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Creative motivation: Creative achievement predicts cardiac autonomic markers of effort during divergent thinking

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ABSTRACT

Executive approaches to creativity emphasize that generating creative ideas can be hard and requires mental effort. Few studies, however, have examined effort-related physiological activity during creativity tasks. Using motivational intensity theory as a framework, we examined predictors of effort-related cardiac activity during a creative challenge. A sample of 111 adults completed a divergent thinking task. Sympathetic (PEP and RZ) and parasympathetic (RSA and RMSSD) outcomes were assessed using impedance cardiography. As predicted, people with high creative achievement (measured with the Creative Achievement Questionnaire) showed significantly greater increases in sympathetic activity from baseline to task, reflecting higher effort. People with more creative achievements generated ideas that were significantly more creative, and creative performance correlated marginally with PEP and RZ. The results support the view that creative thought can be a mental challenge.

People's conceptions of creativity fall along a dimension of *romanticism* to *rationalism* (Sawyer, 2012). Romanticism, by far the most common perspective among the Western public, assumes that creativity is mysterious, that creative ideas arrive seemingly out of nowhere, and that, as a result, creativity is largely a matter of waiting for automatic and effortless inspiration. But rationalism, the guiding perspective in the science of creativity (Finke, Ward, & Smith, 1992; Weisberg, 2006), assumes that creativity involves ordinary cognitive processes and that creativity can be guided, controlled, and trained.

Motivation is a major concept in the rationalist perspective (Sawyer, 2012). Because developing creative ideas is seen as something people can control, motivational processes like incentives (how much do people value doing something creative?), difficulty (how hard is the creative challenge?), and effort (how hard are people trying?) are important for understanding when and why people engage in creative processes rather than stick to the familiar methods. Most research on motivation and creativity, however, has concerned itself with incentives, such as how rewards can inhibit or stimulate creative thought (e.g., Hennessey, 2000, 2010).

In the present work, we examine the relatively unexplored area of effort during creative tasks, using cardiac autonomic markers of motivation. Not much is known about how hard people try during the creative process and whether the effort they exert relates to the creative quality of their work. Motivational intensity theory (Brehm & Self, 1989), a general model of effort (Gendolla, Wright, & Richter, 2012), offers a useful framework for understanding effort during creative activities. When a task allows people to work at their own pace and thus accomplish as little or as much as they would like, effort is a function of the importance of the goal at stake (Wright, 2008; Wright, Killebrew, & Pimpalapure, 2002). The present research used such a task—an unfixed, self-paced divergent thinking task (Silvia et al., 2008; Wallach & Kogan, 1965), in which people are given 4 min to come up with unusual uses for a common object. People are told that the creativity of the ideas is more important than the number of ideas, and they can come up with as many or as few ideas as they wish. For tasks like this, effort should be a function of the importance of doing well.

To explore the role of importance in creative effort, we turned to individual differences in creative achievements. People vary widely in creative achievements (Carson, Peterson, & Higgins, 2005; Feist & Barron, 2003; Grosul & Feist, 2014; Richards, Kinney, Benet, & Merzel, 1988), which are public and observable markers of creative behaviors, such as receiving awards, obtaining fellowships, being reviewed in major periodicals, and publishing, exhibiting, and performing creative work in important venues. Not surprisingly, people with many creative achievements often choose creative college majors and occupations (Silvia & Nusbaum, 2012), see themselves as creative people (Silvia, Wigert, Reiter-Palmon, & Kaufman, 2012), and score much higher in openness to

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experience, a broad personality trait associated with creative and aesthetic interests (Carson et al., 2005; Kaufman, 2013; Nusbaum & Silvia, 2011b; Silvia, Nusbaum, Berg, Martin, & O'Connor, 2009; Silvia, Beaty, et al., in press). People with more creative achievements, given their record of investing their time and energy into creative work, should value doing well on the creativity task relatively more, which should be reflected in physiological markers of effort.

