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Blunted cardiovascular reactivity to acute psychological stress predicts low behavioral but not self-reported perseverance: A replication study

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Abstract

Emerging evidence suggests that individuals with poor behavioral perseverance show low or blunted physiological responses to acute psychological stress. For example, a recent preliminary laboratory study demonstrated that blunted responders give up sooner and take fewer attempts when endeavoring to complete an impossible puzzle, but do not self-report poor perseverance. This present research is a replication of the previous study with an increased sample size, longer recovery periods between tasks and addition of social evaluation to the cold pressor. Participants (147) completed a self-report perseverance questionnaire (Short Grit Scale) and behavioral perseverance tasks (impossible Euler puzzle and socially evaluated cold-pressor (SECPT)). The number of attempts and time spent trying to complete the unsolvable puzzle, and duration of hand submergent during the SECPT, were recorded as behavioral perseverance measures. Difference in blood pressure (BP) and pulse rate (PR) from baseline to a 10-min paced auditory serial addition task (PASAT) were computed as reactivity. As previously, reactivity did not relate to self-reported perseverance and blunted BP reactivity to the PASAT was associated with less time persevering at the unsolvable puzzle. Additionally, blunted BP and PR reactivity to the PASAT related to poorer perseverance during the SECPT. These findings, replicating the previous study, increase confidence that blunted reactivity is a physiological marker of poor behavioral perseverance. Moreover, given that self-reported perseverance does not relate to reactivity, this suggests that blunted responders are not conscious of this detriment in perseverance, but likely need additional support when persistence is critical (e.g., during behavior change).

KEYWORDS

adherence, blood pressure, cardiovascular reactivity, heart rate, PASAT, perseverance, persistence, psychological stress, socially evaluated cold pressor

1 | INTRODUCTION

The link between exaggerated stress responses and cardiovascular disease has long been established (see e.g., Lovallo & Gerin, 2003). Due to the earlier emphasis on high reactivity, it could be implied that low or blunted reactivity to acute stress was protective. More recent research has refuted this notion, with accumulating evidence now suggesting that low or blunted reactivity to stress is also linked to negative health outcomes, conforming to an inverted U-shaped relationship between reactivity and health (for reviews see Carroll et al., 2009, 2017; Lovallo, 2011; Phillips et al., 2013). However, it is important to note that this "inverted U" model is purely theoretical, based on the combination of linear findings from both the exaggerated and blunted literature. More recently, several groups have demonstrated links between blunted reactivity and negative behaviors, such as addiction (al'Absi, 2018; Ginty et al., 2016; Panknin et al., 2002; Phillips et al., 2009).

It has been proposed that health and behavioral correlates associated with blunted reactivity reflect modified frontolimbic function of brain areas essential for motivation and behavioral regulation, that is, motivational dysregulation (Carroll et al., 2009; Ginty et al., 2014; Lovallo, 2011). Interestingly, these brain areas are also involved in autonomic nervous system regulation (Lovallo, 2005; Lovallo et al., 2013). For example, dysregulation in these brain areas can contribute to impulsive behaviors and impaired response inhibition (Allen et al., 2009; Bennett et al., 2014; Bibbey et al., 2016; Muñoz & Anastassiou-Hadjicharalambous, 2011), as well as reduced physiological stress reactivity and unstable affect regulation (Bush et al., 2000; Hagemann et al., 2003; Lovallo, 2005; Lovallo et al., 2013). Thus, such dysregulation might also be expected to relate to other behavioral characteristics which require psychological effort, such as motivational- or goal-directed behavior.

Perseverance is critical during behavior change and when maintaining abstinence from maladaptive behaviors such as addiction (Quinn et al., 1996). Interestingly, individuals with blunted reactivity have been shown to be more likely to relapse after giving up smoking (al'Absi, 2006), alcohol (Junghanns et al., 2003; Lovallo, 2006), and cocaine (Back et al., 2010). Furthermore, lower cardiac output and heart rate reactors to stress show poorer adherence when asked to complete a simple online-based follow-up task 12 months after a laboratory stress session (Ginty et al., 2015). In addition, a very recent study has also demonstrated that blunted reactors show biological disengagement, as measured using the Brief Coping Orientation to Problems Experienced Scale (disengagement subscale), even after adjustment for a battery of important confounders such as depression (Ginty et al., 2020).

To test the association between reactivity and perseverance directly, a recent preliminary laboratory study assessed whether cardiovascular reactivity to active mental arithmetic and passive cold pressor stress related to poorer perseverance, measured through self-report, time spent engaging with the cold pressor task, and perseverance at an insolvable puzzle (Chauntry et al., 2019). This study found that low Paced Auditory Serial Addition Test (PASAT) systolic blood pressure (SBP) and diastolic blood pressure (DBP) reactivity predicted lower behavioral perseverance (fewer attempts trying to solve an impossible puzzle), and low PASAT DBP reactivity related to less time trying to complete the impossible puzzle. Additionally, individuals with blunted PASAT DBP and pulse rate (PR) responses spent less time persevering at the cold pressor task, and those with lower cold pressor DBP reactivity took fewer attempts at the impossible puzzle. Interestingly, self-reported perseverance did not relate to reactivity, and thus it was theorized that blunted responders are not consciously aware of deficiency in their motivation (Brindle et al., 2017). This is supported by the fact that blunted responders do not self-report differences in task engagement or performance markers of effort, in comparison to those displaying higher cardiovascular reactivity (Brindle et al., 2017; Ginty et al., 2012). However, there are of course alternative explanations for this null finding for self-reported perseverance (e.g., social desirability bias) (Bazelais et al., 2016). In addition, the lack of consistency in which cardiovascular measures were related to perseverance, the short duration recovery periods, as well as the moderate sample size for this previous study, result in these findings being preliminary, and, as such, replication is essential before drawing firm conclusions. This is also particularly pertinent in line with the current "replication crisis" in psychological research. For example, the Reproducibility Project evidenced that the findings from only 36% of 100 psychological studies were able to be replicated (Open-Science-Collaboration, 2015). Overall, this instils negative connotations surrounding psychology in general, damages the reputation of the field, and reduces trust in findings that would otherwise be important to health (Broomell & Kane, 2017). For example, the reactivity-perseverance findings above may have important real-world applications when identifying those who may need additional support when attempting to adhere to health-related interventions. Without replication, it is possible that these potentially important findings would be overlooked and not trusted.

