kerr, S.L., O'Donovan, A., Pepping, C.A., 2015. Can gratitude and kindness interventions enhance well-being in a clinical Sample? J. Happiness Stud. 16 (1), 17–36. https://doi.org/10.1007/s10902-013-9492-1.
Kivimäki, M., Steptoe, A., 2018. Effects of stress on the development and progression of cardiovascular disease. Nat. Rev. Cardiol. 15 (4), 215–229. https://doi.org/10.1038/nrcardio.2017.189.
Kivimäki, M., Virtanen, M., Elovainio, M., Kouvonen, A., Väänänen, A., Vahtera, J., 2006. Work stress in the etiology of coronary heart disease—a meta-analysis. Scand. J. Work Environ. Health 32 (6), 431–442.
Klibert, J., Rochani, H., Samawi, H., Leleux-LaBarge, K., Ryan, R., 2019. The impact of an integrated gratitude intervention on positive affect and coping resources. Int. J. Appl. Posit. Psychol. 3 (1), 23–41. https://doi.org/10.1007/s41042-019-00015-6.
Kolanowski, A.M., Van Haitsma, K., Meeks, S., Litaker, M., 2014. Affect balance and relationship to well-being in nursing home residents with dementia. Am. J. Alzheimers Dis. Other Dement. 29 (5), 457–462. https://doi.org/10.1177/1533317513518657.
Kreibig, S.D., 2010. Autonomic nervous system activity in emotion: a review. Biol. Psychol. 84 (3), 394–421. https://doi.org/10.1016/j.biopsycho.2010.03.010.
Kuznetsova, A., Brockhoff, P.B, Christensen, R.H.B., 2017. lmerTest package: Tests in linear mixed effects models. J. Stat. Softw. 82 (13), 1–26. https://doi.org/10.18637/jss.v082.i13.
Kyeong, S., Kim, J., Kim, D.J., Kim, H.E., Kim, J.-J., 2017. Effects of gratitude meditation on neural network functional connectivity and brain-heart coupling. Sci. Rep. 7, 5058. https://doi.org/10.1038/s41598-017-05520-9.
Lehman, B.J., Kirsch, J.A., Jones, D.R., 2015. Effectively analyzing change over time in laboratory research on stress and health: a multilevel modeling approach. Soc. Personal. Psychol. Compass 9 (10), 551–566. https://doi.org/10.1111/spc3.12202.
Levenson, R.W., 2014. The autonomic nervous system and emotion. Emot. Rev. 6 (2), 100–112. https://doi.org/10.1177/1754073913512003.
Llabre, M.M., Spitzer, S., Siegel, S., Saab, P.G., Schneiderman, N., 2004. Applying latent growth curve modeling to the investigation of individual differences in cardiovascular recovery from stress. Psychosom. Med. 66 (1), 29–41. https://doi.org/10.1097/01.PSY.0000107886.51781.9C.
Määttänen, I., Henttonen, P., Väliaho, J., Palomäki, J., Thibault, M., Kallio, J., Mäntyjärvi, J., Harviainen, T., Jokela, M., 2021. Positive affect state is a good predictor of movement and stress: combining data from ESM/EMA, mobile HRV measurements and trait questionnaires. Heliyon 7 (2), e06243. https://doi.org/10.1016/j.heliyon.2021.e06243.
Magder, S., 2018. The meaning of blood pressure. Crit. Care 22 (1), 257. https://doi.org/10.1186/s13054-018-2171-1.
Manthey, L., Vehreschild, V., Renner, K.-H., 2016. Effectiveness of two cognitive interventions promoting happiness with video-based online instructions. J. Happiness Stud. 17 (1), 319–339. https://doi.org/10.1007/s10902-014-9596-2.
Mathers, C.D., Loncar, D., 2006. Projections of global mortality and burden of disease from 2002 to 2030. PLoS Med. 3 (11), e442 https://doi.org/10.1371/journal.pmed.0030442.
Mathias, C.J., Corazza, I., Guaraldi, P., Barletta, G., Cortelli, P., 2017. Autonomic nervous system: clinical testing☆. In: Reference module in neuroscience and biobehavioral psychology. Elsevier. https://doi.org/10.1016/B978-0-12-809324-5.01817-4.
Matuschek, H., Kliegl, R., Vasishth, S., Baayen, H., Bates, D., 2017. Balancing type I error and power in linear mixed models. J. Mem. Lang. 94, 305–315. https://doi.org/10.1016/j.jml.2017.01.001.
Mauss, I.B., Cook, C.L., Cheng, J.Y.J., Gross, J.J., 2007. Individual differences in cognitive reappraisal: experiential and physiological responses to an anger provocation. Int. J. Psychophysiol. 66 (2), 116–124. https://doi.org/10.1016/j.ijpsycho.2007.03.017.
McCullough, M.E., Emmons, R.A., Tsang, J.-A, 2002. The grateful disposition: A conceptual and empirical topography. J. Personal. Soc. Psychol. 82 (1), 112–127. https://doi.org/10.1037/0022-3514.82.1.112.
McCullough, M.E., Tsang, J.-A., Emmons, R.A., 2004. Gratitude in intermediate affective terrain: links of grateful moods to individual differences and daily emotional experience. J. Pers. Soc. Psychol. 86 (2), 295–309. https://doi.org/10.1037/0022-3514.86.2.295.
McNeish, D., 2017. Small sample methods for multilevel modeling: a colloquial elucidation of REML and the kenward-Roger correction. Multivar. Behav. Res. 52 (5), 661–670. https://doi.org/10.1080/00273171.2017.1344538.
Meeks, S., Van Haitsma, K., Kostiwa, I., Murrell, S.A., 2012. Positivity and well-being among community-residing elders and nursing home residents: what is the optimal

