International Journal of Psychophysiology 88 (2013) 200–205

Contents lists available at SciVerse ScienceDirect

International Journal of Psychophysiology

journal homepage: www.elsevier.com/locate/ijpsycho

Gritty people try harder: Grit and effort-related cardiac autonomic activity during an active coping challenge☆

Paul J. Silvia *, Kari M. Eddington, Roger E. Beaty, Emily C. Nusbaum, Thomas R. Kwapil

Department of Psychology, University of North Carolina at Greensboro, United States

ARTICLE INFO

Article history:
Received 19 December 2012
Received in revised form 9 April 2013
Accepted 11 April 2013
Available online 18 April 2013

Keywords:
Grit
Effort
Active coping
Motivational intensity
Impedance cardiography
Pre-ejection period
Respiratory sinus arrhythmia

ABSTRACT

Grit, a recently proposed personality trait associated with persistence for long-range goals, predicts achievement in a wide range of important life outcomes. Using motivational intensity theory, the present research examined the physiological underpinnings of grit during an active coping task. Forty young adults completed the Short Grit Scale and worked on a self-paced mental effort task. Effort-related autonomic nervous system (ANS) activity was assessed using impedance cardiography, which yielded measures of sympathetic activity (pre-ejection period; PEP) and parasympathetic activity (respiratory sinus arrhythmia; RSA). Multilevel models revealed that people high on the Perseverance of Effort subscale showed autonomic coactivation: both PEP and RSA became stronger during the task, reflecting higher activity of both ANS divisions. The Consistency of Interest subscale, in contrast, predicted only weaker sympathetic activity (slower PEP). Taken together, the findings illuminate autonomic processes associated with how "gritty" people pursue goals, and they suggest that more attention should be paid to the facets' distinct effects.

1. Introduction

Why do some people try so much harder than others? The role of individual differences in effort is a classic problem in motivation science (Atkinson, 1964). Recently, researchers have proposed a trait known simply as *grit*, which represents "perseverance and passion for long-term goals" (Duckworth et al., 2007, p. 1087). The growing literature on grit shows that it predicts an impressive set of real-world markers of motivation and perseverance. Gritty adults have higher educational attainment and higher college GPAs (Duckworth et al., 2007), gritty children perform better in the National Spelling Bee (Duckworth et al., 2007), gritty military cadets are more likely to graduate from an elite military academy (Duckworth et al., 2007; Maddi et al., 2012), and gritty teachers foster better academic performance in their students (Duckworth et al., 2009). Grit predicts success in part by promoting self-control, thus allowing people to persist in repetitive, tedious, or frustrating behaviors that are necessary for success (Duckworth et al., 2011).

To date, no psychophysiological studies have examined how individual differences in grit manifest themselves in biological mechanisms of effort and motivation. Given the role of grit in fostering real-world success, it is important to understand the biological processes that allow gritty people to achieve long-range goals. Motivational intensity theory (Brehm and Self, 1989), a general model of how people regulate effort (Gendolla et al., 2012; Wright, 1996; Wright and Kirby, 2001), offers a natural platform for developing predictions about how grit influences effort-related physiology. Motivational intensity theory proposes that effort is a function of two factors: the importance of success and the perceived difficulty of attaining the goal. The importance of success defines how much effort people are willing to expend; the difficulty of attaining it defines actual effort.

How might grit affect effort? According to motivational intensity theory, a trait can affect effort by making goals more or less important or by making achieving the goal seem more or less difficult. We expect, given theorizing about grit, that grit influences effort primarily via the importance pathway. Many traits have been shown to affect effort by affecting the importance of success (e.g., Capa and Audiffren, 2009; Capa et al., 2008; Silvia et al., 2011b). When a goal is more valuable, meaningful, or relevant to the self-concept, people are willing to expend more effort when necessary (Gendolla and Richter, 2010). Research on grit indicates that people high in grit are more passionate about their goals and more dedicated to accomplishing them (Duckworth et al., 2007), so it seems reasonable that the importance of success—and hence the level of potential effort—should be higher for gritty people.

Fortunately, motivational intensity theory offers a robust set of paradigms for illuminating the factors underlying effort, so it is easy to evaluate whether grit affects effort by making goals more important. One way to determine if higher success importance is involved is to analyze effort for unfixed-difficulty tasks (Wright et al., 2002). Also known as self-paced, piece-rate, and do-your-best tasks, unfixed tasks allow

---

☆ We thank Christina Chai Chang, Lance Moore, Joseph Nardello, and Rachel Sopko for their assistance with this research.

* Corresponding author at: Department of Psychology, P. O. Box 26170, University of North Carolina at Greensboro, Greensboro, NC, 27402-6170, United States. Tel.: +1 3362560007.

E-mail address: p_silvia@uncg.edu (P.J. Silvia).