Consequently, the present research sought to replicate and extend the previous reactivity and perseverance study (Chauntry et al., 2019) in a larger sample, with extended recovery periods and addition of social evaluation to the cold pressor paradigm. The primary aim was to further examine whether cardiovascular reactivity relates to self-reported and behavioral perseverance. Given the potential confounding between the length of time persevering at the cold pressor and the associated reactivity, the cold pressor paradigm was used primarily to assess behavioral perseverance in this study, rather than induce cardiovascular

stress. The PASAT was used to assess reactivity and was extended to the 10-min version. As before, it was hypothesized that blunted cardiovascular reactivity would be associated with lower behavioral but not self-reported perseverance.

2 | MATERIALS AND METHODS

2.1 | Participants

Participants were 147 University of Birmingham undergraduate students and there was no overlap between the current sample and the participants that completed the study of Chauntry et al. (2019). A power calculation suggested a suitable sample size of 42, and the previous study recruited 65 participants (Chauntry et al., 2019). An over-recruitment strategy was employed due to the expectedly high data variability, large research team, high study interest, and to address issues of why replication in science can often be difficult. This was deemed ethical due to the noninvasive characteristics of the study, and the fact that throughout the testing session participants were frequently reminded of their right to stop any of the tasks and/or withdraw from the research in full. Participants were excluded if they were currently ill or had an infection, or if they had eaten in the hour before testing, consumed caffeine or smoked 2 hr prior to testing, exercised vigorously 4 hr before testing, or consumed alcohol 12 hr preceding testing.

2.2 | Design

The study was a cross-sectional laboratory-based experiment which examined the association between stress reactivity and perseverance. All participants provided written informed consent and the project was approved by the local STEM Ethics Committee (ERN_14-0089B). Participants were offered 1.5 research hours for their participation in the study.

2.3 | Measures

2.3.1 | Questionnaires

The Short Grit scale (Grit-S) by Duckworth and Quinn (2009) was used to measure trait-level perseverance. The scale consists of eight items, with a 5-point force-choice format, ranging from 1 (not at all like me) to 5 (very much like me); higher scores indicate greater perseverance. The Grit-S boasts acceptable psychometric properties (Duckworth & Quinn, 2009) and in the present study the internal consistency was 0.76.

Sex, age, ethnicity, parental occupation, and whether participants were taking any medication (excluding the contraceptive pill) were collected as sociodemographic data via questionnaire. Ethnicity was determined across four categories (Asian, Black, White, and Other) and due to skew was classified into a binary variable of white versus non-white. Occupation was classified as manual or non-manual using the Registrar General's Classification of Occupations (Office of Population Censuses and Surveys, 1980), by indicating the occupation category (e.g., managerial, and skilled non-Jmanual) of the highest occupational status parent.

Six questions measured how: stressful, difficult, arousing, confusing, embarrassing, and engaging participants found the mental arithmetic stress task and the SECPT. Participants also indicated how successful they perceived their performance to be. This questionnaire was formatted as a 7-point Likert scale, from 0 (not at all stressful/difficult/performed not very well etc) to 6 (extremely stressful/difficult/performed well etc).

2.3.2 | Laboratory tasks

Stress task

The 10-min version of the Paced Auditory Serial Addition Test (PASAT) (Gronwall, 1977) was used as the psychological stress task, and demonstrates both good test–retest reliability (Ginty et al., 2013; Willemsen et al., 1998), and efficacy at perturbing the cardiovascular system (Heaney et al., 2011; Phillips et al., 2005). The PASAT involves memory and attention, as well as simple addition. Participants were presented, using a compact disk player, with a series of numbers, to which the participant had to add the given number to the previously called number, providing their answer verbally, with the interval between numbers reducing throughout the task. The task also involved additional elements of social evaluation and competition. A leader board was positioned directly in front of the participant, and information was provided that they were in direct competition with their peers. Participants started with 1,000 points and were deducted five points for every wrong answer or omission. Additionally, they were informed that they would be video recorded throughout and watched themselves live on a television screen in front of them. Each participant was informed that their recording would be analyzed by a "body language expert," but, in fact, they were not actually recorded. In addition, participants received a brief loud buzzer noise once during the last five numbers of every block of 10, which they were told would be due to an incorrect answer, hesitation or if they looked away from the television screen; but in reality, all participants received the same number of noise bursts. Participants also completed a brief practice test

immediately prior to the stressor, and after the task they completed the PASAT evaluation questionnaire.

