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Instructed reappraisal and cardiovascular habituation to recurrent stress

Siobhán M. Griffin[1,2,3] | **Siobhán Howard**[1,2,3]

[1]SASHLab, Department of Psychology, University of Limerick, Limerick, Ireland

[2]Centre for Social Issues Research, University of Limerick, Limerick, Ireland

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

Correspondence
Siobhán M. Griffin, SASHLab, Department of Psychology, University of Limerick, Limerick, Ireland.

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Abstract

Instructed reappraisal has previously been associated with a challenge-oriented cardiovascular response profile, indexed by greater cardiac output (CO) and lower total peripheral resistance (TPR), in response to a *single* stress exposure. The present study builds on this research by employing a stress habituation paradigm where participants completed a speech task twice; in which prior to the second task participants heard reappraisal instructions (i.e., view feelings of stress *arousal* as something that is beneficial) or control instructions. This paradigm allowed us to (a) test if reappraisal aids cardiovascular habituation to *recurrent* stress, and (b) examine if reappraisal leads to a within-participant change in CO/TPR responding from an uninstructed task to an instructed reappraisal task. Habitual use of reappraisal was assessed using the Emotion Regulation Questionnaire. The analyses report upon 173 young adults (121 women, 52 men). Cardiovascular parameters were measured continuously using the Finometer Pro. All participants demonstrated similar cardiovascular habituation during the second stress exposure (lower SBP, CO, and HR); suggesting that reappraisal did not aid cardiovascular habituation to recurrent stress. Reappraisal instructions did not lead to a challenge-oriented response compared to both the control group and responses to the uninstructed task. This study is the first to examine the relationship between instructed reappraisal and cardiovascular habituation and identifies that habitual use of reappraisal does not interact with reappraisal instructions to influence cardiovascular responses to stress.

KEYWORDS

cardiovascular adaption, cardiovascular habituation, cardiovascular reactivity, challenge and threat, hemodynamic profile, stress reappraisal

1 | INTRODUCTION

Stress reappraisal involves reframing feelings of stress (such as increased heart rate, sweaty palms) as something that is actually beneficial for the body; in other words, that feeling stressed enables the body to adapt to the source of stress and perform better. Based on the principles of the biopsychosocial (BPS) model of challenge and threat (Blascovich et al., 1992; Blascovich & Tomaka, 1996) reappraisal is thought to change our stress appraisals, leading to greater perceived resources to cope with the stressor and this results in a *challenge*-oriented cardiovascular response (for a review see; Jamieson et al., 2018). In contrast, perceiving physiological arousal or feelings of stress as a sign of insufficient personal resources to cope with the stressor, may result in a *threat*-oriented cardiovascular response (e.g., Tomaka et al., 1997). Physiological challenge and threat responses can be identified by examining patterns of cardiac output (CO) and total peripheral resistance (TPR); the two parameters that underlie blood pressure responses. A challenge-oriented response is indicated by an increase in CO accompanied by a comparable decrease in TPR; also known as a myocardial response. Whereas, a decrease in CO accompanied by a similar increase in TPR indicates a threat-oriented response; a cardiovascular response driven by vascular mechanisms (Light & Sherwood, 1989; Light et al., 1993; Manuck et al., 1990).

Across a range of stress tasks, instructed reappraisal is associated with a challenge-oriented cardiovascular response, whether this response is indexed by patterns of greater CO and lower TPR responding (Jamieson et al., 2012, 2013; Oveis et al., 2020) or indexed by the challenge-threat index (Hangen et al., 2019). Consistent with the hypothesis of the BPS model, instructed reappraisal has also been shown to lead to greater perceived resources to cope with a subsequent task (Beltzer et al., 2014; Jamieson et al., 2010, 2012, 2013, 2016). Together, it appears that instructed reappraisal results in an adaptive cardiovascular response profile, at least in response to a *single* stress exposure.

Empirical studies have also reported positive effects of reappraisal on task performance. For instance, participants instructed to reappraise feelings of stress performed better on the math section of a sample Graduate Record Examination (GRE; a graduate admission test) in the laboratory, and later on, the actual GRE, controlling for indices of prior academic ability (Jamieson et al., 2010). In a classroom setting, students instructed to use reappraisal prior to a second math test performed better, and also reported less math anxiety and greater resource appraisals, compared to students told to ignore any signs of stress (Jamieson et al., 2016). These students also had marginally better performance on their end-of-semester math examination. Although these studies did not examine cardiovascular responding, the results suggest that even a brief intervention to view signs of stress as aiding performance can influence performance in the short- and long-term.

Taken together these findings support the hypothesis that reappraisal can buffer the negative effects of stress (for a review see; Crum et al., 2020; Jamieson et al., 2018). However, there are a number of limitations inherent in this research that needs to be addressed before we can be confident of the hypothesized health-protective benefits of reappraisal. For instance, past research typically reports how instructed reappraisal is associated with patterns of CO and TPR responding, without reporting other blood pressure parameters such as systolic blood pressure (SBP), diastolic blood pressure (DBP), and heart rate (HR). Furthermore, patterns of CO and TPR responding can be more sophisticatedly examined to determine the *type* of response elicited (challenge or threat). Elements of past research designs can be improved to further elucidate the relationship between instructed reappraisal and stress responses; for example, past studies tend to employ between-subject designs that include only a *single* stress exposure, and these studies do not consider the role of habitual reappraisal in influencing stress responses. This paper discusses each of these points and addresses these limitations.

1.1 | Instructed reappraisal and habituation to recurrent stress

Interestingly, research on reappraisal focuses on CO and TPR responses, rather than reporting upon traditional indices of cardiovascular reactivity such as SBP and DBP. While acknowledging the role of CO and TPR in elucidating whether a challenge- or threat-oriented cardiovascular response is elicited, there is scant research on the long-term impact of challenge and threat responses on physical health. Conversely, exaggerated SBP and DBP responding to laboratory stressors has the demonstrable predictive ability in determining future cardiovascular disease risk (e.g., Carroll et al., 1995, 2001; Chida & Steptoe, 2010; Menkes et al., 1989; Treiber et al., 2003). Indeed, if reappraisal is an adaptive strategy, we would expect it to be associated with lower SBP, DBP, and HR responses compared to a control group.