Creative effort is intriguing for a few reasons. The specific question of effort-related autonomic activity during creative problems, for example, has received virtually no attention in creativity research or effort research. Creativity tasks are interesting contexts for mental effort because—unlike the simple memory or judgment tasks commonly used in effort research (e.g., Brinkmann & Franzen, 2013; Silvia, 2012)—they require people to apply abstract, higher-order processes to ill-structured problems (Finke et al., 1992; Weisberg, 2006). More generally, studying effort during creativity tasks can inform the broader ongoing debate over the role of controlled, executive processes in creativity. Early creativity theories emphasized automatic and low-level associationistic processes, such as spreading activation in semantic memory and structural differences in knowledge organization (e.g., Mednick, 1962; Wallach & Kogan, 1965). Recent research, however, has argued that deliberate, effortful processes are central to creativity (Benedek & Neubauer, 2013; Jauk, Benedek, & Neubauer, 2014; Nusbaum & Silvia, 2011a). For example, finding and using abstract strategies (Gilhooly, Fioratou, Anthony, & Wynn, 2007), searching for knowledge despite interference (Benedek, Könen, & Neubauer, 2012; Lee & Therriault, 2013; Silvia & Beaty, 2012; Silvia, Beaty, & Nusbaum, 2013), self-regulating to approach-oriented goals (e.g., Zabelina, Felps, & Blanton, 2013), and exerting executive control over thought (Beaty & Silvia, 2012, 2013; Benedek, Franz, Heene, & Neubauer, 2012; Benedek, Jauk, Sommer, Arendasy, & Neunauer, 2014) improve the creativity of people's ideas and typically require mental effort. All of the work to date, however, has used behavioral measures of creative performance, so physiological measures of the underlying effort processes would greatly illuminate whether doing well on creativity tasks is associated with higher effort.

Our physiological outcomes were measures of sympathetic and parasympathetic influences on the heart. Research on motivational intensity theory has emphasized sympathetic outcomes as markers of effort, such as systolic blood pressure (Wright, 1996; Wright & Kirby, 2001) and the cardiac pre-ejection period (PEP; Kelsey, 2012; Obrist, Light, James, & Strogatz, 1987). In our project, we used PEP—the time difference between the onset of contraction (the ECG Q point) and the opening of the aortic valve (the impedance cardiograph's [ICG] B-point)—as our primary sympathetic measure. PEP has been widely used in recent effort research (see Gendolla et al., 2012; Richter, 2013). Many studies have found evidence for its validity as a marker of effort in active coping contexts (for reviews, see Gendolla et al., 2012; Richter, 2012), such as studies that manipulate incentives and rewards (e.g., Brinkmann & Franzen, 2013; Richter & Gendolla, 2009). The RZ interval—the time difference between the ECG R-peak and the ICG *Z*-peak (Cybulski, 2011)—was included as an exploratory sympathetic outcome. Also known as the initial systolic time interval (ISTI; Meijer, Boesveldt, Elbertse, & Berendse, 2008), the RZ interval uses points that are more easily identified (the ECG and ICG peaks) and appears to work as well as or better than PEP in many studies (van der Meer, Noordegraaf, Bax, Kamp, & de Vries, 1999; van Lien, Schutte, Meijer, & de Geus, 2013; Wilde et al., 1981), so it is worth exploring.

To assess parasympathetic influence, we measured heart rate variability (HRV; Grossman & Taylor, 2007). Although motivational intensity theory is primarily concerned with sympathetic processes, several studies have explored possible parasympathetic effects (Richter, 2010; Silvia, Eddington, Beaty, Nusbaum, & Kwapil, 2013). Some research points to HRV as a marker of self-regulation and effort in its own right (Segerstrom, Hardy, Evans, & Winters, 2012; Segerstrom & Nes, 2007), and HRV is prominent in studies of stress, frustration, and emotional control (Graziano & Derefinko, 2013). Research on HRV uses several metrics (Allen, Chambers, & Towers, 2007; Grossman & Taylor, 2007). We quantified HRV with respiratory sinus arrhythmia (RSA), a frequency-domain measure that uses spectral methods to estimate HRV within the respiratory frequency band, and the root mean square of successive differences (RMSSD).

In summary, participants in the present research worked on a divergent thinking task, a classic creative challenge (e.g., Christensen, Guilford, & Wilson, 1957), while being monitored for changes in sympathetic and parasympathetic activity. We expected that people who valued creativity—people with many creative achievements, reflecting their investment in creative pursuits—would show greater effort during the divergent thinking task, as reflected by an increase in sympathetic activity from baseline to task.

1. Method

1.1. Participants

The data are from a larger study on individual differences and cardiac autonomic markers of effort (see Silvia, Nusbaum, Eddington, Beaty, & Kwapil, in press). Neither the creativity task nor the measures of creative achievement have been analyzed or reported in past work. A total of 111 adults—70 women (63%), 41 men (37%)—volunteered to participate and received either $10 USD in cash or credit toward a research option in a psychology class. All but 3 participants were students in the university; most of the people who participated for cash were undergraduate or graduate students from a wide range of majors who were not enrolled in psychology courses. The mean age was 19.3 years (*SD* = 1.7, range from 18 to 28 years), and the sample was diverse: 65% European American, 32% African American, 7% Hispanic or Latino, and 4% Asian or Pacific Islander (people could pick several categories or decline to pick any). The sample, on average, was on the border of overweight and normal weight, according to body mass index (BMI) scores based on self-reported height and weight (*M* = 24.34, *SD* = 4.64). The final sample of 111 was part of a larger sample from which 21 people had been excluded. Sixteen non-native speakers of English were excluded because the main task involved verbal creativity, and 5 people were excluded because of hardware or software problems during the session or cardiovascular disorders.