Perseverance tasks

An impossible Euler puzzle, created by Leonhard Euler, was used to measure behavioral perseverance. Participants were instructed to trace along all of the lines on a puzzle outline without lifting pen from paper and tracing along each line once only. If they made a mistake, they had to use a new piece of paper. Four different puzzles were completed in numerical order and each puzzle was progressively harder, in addition, the final puzzle was impossible, but participants did not know this. During the task, the experimenter was a constant but non-obtrusive presence, ensuring the puzzles were completed correctly without cheating. The experimenter prompted participants to "try their best" if they voiced that they were finding the puzzle too difficult to complete. However, if they said they could not complete the final puzzle or wished to give up, they were allowed to do so. After 30 min if participants were still persevering, they were told that the experiment has come to an end. The time taken and number of attempts endeavoring to complete the impossible puzzle were used as behavioral measures of perseverance.

The Socially Evaluated Cold Pressor Test (SECPT) (Schwabe et al., 2008) was also used as a perseverance task, with measurement of how long each participant held their dominant hand (including the wrist) in the ice-cold water (0–2°C) being recorded (up to a maximum of 4 min). Participants were instructed to keep their hand immersed until the experimenter told them otherwise and were only allowed to take their hand out of the water if they were no longer able to tolerate the cold water or wanted the task to end. Throughout the task participants were instructed to watch themselves on a television screen and the experimenter added to the social pressure by watching closely while holding a clipboard, using a stopwatch and taking notes. The socially evaluated version of the cold pressor task was selected to more closely simulate a real-life situation (as many tasks involve external pressure, observation, and evaluation), and as such it was expected that many participants would consider persevering for longer due to awareness of being evaluated.

2.4 | Cardiovascular measures

Systolic blood pressure (SBP), diastolic blood pressure (DBP), and PR were measured discontinuously from the nondominant arm using a standard brachial artery cuff and semi-automatic sphygmomanometer (Critikon Inc., Tampa, FL). These cardiovascular measures were recorded every 2 min during the baseline, stress, and recovery phase of the PASAT. In addition, a single BP and PR measure was taken 30 s into the SECPT as an index of reactivity, however reactivity to the SECPT was not a main focus of this study. Overall, there was reduction in participant numbers for the SECPT reactivity analyses due to early hand withdrawal ($N = 108$) meaning the task cardiovascular measures were not completed in all participants. Finally, reactivity was not measured during the Euler puzzle task due to the confounding effect of arm movement and fidgeting on BP.

2.5 | Procedure

Participants were informed about the study via email, social media, and word of mouth. On arrival at the laboratory, informed consent was given and height (m) and weight (kg) were measured using a Marsden HM-250P Portable Height Measure and a Marsden M-420 Digital Portable Scale. A brachial artery cuff was then attached to the nondominant arm of each participant, before they reclined quietly during a 10-min adaptation period. During this period, participants provided their sociodemographic information and completed the self-reported perseverance questionnaire. The remaining laboratory session consisted of five main periods: 10-min baseline, 10-min PASAT, 10-min recovery, 4-min SECPT and finally, the Euler puzzle task for up to 30 min.

2.6 | Data analysis

Data analysis was completed using IBM SPSS Statistics Analysis software version 25. Cardiovascular data were averaged across each separate time period (e.g., baseline, stress, and recovery) and reactivity was calculated using average stress value minus average baseline. A repeated measures ANOVA, with time as two points (baseline and stress) was used to check that the PASAT was effective in perturbing BP and PR. Potential confounding variables were identified by examining the links between reactivity and sociodemographic data, questionnaire scores, and task ratings, using one-way ANOVA and correlations. For the main analyses, associations between reactivity and self-reported perseverance (Grit-s score), and behavioral perseverance (time engaging with SECPT, attempts at impossible puzzle, and time taken on impossible puzzle) were explored initially using correlations. Follow-up testing of significant associations, adjusting for any potential confounding variables, was conducted via linear regressions with potential confounders added as covariates in the models. Partial eta-squared and change in R-squared were used as indices of effect size in ANOVAs and regressions, respectively. Variations in degrees of freedom reflect occasional missing data.

3 | RESULTS

A total of 147 participants completed the study, with 22 males, 125 females (85%) and a mean age of 19.3 (*SD* = 1.91) years. Five reported taking ongoing medication (including asthma medication and underactive thyroid gland medication) and none had completed the PASAT before. Table 1 shows the remaining descriptive statistics for sociodemographic and anthropometric data.

3.1 | Cardiovascular reactivity to stress

In repeated measure ANOVAs (baseline, PASAT) there were significant main effects of time for: SBP, $F(1,142) = 347.44$, $p < .001$, $\eta^2 = .710$; DBP, $F(1,142) = 410.71$, $p < .001$, $\eta^2 = .743$; and PR, $F(1,142) = 220.62$, $p < .001$, $\eta^2 = .608$. Figure 1 shows that the PASAT significantly increased cardiovascular activity, and the mean (*SD*) cardiovascular reactivity data are shown in Table 2.

3.2 | Socio-demographics, task variables, and reactivity

There were no PASAT reactivity differences in relation to age, medication status, or body mass index (BMI). However, men had higher PASAT SBP and DBP reactivity when compared to women, $F(1,141) = 7.712$, $p = .01$, and $F(1,141) = 5.829$, $p = .02$, respectively. In addition, non-whites had lower PASAT DBP, $F(1,141) = 4.791$, $p = .03$, and PR reactivity, $F(1,141) = 4.244$, $p = .04$), and persevered for less time during the SECPT, $F(1,143) = 11.07$, $p = .001$, when compared to whites. Furthermore, nonmanual occupational household participants showed higher PASAT PR reactivity, $F(1,141) = 7.15$ $p = .01$, relative to individuals from a manual occupational household. Finally, individuals with higher PASAT DBP reactivity performed better on the PASAT, $r(141) = .23$, $p = .01$, and PASAT SBP, $r(141) = .22$, $p = .01$, DBP, $r(141) = .18$, $p = .03$, and PR reactivity, $r(141) = .22$, $p = .01$, positively related to higher self-ratings of "arousal" during the PASAT.