Following this, within a habituation paradigm we would expect participants instructed to use reappraisal would show significantly lower SBP, DBP, and HR responding during the second task compared to a control group, and this response would be underpinned by a challenge-oriented response. In recent years, the cardiovascular reactivity (CVR) paradigm has been extended to include a second exposure to the same task, thereby allowing adaption to recurrent stress to be examined. Habituators are individuals who show a demonstrable cardiovascular stress response to an initial stress exposure and this response dissipates on the second exposure (for a review see; Hughes et al., 2018); such individuals are hypothesized to demonstrate an optimal stress response in terms of physical health (Dienstbier, 1989). A failure to habituate, or indeed exhibit heightened CVR to the second stress task (sensitization), is thought to reflect an underlying lack of ability to adapt to, and cope, with stress (Howard & Hughes, 2013; Hughes et al., 2018), which over time may have consequences for physical health (e.g., Kelsey, 1993; McEwen & Stellar, 1993). A range of psychosocial variables, including extraversion, rumination, and Type D personality, have been associated with distinct patterns of habituation and sensitization; patterns of cardiovascular responding that are not observable when only one stress exposure is included (Howard & Hughes, 2013; Johnson et al., 2012; Lu & Wang, 2017; Lu, Wang, Hughes, 2016; Lu, Wang, & You, 2016; O'Súilleabháin et al., 2019). No study has yet examined if instructed reappraisal aids cardiovascular habituation to stress.

If reappraisal is a healthful strategy it seems reasonable to expect reappraisal should result in cardiovascular habituation to recurrent stress. Evidence for this hypothesis stems from a study that manipulated cognitive beliefs about performance on a task; participants who received positive feedback regarding their performance during the first task demonstrated significant cardiovascular habituation to the second task, whereas negative feedback resulted in sensitization (Brown & Creaven, 2017). In a similar line of reasoning, it is expected that altering cognitive beliefs about stress arousal would lead to greater cardiovascular habituation. If research can show that the use of reappraisal can dampen a heightened and prolonged cardiovascular response to recurrent stress, this may translate to health-protective benefits in the longer-term.

1.2 | Instructed reappraisal and within-participant effects

Examining the effects of instructed reappraisal on CVR within a habituation paradigm would have an added advantage of allowing within-participant changes in cardiovascular responding to be observed; that is, it would allow cardiovascular responding to an uninstructed task (task 1) to be compared to cardiovascular responding to an instructed reappraisal task (task 2). Prior research has primarily used between-subject designs to test the efficacy of reappraisal in eliciting a challenge-oriented response. For instance, the responses of people instructed to use reappraisal are compared against an ignore stress group (Jamieson et al., 2012), view stress as a debilitating group (Hangen et al., 2019), or a suppression group (Oveis et al., 2020). A habituation paradigm offers a unique method of assessing the effects of reappraisal on cardiovascular responding during stress.

1.3 | Patterns of CO and TPR responding

While past research examines CO and TPR responses during stress, these studies simply report how these parameters change (e.g., an increase in CO, and a decrease in TPR). However, CO and TPR have a compensatory relationship; as one parameter increases, the other should decrease to a similar degree (compensate), to allow for healthy blood flow and to maintain homeostasis. The interpretation of CO and TPR responding in previous reappraisal studies confounds the hemodynamic profile (HP; the way in which these parameters compensate, whether CO predominates, TPR predominates, or both respond equally) and the compensation deficit (CD; the degree to which they compensate). Within the CVR literature, the Hemodynamic Profile-Compensation Deficit (HP-CD) model has been developed to plot CO and TPR values in an orthogonal rotation to create a continuous index of HP, which takes the relationship between CO and TPR into account (for a review; Gregg et al., 2002). Within this quantitative model, CO scores are subtracted from TPR scores (using the log of these scores); thereby, a more positive HP score indicates a vascular (or threat) response, while more negative HP scores indicate a myocardial (or challenge-oriented) response. The validity of this model has been confirmed by a number of studies (Howard et al., 2011; Hughes et al., 2011; James & Gregg, 2004; James et al., 2012; Ottaviani et al., 2006). At present, it is not clear whether the reported patterns of CO and TPR responding associated with instructed reappraisal are truly associated with a challenge-oriented response as the compensatory relationship between CO and TPR is not taken into account.

Interestingly, this method of classifying the underlying hemodynamic response (as either a challenge or threat response) appears similar to a method used within the BPS model literature and within some emotion regulation studies (e.g., Hangen et al., 2019). In these studies, a "challenge-threat index" is calculated by transforming CO and TPR scores; CO and TPR scores are standardized and weighted (TPR scores given a weight of −1, CO a weight of +1), and these scores are then summed so that higher scores represent a more challenge-oriented response and lower scores represent a more threat-oriented response. This computation appears similar to the HP-CD index; in simple terms, the former method subtracts TPR scores from CO scores, while in the latter CO scores are subtracted from TPR scores. Arguably, responses classified as myocardial via the HP-CD model (lower values) are similar to responses classified as a challenge response by the challenge-threat index (higher values). While these methods stem from separate literature they appear to be measuring the same construct (myocardial/challenge responses and vascular/threat responses) in similar ways. However, these approaches have not yet been compared.

1.4 | Individual differences in habitual reappraisal

Furthermore, past research does not consider how individual differences in the habitual tendency to engage in reappraisal may influence the effects of the manipulation (e.g., Hofmann et al., 2009). If the ability to engage in reappraisal is universal, there should be no differences between individuals who habitually engage in reappraisal, and those who do not, when instructed to reappraise stress. However, if the ability to use reappraisal varies between individuals, people who habitually use reappraisal may find it easier to implement reappraisal in the laboratory (Wolgast et al., 2011). Few studies have considered this relationship, and results have been mixed. Some research has shown that habitual reappraisal (as assessed by the Emotion Regulation Questionnaire; Gross & John, 2003) moderates the effects of instructed reappraisal. For instance, individuals scoring high in reappraisal who were instructed to use reappraisal demonstrated lower cortisol responses during stress (Mauersberger et al., 2018). However, other research has found no interaction between trait and instructed reappraisal on skin conductance responses (Wolgast et al., 2011). This relationship has not yet been examined with blood pressure parameters as the outcome.