affect balance? J. Gerontol. Ser. B Psychol. Sci. Soc. Sci. 67 (4), 460–467. https://doi.org/10.1093/geronb/gbr135.

Merz, E.L., Roesch, S.C., 2011. Modeling trait and state variation using multilevel factor analysis with PANAS daily diary data. J. Res. Pers. 45 (1), 2–9. https://doi.org/10.1016/j.jrp.2010.11.003.

Middleton, R., Byrd, E., 1996. Psychosocial factors and hospital readmission status of older persons with cardiovascular disease. J. Appl. Rehabil. Couns. 27, 3–10. https://doi.org/10.1891/0047-2220.27.4.3.

Monfort, S.S., Stroup, H.E., Waugh, C.E., 2015. The impact of anticipating positive events on responses to stress. J. Exp. Soc. Psychol. 58, 11–22. https://doi.org/10.1016/j.jesp.2014.12.003.

Murphy, K.R., Myors, B., Wolach, A., 2014. In: Statistical Power Analysis: A Simple and General Model for Traditional and Modern Hypothesis Tests, 4th ed. Routledge/Taylor & Francis Group, p. xiv. 229.

O'Connell, B.H., Killeen-Byrt, M., 2018. Psychosocial health mediates the gratitude-physical health link. Psychol. Health Med. 23 (9), 1145–1150. https://doi.org/10.1080/13548506.2018.1469782.

O'Connell, B.H., O'Shea, D., Gallagher, S., 2016. Enhancing social relationships through positive psychology activities: a randomised controlled trial. J. Posit. Psychol. 11, 149–162. https://doi.org/10.1080/17439760.2015.1037860.

Okely, J.A., Weiss, A., Gale, C.R., 2017. The interaction between stress and positive affect in predicting mortality. J. Psychosom. Res. 100, 53–60. https://doi.org/10.1016/j.jpsychores.2017.07.005.

Ong, A.D., Allaire, J.C., 2005. Cardiovascular intraindividual variability in later life: the influence of social connectedness and positive emotions. Psychol. Aging 20 (3), 476–485. https://doi.org/10.1037/0882-7974.20.3.476 pdh.