0167-8760/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.ijpsycho.2013.04.007

people to work at their own pace and hence achieve as much or as little as they wish. For unfixed tasks, motivational intensity theory predicts that effort is solely a function of importance (Wright, 2008), a pattern that many experiments have found (e.g., Gendolla et al., 2008; Silvia, 2012; Silvia et al., 2011a).

In the present research, we examined how grit affected cardiac autonomic activity during an active coping challenge. Grit has two facets—Perseverance of Effort and Consistency of Interest, hereafter Perseverance and Consistency—and we were interested in whether these facets differentially affected the physiological mobilization of effort. Perseverance reflects commitment and effort toward one's goals; it is measured with items such as "I finish whatever I begin." Consistency reflects focus and dedication to a small set of important goals; it is measured with items such as "New ideas and projects sometimes distract me from previous ones" (reversed).

Despite the important conceptual differences between these facets, most published work on grit has used the total score and has not reported subscale-specific effects. The subscales correlate highly ($r = .59$; Duckworth and Quinn, 2009) but not so highly to preclude distinct effects. For example, Perseverance more strongly predicted middle- and high-school students' GPAs and extracurricular activities, and Consistency more strongly predicted making fewer career changes during adulthood (Duckworth and Quinn, 2009). Regarding effort on a novel task, one could foresee potential differences. Perseverance should predict higher effort due to a tendency to take goals seriously and to try hard, whereas Consistency may not—novel goals that fall outside the small sphere of central goals might be seen as unimportant.

Effort was quantified in terms of cardiac autonomic activity. Our primary outcome was the cardiac pre-ejection period (PEP; the systolic interval between ventricular depolarization and the opening of the aortic valve), which is commonly used to measure beta-adrenergic sympathetic impact on the heart (Kelsey, 2012; Richter and Gendolla, 2009). Research on motivational intensity theory typically measures how the sympathetic division of the autonomic nervous system (ANS) influences cardiovascular activity (Wright & Gendolla, 2012). Sympathetic activity is a reliable indicator of motivational engagement in contexts requiring "active coping" (Obrist, 1976, 1981), such as when people must expend effort to attain an attractive goal or reward. Most past research has used systolic blood pressure (SBP) to quantify sympathetic impact during effortful engagement (Gendolla et al., 2012; Wright, 1996). In recent research and the present study, impedance cardiography is used to assess sympathetic influences on the heart more directly (Kelsey, 2012).

Sympathetic cardiac processes are more central to effort and motivational intensity theory, so PEP is our primary measure of interest. We also measured, as a secondary and exploratory outcome, parasympathetic influences on the heart. Respiratory sinus arrhythmia (RSA; high-frequency variability in heart rate as a function of respiration) was used to measure parasympathetic activity. A large literature supports PEP and RSA as markers of the activity of the sympathetic and parasympathetic ANS divisions (e.g., Berntson et al., 1993, 1994, 2008; Cacioppo et al., 1994; Schächinger et al., 2001).

For our purposes, RSA was a secondary but interesting dependent variable: it isn't a standard measure of effort during appetitive tasks, but it can illuminate emotional control and "cooling" in response to stress (Segerstrom et al., 2012). Measuring both sympathetic and parasympathetic influences is worthwhile because the divisions of the ANS can operate independently, jointly, or reciprocally (Berntson et al., 1991; Koizumi and Kollai, 1992; Paton et al., 2005). Moreover, some recent applications of motivational intensity theory have suggested measuring RSA, if only to provide additional information about autonomic processes during goal engagement (Richter, 2010). One example comes from recent work on how appraisals of goal relevance and goal conduciveness influence the relative activation of the sympathetic and parasympathetic branches (Kreibig et al., 2012). When an event was appraised as both relevant and conducive to a goal, people showed higher sympathetic and parasympathetic activation, which suggests a profile of heightened motivational engagement in response to an opportunity for reward and achievement (cf. Kreibig et al., 2010). Thus, one can see bridges between how goal-related appraisals affect autonomic activity (Kreibig et al., 2012) and motivational intensity theory's historical interest in active coping processes (Wright, 1996). If both sympathetic and parasympathetic autonomic divisions reflect the cognitive appraisals involved in how people evaluate goals, then it is worth measuring both when evaluating how people engage with goals.

2. Method

2.1. Participants and design

A total of 40 adults—24 men and 16 women—participated in the experiment. Participants were students in psychology courses who volunteered and received credit toward a research option or adults who responded to flyers advertising the study and received $10. Four participants were excluded, leaving a final sample of 36 people (21 men, 15 women). The sample was young ($M = 19.83$, $SD = 2.52$) and mostly European American (58%) or African American (36%). All participants provided informed consent. The experiment was approved and monitored by UNCG's Institutional Review Board.[1]

2.2. Materials and procedure

Each participant was tested individually. The sessions were conducted by a gender-matched experimenter, who explained that the study was about how mental effort was reflected in the body, particularly in the activity of the cardiovascular system. The participants completed a series of personality questionnaires and then a computer-based cognitive task requiring mental effort. The questionnaires and tasks were completed using MediaLab and DirectRT (Empirisoft, NY). After the experimenter prepped the skin with alcohol wipes and placed the electrodes, the participants sat quietly and completed demographic and personality questionnaires on the computer for approximately 10 min. During the middle of this period, 5 min of baseline readings was taken.

