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Blunted cardiovascular responses to acute psychological stress predict low behavioral but not self-reported perseverance

Aiden J. Chauntry[1,2] | **Sarah E. Williams**[1] | **Anna C. Whittaker**[1,3]

[1]School of Sport, Exercise & Rehabilitation Sciences, University of Birmingham, Birmingham, UK

[2]School of Sport, Exercise, and Health Sciences, National Centre for Sport and Exercise Medicine, Loughborough University, Loughborough, UK

[3]Faculty of Health Sciences and Sport, University of Stirling, Stirling, UK

Correspondence
Anna C. Whittaker, School of Sport, Exercise & Rehabilitation Sciences, University of Birmingham, Edgbaston, Birmingham B15 2TT, UK.
Email: a.c.whittaker@bham.ac.uk

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Abstract

Emerging evidence relates attenuated physiological stress reactions to poor behavioral regulation. However, only a small number of behaviors such as impulsivity and risk taking have been explored. Nevertheless, one opportunistic study suggested that blunted reactivity might relate to poor perseverance. The present study examined the relationship between cardiovascular reactivity to acute active psychological stress and self-reported and behavioral perseverance. Participants ($N = 64$) completed a self-report perseverance questionnaire before heart rate (HR) and blood pressure (BP) were measured at rest and in response to 4-min active (paced auditory serial addition; PASAT) and passive (cold pressor) stress tests. This was followed by an unsolvable Euler puzzle tracing task, with the time spent and number of attempts endeavoring to solve the puzzle recorded as behavioral perseverance measures. Blunted systolic and diastolic BP reactivity to the PASAT was associated with fewer attempts at the impossible puzzle, and lower diastolic BP PASAT reactivity related to less time persevering at the puzzle. Moreover, attenuated diastolic BP and HR PASAT reactivity predicted poorer perseverance at keeping one's hand in the iced water of the cold pressor task. There was no association between reactivity and self-reported perseverance. These preliminary findings add to the evidence that implicates blunted reactivity as a physiological marker of poor behavioral regulation, and this may indicate why individuals with blunted reactivity are at increased risk of developing negative health outcomes (e.g., obesity and addictions).

KEYWORDS

blood pressure, cardiovascular reactivity, heart rate, perseverance, psychological stress

1 | INTRODUCTION

There are large individual differences in cardiovascular stress reactions during acute exposure to stressful stimuli, the magnitude of which are relatively consistent and stable over time (Ginty, Gianaros, Derbyshire, Phillips, & Carroll, 2013; Manuck & Schaefer, 1978). It is also established that responses to stress impact health and behavior (Chida & Steptoe, 2010), depending on whether one exhibits exaggerated or blunted responses (Carroll, Ginty, Whittaker, Lovallo, & de Rooij, 2017; Carroll, Lovallo, & Phillips, 2009).

The reactivity hypothesis postulated that consistently exaggerated cardiovascular reactions to acute stress are implicated in the etiology of cardiovascular pathologies (Obrist, 1981). This is now supported via a plethora of compelling evidence from many large-scale, cross-sectional, and prospective observational studies (Carroll et al., 1996, 2001; Carroll, Bibbey et al., 2012; Carroll, Ginty et al., 2012; Carroll, Phillips, Der, Hunt, & Benzeval, 2011; Markovitz, Raczynski, Wallace, Chettur, & Chesney, 1998; Matthews et al., 2004) and meta-analyses/reviews (Chida & Steptoe, 2010; Schwartz et al., 2003; Treiber et al., 2003). Taken together, these findings emphasize the reliability of this association across samples in different countries/cultures and in laboratories using various protocols and stress tasks.

Due to the overwhelming evidence linking exaggerated stress reactivity with negative health outcomes, one might expect low or blunted cardiovascular reactivity, that is, small increases or even decreases in heart rate (HR) and blood pressure (BP), to be an adaptive response. However, it is clear that this is incorrect; blunted reactivity is also related to a range of deleterious health outcomes such as depression, obesity, and poor self-reported health (Phillips, 2011) and to many substance (e.g., smoking, alcohol) and nonsubstance (e.g., exercise) dependencies (Carroll et al., 2017). There is also a range of negative personality traits observed in those with blunted reactivity, such as higher levels of neuroticism and lower agreeableness and openness (Bibbey, Carroll, Roseboom, Phillips, & de Rooij, 2013). A meta-analysis also demonstrated that neuroticism and negative affect are characteristic of those with an attenuated cardiovascular stress profile (Chida & Hamer, 2008). In sum, both blunted and exaggerated cardiovascular responses to acute stress are maladaptive and reflect a curvilinear relationship between reactivity and health (Carroll, Phillips, & Lovallo, 2009; Phillips, 2011).