TABLE 1 Sociodemographic and anthropometric characteristics of the sample ($N = 147$)

Participant characteristics ($N = 147$)	Mean (*SD*)/*N* (%)
Age (years)	19.4 (1.9)
Sex (female)	125 (85)
Ethnicity (white)	101 (69)
(black)	14 (10)
(Asian)	27 (18)
(other)	5 (3)
Body mass index (kg/m^2)	22.7 (3.8)
Parental occupation (non-manual)	119 (81)

3.3 | Self-reported and behavioral perseverance

Table 2 shows the mean (*SD*) total score for the Grit-s (self-reported perseverance) as well as the behavioral perseverance data. There were no significant relationships between self-reported and behavioral perseverance (number of impossible puzzle attempts, time taken on impossible puzzle, or SECPT perseverance time).

Among the behavioral perseverance measures, time taken on the impossible puzzle related significantly to SECPT time, $r(138) = .33$, $p < .001$, such that those who spent longer on the impossible puzzle also persevered for longer during the SECPT. Furthermore, as might be expected, individuals who persevered for longer on the impossible puzzle also took more attempts, $r(140) = .62$, $p < .001$.

3.4 | Cardiovascular reactivity and perseverance

There were no significant correlations between reactivity for SBP, $r(141) = -.04$, $p = .68$, 95%CI −.20, 0.13, DBP, $r(141) = .04$, $p = .65$, 95%CI −.13, .21, and PR, $r(141) = -.05$, $p = .53$, 95%CI −.20, .10, reactivity, and self-reported perseverance (Grit-s score). For behavioral perseverance, there was a positive correlation between SBP, $r(136) = .20$, $p = .02$, 95%CI .04, .36, and DBP, $r(136) = .23$, $p = .01$, 95%CI .06, .39, reactivity, and time spent on the impossible puzzle, such that lower reactivity related to less time spent persevering on the puzzle. However, puzzle time was *ns* for PR reactivity, $r(136) = .12$, $p = .16$, 95%CI −.03, .28. Figure 2 presents scatterplots of all three associations. Furthermore, reactivity was not significantly associated with number of impossible puzzle attempts for SBP, $r(136) = -.02$, $p = .81$, 95%CI −.19, .15, DBP, $r(136) = -.005$, $p = .96$, 95%CI −.17, .16, or PR reactivity, $r(136) = .003$, $p = .97$, 95%CI −.14, .16.

SECPT time, a secondary measure of behavioral perseverance, also significantly related to SBP, $r(139) = .35$, $p = < .001$, 95%CI .21, .47, DBP, $r(139) = .33$, $p < .001$, 95%CI .19, .46, and PR reactivity, $r(139) = .35$, $p < .001$, 95%CI .24, .46; individuals with lower cardiovascular reactivity showed poorer perseverance. Figure 3 presents scatterplots of these associations.

As PASAT performance and some sociodemographic (sex and ethnicity) and self-report (PASAT arousing rating) data were associated with PASAT reactivity, analyses predicting

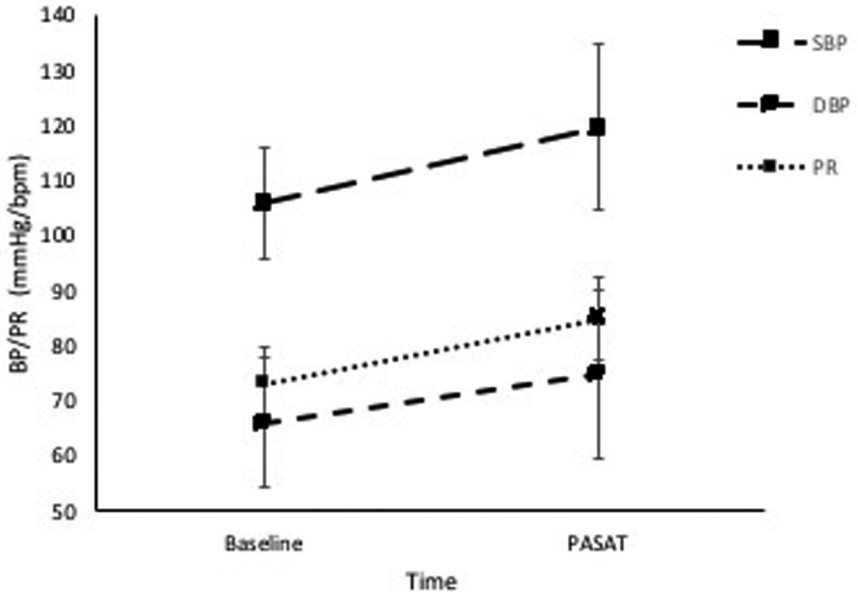


FIGURE 1 Mean (SE) systolic blood pressure, diastolic blood pressure, and pulse rate during baseline and the PASAT task