2.2.1. Grit scale

Grit was assessed using the Short Grit Scale (Grit-S; Duckworth and Quinn, 2009). This scale has eight items—four for Perseverance, four for Consistency—rated on five-point scales (1 = *not like me at all*, 5 = *very much like me*). Based on Cronbach's alpha, internal consistency was $\alpha = .52$ for Perseverance, $\alpha = .69$ for Consistency, and $\alpha = .74$ for the full scale. The Perseverance and Consistency subscales correlated $r = .54$ ($p < .001$), which is similar to past work ($r = .59$; Duckworth and Quinn, 2009). The scores were relatively normal: neither skewness nor kurtosis values were significant for the total scale or the subscales.

2.2.2. Parity task

After the baseline period, participants were introduced to the mental effort task. The parity task, developed by Wolford and Morrison (1980), involves presenting a word flanked by two numbers, such as "3 BENCH 8." Participants must ignore the word and decide if the two numbers have the same parity (both even or both odd) or a different parity (one even, one odd). The parity task is challenging because the

---

[1] People were excluded for the following reasons: one person disclosed a serious heart condition after the session; one case had poor signal quality; one male was inadvertently scheduled and run by a female experimenter; and one person was screened out due to high scores (greater than 2) on a 7-item revised version of Chapman and Chapman's (1983) "infrequency scale," a set of true/false items that capture inattentive and rapid responding (e.g., answering "false" to items like "There have been a number of occasions when I have sat in a chair" and "true" to items like "I cannot remember a single occasion when I have spoken English out loud.").

centrally presented word is hard to ignore and because digit parity judgments are unfamiliar (Aquino and Arnell, 2007; Harris and Pashler, 2004), and it has been used successfully in past research on behavioral effort (Silvia and Phillips, 2013).

The numbers 2, 3, 5, and 8 were used to flank 16 neutral nouns (e.g., BOAT, CHAIR, and MARKET). Each trial began with an intertrial interval (750 ms) and a fixation cross (350 ms) followed by a parity item. The black text was displayed in 28 pt Tahoma on a white background. The parity item remained on screen until people gave a response. They pressed a green key for "same parity" and a red key for "different parity," using a DirectIN high-speed keyboard (Empirisoft, NY), which has a timing accuracy of under 1 ms.

The parity task was "unfixed" in difficulty because people could work at their own pace (Wright et al., 2002). The trial didn't terminate until people responded, so responding more quickly allowed people to potentially get more correct. The task terminated after five minutes. Unfixed do-your-best tasks can become "quasi-fixed" if people are asked about their impressions of the task's difficulty beforehand or if a fixed standard for performance is implied (Richter, 2010). To avoid this, we did not ask for ratings of the task's difficulty or of people's impressions of the task, and the task instructions focused on people doing their best and getting as many correct as they could.

2.3. Measurement of cardiac autonomic activity

Cardiac activity was measured using a Bionex hardware system (Mindware, Gahanna, OH). An electrocardiogram (ECG) was assessed using a modified Lead-II configuration, in which electrodes were placed on the right clavicle and the left and right lowest ribs. An impedance cardiogram (ICG) was assessed using disposable spot electrodes placed in a standard tetrapolar configuration: two receiving electrodes were placed on the front of the body (an upper one 4 cm above the suprasternal notch, and a lower one at the base of the sternum on the xiphoid process), and two were placed on the back (one 4 cm above the horizontal plane of the first and one 4 cm below the horizontal plane of the xiphoid, roughly at the 3rd and 9th vertebrae). The signals were sampled at 1000 Hz and processed offline using bandpass filters (ECG and dZ/dt, .5 to 45 Hz; Z_0, 10 to 45 Hz).

The five-minute baseline period and five-minute task period were divided into 60-second epochs, and PEP and RSA values were obtained for each epoch. For PEP, the ECG and ICG dZ/dt waveforms were ensemble-averaged (Kelsey et al., 1998) for each 60-second epoch, and PEP was computed as the difference between the ECG Q-point (denoting the onset of ventricular depolarization; Berntson et al., 2004) and the dZ/dt B-point (denoting the opening of the aortic valve and hence left ventricular ejection onset; Lozano et al., 2007). These points were automatically identified by the software (Mindware, Gahanna, OH). When corrected manually in a small number of cases, B-points were identified as the notch or inflection prior the dz/dt wave's final upstroke (see Sherwood et al., 1990). For RSA, spectral methods were used to compute high-frequency heart rate variability in the respiratory frequency range (0.12–0.40 Hz) for each 60-second epoch. Respiration rate was estimated from the ICG Z_0 thoracic impedance signal (see Ernst et al., 1999). Variation in Z_0 due to respiration can be identified using spectral analysis (see Ernst et al., 1999, for details). Only respiration rate (in cycles per minute), not peak volume or inspiration/exhalation intervals, was analyzed. Several studies have shown that thoracic impedance measures of respiratory rates are very close to spirometric measures (de Geus et al., 1995; Ernst et al., 1999; Houtveen et al., 2006).