1.5 | Aims of the current study

The current study employed a standardized laboratory habituation paradigm to examine if reappraisal instructions aid cardiovascular habituation to the task. Participants were presented with the same stressor, twice, and prior to the second stress exposure heard reappraisal instructions or control instructions. We expected that all participants would demonstrate significant cardiovascular habituation to the second task (e.g., lower SBP and DBP responses); however, we expected this decrease to be more pronounced for individuals in the reappraisal group. Furthermore, we expected this profile of responding to be underpinned by a challenge-oriented response for participants in the reappraisal group. Likewise, reappraisal instructions were hypothesized to lead to better performance, greater self-reported resources to cope with the stressor and lower task demands. We expected these effects to be more pronounced in individuals who habitually engage in this strategy. A notable limitation of past research is the compensatory relationship between CO and TPR responding is largely ignored; this study is the first to apply the HP-CD model to CO/TPR responding to identify if reappraisal is associated with a myocardial/challenge-oriented response. Furthermore, we address a methodological gap by comparing two approaches to classifying challenge/threat responses, and examining if they are assessing the same underlying concept.

2 | METHOD

2.1 | Participants

A final sample of 173 healthy young adults, testing as normotensive, were included in the analyses (121 women and 52 men) aged 18–25 (M = 19.50, SD = 1.72). Participants were randomly assigned to either the control (n = 81) or reappraisal experimental group (n = 92). Analyses on performance reports on 135 participants (control, n = 65, reappraisal, n = 70), as performance data for 38 participants were missing due to equipment malfunction. Participants reported good health, no history of cardiovascular disease, and were not taking medication known to affect blood pressure. Only non-smokers were recruited due to the influence of smoking on cardiovascular responses to stress (e.g., Ginty et al., 2014; James & Richardson, 1991; Saladini et al., 2016). An initial sample of 225 non-smokers participated in the study; however, 52 participants were excluded from the analyses resulting in the final sample; cardiovascular assessment was not available for 25 participants, eight participants reported English as their second language, one participant was over the threshold of 25-years of age, and 18 participants had resting blood pressure classified as potentially hypertensive (SBP/DBP > 140/90 mmHg). Participants with resting blood pressure classified as hypertensive were removed from analyses as research has shown these individuals tend to show exaggerated cardiovascular responses during stress (e.g., Georgiades et al., 1996; Steptoe et al., 1984).

Previous research has reported medium to large effect sizes for the influence of instructed reappraisal on cardiovascular parameters (e.g., Jamieson et al., 2010, 2012, 2013) and performance (e.g., Jamieson et al., 2010, 2016). A priori power analyses were conducted using G*Power (Faul et al., 2007), using an alpha of .05, and power of .80. To detect significant Phase × Group interactions, a minimum of 44 participants was needed to detect large effects (f = 0.40) and a minimum of 110 participants was needed to detect medium effects (f = 0.25). To detect significant Phase × Group × Trait Reappraisal interactions, a minimum of 57 participants were needed to detect large effects (f = 0.40) and a minimum of 135 were needed to detect medium effects (f = 0.25). To compare within-participant changes in physiological responding from the first "uninstructed" task, to the second "instructed" task, for those in the reappraisal group, a sample size of 34 participants to detect medium effects (d_z = 0.50), and 15 participants were needed to detect large effects (d_z = 0.80). The current sample, therefore, had sufficient power to detect medium-to-large effects.

Ethical approval was obtained from the institutional research ethics committee. Participation was voluntary, participants signed an informed consent form and could withdraw from the study at any time. Participants received course credit for their participation.

2.2 | Materials and apparatus

2.2.1 | Individual differences in emotion regulation

The six-item reappraisal subscale of the Emotion Regulation Questionnaire (ERQ; Gross & John, 2003) assessed individual differences in the habitual use of cognitive reappraisal. Good internal reliability and test–retest reliability across a range of samples have been demonstrated (e.g., Gross & John, 2003; Perez & Soto, 2011). In the current sample, this subscale demonstrated excellent reliability, with a Cronbach's α = .80.

2.2.2 | Pre-task stress appraisals

Resource and demand appraisals of each task were assessed on a six-point Likert scale from 1 (*not at all/strongly disagree*) to 6 (*very/agree strongly*) prior to each task. Three items assessed perceived demands and four items assessed perceived resources. Items were adapted from resource/demand appraisal questionnaires (e.g., Mendes et al., 2001, 2007; Tomaka et al., 1993). Both questionnaires demonstrated good to excellent reliability at pre-task 1 (demand; $\alpha = .73$, resource; $\alpha = .65$) and at pre-task 2 (demand; $\alpha = .83$, resource; $\alpha = .77$).

2.2.3 | Post-task challenge appraisal

A single item was employed to assess challenge appraisals of the task ("I viewed the task as a challenge"). Participants rated their agreement with this item on a six-point Likert scale from 1 (*strongly disagree*) to 6 (*strongly agree*).

2.2.4 | Self-reported stress

Perceived stress was assessed at baseline, immediately after each task, and after the inter-task interval. Participants rated on a ten-point Likert scale from 1 (*not at all*) to 10 (*extremely*) the degree to which they felt stressed ("How stressed do you feel right now?").

2.2.5 | Stressor task

A socio-evaluative speech task was employed, using the standardized presentation of word stimuli. A block of forty negative-emotion words was presented on DirectRT, a stimulus presentation software that records reaction times (Jarvis, 2014). Words were chosen from the Affective Norms for English Words (ANEW; Bradley & Lang, 1999); a set of words rated in terms of valence and arousal. Words with an arousal value greater than 6.00 and a valence value less than 4.00 were deemed as negative, consistent with previously reported cut-offs (Scott et al., 2009). This task has previously been shown to reliably elicit activity of the cardiovascular system (Griffin & Howard, 2020), and other studies using this task format (block of specific words presented) have also confirmed this (e.g., Hughes & Callinan, 2007; O'Súilleabháin et al., 2018).