TABLE 2 Mean (*SD*) cardiovascular reactivity and perseverance data

	n	Mean	*SD*
PASAT SBP reactivity (mmHg)	143	14.0	8.98
PASAT DBP reactivity (mmHg)	143	8.8	5.18
PASAT PR reactivity (bpm)	143	11.7	9.46
SECPT SBP reactivity (mmHg)	108	17.6	9.95
SECPT DBP reactivity (mmHg)	108	14.7	8.75
SECPT PR reactivity (bpm)	108	4.5	9.28
Grit-s total score	147	3.3	0.56
Cold pressor time spent in water (seconds)	145	176.5	83.87
PASAT Score (out of 1,000)	146	642.4	143.49
Number of sheets of attempts at the impossible puzzle	142	23.0	16.86
Time taken on the impossible puzzle (seconds)	142	1,035.2	536.73

perseverance from PASAT reactivity were repeated in regression models adjusting for these variables as confounders. The associations between PASAT SBP, $\beta = .21$, $p = .02$, $\Delta R^2 = .041$, and DBP reactivity, $\beta = .21$, $p = .03$, $\Delta R^2 = .035$, and impossible puzzle time were still significant when adjusted for sex, ethnicity, PASAT score (for DBP reactivity only), and PASAT arousal rating. All PASAT reactivity measures remained significantly related to SECPT time post-adjustment for confounding variables (sex for SBP and DBP, PASAT score for DBP, occupational group for PR, and ethnicity and PASAT arousal rating for all associations); SBP, $\beta = .29$, $p = .03$, $\Delta R^2 = .072$, DBP, $\beta = .25$, $p = .004$, $\Delta R^2 = .052$, and PR reactivity, $\beta = .31$, $p < .001$, $\Delta R^2 = .085$.

3.5 | Sensitivity analyses

Given that the impossible puzzle paradigm and SECPT are capped in terms of time, it could be argued that nonparametric statistics would be more appropriate for the non-normally distributed time variables. These variables were not bimodal but were skewed and not normally distributed. Consequently, the correlation analyses were repeated using Spearman's rho. For time spent on the impossible puzzle, there remained significant positive correlations with SBP, $r(136) = .25$, $p = .003$, 95%CI .09, .41, and DBP reactivity, $r(136) = .21$, $p = .01$, 95%CI .04, .36, and a significant association also now emerged for PR reactivity, $r(136) = .18$, $p = .04$, 95%CI .03, .35. Similarly, for SECPT time, correlations remained significant with SBP, $r(139) = .36$, $p < .001$, 95%CI .21, .49, DBP, $r(141) = .30$, $p < .001$, 95%CI .16, .44, and PR reactivity, $r(139) = .37$, $p < .001$, 95%CI .23, .50. Finally, and as before, reactivity was not significantly associated with number of impossible puzzle attempts for SBP, $r(136) = .07$, $p = .40$, 95%CI −.10, .24, DBP, $r(136) = .06$, $p = .49$, 95%CI −.11, .23, or PR reactivity, $r(136) = .02$, $p = .83$, 95%CI −.16, .20.