3. Results

3.1. Analytic model and specification

We used multilevel models to accommodate the repeated-measures data structure (Kristjansson et al., 2007; Llabre et al., 2004). The analyses were conducted with Mplus 7 using maximum likelihood with robust standard errors. Task period—baseline (scored 0) vs. task (scored 1)—was a within-person predictor. Grit scores—the Perseverance and Consistency subscales—were between-person predictors. In each model, we estimated the intercepts and slopes as random effects. The random intercepts and slopes were allowed to covary to reflect possible initial value effects. Because RSA varies with respiration rate (Berntson et al., 1993; Grossman and Taylor, 2007), the multilevel model for RSA included respiration rate as a time-varying (within-level) predictor. All within-person predictors were centered at each person's own mean; all between-person predictors were centered at the sample's grand mean (Enders and Tofighi, 2007). Table 1 displays the descriptive statistics.[2]

Table 1
Descriptive statistics.

	M	SE
Grit: Perseverance of effort	3.78	.09
Grit: Consistency of interests	2.71	.14
Number of correct responses	136.05	1.92
Response time	964.32	32.11
PEP (baseline)	125.06	1.87
PEP (task)	124.84	2.18
RSA (baseline)	6.06	.21
RSA (task)	6.06	.18
Respiration rate (baseline)	18.09	.48
Respiration rate (task)	18.85	.48
IBI (baseline)	760.20	18.17
IBI (task)	773.26	17.03

Note. $n = 36$. PEP = pre-ejection period (in ms); RSA = respiratory sinus arrhythmia (in ms^2); IBI = interbeat interval (in ms); respiration rate is in cycles per minute.

3.2. PEP

Did grittier people show higher sympathetic activity during the parity task? Our first multilevel model estimated the effects of task period and grit scores on PEP. The within-person main effect of task period was significant, $b = -1.26$, $SE = .59$, $p = .032$. As expected, PEP became faster from baseline to task, reflecting higher contractility due to greater sympathetic activity. The between-person main effects were not significant: neither Perseverance ($b = 2.29$, $SE = 4.94$, $p = .643$) nor Consistency ($b = -.47$, $SE = 2.78$, $p = .865$) significantly predicted PEP overall.

The interactions between task period and both subscales, however, were significant, albeit in different directions. The Perseverance subscale had a significant negative effect, $b = -2.46$, $SE = .72$, $p = .001$: as Perseverance increased, PEP declined more from baseline to task, reflecting greater effort. The Consistency subscale, in contrast, had a significant positive effect, $b = 1.73$, $SE = .51$, $p = .001$: as Consistency increased, PEP declined less from baseline to task. Stated differently, people high in Perseverance showed higher sympathetic activity during the task (faster PEP values), whereas people high in Consistency showed weaker sympathetic activity (slower PEP values).

3.3. RSA and respiration rate

Did grittier people show higher parasympathetic activity during the parity task? The within-person main effect of task period was

---

[2] The Grit subscales correlated with some of the baseline scores. No significant correlations were found for PEP and for respiration rate. The Persistence subscale was negatively correlated with RSA baseline values ($r = -.33$, $p = .011$) and positively correlated with IBI baseline values ($r = .32$, $p = .015$). The Consistency subscale correlated negatively with IBI baseline values ($r = -.32$, $p = .015$). Multilevel models estimate individual intercepts and slopes simultaneously and can control for initial value effects by modeling residual covariances between them. As a result, unlike with simple difference scores, changes in physiological outcomes from baseline to task are not confounded with initial values or baseline differences.

not significant—overall, RSA values did not change from baseline to task, $b = .09$, $SE = .09$, $p = .284$. Moreover, there were no between-person main effects of the Grit subscales on RSA (Perseverance: $-.31$, $SE = .39$, $p = .418$; Consistency: $b = -.03$, $SE = .26$, $p = .912$). There was, however, a marginally significant interaction for Perseverance, $b = .32$, $SE = .17$, $p = .056$. As Perseverance increased, RSA went up from baseline to task, reflecting higher parasympathetic activity. The interaction for Consistency was not significant, $b = -.06$, $SE = .13$, $p = .654$.

For respiration rate, the within-person main effect of task period was significant: respiration rates were higher in the task period than the baseline period ($b = .72$, $SE = .36$, $p = .044$). There were no between-person main effects of the Grit subscales on respiration rate (Perseverance: $b = 1.30$, $SE = 1.25$, $p = .299$; Consistency: $b = -.85$, $SE = .76$, $p = .264$), and there were no interactions (Perseverance: $b = 1.03$, $SE = .73$, $p = .162$; Consistency: $b = -.42$, $SE = .53$, $p = .430$).