Panaite, V., Salomon, K., Jin, A., Rottenberg, J., 2015. Cardiovascular recovery from psychological and physiological challenge and risk for adverse cardiovascular outcomes and all-cause mortality. Psychosom. Med. 77 (3), 215–226. https://doi.org/10.1097/PSY.0000000000000171.

Papousek, I., Nauschnegg, K., Paechter, M., Lackner, H.K., Goswami, N., Schulter, G., 2010a. Trait and state positive affect and cardiovascular recovery from experimental academic stress. Biol. Psychol. 83 (2), 108–115. https://doi.org/10.1016/j.biopsycho.2009.11.008.

Park, H.-J., Bonmassar, G., Kaltenbach, J.A., Machado, A.G., Manzoor, N.F., Gale, J.T., 2013. Activation of the central nervous system induced by micro-magnetic stimulation. Nat. Commun. 4 (1), 2463. https://doi.org/10.1038/ncomms3463.

Peters, B.J., Overall, N.C., Jamieson, J.P., 2014. Physiological and cognitive consequences of suppressing and expressing emotion in dyadic interactions. Int. J. Psychophysiol. 94 (1), 100–107. https://doi.org/10.1016/j.ijpsycho.2014.07.015.

Phillips, A.C., Gallagher, S., Carroll, D., 2009a. 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.

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., 2005. Recommendations for blood pressure measurement in humans and experimental animals. Hypertension 45 (1), 142–161. https://doi.org/10.1161/01.HYP.0000150859.47929.8e.

Pressman, S.D., Cohen, S., 2005. Does positive affect influence health? Psychol. Bull. 131 (6), 925–971. https://doi.org/10.1037/0033-2909.131.6.925.

Pressman, S.D., Jenkins, B.N., Moskowitz, J.T., 2019. Positive affect and health: what do we know and where next should we go? Annu. Rev. Psychol. 70 (1), 627–650. https://doi.org/10.1146/annurev-psych-010418-102955.

R Core Team, 2022. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. https://www.R-project.org/.

Rash, J.A., Matsuba, M.K., Prkachin, K.M., 2011. Gratitude and well-being: who benefits the most from a gratitude Intervention? Appl. Psychol. Health Well Being 3 (3), 350–369. https://doi.org/10.1111/j.1758-0854.2011.01058.x.

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.

Russell, J.A., Carroll, J.M., 1999. On the bipolarity of positive and negative affect. Psychol. Bull. 125 (1), 3–30. https://doi.org/10.1037/0033-2909.125.1.3.

Schlauch, R.C., Gwynn-Shapiro, D., Stasiewicz, P.R., Molnar, D.S., Lang, A.R., 2013. Affect and craving: positive and negative affect are differentially associated with approach and avoidance inclinations. Addict. Behav. 38 (4), 1970–1979. https://doi.org/10.1016/j.addbeh.2012.12.003.

Shiota, M.N., Danvers, A.F., 2014. Another little piece of my heart: positive emotions and the autonomic nervous system. In: Gruber, J., Moskowitz, J.T. (Eds.), Positive Emotion: Integrating the Light Sides and Dark Sides. Oxford University Press, p. 0. https://doi.org/10.1093/acprof:oso/9780199926725.003.0006.

Shiota, M.N., Neufeld, S.L., Yeung, W.H., Moser, S.E., Perea, E.F., 2011. Feeling good: autonomic nervous system responding in five positive emotions. Emotion (Washington, D.C.) 11 (6), 1368–1378. https://doi.org/10.1037/a0024278.

Sinha, R., Lovallo, W.R., Parsons, O.A., 1992. Cardiovascular differentiation of emotions. Psychosom. Med. 54 (4), 422–435. https://doi.org/10.1097/00006842-199207000-00005.

Snijders, T., 2005. In: Power and Sample Size in Multilevel Modeling, 3, pp. 1570–1573.

Snijders, T.A.B., Bosker, R.J., 2011. Multilevel Analysis: An Introduction to Basic and Advanced Multilevel Modeling. SAGE.