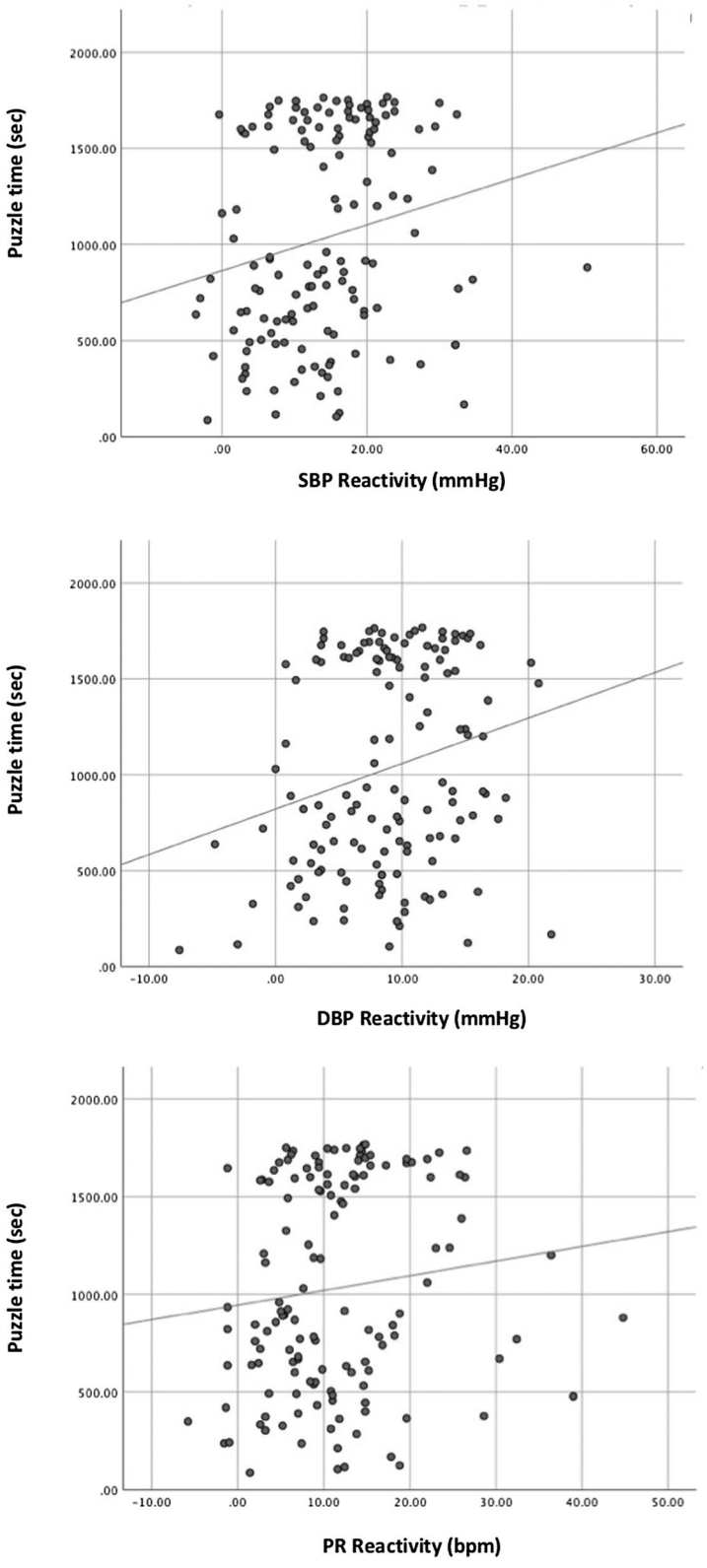
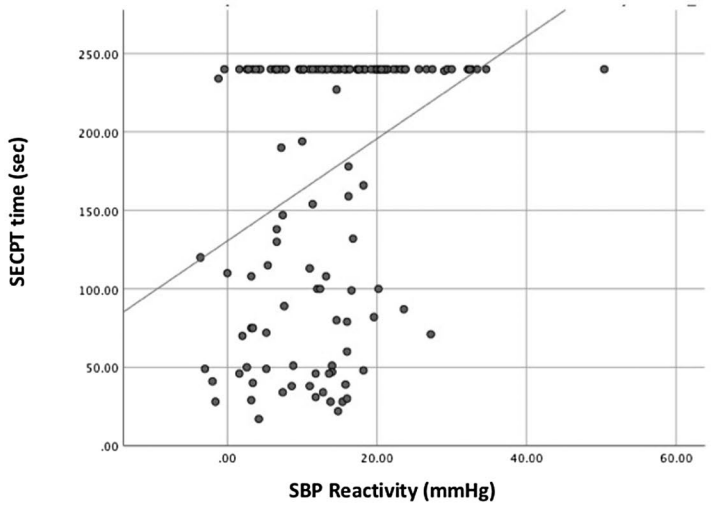
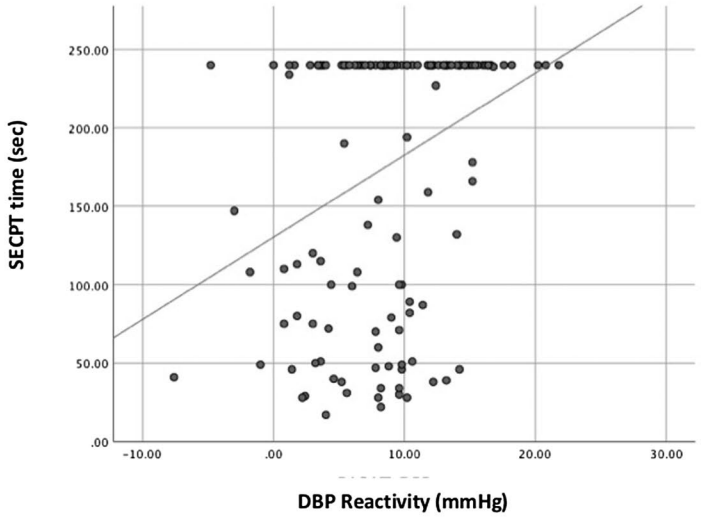


FIGURE 2 Scatterplots depicting the significant relationships between cardiovascular reactivity variables and impossible puzzle time perseverance

3.5.1 | SECPT reactivity

Although SECPT reactivity was not a main focus of this study (given the confounding effects of SECPT engagement time on SECPT reactivity, loss of data due to hand withdrawal, and only taking one stress measure of BP and PR) a final set of sensitivity analysis considered the associations between SECPT reactivity and perseverance. The SECPT lasted long enough to take one complete reading of BP and PR in 108 participants. PASAT and SECPT reactivity did not correlate significantly with one another ($p = .17$ to $.98$, full results available on request). As previously, Grit-s score did not relate to





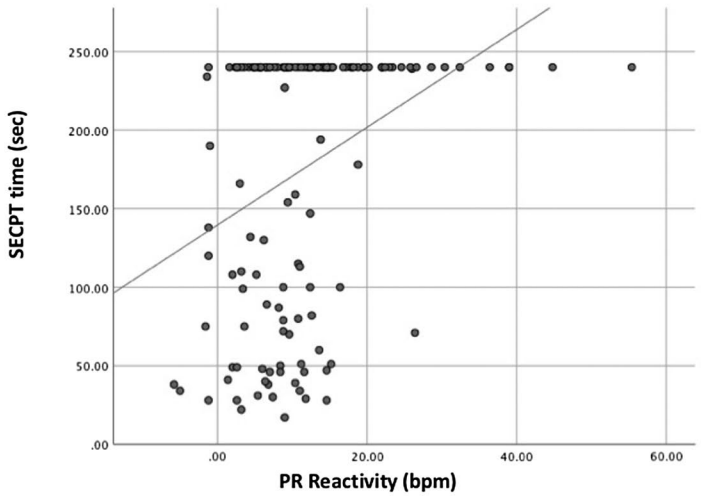


FIGURE 3 Scatterplots depicting the significant relationships between cardiovascular reactivity variables and SECPT perseverance time