2.2.6 | Finometer PRO

Cardiovascular parameters, SBP, DBP, HR, CO, and TPR, were measured non-invasively using the Finometer PRO (Finapres Medical Systems BV, BT Arnhem, The Netherlands). The Finometer provides beat-to-beat measures of blood pressure and hemodynamic monitoring, based on the volume-clamp method (Peňaz, 1973). An upper arm cuff is attached to the participant's non-dominant hand, and a finger cuff is attached to the participant's middle finger on the non-dominant hand. Inside the inflatable finger cuff is an infrared transmission plethysmograph which detects changes in the diameter of the arterial wall. When the intra-arterial pressure increases the finger cuff inflates to maintain the arterial walls at a set diameter. A pneumatic servo system keeps the arterial size and transmural pressure constant. This cuff provides an indirect measurement of the intra-arterial pressure waveform (Langewouters et al., 1998). Two minutes after the Finometer begins recording cardiovascular assessment, a return-to-flow systolic calibration is conducted. This is an individual-level adjustment that involves calibrating finger pressure against brachial measurements using an upper arm cuff. The calibrated pressure waveform is then used to determine SBP and DBP per heartbeat, and by integrating the pressure waveform over one heartbeat, mean pressure is then computed (for a more detailed description see; Imholz et al., 1998; Wesseling et al., 1995). The Finometer uses Physiocal (Finapres Medical Systems, Amsterdam), an algorithm, that allows for the correction of errors without interpreting the continuous measurement (Wesseling et al., 1995). CO and TPR indicators are estimated, by the Finometer, from arterial blood pressure waveforms using a three-element non-linear equation (assumed values for aortic characteristic impedance, Windkessel compliance, and peripheral resistance), based on the validated Model flow modeling method (see; Wesseling et al., 1993, 1995).The Finometer has been used extensively in cardiovascular and clinical research, and meets the validation criteria of the Association for the Advancement of Medical Instrumentation and the revised protocol of the British Hypertension Society (Schutte et al., 2003).

2.3 | Procedure

Participants were non-smokers and were asked to refrain from drinking caffeinated products for 6 hr prior to participation, and avoid alcohol and vigorous exercise for 12 hr prior to participation. Participants were randomly assigned to either the reappraisal or control condition prior to data collection commencement using an online randomizer tool (https://stattrek.com/). Participants were greeted by the researcher and seated at a desk with a personal computer screen, separated from the experimenter by a partition. Demographic information was recorded, and participants completed a 20-min acclimatization period; during which participants completed a series of psychometric scales and were given neutral reading material. Participants were then connected to the Finometer PRO. The

Finometer cuff was attached to the middle finger of the non-dominant hand. Resting cardiovascular measures were taken during an official 10-min baseline period, while participants completed the affective scales. Again, reading material was provided to lower the risk of potential boredom and/or rumination arousal, employing the Vanilla resting baseline as recommended by (Jennings et al., 1992). Following this, participants were verbally informed that words would appear on the computer screen, and to talk about each word for as long as possible. The experimenter evaluated when to change the word presented; after three seconds of silence (as measured by a stopwatch), or repetition. In order to heighten the socio-evaluative aspects of the task, participants were video-recorded during the task and informed that the recorded video-clips would later be analyzed for body language. The task lasted for five minutes. Participants were asked to fill out affective rating scales.

After a ten-minute inter-task interval, participants received either reappraisal or control instructions depending on their assigned experimental condition. Participants in the reappraisal condition heard the following:

> During the task you may feel anxious or stressed. For example, you might notice that your palms are sweaty, your heart may be beating faster. This is a normal stress response to the task. Increased arousal during stressful situations is not harmful. In fact, research has shown that increased arousal actually helps us perform better at tasks. Therefore, while doing this task remind yourself that arousal is beneficial and adaptive. It is helping you adapt to the stressor and perform better.

To control for time and experimental instructions, individuals in the control condition also heard a set of instructions:

> The goal of this research is to examine how physiological arousal during a speech task relates to performance. During the task you may feel anxious or stressed. For example, you might notice that your palms are sweaty, your heart may be beating faster. This is a normal stress response to the task. We will analyse your blood pressure during the task as this indicates your arousal level.

Reappraisal instructions were adapted from past research (Jamieson et al., 2010, 2012, 2013, 2016). Control instructions were adapted from instructions employed by Jamieson et al. (2010). Participants then completed the speech task for a second time. DirectRT recorded the number of words spoken about in each five-minute block. Performance on each task was indicated by the number of words participants spoke about; less words indicated better performance as participants were informed the goal was to talk about each word for as long as possible. Following the completion of the laboratory session, participants were debriefed and thanked for their participation.

2.4 | Data reduction

Cardiovascular parameters (SBP, DBP, HR, CO, and TPR) were measured continuously throughout the experiment using the Finometer PRO. BeatScope Software was used to reduce the data to one-minute mean values for each parameter. The mean values for each cardiovascular parameter during each experimental phase (baseline, task 1, inter-task interval, task 2) were then averaged. Internal consistency for each cardiovascular variable was excellent with Cronbach's αs > .95. Change scores were computed for SBP, DBP, HR, CO, and TPR reactivity to each task by subtracting mean responses during the task period from baseline; consistent with previous approaches (e.g., Brindle et al., 2017; Gallagher et al., 2015; Hughes, 2007).

3 | RESULTS

3.1 | Overview of statistical analyses

Repeated measures ANOVAs were conducted on the four experimental phases (baseline, task 1, inter-task interval, task 2) to examine if both tasks significantly elicited a stress response and if cardiovascular habituation to the second task occurred. Mean cardiovascular values during each phase, and self-reported stress were the dependent variables. Greenhouse-Geisser corrections were applied where assumptions of sphericity were violated. Means and standard deviations are presented in Table 1.

To examine the influence of reappraisal instructions on habituation to stress between the control and reappraisal groups (hence referred to as between-subject effects for clarity), a series of 2 × 2 ANOVAs were conducted. The between-subjects factor was the group (reappraisal, control). The within-subjects factor was the task (task 1, task 2). The dependent variables were cardiovascular reactivity to each task, task appraisals, and performance. Using the same variables, a series of 2 × 2 × 1 custom-built ANCOVAs were then conducted to examine the potential influence of habitual use of reappraisal. Habitual use of reappraisal scores was entered as a covariate.[1] Means and standard deviations for cardiovascu-

[1] All analyses conducted with CVR were computed by subtracting mean responses during task 2 from baseline; these analyses were repeated (not shown) with CVR to task 2 computed by subtracting mean responses during task 2 from the preceding inter-task period; the pattern of results did not change. Furthermore, analyses were repeated with covariates included (age, sex, BMI); this did not alter the results.