3.4. Task performance

The goal for the task was to get as many correct as possible within the 5-minute task period. The task yielded two scores: the total number of correct responses achieved and response time for correct responses, which were correlated, $r = -.81$, $p < .001$. To explore performance effects, we ran a multivariate regression model with Perseverance and Consistency as predictors and the number of correct responses and response time as outcomes. Perseverance had a weak effect on the number of correct responses ($\beta = .26$, $p = .149$) and a marginally significant effect on response time ($\beta = -.35$, $p = .080$). Consistency was essentially unrelated to the number of correct responses ($\beta = .05$, $p = .805$) and to response time ($\beta = .11$, $p = .629$). Overall, then, grit scores had larger effects on the mobilization of effort during the task than on actual achievement, which is common given the imperfect relationships between effort and performance for most cognitive tasks.

Regarding task performance and cardiac autonomic activity, for the sample as a whole, as PEP declined the number of correct trials increased weakly ($r = -.22$, $p = .214$) and response time declined ($r = .23$, $p = .162$), but not significantly so. As RSA changed, neither the number of correct responses ($r = -.03$, $p = .869$) nor response time ($r = -.01$, $p = .942$) changed.

4. Discussion

4.1. Grit and effort

Given the role of grit in real-world goal achievement, the present experiment examined how people who vary in facets of grit responded to a mental effort challenge. The study found support for an influence of individual differences in grit on effort-related cardiac activity. Based on theorizing about grit, which emphasizes dedication to goals (Duckworth et al., 2007), we expected that grit would influence effort via the potential motivation pathway: if grit makes goals more valuable, then people high in grit would be willing to expend more effort to achieve a goal. People high in Perseverance showed faster PEP values and marginally higher RSA values during the active coping task. Because the degree of effort during an unfixed, do-your-best task reflects the importance of success (Wright et al., 2002), this pattern suggests that people high in Perseverance appraised the task as more important, as one would expect.

From an autonomic space perspective (Berntson et al., 1991), people high in Perseverance showed a pattern of autonomic coactivation: sympathetic and parasympathetic activity both increased during the task. These ANS branches are often coactivated, and their joint influence can confer functional benefits (Koizumi and Kollai, 1992; Paton et al., 2005). When both branches are active, for example, the sympathetic branch can increase myocardial contractility without simultaneously increasing heart rate, which is reduced by the parasympathetic branch. This allows for more efficient cardiac output by affording longer ventricular filling times paired with higher contractility (Koizumi et al., 1982).

People high in Consistency, in contrast, showed slower PEP values and no change in RSA. The PEP finding suggests that Consistency reduced the importance of succeeding at the parity task. Although not intuitive, this finding is consistent with the psychological basis of having consistent interests. The Consistency subscale measures focusing on and sticking with a small cluster of valuable goals. In past work, research examined how Consistency predicted the achievement of long-term goals that participants selected and found personally meaningful (Duckworth et al., 2007, 2009). In the present experiment, in contrast, people worked on a short-term goal with a standard that was assigned by the experimenter. Because the parity task is short-term and surely not in people's set of valued goals, it's possible that people high in Consistency found it less important. This interpretation is speculative and awaits further research, but it does suggest that there are cases in which grit, by fostering the selective prioritization of effort, can occasionally lead to lower effort. One way to test this possibility in future work would be to manipulate self-relevance, which should moderate the effect of Consistency on effort.

The effects were stronger for effort-related physiology than for behavioral task performance, a common finding in our research (e.g., Silvia, 2012; Silvia et al., 2010, 2011a, 2011b, 2013) and in motivational intensity research generally. Effort is one of several contributions to task performance. For cognitive tasks, cognitive abilities (e.g., fluid intelligence, mental speed) and task strategies contribute substantial variance as well. Indeed, in instances of "compensatory effort"—such as when people try to overcome the effects of fatigue or sleep deprivation—high effort will be associated with poorer performance (e.g., Hockey, 1997; Schmidt et al., 2010; Wright and Stewart, 2012). It is notable, however, that the effect sizes were in the expected directions: both higher Perseverance and faster PEP were associated with getting more correct responses, albeit not significantly so.

One limitation of the proposed work was the inability to control for possible preload and afterload effects. PEP values can be influenced both by sympathetically-mediated contractility and by changes in ventricular preload and afterload (Sherwood et al., 1990). It is difficult to evaluate the potential contributions of preload and afterload effects without assessments of blood pressure, which weren't available in the present analyses. An additional issue to be considered for future work is the manipulation of task difficulty. The present work clearly indicated that grit was associated with differences in potential motivation, one pathway in motivational intensity theory, but it might also influence perceptions of task difficulty, the other pathway. Because task difficulty wasn't varied in the present study, this issue is worth examining in future research. Finally, we recognize that the assessment of heart rate variability is complex and contentious, with a great many metrics and disagreement among researchers (e.g., Allen et al., 2007). Our study used the spectral approach while controlling for (at the within-person level) variation in respiration rate, which is consistent with best practices. One virtue of our assessment approach is that it follows past work on autonomic coactivation, which typically used measures of PEP and frequency-based RSA as indicators of sympathetic and parasympathetic activity (e.g., Berntson et al., 2008). Nevertheless, we recognize the complexities involved in assessing RSA (e.g., Grossman and Taylor, 2007), which await resolution from future research.