SECPT reactivity for SBP, $r(106) = -.07$, $p = .47$, 95%CI −.26, .10, DBP, $r(106) = -.03$, $p = .79$, 95%CI −.23, .16, or PR, $r(106) = -.16$, $p = .09$, 95%CI −.35, .03. Furthermore, only SECPT PR reactivity significantly related to behavioral perseverance, for impossible puzzle time, $r(104) = -.24$, $p = .01$, 95%CI −.44, −.04, but PR reactivity also marginally predicted impossible puzzle attempts, $r(104) = -.20$, $p = .05$, 95%CI −.38, −.003. Interestingly, lower SECPT reactivity was this time implicated in greater rather than poorer behavioral perseverance. SECPT PR reactivity was also marginally associated with SECPT engagement time, $r(106) = -.17$, $p = .08$, 95%CI −.32, −.04; again, greater perseverance was

linked to lower PR reactivity. SECPT SBP and DBP reactivity did not relate to impossible puzzle time, SBP: $r(104) = -.05$, $p = .60$, 95%CI −.23, .14; DBP: $r(104) = -.01$, $p = .93$, 95%CI −.19, .17), or number of puzzle attempts, SBP: $r(104) = -.06$, $p = .58$, 95%CI −.24, .16; DBP: $r(104) = -.01$, $p = .95$, 95%CI −.21, .20.

4 | DISCUSSION

The primary aim of this study was to further investigate the link between cardiovascular reactivity and perseverance, as a larger scale replication of a previous preliminary study (Chauntry et al., 2019). This study again found that cardiovascular reactivity does not relate to self-reported perseverance, but does predict poorer behavioral perseverance, such that those with blunted SBP and DBP reactivity persevered for less time on an impossible puzzle, and those with blunted SBP, DBP, and PR reactivity persevered for less time during the SECPT. Self-report and behavioral perseverance were not significantly related.

These findings support our original hypothesis and almost entirely replicate the preliminary findings from a previous small-scale study (Chauntry et al., 2019). This study also extends the study of Chauntry et al. (2019) using a much larger sample, a longer mental arithmetic task to initiate reactivity, a socially evaluated version of the cold pressor test, and more adequate recovery periods between tasks. All in all, this study does not generate new knowledge as such, but has the major strength of replicating important findings and at the same time increasing confidence in such findings being legitimate. Thus, this study makes strides in addressing the important "replication crisis" issue in psychology.

Nevertheless, in the previous study by Chauntry et al. (2019) there was an association between SBP and DBP reactivity and number of attempts at the impossible puzzle, whereas only PR reactivity related to time spent on the puzzle. In the present study, the effects emerged more strongly for time spent on the puzzle and less so for number of puzzle attempts. These small differences between studies are difficult to explain given that the studies are very similar in terms of methodology and population sampled. However, as number of attempts and time taken on the impossible puzzle are highly correlated, it seems likely that these minor differences are not particularly relevant. The present results are also in agreement with the remainder of the existing literature, that suggest blunted physiological reactivity to acute active stress is associated with low perseverance, both in terms of study non-completion (Ginty et al., 2015) and quicker relapse after cessation from alcohol (Junghanns et al., 2003; Lovallo, 2006) and smoking (al'Absi, 2006).

In the present study, both blunted BP and PR reactivity were predictors of poorer perseverance, although associations were more robust for BP in nonparametric statistical analyses. Overall, these findings are consistent with other studies showing that negative behavioral correlates of blunted reactivity relate to both BP and HR responses, for example, both SBP and HR reactivity were found to relate to depression (Carroll et al., 2007) and smoking (Phillips et al., 2009) in the West of Scotland Twenty-07 study. In contrast, the drug cessation and reactivity literature has focused on cortisol reactivity (e.g., al'Absi, 2006; Junghanns et al., 2003; Lovallo, 2006), but given that hypothalamic–pituitary–adrenal (HPA) axis and cardiovascular stress responses are strongly correlated (Cacioppo, 1994), it is expected that had cortisol been measured in the present study, blunted cortisol reactivity would also have emerged in relation to poorer behavioral perseverance. Taken together, these results support the argument that attenuated stress response patterns are predictive of dysfunctional perseverance, be it the ability to persevere at the *cessation* of a behavior, or to persevere with an unpleasant behavior, as in the present study.

Interestingly, when using the CP task (or the SECPT as it was in the present study) to initiate reactivity, it was found that lower reactivity actually related to greater rather than poorer perseverance (but only for PR reactivity). This is in contrast to the previous study, where lower CP perseverance was linked to blunted CP DBP responsivity (Chauntry et al., 2019). This inter-study variability is difficult to explain, but might relate to discrepancies in sample size and/or the social evaluative element of the cold pressor paradigm in the present study, such that the additional psychological threat may have manifested in primarily dysregulated autonomic activity (i.e., PR) as opposed to BP changes (Wager et al., 2009). However, this fails to explain the differences in directionality of findings across the studies, but this may be a result of the timing of the cardiovascular measurement in the SECPT being earlier in the present study, or the severe confounding between reactivity and perseverance through using the cold pressor paradigm in this way. This supports our original decision to not focus on SECPT reactivity as a primary variable. As a possible explanation, PR reactivity was low during the SECPT compared to the PASAT, and PASAT and SECPT reactivity did not significantly relate to one another, suggesting, as we have said elsewhere (Brindle et al., 2017) that responses to active and passive stress tasks are not consistent, particularly among blunted reactors. Further research is required to directly explore reactivity-perseverance differences across active versus passive stress.