TABLE 1 Mean (with *SD*) cardiovascular variables, and self-reported stress, at each phase

	Baseline		Task 1		Inter-task		Task 2	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Control ($n = 81$)								
SBP (mmHg)	125.03	12.10	142.49 (17.45)	15.44 (9.07)	131.15	14.07	140.75 (15.61)	16.95 (10.62)
DBP (mmHg)	75.12	11.32	87.65 (12.54)	13.03 (5.17)	79.81	13.69	87.99 (12.86)	15.16 (7.40)
HR (bpm)	79.12	9.92	85.53 (5.74)	10.17 (6.54)	77.95	9.20	81.67 (1.75)	9.33 (5.61)
CO (lpm)	5.59	1.84	5.91 (0.32)	2.05 (0.67)	5.41	1.82	5.38 (−0.23)	1.95 (0.67)
TPR (pru)	1.19	0.60	1.31 (0.13)	0.63 (0.20)	1.35	0.82	1.52 (0.33)	1.03 (0.59)
HP (CD)			0.02 (0.05)	0.07 (0.02)			0.08 (0.05)	0.10 (0.03)
CT-index			0.21	1.55			0.10	1.84
Demands			8.43	2.97			9.61	3.31
Resources			14.22	3.19			12.44	3.02
Challenge			4.33	1.18			4.11	1.26
Performance			8.89	3.96			7.63	3.86
Perceived stress	3.42	2.01	4.39	1.96	2.74	1.60	3.72	2.11
Reappraisal ($n = 92$)								
SBP (mmHg)	124.56	11.78	142.48 (17.69)	16.58 (11.16)	132.24	15.47	140.60 (15.79)	17.30 (11.92)
DBP (mmHg)	74.52	9.73	87.29 (12.63)	11.79 (6.59)	80.07	11.22	87.64 (12.63)	12.05 (6.59)
HR (bpm)	78.85	11.89	85.82 (6.90)	12.75(6.04)	77.24	11.72	81.27 (6.90)	12.05 (6.04)
CO (lpm)	5.58	1.47	5.91 (0.32)	1.56 (0.76)	5.44	1.52	5.29 (−0.30)	1.47 (0.78)
TPR (pru)	1.12	0.39	1.27 (0.15)	0.50 (0.27)	1.25	0.52	1.40 (0.28)	0.57 (0.32)
HP (CD)			0.02 (0.05)	0.09 (0.04)			0.08 (0.12)	0.10 (1.52)
CT-index			0.11	1.95			9.76	3.29
Demands			8.30	2.52			12.95	3.58
Resources			14.11	2.88			4.04	1.18
Challenge			4.15	1.15			8.34	4.02
Performance			10.49	9.05			0.12	1.52
Perceived stress	3.48	2.06	4.36	2.04	2.79	1.73	3.74	1.92

Note: Mean cardiovascular parameters for each phase are presented, and in brackets, CVR scores for each phase are presented. mmHg = millimeters of mercury, bpm = beats per minute, lpm = liters per minute, and pru = peripheral resistance units. Task 1 was uninstructed for both groups. Task 2 reflects responses after the experimental manipulation. CT-index = challenge-threat index.

lar reactivity to each task are presented in Table 1. Follow-up paired samples *t* tests were conducted to confirm within-participant changes in CVR and self-reported measures between the first and second task, for participants in the reappraisal and control groups separately (henceforth referred to as within-participant effects).

Effect sizes are presented as partial η^2 for ANOVA analyses with values of 0.04, 0.25, and 0.64 taken to demonstrate small, medium, and large effects, respectively (Cohen, 1992). Effect sizes for correlations are presented as *r*, with values of .10, .30, and .50 taken to be indicative of small, medium, and large effect sizes respectively (Cohen, 1988, 1992). Effect sizes for paired sample *t* tests were calculated using G*Power, and are presented as d_z, with values of .20, .50, and .80 indicative of small, medium, and large effect sizes (Cohen, 1988).

3.2 | Confirmation of random assignment

A series of independent samples *t* tests were conducted to examine random assignment to the experimental group. There were no differences between the groups in terms of cardiovascular parameters at rest, CVR to Task 1 (uninstructed task), and self-report measures, all $ps > .193$. The two groups did not significantly differ on gender composition, $\chi^2 = .047$, $p = .828$. The results suggest that random assignment to the group was successful.

3.3 | Confirmation of CVR

Repeated measures ANOVAs confirmed the main effect of phase on all cardiovascular parameters, $ps < .001$. Bonferroni tests for pairwise comparisons confirmed SBP, DBP, HR, CO, and TPR increased from baseline to task 1 ($ps < .001$). Similarly, SBP, DBP, HR, and TPR increased from baseline to task 2. However, CO decreased from baseline to task 2 ($ps < .001$). Similarly, SBP, DBP, HR, and TPR increased from the inter-rest period to task 2 ($ps < .001$), while CO remained unchanged ($p = .055$). This confirms that both tasks successfully elicited a physiological stress response. Comparing the two tasks, SBP, HR, and CO were lower during task 2 compared to task 1 ($ps < .001$); indicating cardiovascular habituation. Figure 1 demonstrates cardiovascular responses, across the four phases, for both the reappraisal and control groups.

3.4 | Reappraisal and CVR

3.4.1 | Between-participant effects

A series of 2 × 2 ANOVAs found there was no significant Phase × Group interaction effect on cardiovascular reactivity for any parameter: SBP, $F(1, 169) = 1.23$, $p = .892$, partial $\eta^2 = 0.001$; DBP, $F(1, 169) = 0.01$, $p = .998$, partial $\eta^2 = 0.001$; HR, $F(1, 169) = 0.67$, $p = .415$, partial $\eta^2 = 0.004$; CO, $F(1,169) = 0.54$, $p = .463$, partial $\eta^2 = 0.003$; TPR, $F(1, 169) = 1.42$, $p = .236$, partial $\eta^2 = 0.008$. There was no difference between the reappraisal and control group in terms of cardiovascular habituation to the task.

Furthermore, there were no significant Phase × Group ×Trait reappraisal interaction effects on any cardiovascular reactivity parameter: SBP; $F(1, 167) = 0.61$, $p = .437$, partial $\eta^2 = 0.004$; DBP, $F(1, 167) = 0.45$ $p = .503$, partial $\eta^2 = 0.003$; HR, $F(1, 167) = 0.93$, $p = .336$, partial $\eta^2 = 0.006$; CO, $F(1, 167) = 0.44$, $p = .509$, partial $\eta^2 = 0.003$; TPR; $F(1, 167) = 0.44$, $p = .509$, partial $\eta^2 = 0.003$. Trait reappraisal did not interact with reappraisal instructions to influence cardiovascular habituation to the task.