1.2. Measures

1.2.1. Creative achievement

To measure past creative achievements, we included the Creative Achievement Questionnaire (CAQ; Carson et al., 2005). The CAQ is a widely used measure of major creative accomplishments that has strong psychometric properties (for a review, see Silvia et al., 2012). The CAQ has 10 subscales that assess creative achievements in different domains, such as music, visual art, and writing. Receiving high scores requires having creative achievements that are public, observable, and recognized by people important in the domain. CAQ scores are thus highly skewed. For example, most college students receive a total score of 0 or 1 when all 10 subscales are summed (Silvia, Kaufman, & Pretz, 2009), so getting beyond a 1 takes notable public accomplishments. As in past research, we averaged the 10 domain scores and then log-transformed the overall score to adjust for the significant skew (see Silvia et al., 2012).

1.2.2. Divergent thinking

For the creative challenge, we used a divergent thinking task. Divergent thinking tasks are among the oldest and best established tasks in creativity research (see Kaufman, Plucker, & Baer, 2008). They appraise creative thought by asking people to move beyond obvious, common ideas and to generate unusual and interesting ideas. The most common variant is probably the unusual uses task, in which people are asked to come up with unusual uses for a common object. In our task, we asked people to come up with unusual uses for a brick. As in our extensive past work with these tasks (Silvia et al., 2008; Silvia, Kaufman, et al., 2009; Silvia, Martin, & Nusbaum, 2009; Silvia, Nusbaum, et al., 2009; Silvia, Beaty, et al., 2013; Silvia & Kimbrel, 2010), we instructed the participants to "be creative" and to "come up with something clever, humorous, original, compelling, or interesting." People could come up with as many responses as they wished, but we emphasized that creative quality was more important than quantity. The task lasted for 4 min.

Responses to the brick task were scored for quantity and quality. Quantity—usually known as *fluency*—was simply the total number of responses people generated. Creative quality was measured using subjective scoring

Table 1
Descriptive statistics for creative achievement and divergent thinking.

Variable	Mean	*SE*	Min, max
Creative Achievement Questionnaire (raw average)	1.40	.16	0.00, 13.20
Creative Achievement Questionnaire (log transformed)	.39	.07	−.69, 2.62
Brick Task, Rater 1	1.88	.04	1.00, 3.50
Brick Task, Rater 2	1.32	.03	1.00, 2.17
Brick Task, Rater 3	1.53	.04	1.00, 2.80
Brick Task, Fluency	12.27	.61	1, 35

Note. $n = 111$. *SE* = standard error. The creativity ratings have a 1–5 scale, with higher scores reflecting higher rated creativity.

methods (Benedek, Mühlmann, Jauk, & Neubauer, 2013; Silvia, 2011; Silvia et al., 2008; Silvia, Martin, et al., 2009). Each response was scored independently by three raters (the first three authors) using a 1 (*not at all creative*) to 5 (*very creative*) scale (see Table 1). The responses were sorted alphabetically and stripped of identifying information, so the raters were unaware of the other raters' scores and all information about the participants, which responses were given by any given person, and how many responses each person generated. Responses that receive low scores are listed by many people (e.g., doorstop, paperweight) or are common uses for bricks (e.g., building walls, pathways, and fireplaces from bricks). Responses that receive high scores, in contrast, are rare in the sample and typically clever. Many of the best responses involve transforming the brick or shifting it to different conceptual domains (e.g., "bowling pins"; "bleachers for Troll Dolls"; and "a much more intimidating version of Jenga"). A great deal of recent work shows that quality scores (measured via ratings) are much better markers of creativity than quantity scores, particularly when people are instructed to be creative and to emphasize quality over quantity (e.g., Benedek et al., 2013; Nusbaum, Silvia, & Beaty, in press; Silvia et al., 2008; Silvia, Kaufman, et al., 2009; Silvia, Martin, et al., 2009; Silvia, Nusbaum, et al., 2009).

1.3. Procedure

The project was approved, monitored, and audited by the Institutional Review Board at the University of North Carolina at Greensboro. Participants took part individually, and the sessions were conducted by an experimenter with the same gender as the participant. After participants completed informed consent forms, the experimenter explained that the study was about how the body responded to different kinds of mental tasks and challenges. People expected to complete personality and self-report scales and to work on some cognitive tasks while having physiological responses monitored via electrodes on the chest and back. After placing the electrodes, the experimenter allowed the signals to stabilize and started a baseline period in which the participants completed a range of demographic and self-report scales. Later in the session, people completed the divergent thinking task. Participants were seated upright throughout the recording period. At the conclusion of the session, the experimenter removed the electrodes, explained the purpose of the research in more detail, and answered questions about the project.