Steptoe, A., Kivimäki, M., 2012. Stress and cardiovascular disease. Nat. Rev. Cardiol. 9 (6), 360–370. https://doi.org/10.1038/nrcardio.2012.45.

Steptoe, A., O'Donnell, K., Marmot, M., Wardle, J., 2008. Positive affect, psychological well-being, and good sleep. J. Psychosom. Res. 64 (4), 409–415. https://doi.org/10.1016/j.jpsychores.2007.11.008.

Teoh, A.N., Hilmert, C., 2018. Social support as a comfort or an encouragement: a systematic review on the contrasting effects of social support on cardiovascular reactivity. Br. J. Health Psychol. 23 (4), 1040–1065. https://doi.org/10.1111/bjhp.12337.

Thayer, J.F., Hansen, A.L., Saus-Rose, E., Johnsen, B.H., 2009. Heart rate variability, prefrontal neural function, and cognitive performance: the neurovisceral integration perspective on self-regulation, adaptation, and health. Ann. Behav. Med. 37 (2), 141–153. https://doi.org/10.1007/s12160-009-9101-z.

Tortora, G.J., Derrickson, B., 2019. Introduction to the Human Body: The Essentials of Anatomy and Physiology. John Wiley & Sons.

Treiber, F.A., Kamarck, T., Schneiderman, N., Sheffield, D., Kapuku, G., Taylor, T., 2003. Cardiovascular reactivity and development of preclinical and clinical disease states. Psychosom. Med. 65 (1), 46–62. https://doi.org/10.1097/00006842-200301000-00007.

Veilleux, J.C., Lankford, N.M., Hill, M.A., Skinner, K.D., Chamberlain, K.D., Baker, D.E., Pollert, G.A., 2020. Affect balance predicts daily emotional experience. Personal. Individ. Differ. 154, 109683 https://doi.org/10.1016/j.paid.2019.109683.

Verkuil, B., Brosschot, J.F., Thayer, J.F., 2014. Cardiac reactivity to and recovery from acute stress: temporal associations with implicit anxiety. Int. J. Psychophysiol. 92 (2), 85–91. https://doi.org/10.1016/j.ijpsycho.2014.03.002.

Watson, D., Clark, L.A., Tellegen, A., 1988. Development and validation of brief measures of positive and negative affect: the PANAS scales. J. Pers. Soc. Psychol. 54 (6), 1063–1070. https://doi.org/10.1037//0022-3514.54.6.1063.

Whittaker, A.C., Ginty, A., Hughes, B.M., Steptoe, A., Lovallo, W.R., 2021. Cardiovascular stress reactivity and health: recent questions and future directions. Psychosom. Med. 83 (7), 756–766. https://doi.org/10.1097/PSY.0000000000000973.

Wood, A.M., Joseph, S., Linley, P.A., 2007. Coping style as a psychological resource of grateful people. J. Soc. Clin. Psychol. 26 (9), 1076–1093. https://doi.org/10.1521/jscp.2007.26.9.1076.

Wood, A.M., Froh, J.J., Geraghty, A.W.A., 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.

Woody, A., Hooker, E.D., Zoccola, P.M., Dickerson, S.S., 2018. Social-evaluative threat, cognitive load, and the cortisol and cardiovascular stress response. Psychoneuroendocrinology 97, 149–155. https://doi.org/10.1016/j.psyneuen.2018.07.009.

Yuenyongchaiwat, K., 2015. PB.02. Preliminary outcome evaluation of the exaggerated cardiovascular reactions to mental stress tests and the prediction of future blood pressure in healthy thai participants: forty months follow-up. J. Hum. Hypertens. 29 (10), 634–635. https://doi.org/10.1038/jhh.2015.90.

Zhang, Y., Han, B., 2016. Positive affect and mortality risk in older adults: a meta-analysis. PsyCh J. 5 (2), 125–138. https://doi.org/10.1002/pchj.129.