3.4.2 | Within-participant effects

Paired samples *t* tests found that participants in the reappraisal group demonstrated lower SBP ($p = .013$), lower HR, and lower CO reactivity ($ps < .001$) in response to the second task, while TPR reactivity increased ($p < .001$). DBP reactivity did not differ between the two tasks ($p = .502$). However, similar patterns were seen in the control group; HR ($p < .001$) and CO ($p = .002$) decreased from task 1 to task 2, TPR increased ($p < .001$), and SBP and DBP did not change ($p = .050$ and $p = .595$, respectively). It appears that within-participant changes in CVR for those in the reappraisal group are a result of habituation to the task, rather than reappraisal use. Means and standard deviations for CVR to each task are reported in Table 1.

3.5 | Hemodynamic profile

HP and CD scores in response to each task were calculated using the method proposed by Gregg et al. (2002); positive HP values indicate a vascular response pattern (threat-oriented response), while negative HP values indicate a myocardial response pattern (challenge-oriented response). The challenge-threat index was calculated using the recommended approach (e.g., Blascovich et al., 2004; Shimizu et al., 2011). Higher scores indicate a more challenge-oriented response. Means and standard deviations are reported in Table 1.

3.5.1 | Comparison of HP-CD values and the challenge-threat index

Pearson's *r* correlation coefficients confirmed there was a strong negative correlation between HP values and challenge-threat index values (task 1, $r = -.970$, $p < .001$, task 2, $r = -.974$, $p < .001$); confirming that the HP-CD model and the challenge-threat index share considerable statistical overlap.

3.5.2 | Reappraisal and hemodynamic responding

Between-participant effects

There was no significant Phase × Group interaction effect on HP scores ($p = .919$) or on CD scores ($p = .349$). There was also no significant Phase × Group ×Trait reappraisal interaction effect on HP scores ($p = .380$) or on CD scores ($p = .075$). Similarly, there was no significant Phase × Group interaction effect on challenge-threat scores ($p = .703$) or significant Phase × Group × Trait Reappraisal interaction on challenge-threat scores ($p = .266$). Full results are reported in Table 2. The reappraisal manipulation did not influence the underlying hemodynamic response profile, nor did habitual emotion regulation style influence responses.

Within-participant effects

Paired samples *t* tests found that for participants in the reappraisal group, HP scores during task 2 were more vascular than HP scores during task 1, $t(91) = -8.71$, $p < .001$, $d_z = 0.83$, [−0.08, −0.05]. However, the same pattern was found for participants in the control group, $t(78) = -6.11$, $p < .001$, $d_z = 0.68$, [−0.08, −0.04]. Likewise, for both groups, there were no differences in CD values between task 1 and task 2 ($ps > .137$). In terms of the challenge-threat index, neither the reappraisal or control group, showed differences between responses to task 1 and task 2: reappraisal group; $t(91) = -0.01$, $p = .991$, $d_z = 0.01$, [−0.28, 0.27], control group; $t(78) = 0.60$, $p = .550$,

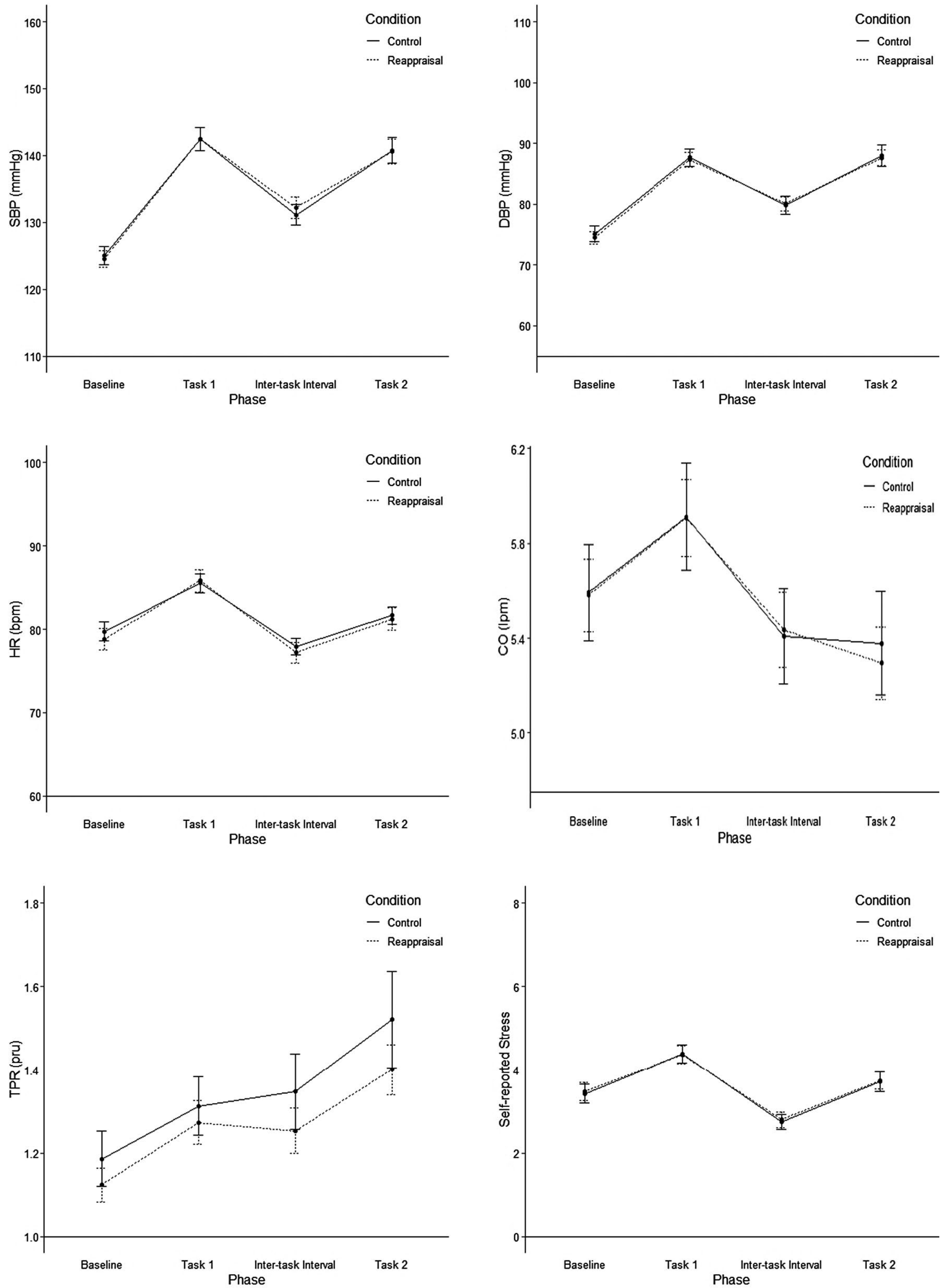

FIGURE 1 Cardiovascular responding and self-reported stress across each phase

$d_z = 0.07$, [−0.26, 0.49]. Means and standard deviations are presented in Table 1. Overall this pattern of results demonstrates that instructions to reappraise the second task did not result in a challenge-oriented response.