1.3.1. Physiological assessment

Autonomic influences on the heart were assessed using impedance cardiography. Three electrodes in a modified Lead-II configuration (right clavicle and left and right lower ribs) provided an electrocardiogram (ECG). Four electrodes in a standard tetrapolar configuration provided an impedance cardiogram (ICG). Receiving electrodes were placed on the front of the body (one 4 cm above the suprasternal notch, and one at the base of the sternum), and sending electrodes were placed on the back (at 4 cm above the upper receiving electrode and 4 cm below the lower receiving electrode). Disposable spot electrodes were used. A Mindware Bionex hardware system sampled the signals at 1000 Hz. The signals were stored and processed offline using bandpass filters (ECG and dZ/dt, .5–45 Hz; Z_0, 10–45 Hz), which were suitable for the range of normal, at-rest heart rates observed in the experiment (see Hurwitz et al., 1993).

The baseline period was 5 min, and the divergent thinking task was 4 min. The physiological outcomes were calculated for these 9 60-s epochs. The ECG series was screened for artifacts and ectopic beats; the R-peaks were corrected manually when necessary (less than .1% of the beats), either by manually specifying the correct R-peak, deleting improperly identified R-peaks, or using midbeat values to correct for ectopy. PEP and RZ, our sympathetic outcomes, were calculated using points on the ensemble-averaged ECG and ICG waveforms (Kelsey et al., 1998). PEP was calculated as the difference in ms between the ECG Q-point (the start of ventricular depolarization; Berntson, Lozano, Chen, & Cacioppo, 2004) and the dZ/dt B-point (the opening of the aortic valve; Lozano et al., 2007). The ICG Q-point was identified using the R-onset method (Berntson et al., 2004). The ICG B-point was identified using the proportional method developed by Lozano et al. (2007). The IMP software (Mindware Technologies, Gahanna, OH) identified the B-point using the linear function reported by Lozano et al. (2007), at 55% of the RZ distance plus a constant of 4 ms. (Only the linear function and whole ms constants are afforded by the IMP software, so the non-linear function and constant described by Lozano et al. (2007) was not used.) RZ was calculated as the difference between the peak of the ECG wave (the R peak) and the peak of the dZ/dt wave (the Z point). The points were identified by the IMP software but screened and corrected manually when necessary.

RSA and RMSSD were our parasympathetic outcomes. For RSA, a frequency domain measure, spectral analysis was used to compute high-frequency HRV. A Hamming windowing function was applied to the IBI series, and fast Fourier transformations were used to determine spectral power values; values in the .12–.40 Hz respiratory frequency range were integrated and natural-log transformed for an RSA value. Respiration rate (cycles per minute) was measured using the ICG Z_0 impedance signal. Spectral analysis can effectively estimate the variation in Z_0 caused by respiration (de Geus, Willemsen, Klaver, & van Doornen, 1995; Ernst, Litvack, Lozano, Cacioppo, & Berntson, 1999; Houtveen, Groot, & de Geus, 2006). For RMSSD, a time-domain measure, the interbeat interval (IBI) series from the ECG was used to calculate the root mean square of the successive IBI differences.

1.4. Data reduction and analysis plan

As in our past work (Silvia, Eddington, et al., 2013; Silvia, Nusbaum, et al., in press), we analyzed the data using multilevel models. These models can simultaneously estimate within-person effects (such as change in PEP from the baseline period to the brick task), between-person effects (such as whether creative achievement has a main effect on PEP), and their interactions (such as whether creative achievement predicts the baseline-to-task change). Multilevel modeling is a versatile method for psychophysiological research (Kristjansson, Kircher, & Webb, 2007; Llabre, Spitzer, Siegel, Saab, & Schneiderman, 2004). Among other things, it can flexibly model missing observations, random effects, and within-person covariates.

In our models, the central within-person predictor was time, which was scored as 0 (for the 5 baseline periods) and 1 (for the four brick task periods). This method is akin to simply averaging the 5 baseline values and the 4 task values, but it allows the multilevel model to differentially weight cases based on the number and reliability of the within-person scores (Heck & Thomas, 2009; Raudenbush & Bryk, 2002). Effects of time within each period (such as change within the 5 baseline periods, or within the 4 task periods) were not estimated (see Table 2). The central between-person predictor was creative achievement; it was centered at the sample's grand mean, so its values represent deviation scores. The intercepts and slopes were modeled as random. The random intercepts and slopes were allowed to covary, which estimates and controls for potential correlation between baseline levels and change. Measures of HRV are inversely and substantially related to respiration rate (Grossman & Taylor, 2007). To control for respiration rate, the models for RSA and RMSSD included respiration rate (centered at each person's own mean) as a within-person covariate. Unlike between-person models (e.g., ANCOVAs), the multilevel analytic approach affords controlling for respiration rate at the within-person level (see Grossman & Taylor, 2007, p. 268). Unless noted, all effects are unstandardized. The models were estimated in Mplus 7.11 using maximum likelihood with robust standard errors.