A common feature shared between the correlates of blunted cardiovascular reactivity is a dysfunction in the fronto-limbic brain regions associated with motivation and goal-directed behaviors (Carroll et al., 2009, 2017; Phillips, 2011), such that blunted reactivity may be a peripheral marker for central motivational dysregulation (Carroll et al., 2009; Lovallo, 2006). fMRI studies have provided evidence in favor of this, demonstrating amygdala and anterior/posterior cingulate cortex deactivation in blunted responders exposed to stressful stimuli (Gianaros, May, Siegle, & Jennings, 2005; Ginty et al., 2013). Interestingly, it is these brain areas that support cardiovascular responses to stress, co-ordinate motivational/behavioral processes, modulate autonomic regulation (Bush, Luu, & Posner, 2000; Carroll et al., 2009; Hagemann, Waldstein, & Thayer, 2003; Lovallo, 2005), and determine personality (Cremers et al., 2010; Deyoung & Gray, 2012).

If blunted reactivity is a marker of central dysfunction, one might assume that it would also be associated with general manifestations of poor behavioral regulation. Although limited, there is preliminary evidence in support of this. Specifically, diminished reactivity is associated with high impulsivity/impaired response inhibition (Allen, Hogan, & Laird, 2009; Bennett, Blissett, Carroll, & Ginty, 2014; Bibbey, Ginty, Brindle, Phillips, & Carroll, 2016; Muñoz & Anastassiou-Hadjicharalambous, 2011) and externalizing psychopathology (i.e., behavioral problems directed toward the external environment; Heleniak, McLaughlin, Ormel, & Riese, 2016). Finally, blunted reactivity also predicts poor performance during tasks that are motivation and effort contingent, such as lung function spirometry (Carroll et al., 2013; Carroll, Bibbey et al., 2012; Crim et al., 2011).

Thus, blunted reactivity appears to signify central motivational dysregulation, in that it relates to motivation-contingent behaviors/tasks that require effort. Blunting also increases risk for deleterious outcomes, such as substance addictions. As such, it seems highly plausible that blunted reactors will show behaviors that increase the risk of developing such outcomes, such as low perseverance, which is also motivation dependent (Lovallo, 2013).

Perseverance is an important behavior and personality facet that shares similarly with conscientiousness (Credé, Tynan, & Harms, 2017). It is critical for academic/career progression (Andersson & Bergman, 2011) and when refraining from maladaptive behaviors (Quinn, Brandon, & Copeland, 1996). In parallel with blunted reactivity, dysfunctional perseverance is also implicated in obesity development (Murphy, Stojek, & MacKillop, 2014) and faster relapse during cigarette and other substance cessation (Abrantes et al., 2008; Steinberg et al., 2012). Given the links between obesity/smoking and cardiovascular disease (Ambrose & Barua, 2004; Van Gaal, Mertens, & De Block, 2006), diabetes (Patja et al., 2005), and cancer (Le Marchand, Wilkens, Kolonel, Hankin, & Lyu, 1997), perseverance is an important behavior. Perseverance is also predictive of future disease, including cardiovascular disease (Cramer, Benedict, Muszbek, Keskinaslan, & Khan, 2008).

There is tentative evidence to suggest that perseverance may be associated with blunted reactivity. As previously mentioned, those who mount diminished physiological stress responses are more likely to relapse during alcohol (Junghanns et al., 2003; Lovallo, 2006) and smoking (Al'Absi, 2006) cessation, as well as during treatment for cocaine addiction (Back et al., 2010). Although one may infer this behavior as an index of reduced perseverance, it is possible that these findings actually reflect relapse as opposed to perseverance per se. Perhaps more compelling evidence is available from a study showing that diminished cardiovascular stress reactivity (cardiac output and HR) predicted the failure to complete a simple online-based 1-year follow-up task, despite participants initially agreeing to complete the follow-up phase, repeated promptings, and the offering of a financial incentive (Ginty, Brindle, & Carroll, 2015). Nevertheless, study noncompletion might still be considered an indirect measure of perseverance. A more direct study demonstrated significant associations between a range of behavioral tasks (e.g., circle tracing and stop-go inhibition) and reactivity but did not find difference in perseverance, measured by an impossible puzzle paradigm, between high and low stress reactors (Bibbey, 2015). However, it is possible that this null relationship reflects participant fatigue, as the perseverance measure was completed last, after participants attempted multiple behavioral tasks. Overall, although tentative and indirect evidence suggests blunted reactivity predicts dysfunctional perseverance, the direct reactivity-perseverance relationship has received only sparse attention.