3.6 | Performance

There was a main effect of phase on performance in the overall sample, $p = .003$, where performance increased from task

TABLE 2 Results of ANOVA analysis (Phase, Phase × Group) and ANCOVA analysis (Phase × Group × Trait)

	Phase (Main effect)			Phase × Group			Phase × Group ×Trait		
	F	η_p^2	p	F	η_p^2	p	F	η_p^2	p
HP	104.72	0.383	<.001*	0.01	<0.001	.919	0.78	0.005	.380
CD	2.36	0.014	.127	0.88	0.005	.349	3.21	0.019	.075
CT-index	0.24	0.001	.627	0.25	0.001	.617	0.90	0.005	.345
Demands	24.82	0.128	<.001*	0.28	0.002	.598	10.05	0.057	.002*
Resources	46.03	0.214	<.001*	1.98	0.012	.161	3.91	0.023	.050
Perceived stress	37.99	0.184	<.001*	0.05	<0.001	.969	3.36	0.020	.027*
Challenge	3.41	0.020	.067	0.40	0.002	.528	0.03	0.001	.865
Performance	9.36	0.066	.003*	0.63	0.005	.429	0.61	0.005	.607

*$p < .05$.

1 ($M = 9.72$, $SD = 7.09$) to task 2 ($M = 8.00$, $SD = 3.95$); indexed by speaking longer about each word (fewer words in the 5-min block). Paired samples *t* tests confirmed performance increased from task 1 to task 2 for both groups (reappraisal, $p = .047$; control, $p < .001$). However, there was no significant Phase × Group interaction effect ($p = .429$), or Phase × Group × Trait Reappraisal interaction effect ($p = .607$), on performance. Increases in performance from task 1 to task 2 appear to be due to habituation or practice effects, rather than reappraisal instructions. Full results are reported in Table 2.

3.7 | Task appraisals

Means and standard deviations for pre-task demand and resource appraisals and post-task challenge appraisals are reported in Table 1. Full results for analyses involving task appraisals and self-reported stress are reported in Table 2.

3.7.1 | Pre-task appraisals

There was a main effect of phase on perceived demands ($p < .001$) and perceived resources ($p < .001$). Participants reported more demands prior to task 2 ($M = 9.69$, $SD = 3.29$) compared to task 1 ($M = 8.36$, $SD = 2.73$), and reported less resources prior to task 2 ($M = 12.71$, $SD = 3.58$) compared to task 1 ($M = 14.16$, $SD = 2.88$). This effect was seen in both the reappraisal (*p*s < .001) and control group (demands, $p = .004$, resources, $p < .001$).

While there was no significant Phase × Group interaction effect on perceived demands ($p = .598$), there was a Phase × Group × Trait Reappraisal interaction effect ($p = .002$). Post-hoc analyses found that reappraisal scores were uncorrelated with perceived demands, in both groups, suggesting that this effect was due to chance, all *p*s > .098. There was no significant Phase × Group interaction effect ($p = .161$) or Phase × Group × Trait Reappraisal interaction effect on resources ($p = .157$). It appears that the second task elicited greater perceived threat than the first task for all participants, but reappraisal instructions did not influence perceived threat.

3.7.2 | Post-task challenge appraisal

There was no main effect of phase on viewing the task as a challenge ($p = .067$). There was no significant Phase × Group interaction effect ($p = .528$) or Phase × Group × Trait Reappraisal interaction effect on challenge appraisals ($p = .865$).

3.7.3 | Self-reported stress

A 4 × 2 ANOVA was conducted to examine changes in self-reported stress across each phase; phase was the within-subjects factor (baseline, task 1, inter-task interval, task 2) and the group was the between-subjects factor (reappraisal, control). Self-reported stress at each time-point was the dependent variable. There was a main effect for phase, $F(2.40, 407.79) = 38.22$, $p < .001$, partial $\eta^2 = 0.184$. Pairwise comparisons confirmed that self-reported stress increased from baseline to task 1 ($p < .001$). While there was no difference between self-reported stress at baseline and task 2 ($p = .716$), self-reported stress decreased from task 1 to the inter-task interval ($p < .001$) and increased from the inter-rest period to task 2 ($p < .001$); indicating that the second task also elicited a significant psychological stress response compared to the period immediately preceding the task; however, this was lower than self-reported stress during Task 1 ($p < .001$). Means and standard deviations are presented in Table 1. Figure 1 shows self-reported stress for each group across the four phases.

There was no significant Phase × Group interaction effect ($p = .969$). However, there was a significant, Phase × Group × Trait Reappraisal interaction effect, ($p = .027$). For individuals in the reappraisal group, higher habitual reappraisal use was associated with lower self-reported stress after the uninstructed task (task 1; $r = -.213$, $p = .043$) and after the instructed reappraisal task (task 2; $r = -.244$, $p = .019$); this was not observed in the control group (task 1; $r = +.027$, $p = .811$, task 2; $r = +.030$, $p = .790$). Full results are reported in Table 2.

4 | DISCUSSION

The present study examined if instructed reappraisal aids cardiovascular habituation to stress. While all participants exhibited significant cardiovascular habituation to the second of two consecutively presented stress tasks, reappraisal instructions did not influence adaption to the task compared to the control group. It was also expected that reappraisal instructions would be associated with a challenge-oriented cardiovascular response to the task; this was not observed. Likewise, instructed reappraisal was not associated with changes in perceived stress, resource/demand appraisals, or performance. Furthermore, habitual use of reappraisal did not interact with instructed reappraisal to influence responses to the task.