2. Results

2.1. Creative achievement and sympathetic activity

Did people with more creative achievements try harder during the divergent thinking task? We estimated a multilevel model with time (0 = baseline, 1 = task) as a within-person variable and creative achievement as a between-person variable. For PEP, our primary measure of sympathetic activity, we found a significant within-person main effect, $b = .88$, $SE = .37$, $p = .018$: for the sample overall, PEP slowed from baseline to task, indicating lower sympathetic activity during the creativity task. There was no between-person main effect of creative achievement, $b = 1.49$, $SE = 1.24$, $p = .229$.

Finally, there was a significant interaction between creative achievement and time, $b = -.93$, $SE = .47$, $p = .048$. The form of the interaction supported our predictions: as creative achievement increased, PEP decreased from baseline to task. Stated differently, people high in creative achievement showed stronger sympathetic activity (decreased PEP) during the creativity task compared to the baseline. This interaction is depicted in Fig. 1 as a scatterplot between each person's creative achievement score and the model-estimated change from baseline to task.

For RZ, our exploratory measure of sympathetic activity, we found similar effects. Neither the overall within-person main effect of time ($b = .91$, $SE = .62$, $p = .143$) nor the between-person main effect of creative achievement ($b = 2.06$, $SE = 1.87$, $p = .270$) was significant. The interaction, however, was significant and had the

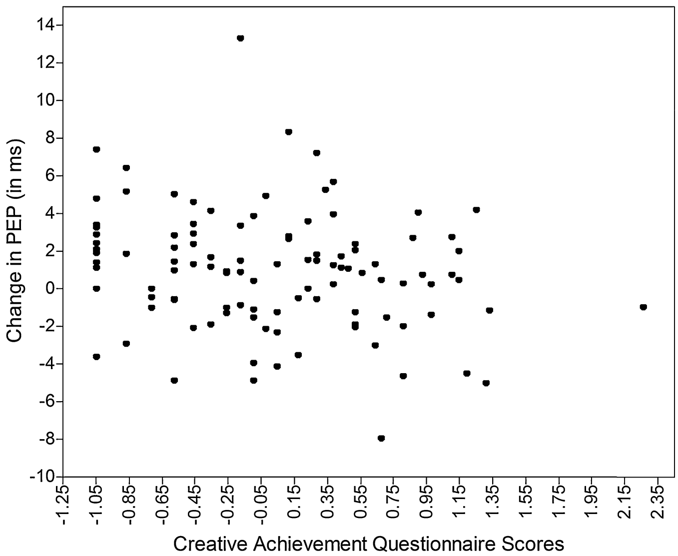

Fig. 1. The relationship between Creative Achievement Questionnaire scores (log-transformed) and change in PEP (in ms) from baseline to task.

predicted form, $b = -1.89$, $SE = .86$, $p = .027$. As with PEP, the RZ period decreased as creative achievement increased: people high in creative achievement had shorter RZ periods in the creativity task compared to the baseline (see Fig. 2).

2.2. Creative achievement and parasympathetic activity

Did parasympathetic activity change during the creativity task? As noted earlier, motivational intensity theory is primarily concerned with sympathetic processes, but possible parasympathetic changes have been explored in several recent studies (e.g., Richter, 2010; Silvia, Nusbaum et al., in press). For RSA and RMSSD, we estimated multilevel models that included respiration as a within-person covariate. RSA declined as respiration rate increased ($b = -.04$, $SE = .01$, $p = .001$), a common finding (Allen et al., 2007). Beyond that, we found a significant within-person main effect of time, $b = .26$, $SE = .07$, $p < .001$: RSA increased from the baseline to the divergent thinking task. There was no between-person main effect of creative achievement $b = -.22$, $SE = .21$, $p = .297$, and no interaction, $b = -.01$, $SE = .09$, $p = .999$.

RMSSD, a time-domain measure, showed a similar pattern of effects. There was a marginal within-person main effect, $b = 3.57$, $SE = 1.92$, $p = .063$: RMSSD tended to increase from baseline to task, suggesting increased parasympathetic activity. Respiration rate did not significantly predict RMSSD at the within-person level, $b = -.12$, $SE = .22$, $p = .580$. There was no between-person main effect of creative achievement, $b = -8.63$, $SE = 7.16$, $p = .228$, and no interaction, $b = -1.43$, $SE = 2.00$, $p = .474$.