Consequently, the aim of the present study was to examine the direct relationship between cardiovascular reactivity to active and passive psychological stress and self-reported and behavioral perseverance. However, given that blunted reactivity has been shown to be a phenomenon observed in response to active but not passive stress tasks (i.e., blunted responders still have the capacity to respond to passive tasks but show evidence of blunting in response to active stressors only; Brindle, Whittaker, Bibbey, Carroll, & Ginty, 2017), hypothesis testing was restricted to associations between paced auditory serial addition (active stressor) reactivity and perseverance. We hypothesized that attenuated cardiovascular reactivity to active stress would be associated with lower self-reported and behavioral perseverance. In addition, a secondary objective was to examine whether self-report and behavioral perseverance measurements correlate; this is the first study the authors are aware of to directly investigate this methodological relationship, particularly in the context of stress reactivity. We expected self-reported and behavioral perseverance measurements to positively correlate.

2 | METHOD

2.1 | Participants

Participants were 64 mixed-sex University of Birmingham students. A minimum sample size of 42 for this study was determined from a previous cardiovascular stress reactivity study, which found significant correlations between behavioral/psychosocial factors and reactivity in a sample of 31 participants (Black, Balanos, & Whittaker, 2017). Using *G*-power and the R^2 of .248 to calculate the f^2 effect size from this previous study equals $f^2 = 0.33$, and when $\alpha = .05$ and power is set at .95, this equals a recommended sample size of 42. The present study over-recruited to take account of any sociodemographic differences in reactivity or perseverance. In our study, participants were excluded if they were currently infected or acutely ill but were not excluded on the basis of any other psychopathological or medical conditions. All participants provided written informed consent, and the project was approved by the local STEM Ethics Committee (ERN_14-0089A).

2.2 | Questionnaires

2.2.1 | Self-reported perseverance

The Short Grit Scale (Grit-S; Duckworth & Quinn, 2009) measured self-reported perseverance or grit, defined by Duckworth and Quinn as "perseverance and passion for long-term goals" (p. 1087). When completing this eight-item instrument, participants used a 5-point Likert scale ranging from 1 (*not at all like me*) to 5 (*very much like me*) to indicate their agreement with each item. Four statements examined the consistency of interests/passions (e.g., "I often set a goal but later choose to pursue a different one," and four measured tendency to maintain effort, e.g., "I am a hard worker"). Scores were averaged, and higher scores indicated greater perseverance. The Grit-S boasts acceptable psychometric properties (Duckworth & Quinn, 2009; Schmidt, Fleckenstein, Retelsdorf, Eskreis-Winkler, & Möller, 2017), and in the present study the internal reliability was .74.

2.2.2 | Sociodemographic information

Participants provided information on their age, sex, ethnicity, and parental occupation. Additionally, female participants were asked to report whether they were taking the contraceptive pill or not.

2.2.3 | Stress task evaluation

Six questions measured how stressful, difficult, arousing, confusing, embarrassing, and engaging participants found the mental arithmetic stress task. Participants also indicated how successful they perceived their performance to be. For the cold pressor task, participants completed only the items for stressfulness and difficulty. For all questions, participants responded using 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 | Laboratory tasks

2.3.1 | Active stress task

The active psychological stress task was a 4-min version of the Paced Auditory Serial Addition Test (PASAT; Gronwall, 1977), which has been shown to reliably perturb the cardiovascular system (Phillips, Carroll, Burns, & Drayson, 2005; Phillips, Carroll, Hunt, & Der, 2006; Phillips, Der, Hunt, & Carroll, 2009) with good test-retest reliability (Willemsen et al., 1998). Participants were presented, via a compact disc player, with a series of single digit numbers and were required to add the present number heard to the number previously heard and state their answer aloud. They then had to remember the last number read out and add it to the next number presented. Thus, the PASAT involves both mental arithmetic and working memory. Throughout the test, the time intervals between the numbers began at 2 s for the first 2 min but were shortened to 1 s for the final 2 min to induce time pressure. An experimenter wearing a white laboratory coat sat close to the participant and obtrusively scored their performance; all participants began with a total of 1,000 points and were deducted five points for every missed or incorrect answer. The final points total was used as a measure of objective performance. All participants received a single aversive noise burst during the last five numbers of every block of 10. If possible, this was aligned with providing an incorrect answer or hesitation, but if not, randomly. However, prior to the task, all participants were informed that any noise bursts would be related to their behavior and performance. The PASAT also induced competition and social evaluation; a leaderboard encouraged participants to attempt to better the score/avoid performing worse than others. In addition, participants were informed that they would be videotaped throughout the task and watched themselves live on a television screen; they were told that their performance would be recorded and assessed by "independent body language experts"; however, in reality, no such recording/assessment occurred.