Previous research has shown that instructed reappraisal influences physiological responses to a single stress exposure (e.g., Jamieson et al., 2012, 2013). It was expected that instructions to reappraise stress would lead to a clear pattern of habituation considering the hypothesized psychological and physical health benefits of reappraisal use (for a review see; Gross, 2013, 2015; Jamieson et al., 2018); however, in the present study reappraisal did not aid habituation to the second stress, compared to the control group. While we expected cardiovascular responses to be lower during the second task for those in the reappraisal group, we also expected this response to be underpinned by a challenge-oriented response; this was not the case. We extend research in this area by showing that reappraisal was not associated with a more challenge-oriented response compared to the control group (between-participant effects), but also compared to responses from the same participants during the uninstructed initial stress exposure (within-participant effects). While this contrasts with most past research (Jamieson et al., 2012, 2013; Oveis et al., 2020), it replicates a previous study where reappraisal did not lead to observable cardiovascular changes compared to a control group (Hangen et al., 2019). Interestingly, Hangen et al. (2019) also used the challenge-threat index and found null findings.

Our results are further strengthened in that we assessed general patterns of CO and TPR responding using both the challenge-threat index and a validated index of challenge-threat responding, the HP-CD model (for a review see; James et al., 2012). Indeed, this is the first study to apply *both* these models to CO/TPR responses and to compare these models. We advance research that attempts to classify the underlying hemodynamic response profile of cardiovascular responses, by providing evidence that the challenge-threat index shares considerable conceptual overlap with the HP-CD model; adding support to the validity of these models. Two separate literatures have sought to classify underlying hemodynamic response patterns using a mathematical transformation of CO and TPR scores; and the results of this study add confidence to the hypothesis that these methods are identifying challenge and threat responders.

It is unclear why, in the present sample, instructed reappraisal had no effects across a range of measures including CVR, task appraisals, and performance. One hypothesis is that, similar to Hangen et al. (2019), we have provided evidence that reappraisal does not affect cardiovascular responses to stress. We provide a methodologically rigorous test of the claim that reappraisal has a positive influence on cardiovascular responses to stress, and we do not find a detectable effect. Furthermore, in the present sample reappraisal did not lead to greater perceived resources to cope with the stressor. Indeed, as changes in resource appraisals are argued to be the mechanism through which reappraisal influences physiological responding (Lazarus & Folkman, 1987; Tomaka et al., 1997) this may, or may not, explain why reappraisal had no demonstrable effects on cardiovascular responding. However, we must note that this study had sufficient power to detect significant medium-to-large effects. Considering that cardiovascular responding during the second task was attenuated, it is plausible that effects may have been smaller and we may have lacked sufficient power to detect such effects, should they exist.

While we provide evidence that reappraisal does not influence physiological stress responses, methodological differences between our study and others must be considered. For instance, we employed a short reappraisal instruction (e.g., Jamieson et al., 2010; John-Henderson et al., 2015), but other studies used a longer reappraisal manipulation (Hangen et al., 2019; Jamieson et al., 2012, 2013, 2016). However, Hangen et al. (2019) employed the longer manipulation and also found null effects between the reappraisal and control group (but found significant effects between the reappraisal and the "view stress as debilitating" group). Certainly, further research is warranted to examine if the type of instruction period influences the relationship between instructed reappraisal and physiological responding.

We anticipated that reappraisal instructions would result in improved task performance during the second task in comparison to the control group. As expected all participants exhibited improvements in performance from task 1 to task 2 (due to practice), but there was no difference between the reappraisal and control group. It is unlikely that this was due to a ceiling effect of performance; examination of plots of normality confirmed performance data was not skewed. The results are somewhat inconsistent with previous research (Jamieson et al., 2010, 2016). However, Hangen et al. (2019) also found reappraisal had no influence on performance during a competitive math task. Notably, all past research reporting an effect of reappraisal on performance has employed mathematical tasks. This may reflect a role of context under which reappraisal has gains for performance, but it is difficult to draw clear conclusions considering that previous research employing speech tasks did not quantify performance (e.g., Beltzer et al., 2014; Jamieson et al., 2012, 2013).

In the present study, individual differences in trait reappraisal did not moderate the relationship between stress responsivity and instructed reappraisal. Only a handful of studies have previously considered the interplay between trait and instructed reappraisal, with some evidence to suggest that the use of reappraisal may only be effective for individuals who regularly engage in this strategy (e.g., Mauersberger et al., 2018; Ortner et al., 2016), in terms of cortisol responding and self-reported affect. However, considering that the reappraisal manipulation had little effect on CVR in the current sample, the potential moderating role of habitual reappraisal needs further examination.

Further research is needed to clarify if the timing of reappraisal instructions influences the ability to engage in reappraisal. Future research could include a third experimental group, where participants receive reappraisal instructions prior to the first task. This would allow the replication of past research, and also allow patterns of habituation to stress to be assessed within a different paradigm.

The present study is the first to test the effectiveness of instructed reappraisal during repeated stress exposure. We provide evidence that instructed reappraisal does not aid cardiovascular habituation to recurrent stress, and that reappraisal does not lead to a challenge-oriented cardiovascular response. The findings of this study question the efficacy of reappraisal. We offer an important first step in examining if the effects of instructed reappraisal extend beyond a single stress exposure. We also provide support for using more sophisticated methods to examine the underlying hemodynamic response patterns elicited during stress—the HP-CD model and challenge-threat index. We demonstrate that these methods are essentially classifying challenge and threat responses in the same way. Future research should employ one, if not both, of these approaches to classify the underlying cardiovascular response profile rather than simply reporting upon patterns of CO and TPR responding.

CONFLICT OF INTEREST

The authors declare that there are no potential conflicts of interest with respect to the research, authorship, and/or publication of this article. All authors consented to the submission of this manuscript.

AUTHOR CONTRIBUTION

Siobhán Mary Griffin: Conceptualization; Data curation; Formal analysis; Investigation; Methodology; Project administration; Visualization; Writing-original draft; Writing-review & editing. **Siobhán Howard:** Conceptualization; Formal analysis; Funding acquisition; Investigation; Methodology; Resources; Supervision; Writing-review & editing.

ORCID

Siobhán M. Griffin https://orcid.org/0000-0002-3613-2844
Siobhán Howard https://orcid.org/0000-0002-1689-0867

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