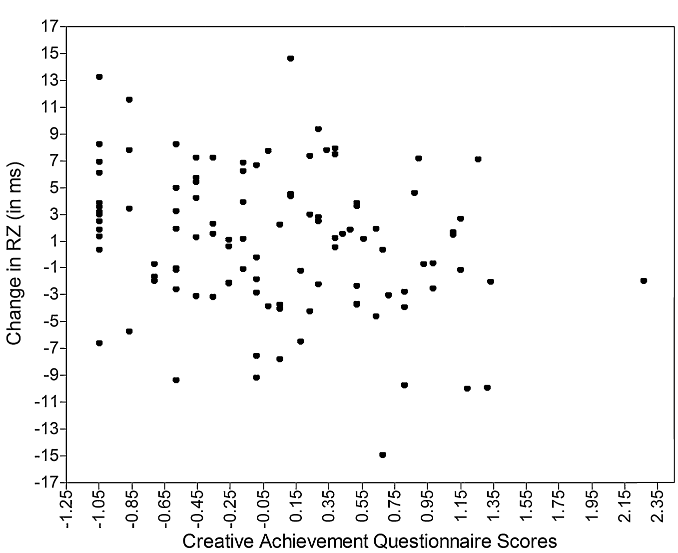

Fig. 2. The relationship between Creative Achievement Questionnaire scores (log-transformed) and change in RZ interval (in ms) from baseline to task.

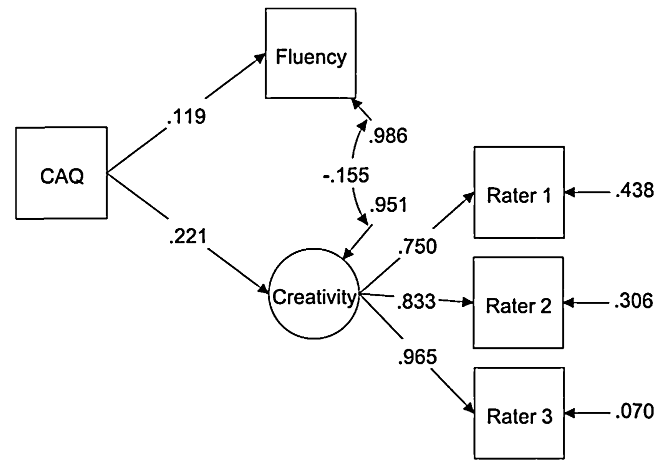

Fig. 3. Standardized effects of Creative Achievement Questionnaire scores (log transformed) on the creativity and fluency of divergent thinking during the Brick Task.

2.3. Additional autonomic outcomes

We had no predictions concerning interbeat interval (IBI, in ms) and respiration rate (in cycles per minute), but we explored them as outcomes. For IBI, there was a significant within-person main effect, $b = 15.11$, $SE = 4.57$, $p = .001$: IBI was longer (heart rate was lower) in the creativity task than in the baseline. For respiration rate, we found only a significant within-person main effect, $b = -.48$, $SE = .22$, $p = .033$: respiration rate was lower in the creativity task compared to the baseline. Creative achievement did not significantly interact with time to predict IBI and respiration rate.

2.4. Divergent thinking performance

How well did people do on the divergent thinking task? As noted earlier, these tasks provide two scores: fluency (the simple number of responses generated) and creativity (the scores given to the responses by raters). Creativity scores are our central outcome. Because we instructed the participants to emphasize quality over quantity, creativity scores reveal more about their success on the task than fluency scores. The three raters' creativity scores were highly correlated: Cronbach's alpha for the three ratings was .87. We estimated creativity by forming a latent variable: the three raters' scores served as the indicators. The reliability of this latent variable can be estimated using *H*, known as maximal reliability (Drewes, 2000; Hancock & Mueller, 2001). Maximal reliability was quite good, $H = .94$, consistent with past work with subjective scoring of divergent thinking tasks (Silvia, 2011). As in our past work (see Silvia et al., 2008), fluency and creativity were weakly (and negatively) correlated, $r(111) = -.12$, $p = .12$.

Our first model examined if people with more creative achievements performed better on the task. CAQ scores were the predictor, and creativity and fluency were outcomes. As Fig. 3 shows, CAQ scores significantly predicted the creativity of the responses (standardized β = .22, p = .033) but not fluency, the simple number of responses (standardized β = .12, p = .17). As expected, people with more creative achievements generated uses for a brick that were more creative.