2.3.2 | Passive stress task

The cold pressor (Barnett, Hines, Schirger, & Gage, 1963) stress task involved each participant attempting to keep their right hand, up to the wrist fold, submerged in cold water (0–2°C) for as long as possible. However, participants were reminded that they were free to withdraw their hand at any time. After 4 min, participants were asked to remove their hand if it was still submerged. Overall, research has demonstrated the reliability of the cold pressor task in provoking a cardiovascular response (Allen, Sherwood, Obrist, Crowell, & Grange, 1987).

2.3.3 | Perseverance puzzle task

Participants were asked to complete four Euler puzzles, a paradigm used in previous research to examine perseverance (Bibbey, 2015). Participants had to trace along all of the lines on a puzzle shape on a piece of paper without lifting the highlighter from the page and tracing along each line once only. If they made a mistake, they were instructed to use another piece of paper, and this was continued until they successfully completed the puzzle. The puzzles involved more complex patterns to trace as the participants progressed; however, the final puzzle was impossible to solve. The time taken and number of attempts endeavoring to complete the impossible puzzle were used as behavioral measures of perseverance.

2.4 | Cardiovascular measures

Systolic blood pressure (SBP), diastolic blood pressure (DBP), and HR were measured discontinuously from the left arm using a standard brachial artery cuff and Omron (model M5-I) semiautomatic sphygmomanometer (Omron Healthcare UK Ltd., West Sussex, UK). These cardiovascular measures were taken during Minute 2, 4, 6, and 8 of the first baseline period, and the second and fourth minutes of each stress task and second baseline (i.e. recovery) phase.

2.5 | Procedure

Participants were informed about the study via email, social media, and word of mouth. Before taking part, all participants read an information sheet and signed a written informed consent form. Participants were asked to refrain from eating for 1 hr, smoking or consuming caffeine for 2 hr, exercising vigorously for 4 hr, and consuming alcohol in the 12 hr preceding the testing session. The laboratory session consisted of six main periods: 10-min adaptation, 10-min baseline, 4-min PASAT, 4-min recovery/second baseline, 4-min cold pressor task, and, finally, the Euler puzzle task. To begin, height and weight measurements were taken and body mass index (BMI) was subsequently calculated (weight/height^2). A brachial artery cuff was then attached to the left 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. Following this, a formal 10-min resting baseline period occurred. Participants then completed a brief practice test and the 4-min PASAT. Immediately after the task, participants completed the PASAT evaluation questionnaire before entering a 4-min recovery period; this period also served as the second baseline for the cold pressor task. Participants then completed the cold pressor stress task and the cold pressor evaluation questionnaire. Finally, participants completed the Euler puzzle perseverance task.

2.6 | Data analysis

Data analysis was conducted using IBM SPSS software, version 23. Cardiovascular data were averaged across each period (Baseline 1, PASAT, Baseline 2, and cold pressor task). To check that the PASAT and cold pressor task perturbed cardiovascular activity, repeated measures analyses of variance (ANOVAs) were conducted. Cardiovascular reactivity to the PASAT and cold pressor task was calculated by subtracting average stress values from average baseline. Ethnicity and parental occupation (as an indicator of socioeconomic status) were converted into binary variables of white/nonwhite and manual/nonmanual, respectively. To identify potential confounding variables, one-way ANOVAs and correlations were run to examine associations between sociodemographics, task ratings, and cardiovascular reactivity. For the main analyses, correlations examined the relationship between cardiovascular reactivity to the active PASAT stress task and self-reported and behavioral perseverance. Secondary exploratory analyses investigated the correlations between passive stress (cold pressor) reactivity and perseverance. Any significant relationships were reexamined using linear regression adjusting for any associated confounding variables as covariates in the model (as appropriate). Partial eta-squared (η^2) and change in R-squared (ΔR^2) were used as indices of effect size in ANOVAs and regressions, respectively. Slight variations in degrees of freedom reflect occasional missing data.

3 | RESULTS

The sociodemographic, anthropometric, and previous PASAT characteristics of the sample are summarized in Table 1.

3.1 | Cardiovascular reactions to the PASAT and cold pressor task

Three repeated measures ANOVAs (Baseline 1, PASAT, Baseline 2, cold pressor) were run for each of SBP, DBP, and HR reactivity. There were significant main effects of time for SBP, $F(3, 61) = 74.46$, $p < .001$, $\eta^2 = .785$; DBP, $F(3, 61) = 85.92$, $p < .001$, $\eta^2 = .809$; and HR, $F(3, 61) = 40.69$, $p < .001$, $\eta^2 = .667$. As illustrated in Figure 1, both the PASAT and cold pressor task significantly increased cardiovascular (SBP, DBP, HR) activity. There were some baseline differences in resting cardiovascular levels prior to each task; DBP was higher at the second baseline prior to the cold pressor, $p = .01$, and HR was lower prior to the cold pressor, $p = .003$, than before the PASAT. Consequently, baseline cardiovascular levels were not aggregated, and cardiovascular reactivity was calculated separately for each task using each independent baseline value. The mean (*SD*) cardiovascular reactivity data is shown in Table 2.