4.2. Implications for motivational intensity theory

Motivational intensity theory has historically been concerned with sympathetic activity. Most studies have assessed measures of sympathetic cardiovascular activity, particularly systolic blood pressure and PEP (see Gendolla et al., 2012; Wright, 1996). This is largely due to the influence of Obrist's (1981) active coping approach, which emphasized sympathetic adjustments to mental and behavioral challenges, on early motivational intensity research (e.g., Wright et al., 1986). Nevertheless, recent research has begun to consider parasympathetic parameters, such as time- and frequency-domain measures of heart-rate variability (Richter, 2010).

Expanding motivational intensity research to include both ANS branches has several virtues. First, there is a large literature on the role of parasympathetic activity in both the functional and dysfunctional regulation of emotion and action (e.g., Segerstrom and Nes, 2007; Rottenberg, 2007). Motivational intensity theory, as a general model of effort regulation, could offer insight into such processes. Second, and more generally, assessing both branches affords a look at their joint activation. Some contexts promote coactivation of the sympathetic and parasympathetic branches. Kreibig et al. (2012), for example, found that appraising an event as relevant and congruent with a goal caused coactivation, which they interpreted as an engagement profile. In the present research, people high in Perseverance showed coactivation, which implies a more efficient cardiovascular profile when coping with the challenge (Koizumi et al., 1982). But relatively little is known about how these branches interact during active coping or what the consequences might be for effort, performance, recovery, and health. Understanding coactivation may thus further illuminate how the body mobilizes effort in the service of confronting challenges and achieving goals.

References

Allen, J.J.B., Chambers, A.S., Towers, D.N., 2007. The many metrics of cardiac chronotropy: a pragmatic primer and a brief comparison of metrics. Biological Psychology 74, 243–262.

Aquino, J.M., Arnell, K.M., 2007. Attention and the processing of emotional words: dissociating effects of arousal. Psychonomic Bulletin and Review 14, 430–435.

Atkinson, J.W., 1964. An Introduction to Motivation. Van Nostrand, New York.

Berntson, G.G., Cacioppo, J.T., Quigley, K.S., 1991. Autonomic determinism: the modes of autonomic control, the doctrine of autonomic space, and the laws of autonomic constraint. Psychological Review 98, 459–487.

Berntson, G.G., Cacioppo, J.T., Quigley, K.S., 1993. Respiratory sinus arrhythmia: autonomic origins, physiological mechanisms, and psychophysiological implications. Psychophysiology 30, 183–196.

Berntson, G.G., Cacioppo, J.T., Binkley, P.F., Uchino, B.N., Quigley, K.S., Fieldstone, A., 1994. Autonomic cardiac control: III. Psychological stress and cardiac response in autonomic space as revealed by pharmacological blockades. Psychophysiology 31, 599–608.

Berntson, G.G., Lozano, D.L., Chen, Y., Cacioppo, J.T., 2004. Where to Q in PEP. Psychophysiology 41, 333–337.

Berntson, G.G., Norman, G.J., Hawkley, L.C., Cacioppo, J.T., 2008. Cardiac autonomic balance versus cardiac regulatory capacity. Psychophysiology 45, 643–652.

Brehm, J.W., Self, E., 1989. The intensity of motivation. Annual Review of Psychology 40, 109–131.

Cacioppo, J.T., Berntson, G.G., Binkley, P.F., Quigley, K.S., Uchino, B.N., Fieldstone, A., 1994. Autonomic cardiac control. II. Noninvasive indices and basal response as revealed by autonomic blockades. Psychophysiology 31, 586–598.

Capa, R.L., Audiffren, M., 2009. How does achievement motivation influence mental effort mobilization? Physiological evidence of deteriorative effects of negative affects on the level of engagement. International Journal of Psychophysiology 74, 236–242.

Capa, R.L., Audiffren, M., Ragot, S., 2008. The interactive effect of achievement motivation and task difficulty on mental effort. International Journal of Psychophysiology 70, 144–150.

Chapman, L.J., Chapman, J.P., 1983. *Infrequency Scale*. Unpublished test (copies available from T.R. Kwapil, Department of Psychology, University of North Carolina at Greensboro, Greensboro, NC, 27402–6170).

de Geus, E.J.C., Willemsen, G.H.M., Klaver, C.H.A.M., van Doornen, L.J.P., 1995. Ambulatory assessment of respiratory sinus arrhythmia and respiration rate. Biological Psychology 41, 205–227.

Duckworth, A.L., Quinn, P.D., 2009. Development and validation of the Short Grit Scale (Grit-S). Journal of Personality Assessment 91, 166–174.