We next explored whether task performance was associated with physiological changes in the creativity task. In a series of multilevel models, we included fluency and creativity as between-person predictors of within-person change from baseline to task. For PEP and RZ, our measures of sympathetic activity, fluency had marginal effects on PEP (b = −.09, SE = .05, p = .06) and RZ (b = −.14, SE = .51, p = .124); creativity, too, had marginal effects on PEP (b = −.72, SE = .45, p = .112) and RZ (b = −1.25, SE = .80, p = .119). In all cases, the direction of the effect indicated that as fluency and creativity increased, PEP and RZ decreased. The pattern of effects thus offers tentative, suggestive support for a link between sympathetic activity and task performance. For RSA and RMSSD, our measures of parasympathetic activity, no effects appeared.[1],[2]

3. Discussion

Creative thought has attracted widespread interest in cognitive neuroscience, but there is relatively little research on autonomic physiology when people engage with creative goals and challenges. One study, for example, found that subjective flow states during musical performance correlated with a range of autonomic outcomes, such as reduced RSA and higher blood pressure (de Manzano, Theorell, Harmat, & Ullén, 2010). Other research has examined heart rate change during different kinds of reasoning tasks (Jausovec & Bakracevic, 1995), including divergent thinking and insight tasks.

In the present research, we explored mental effort during a creativity task, using motivational intensity theory as a framework (Brehm & Self, 1989). We expected that people with high creative achievements would find coming up with creative ideas more important and self-relevant (Gendolla & Richter, 2010), which should thus increase the amount of effort people are willing to expend (Wright, 2008). For do-your-best tasks in which people can work at their own pace, effort is largely a function of the importance of the goals and rewards at stake (Wright et al., 2002). We thus expected people with higher creative achievements would try harder during the creativity task. For measures of sympathetic activity—the outcomes most closely tied to mental effort in past work (Gendolla et al., 2012), the findings supported our expectations. As creative achievement—measured with CAQ scores—increased, PEP and RZ decreased from baseline to task, reflecting an increase in sympathetic activation (see Figs. 1 and 2) that is consistent with greater mental effort during the task.

For task performance, we found—consistent with much past research—that people who had more creative achievements did better on the divergent thinking task: their responses were rated as significantly more creative. The creativity of people's responses, in turn, was marginally related to physiological markers of effort. People with smaller PEP and RZ scores during the task tended to give more creative responses. The marginal significance level makes these findings only tentative, but they are consistent with the higher effort and better responses shown by people with higher creative achievements, and they suggest that higher effort could in part mediate the effects of creative achievements on creative performance.

For the sample as a whole, the overall autonomic profile of the divergent thinking task suggests parasympathetic activation and sympathetic withdrawal. For parasympathetic activity, both RSA and RMSSD increased from baseline to task. Not much work has examined parasympathetic relationships with creativity, and the findings are inconsistent. In a within-person design, vagus nerve stimulation in a small sample of epilepsy patients reduced the creativity of divergent thinking responses (Ghacibeh, Shenker, Shenal, Uthman, & Heilman, 2006). In a study of creativity during musical performance (de Manzano et al., 2010), RSA declined during a musical creativity task, but the task had a substantial motor component and induced large respiratory changes.

For sympathetic activity, PEP and RZ were slightly higher in the task period (PEP increase of roughly 1 ms) than the baseline period, reflecting less sympathetic activity. Cardiovascular reactivity research often finds a decrease in PEP, but divergent thinking tasks differ from common tasks used in past reactivity research in many respects. First, the tasks are not obviously appetitive or avoidant: people are not seeking obvious rewards or trying to avoid aversive outcomes. Second, the tasks are not designed to be or experienced as stressful: people are not doing math under pressure, enduring physical discomfort, or performing before others, for example. Finally, an interesting feature of divergent thinking tasks is that people who do poorly experience them as easier than people who do well. People who get low scores tend to retrieve salient, accessible, and obvious ideas from memory (Gilhooly et al., 2007); people with high scores tend to develop and enact abstract, executively-demanding strategies (Benedek, Jauk, Fink, et al., 2014; Benedek, Jauk, Sommer, et al., 2014; Nusbaum et al., in press). As a result, the task feels easier and more effortless when people churn out obvious ideas and harder when people apply executive mechanisms to strategically develop ideas. The overall pattern—higher sympathetic activity among people with higher creative achievements, who performed better—thus fits what past research shows about the psychological dynamics of divergent thinking.

Regarding limitations, measures of contractility, such as PEP and RZ, are influenced by ventricular preload and, to a lesser extent, afterload (Obrist et al., 1987). A confounding effect of preload seems unlikely because the pattern of IBI changes does not match the pattern of PEP and RZ changes. IBI increased slightly from baseline to task (around 15 ms; see Table 2), but unlike PEP and RZ it did not interact with creative achievement scores, so it is highly unlikely that the interactive effects on PEP and RZ are confounded by a small HR main effect. We cannot rule out afterload changes because diastolic blood pressure was not measured. Obrist et al. (1987), however, found that PEP is less likely to be biased by afterload for tasks with stationary participants working on mental tasks, such as in the present paradigm, in contrast to tasks that create strong alpha-adrenergic sympathetic changes (e.g., cold pressor tasks). Furthermore, respiratory parameters beyond rate were not measured, and some of them, such as tidal volume, are known to affect HRV separately from respiration rate (Grossman & Taylor, 2007; Hirsch & Bishop, 1981). Assessing and controlling for those variables could sharpen the findings for parasympathetic activity.