3.2 | Sociodemographics, task variables, and cardiovascular reactivity

There were no PASAT reactivity differences for age, sex, occupational group, or BMI. Additionally, task ratings and PASAT score were not significantly associated with cardiovascular reactivity to the PASAT. Finally, and as expected, those who spent longer with their hand submerged during the

TABLE 1 Sociodemographic, anthropometric, and previous PASAT characteristics of the sample

Participant characteristics	Mean (*SD*), range	*N* (%)
Age (years)	19.8 (1.82), 18–19	
Sex (female)		49 (77)
Ethnicity (white)		52 (81)
Black		3 (5)
Asian		7 (11)
Other		2 (3)
Body mass index (kg/m^2)	23.1 (3.31), 17.5–35.0	
Parental occupation (nonmanual)		59 (92)
Completed PASAT before (no)		60 (94)

Note: $N = 64$.
Abbreviation: PASAT, Paced Auditory Serial Addition Test.

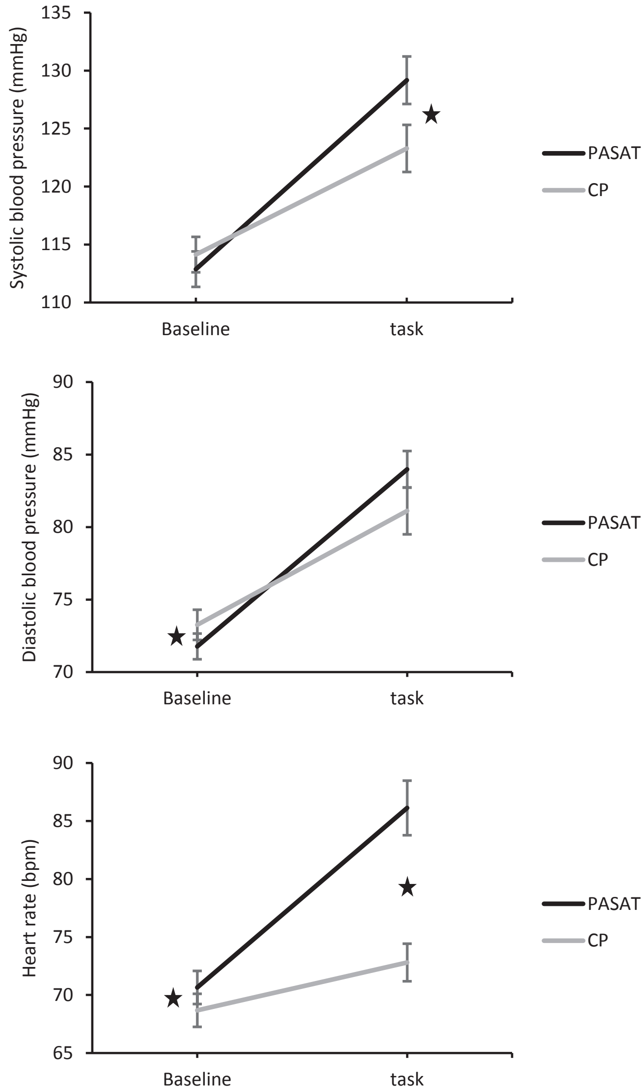

FIGURE 1 Mean (*SE*) systolic blood pressure, diastolic blood pressure, and heart rate during PASAT baseline, the PASAT, cold pressor baseline, and the cold pressor task. ★Significant difference between task values

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

	Mean	*SD*
PASAT SBP reactivity (mmHg)	16.3	10.50
PASAT DBP reactivity (mmHg)	12.2	6.06
PASAT heart rate reactivity (bpm)	15.5	12.98
Cold pressor SBP reactivity (mmHg)	9.2	10.40
Cold pressor DBP reactivity (mmHg)	7.9	9.10
Cold pressor heart rate reactivity (bpm)	4.1	7.79
Grit-S total	3.4	0.55
Cold pressor time spent in water (seconds)	155.5	92.24
PASAT score (out of 1,000)	713.8	114.73
Number of sheets of attempts at the impossible puzzle	24.8	19.25
Time taken on the impossible puzzle (seconds)	1,054.0	613.58

Abbreviations: DBP, diastolic blood pressure; Grit-S, Short Grit Scale; PASAT, Paced Auditory Serial Addition Test; SBP, systolic blood pressure.

cold pressor task showed higher cold pressor reactivity: SBP, $r(62) = .62$, $p < .001$; DBP, $r(62) = .66$, $p < .001$; and HR, $r(62) = .59$, $p < .001$.