Duckworth, A.L., Peterson, C., Matthews, M.D., Kelly, D.R., 2007. Grit: perseverance and passion for long-term goals. Journal of Personality and Social Psychology 92, 1087–1101.

Duckworth, A.L., Quinn, P.D., Seligman, M.E.P., 2009. Positive predictors of teacher effectiveness. The Journal of Positive Psychology 4, 540–547.

Duckworth, A.L., Kirby, T.A., Tsukayama, E., Berstein, H., Ericsson, K., 2011. Deliberate practice spells success: why grittier competitors triumph at the National Spelling Bee. Social Psychological and Personality Science 2, 174–181.

Enders, C.K., Tofighi, D., 2007. Centering predictor variables in cross-sectional multilevel models: a new look at an old issue. Psychological Methods 12, 121–138.

Ernst, J.M., Litvack, D.A., Lozano, D.L., Cacioppo, J.T., Berntson, G.G., 1999. Impedance pneumography: noise as signal in impedance cardiography. Psychophysiology 36, 333–338.

Gendolla, G.H.E., Richter, M., 2010. Effort mobilization when the self is involved: some lessons from the cardiovascular system. Review of General Psychology 14, 212–226.

Gendolla, G.H.E., Richter, M., Silvia, P.J., 2008. Self-focus and task difficulty effects on cardiovascular reactivity. Psychophysiology 45, 653–662.

Gendolla, G.H.E., Wright, R.A., Richter, M., 2012. Effort intensity: some insights from the cardiovascular system. In: Ryan, R.M. (Ed.), The Oxford Handbook of Human Motivation. Oxford University Press, New York, pp. 420–438.

Grossman, P., Taylor, E.W., 2007. Toward understanding respiratory sinus arrhythmia: relations to cardiac vagal tone, evolution, and biobehavioral functions. Biological Psychology 74, 263–285.

Harris, C.R., Pashler, H., 2004. Attention and the processing of emotional words and names: not so special after all. Psychological Science 15, 171–178.

Hockey, G.R.J., 1997. Compensatory control in the regulation of human performance under stress and high workload: a cognitive-energetical framework. Biological Psychology 45, 73–93.

Houtveen, J.H., Groot, P.F., de Geus, E.J., 2006. Validation of the thoracic impedance derived respiratory signal using multilevel analysis. International Journal of Psychophysiology 59, 97–106.

Kelsey, R.M., 2012. Beta-adrenergic cardiovascular reactivity and adaptation to stress: The cardiac pre-ejection period as an index of effort. In: Wright, R.A., Gendolla, G.H.E. (Eds.), How motivation affects cardiovascular response: Mechanisms and applications. American Psychological Association, Washington, DC, pp. 43–60.

Kelsey, R.M., Reiff, S., Wiens, S., Schneider, T.R., Mezzacappa, E.S., Guethlein, W., 1998. The ensemble-averaged impedance cardiogram: an evaluation of scoring methods and interrater reliability. Psychophysiology 35, 337–340.

Koizumi, K., Kollai, M., 1992. Multiple modes of operation of cardiac autonomic control: development of the ideas from Cannon and Brooks to the present. Journal of the Autonomic Nervous System 41, 19–30.

Koizumi, K., Terui, N., Kollai, M., Brooks, C.M., 1982. Functional significance of coactivation of vagal and sympathetic cardiac nerves. Proceedings of the National Academy of Sciences 79, 2116–2120.

Kreibig, S.D., Gendolla, G.H.E., Scherer, K.R., 2010. Psychophysiological effects of emotional responding to goal attainment. Biological Psychology 84, 474–487.

Kreibig, S.D., Gendolla, G.H.E., Scherer, K.R., 2012. Goal relevance and goal conduciveness appraisals lead to differential autonomic reactivity in emotional responding to performance feedback. Biological Psychology 91, 365–375.

Kristjansson, S.D., Kircher, J.C., Webb, A.K., 2007. Multilevel models for repeated measures designs in psychophysiology: an introduction to growth curve modeling. Psychophysiology 44, 728–736.

Llabre, M.M., Spitzer, S., Siegel, S., Saab, P.G., Schneiderman, N., 2004. Applying latent growth curve modeling to the investigation of individual differences in cardiovascular recovery from stress. Psychosomatic Medicine 66, 29–41.

Lozano, D.L., Norman, G., Knox, D., Wood, B.L., Miller, B.D., Emery, C.F., Berntson, G.G., 2007. Where to B in dZ/dt. Psychophysiology 44, 113–119.

Maddi, S.R., Matthews, M.D., Kelly, D.R., Villarreal, B., White, M., 2012. The role of hardiness and grit in predicting performance and retention of USMA cadets. Military Psychology 24, 19–28.

Obrist, P.A., 1976. The cardiovascular-behavioral interaction as it appears today. Psychophysiology 13, 95–107.