The nonsignificant findings for self-reported perseverance and reactivity are perhaps not surprising, as previous research has also found no relationship between Grit-s score and short-term task performance (Egalite et al., 2016). These findings also align completely with the results of Chauntry et al. (2019) and, therefore, suggest that reactivity and self-reported perseverance are not linked. However, other research

has found association between blunted reactivity and other self-reported constructs similar to perseverance, such as biological disengagement (Ginty et al., 2020). Overall, this may suggest issues with the Grit-s, such as social desirability bias having a significant effect (Bazelais et al., 2016), or that the Grit-s is measuring different aspects of perseverance relative to the behavioral tasks, such as trait rather than state perseverance (Steinberg & Williams, 2013). Moreover, and in line with previous research, self-reported perseverance did also not relate to behavioral perseverance (Chauntry et al., 2019; Steinberg & Williams, 2013). Additionally, this lack of concordance across behavioral and self-report measures is not without precedence in other literature, such as physical activity research (Dyrstad et al., 2014). Consequently, this finding may interestingly suggest that individuals can be poor perseveres in terms of behavior even if they consider themselves to be gritty and persevering. This is consistent with the previous findings that blunted stress responders are not consciously aware of deficiency in their motivation (Brindle et al., 2017) and do not self-report consistent differences in task engagement or performance, compared to exaggerated responders (Brindle et al., 2017; Ginty et al., 2012). Consequently, self-report measures of perseverance may not be useful in determining perseverance or risk of relapse in real world situations (e.g., addiction cessation or behavior restriction/change) as these individuals do not self-identify as poor perseveres or those who put in less effort. All in all, reactivity testing rather than traditional questionnaire screening may be a better strategy to identify those who might need additional support during behavior change.

4.1 | Limitations and future directions

The present study has several limitations. First, it was cross-sectional, so cannot be used to determine whether an individual's typical stress reactivity predicts future perseverance, although the cessation literature cited above suggests this would be the case. Second, although adjustment was made for various potential confounding variables, it is possible that other crucial confounders or mediators were not measured, due to the effort of attempting to reduce participants' questionnaire burden. Third, as mentioned above, the present study measured cardiovascular but not cortisol stress reactivity. This was due to the time that cortisol takes to respond, meaning that the protocol would need to have been significantly extended to measure both response and return to baseline; this would potentially have negatively affected both recruitment efficiency and perseverance. Fourth, the study did not counterbalance task order, and it could be argued that having been previously exposed to acute stress may have influenced perseverance. However, this design decision was taken to protect from the Zeigarnik effect of intrusive thoughts, caused by failure to complete a task (Zeigarnik, 2007), which we believe would have had more of a negative effect during the stress test, and, therefore, not given a true picture of individuals' reactivity. Furthermore, a sufficient recovery period of 10 min was given between the stress test and other tasks, which extends the previous study by Chauntry et al which used only a limited recovery period. Moreover, behavioral perseverance was not associated with self-reported stress ratings or PASAT score, suggesting effort and stress on the PASAT did not influence subsequent perseverance. Next, the presence of the experimenter during the behavioral perseverance tasks may have impacted on participants in such a way that it led to atypical perseverance. However, it could be argued that this added pressure contributes to ecological validity, as many real-life situations involve external pressure, observation, and evaluation. Nevertheless, it would be interesting in the future to determine whether this same relationship, and indeed same behavior, exists when behavioral perseverance is not being observed. Finally, there was a clear gender bias which negatively impacts the generalizability to males in the present study. However, this unintentionally helps to balance the heavily male dominated samples that makes up traditional stress psychophysiological research. Nevertheless, future research might benefit from confirming this current relationship in male- or sex-balanced samples.

In addition, future studies may also seek to extend the present findings through incorporation of additional cardiovascular and cortisol measures, although the design would need to be altered to accommodate this. Furthermore, a range of different behavioral perseverance tasks could be employed to strengthen the evidence for a blunted reactivity—poor perseverance relationship. However, the concordance with previous literature, is already a strength and suggests that this association is not specific to one type of perseverance task. It may be beneficial for future studies to utilize behavioral perseverance measures with a less severe time or effort limit (i.e., many participants met the 30-min limit for the puzzle and 4-min cap for the cold pressor task) and this contributed to a significant ceiling effect. Although it should be noted that this was taken into consideration in the present study using nonparametric sensitivity analyses, where the results remained intact. Other tasks that may be selected are hand grip endurance, verbal reasoning, or anagram tasks (Egalite et al., 2016; Hagger et al., 2010).

In conclusion, dysfunctional behavioral perseverance, conceptualized as recording less time endeavoring to solve an impossible puzzle and less time persevering at a cold pressor test, were predicted by blunted cardiovascular reactivity. This adds further support to the "inverted U" model of reactivity, by showing the blunted, as well as exaggerated reactivity is related to negative health and behavioral outcomes. However, it is important to highlight that this "inverted U" model is underpinned by linear relationships

in both the exaggerated and blunted literature, and an "optimal" level of reactivity has not yet been established. Overall, blunted reactivity appears to be a physiological marker of poor behavioral regulation but does not relate to self-reported perseverance. This relationship may contribute to explain why certain negative health outcomes are observed among those with blunted cardiovascular reactivity (e.g., obesity and addictions) and suggests that blunted stress responders may need additional support when adhering to health and behavioral change interventions.

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CONFLICT OF INTEREST

No conflict of interest.

AUTHOR CONTRIBUTION

Anna Whittaker (Phillips): Conceptualization; Data curation; Formal analysis; Funding acquisition; Investigation; Methodology; Project administration; Resources; Supervision; Writing-original draft; Writing-review & editing. **Aiden J Chauntry:** Writing-review & editing.

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