3.3 | Self-reported perseverance and behavioral perseverance

Table 2 shows the mean (*SD*) total score for the Grit-S (self-reported perseverance), the behavioral perseverance data, and the reactivity for both stress tasks. Pearson correlations revealed that self-reported perseverance did not relate to behavioral perseverance measures: number of attempts at the impossible puzzle, time taken on the impossible puzzle, or time spent in the cold pressor task. Self-reported perseverance was also not associated with PASAT or cold pressor evaluation ratings. Among the behavioral perseverance measures, time taken on the impossible puzzle related significantly to cold pressor time, $r(60) = .32$, $p = .01$, such that those who spent longer on the impossible puzzle also persevered for longer during the cold pressor task.

3.4 | Perseverance and cardiovascular reactivity to acute stress

Correlation analyses revealed that the relationships between PASAT cardiovascular reactivity and self-reported perseverance (Grit-S score) were nonsignificant. However, some significant associations emerged between PASAT cardiovascular reactivity and behavioral perseverance measures. As shown in Table 3, PASAT SBP and DBP reactivity was significantly positively related to the number of attempts at the impossible puzzle, such that participants with lower PASAT BP reactivity used fewer sheets attempting to complete the impossible puzzle. Similarly, time taken on the impossible puzzle was positively related to PASAT DBP reactivity; participants with lower DBP reactivity to the PASAT spent less time attempting to solve the impossible puzzle (i.e., gave up sooner). Figure 2 presents scatter plots of these associations. Finally, PASAT DBP and HR reactivity were positively associated with the time participants remained in the cold pressor task; again, blunted reactors showed poorer perseverance. As sociodemographic or self-report variables were not associated with PASAT reactivity, analyses predicting perseverance from PASAT reactivity were not repeated in regression models.

3.5 | Sensitivity analyses: Cold pressor duration

Although not the main hypotheses of interest, cold pressor SBP, DBP, and HR reactivity were significantly related to number of attempts at to time taken on the impossible puzzle. However, cold pressor reactivity was confounded (positively associated with cold pressor time) as earlier described. One-way ANOVA also revealed that cold pressor activity differed by sex; male participants produced larger SBP reactions to the cold pressor task, $F(1, 62) = 6.67$, $p = .01$, compared to female. Regression analyses were conducted to repeat the significant correlations adjusting for confounders (sex for cold pressor SBP reactivity, cold pressor time for all cold pressor reactivity data) in the model. Overall, cold pressor DBP reactivity, $\beta = .41$, $p = .01$, $\Delta R^2 = .098$, still predicted

TABLE 3 Correlations between cardiovascular reactivity to the PASAT and behavioral perseverance measures

	Attempts at the impossible puzzle	Time taken on the impossible puzzle	Cold pressor time
PASAT SBP reactivity	.28*	.16	.14
PASAT DBP reactivity	.35*	.25*	.28*
PASAT heart rate reactivity	.12	.19	.50*

Abbreviations: DBP, diastolic blood pressure; PASAT, Paced Auditory Serial Addition Test; SBP, systolic blood pressure.
*$p < .05$.