Obrist, P.A., 1981. Cardiovascular Psychophysiology: a Perspective. Plenum, New York.

Paton, J.F.R., Boscan, P., Pickering, A.E., Nalivaiko, E., 2005. The yin and yang of cardiac autonomic control: vago-sympathetic interactions revisited. Brain Research Reviews 49, 555–565.

Richter, M., 2010. Pay attention to your manipulation checks! Reward impact on cardiac reactivity is moderated by task context. Biological Psychology 84, 279–289.

Richter, M., Gendolla, G.H.E., 2009. The heart contracts to reward: monetary incentives and preejection period. Psychophysiology 46, 451–457.

Rottenberg, J., 2007. Cardiac vagal control in depression: a critical analysis. Biological Psychology 74, 200–211.

Schächinger, H., Weinbacher, M., Kiss, A., Ritz, R., Langewitz, W., 2001. Cardiovascular indices of peripheral and central sympathetic activation. Psychosomatic Medicine 63, 788–796.

Schmidt, R.E., Richter, M., Gendolla, G.H.E., Van der Linden, M., 2010. Young poor sleepers mobilize extra effort in an easy memory task: evidence from cardiovascular measures. Journal of Sleep Research 19, 487–495.

Segerstrom, S.C., Hardy, J.K., Evans, D.R., Winters, N.F., 2012. Pause and plan: Self-regulation and the heart. In: Wright, R.A., Gendolla, G.H.E. (Eds.), How motivation affects cardiovascular response: Mechanisms and applications. American Psychological Association, Washington, DC, pp. 181–198.

Segerstrom, S.C., Nes, L.S., 2007. Heart rate variability reflects self-regulatory strength, effort, and fatigue. Psychological Science 18, 275–281.

Sherwood, A., Allen, M.T., Fahrenberg, J., Kelsey, R.M., Lovallo, W.R., van Doornen, L.J., 1990. Methodological guidelines for impedance cardiography. Psychophysiology 27, 1–23.

Silvia, P.J., 2012. Mirrors, masks, and motivation: implicit and explicit self-focused attention influence effort-related cardiovascular reactivity. Biological Psychology 90, 192–201.

Silvia, P.J., Phillips, A.G., 2013. Self-awareness without awareness? Implicit self-focused attention and behavioral self-regulation. Self and Identity 12, 114–127.

Silvia, P.J., McCord, D.M., Gendolla, G.H.E., 2010. Self-focused attention, performance expectancies, and the intensity of effort: do people try harder for harder goals? Motivation and Emotion 34, 363–370.

Silvia, P.J., Jones, H.C., Kelly, C.S., Zibaie, A., 2011a. Masked first name priming increases effort-related cardiovascular reactivity. International Journal of Psychophysiology 80, 210–216.

Silvia, P.J., Jones, H.C., Kelly, C.S., Zibaie, A., 2011b. Trait self-focused attention, task difficulty, and effort-related cardiovascular reactivity. International Journal of Psychophysiology 79, 335–340.

Silvia, P.J., Kelly, C.S., Zibaie, A., Nardello, J.L., Moore, L.C., 2013. Trait self-focused attention increases sensitivity to nonconscious primes: Evidence from effort-related cardiovascular reactivity. International Journal of Psychophysiology 88, 143–148.

Wolford, G., Morrison, F., 1980. Processing of unattended visual information. Memory and Cognition 8, 521–527.

Wright, R.A., 1996. Brehm's theory of motivation as a model of effort and cardiovascular response. In: Gollwitzer, P.M., Bargh, J.A. (Eds.), The Psychology of Action: Linking Cognition and Motivation to Behavior. Guilford, New York, pp. 424–453.

Wright, R.A., 2008. Refining the prediction of effort: Brehm's distinction between potential motivation and motivation intensity. Social and Personality Psychology Compass 2, 682–701.

Wright, R.A., Kirby, L.D., 2001. Effort determination of cardiovascular response: an integrative analysis with applications in social psychology. In: Zanna, M.P. (Ed.), Advances in experimental social psychology, vol. 33. Academic Press, New York, pp. 255–307.

Wright, R.A., Gendolla, G.H.E. (Eds.), 2012. How motivation affects cardiovascular response: Mechanisms and applications. American Psychological Association, Washington, DC.

Wright, R.A., Stewart, C.C., 2012. Multifaceted effects of fatigue on effort and associated cardiovascular responses. In: Wright, R.A., Gendolla, G.H.E. (Eds.), How motivation affects cardiovascular response: mechanisms and applications. American Psychological Association, Washington, DC, pp. 199–218.

Wright, R.A., Contrada, R.J., Patane, M.J., 1986. Task difficulty, cardiovascular response, and the magnitude of goal valence. Journal of Personality and Social Psychology 51, 837–843.

Wright, R.A., Killebrew, K., Pimpalapure, D., 2002. Cardiovascular incentive effects where a challenge is unfixed: demonstrations involving social evaluation, evaluator status, and monetary reward. Psychophysiology 39, 188–197.