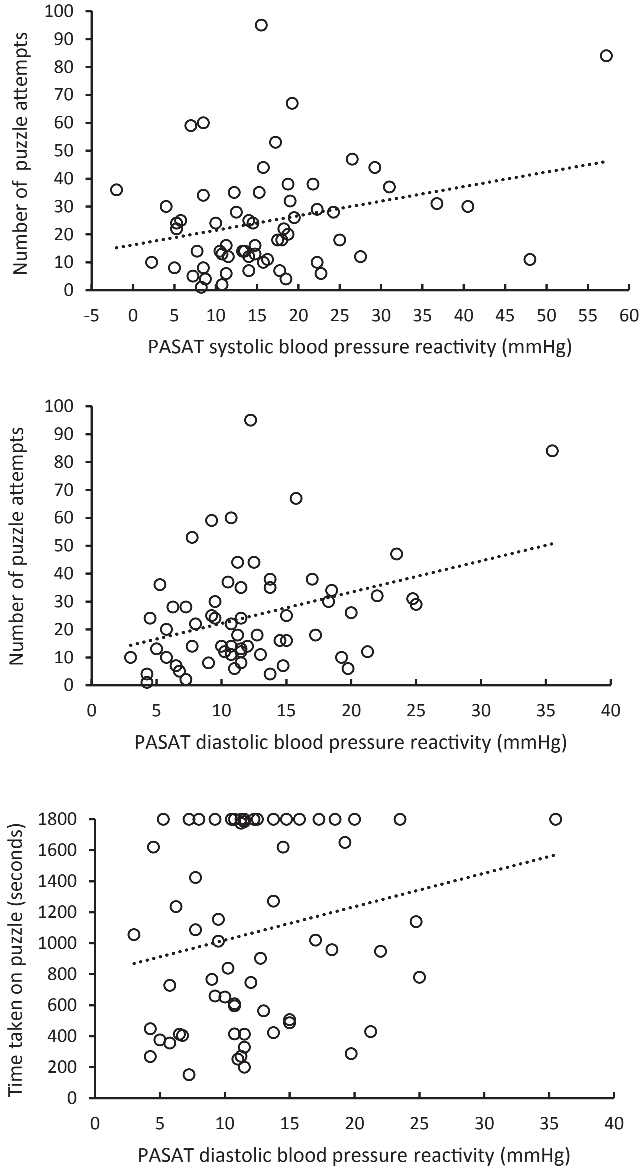

FIGURE 2 Scatter plots depicting the significant relationships between cardiovascular reactivity variables and behavioral measures of perseverance

number of impossible puzzle attempts, but cold pressor SBP and HR reactivity were no longer significant. For time taken on the impossible puzzle, associations were no longer significant for SBP, DBP, or HR cold pressor reactivity.

4 | DISCUSSION

The present study examined the relationship between cardiovascular reactivity to acute stress and self-reported and behavioral perseverance. It also explored whether self-report and behavioral perseverance measurements correlate. Cardiovascular reactivity was not related to self-reported perseverance. However, low PASAT SBP and DBP reactivity significantly predicted dysfunctional behavioral perseverance (conceptualized as recording fewer attempts endeavoring to solve an impossible puzzle). Similarly, low PASAT DBP reactivity predicted participants giving up more quickly while trying to complete an impossible puzzle. Finally, individuals with blunted DBP and HR responses to the PASAT spent less time persevering at the cold pressor task (i.e., withdrew their hand sooner). Overall, this preliminary study provides evidence to show that blunted cardiovascular reactivity can predict low behavioral perseverance, with DBP reactivity emerging as the most consistent predictor. However, given the modest sample size and that this relationship was not consistently demonstrated for all cardiovascular measures, further replication is warranted. Finally, self-reported and behavioral perseverance measures did not correlate.

Overall, the results from the current study support our original hypothesis that blunted reactivity would be associated with low behavioral perseverance. However, these findings differ from that of a previous study, which found no significant association between reactivity to the PASAT and behavioral perseverance (Bibbey, 2015). This can perhaps be attributed to disparities in study design; Bibbey initially screened participants and selected extreme groups on the basis of HR reactivity to complete the impossible puzzle task. However, in the present cross-sectional study, participants attended only one testing session, during which the association between blunted PASAT reactivity and low puzzle perseverance manifested only for blood pressure reactivity. Thus, it is a parsimonious explanation that, if Bibbey had selected extreme groups on the basis of blood pressure rather than HR reactivity or used a similar design to the present study, comparable findings may have emerged. Additionally, Bibbey (2015) administered many behavioral tasks in his study, including impulsivity tests, and participants completed the behavioral perseverance task last. Thus, it is conceivable that the lack of significance for perseverance may have been an effect of participant fatigue, rather than true nonsignificance.

The findings of the present study are in agreement with the remainder of the existing literature that suggest blunted physiological reactivity to acute stress is associated with low perseverance, both in terms of study noncompletion (Ginty et al., 2015) and quicker relapse times during alcohol (Junghanns et al., 2003; Lovallo, 2006) and smoking (Al'Absi, 2006) cessation. In our study, although both blunted BP and HR reactivity were observed, low DBP reactivity emerged as the most robust predictor of low perseverance. This is perhaps surprising, as most negative behavioral correlates associated with blunted reactivity appear to be more strongly and reliably predicted by lower HR, not BP reactivity (e.g., Bennett et al., 2014; Ginty et al., 2012). However, other research corroborates our findings; for example, Carroll, Phillips, Hunt, and Der (2007) found a negative relationship between both SBP and HR reactivity and depression, and Phillips, Der, and

Carroll (2009) showed a negative association for self-rated health and BP but not HR reactivity.

The studies that implicate blunted physiological reactivity in faster cessation relapse times have focused entirely on the hypothalamic-pituitary-adrenal (HPA) axis (i.e., participants exhibit blunted cortisol responses). This therefore differs from the present study, which examined the cardiovascular system. However, cardiovascular and cortisol stress responses are often strongly correlated (Cacioppo, 1994). Thus, if these cessation studies also examined the sympathetic-adrenal-medullary axis, it is highly conceivable that blunted cardiovascular activity would have been observed. This is corroborated by studies showing associations between smoking behavior itself and blunted BP and HR reactivity (e.g., Phillips, Der, Hunt, & Carroll, 2009). Regardless of these differences, the results from the present study help to generate a stronger overall argument that attenuated stress response patterns are predictive of dysfunctional perseverance. This is because a multitude of blunted physiological reactions to acute stress (e.g., HR, BP, cardiac output, and cortisol) have now been related to poor behavioral perseverance.

In addition, the present study extends the current literature by demonstrating the reactivity-perseverance relationship in response to multiple stress tasks, including a passive psychological stressor (i.e., the cold pressor task). However, these cold pressor effects were less evident after adjustment for potential confounding variables, perhaps providing further evidence that blunted reactivity among certain individuals is more likely to be apparent in response to active stress, as observed previously (Brindle et al., 2017). In addition, much of the previous reactivity-perseverance research has centered around cessation and the ability to persevere by refraining from unhealthy addictive behavior choices. However, this present study has furthered the literature by demonstrating the same positive relationship when examining whether individuals would actively persevere with a somewhat unpleasant task. In terms of real-world generalizability, this could perhaps be likened to persevering with a new dietary plan.

In relation to the secondary hypothesis, self-reported perseverance did not relate to any behavioral perseverance measure. This aligns with a previous perseverance-based study, which also reported significant associations (with negative affect) only for behavioral and not self-reported perseverance (Steinberg & Williams, 2013). Our findings suggest that low behavioral perseverers do not consider themselves to have dysfunctional perseverance, as revealed by their self-reported perseverance scores. This may reflect social desirability bias for the Grit-S scale (Bazelais, Lemay, & Doleck, 2016; Duckworth, Peterson, Matthews, & Kelly, 2007), the neglect of measuring important mediators between self-report and behavioral measures, or that behavioral perseverance assessments examine *state* whereas self-report questionnaires assess *trait* perseverance (Steinberg & Williams, 2013). On the other hand, this lack of association may be consistent with the more interesting finding that blunted responders are not consciously aware of deficiency in their motivation (Brindle et al., 2017) and 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). This would suggest that self-report measures of perseverance are not useful in determining perseverance/relapse in real-world situations, for example, during addiction cessation or dietary programs. In sum, blunted reactors are not only more likely to have addictions or disordered eating but when undergoing cessation programs think they are trying as hard to persevere and not relapse as nonblunted responders. However, it would seem that these individuals would be, in fact, less likely to persevere and more prone to relapse.

Although there are many strengths, the present study is not without limitations. First, the sample was modest in size and the study was cross-sectional. Thus, the results are preliminary, despite the fact that we adjusted for many potential confounding variables. It is also possible that other confounders/mediators were missed, but we were keen to reduce participant burden. Second, it is plausible that being previously stressed might have influenced perseverance on the Euler puzzles. The design was not counterbalanced in the present study to protect from the Zeigarnik effect (i.e., intrusive thoughts caused by failure to complete a task; Zeigarnik, 1935). However, there was no relationship between self-reported stress ratings during the two stress tasks and time and number of attempts attempting to complete the impossible puzzle. This suggests that prior stress exposure did not influence behavioral perseverance. Finally, the behavior or mere presence of the investigator recording the time and attempts on the Euler puzzle task may have impacted the participants in such a way that it led to an atypical perseverance measurement. However, this added pressure could be comparable to external pressures in real-life settings. Moreover, the experimenter read a set of standardized Euler instructions and observed out of the participants' range of vision.

Due to the small sample and inconsistencies across perseverance and cardiovascular measures, it is important for future research to attempt to replicate our findings. Such studies may also choose to extend our work by including additional physiological measures (e.g., cortisol) and using different behavioral perseverance tasks, such as mirror tracing (Quinn et al., 1996) and breath holding (Hajek, Belcher, & Stapleton, 1987). If the present findings are confirmed, it may then be interesting to explore the impact of real-world factors, such as the deemed importance of the task/situation and/or consequences of persevering/giving up on the reactivity-perseverance relationship.

In conclusion, the present preliminary study examined the relationship between cardiovascular reactivity to acute active psychological stress and self-reported and behavioral perseverance. Dysfunctional behavioral perseverance, conceptualized as recording less time and attempts endeavoring to solve an impossible puzzle, was predicted by blunted cardiovascular reactivity. However, it is important to note that there were inconsistencies across cardiovascular and behavioral perseverance measures. Blunted reactivity appears to be a physiological marker of motivational dysregulation and poor behavioral regulation, and this may explain why those with blunted cardiovascular reactivity are more likely to develop deleterious health outcomes (e.g., obesity and addictions). In addition, measuring blunted reactivity has the potential to be a means of identifying nonadherers or those more likely to need additional support when trying to increase positive and decrease negative health behaviors.

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CONFLICTS OF INTEREST

The authors have no conflicts of interest.

ORCID

Aiden J. Chauntry https://orcid.org/0000-0001-6927-4737
Anna C. Whittaker https://orcid.org/0000-0002-5461-0598

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