Overall, the present study supports the view of creative thought as something that requires mental control and is thus usually

[1] We should note that with a 60-s sampling period, the 0.12 Hz lower-bound limit we used, like the common 0.15 Hz lower-bound limit, is not long enough to meet the guideline of having a sampling period that is at least 10 times the frequency of interest. The 60-s epochs used, however, do meet the guidelines of having the cycle of interest (respiration) be observed at least 10 times per epoch, and our observed heart rates are more than twice the respiratory rate (e.g., Berntson et al., 1997). The use of 60-s periods for a 0.12 Hz lower-bound should thus be minimally distorting at most in light of the observed respiration rates and heart rates.

[2] Additional analyses explored possible gender effects. Gender did not significantly predict baseline values for any of the autonomic outcomes or change from baseline to task. The one exception was a marginal effect for PEP (b = 1.25, SE = 0.74, p = 0.093), reflecting a marginally smaller decline for women compared to men; no corresponding effect appeared for RZ. Likewise, gender did not significantly affect task performance. Finally, including gender in the models did not change the effects of creative achievement on the physiological or performance outcomes.

Table 2
Descriptive statistics for the physiological outcomes.

	Baseline periods						Task periods				
	1	2	3	4	5	Model estimated	1	2	3	4	Model estimated
PEP	120.43 (.97)	121.26 (.94)	121.44 (.98)	121.91 (.96)	122.28 (.99)	121.44 (.95)	121.98 (1.05)	122.72 (1.09)	122.82 (1.03)	122.28 (1.11)	122.42 (1.05)
RZ	155.85 (1.63)	157.36 (1.57)	157.84 (1.65)	158.63 (1.59)	159.26 (1.66)	157.77 (1.59)	157.86 (1.78)	159.08 (1.84)	159.49 (1.69)	158.53 (1.88)	158.70 (1.76)
RSA	6.21 (.14)	6.24 (.15)	6.16 (.15)	6.14 (.14)	6.06 (.15)	6.17 (.14)	6.34 (.13)	6.39 (.14)	6.43 (.13)	6.47 (.13)	6.42 (.12)
RMSSD	52.50 (4.95)	50.80 (4.20)	49.12 (4.17)	48.90 (4.07)	48.73 (4.82)	50.24 (4.29)	51.73 (4.08)	52.01 (3.65)	54.41 (4.71)	52.59 (4.20)	52.93 (3.98)
IBI	775.42 (12.90)	773.83 (12.58)	764.64 (12.30)	768.06 (11.94)	766.81 (12.17)	769.56 (12.22)	780.58 (12.64)	787.81 (11.91)	786.08 (12.34)	778.66 (11.94)	783.75 (11.79)
Respiration rate	18.39 (.33)	18.01 (.33)	17.77 (.33)	18.00 (.31)	17.91 (33)	18.04 (.27)	18.14 (.36)	17.50 (.35)	17.56 (.34)	17.18 (.34)	17.59 (.28)

Note. $n = 111$. Standard errors are in parentheses. PEP, pre-ejection period (in ms); RZ, RZ interval (in ms); RSA, respiratory sinus arrhythmia (in ms^2); RMSSD, root mean square of successive differences in the IBI series; IBI, interbeat interval (in ms); respiration rate is in cycles per minute. These values are raw descriptive statistics, except for the "Model Estimated" columns, which report the baseline and task values estimated from the multilevel models. Note that the model-estimated values do not vary *within* the baseline and task periods.

challenging. As discussed earlier, creativity theories disagree about whether creative thought is primarily automatic and associationistic (e.g., Mednick, 1962; Wallach & Kogan, 1965) versus effortful and controlled (Benedek & Neubauer, 2013; Nusbaum & Silvia, 2011a). The present findings support the controlled, executive perspective on creative thought. The people who did the best on the creativity task—people with the most past creative achievements—were the ones who showed the strongest effort-related sympathetic activity during the divergent thinking task. This is consistent with the assumption that when people find a creativity task important (e.g., they have more creative achievements), the process of generating creative ideas is more likely to be controlled and challenging than automatic and effortless. The findings thus mesh with the large behavioral literature that indicates that deliberate and challenging executive processes—from using abstract strategies (Nusbaum & Silvia, 2011a) to inhibiting irrelevant and obvious ideas (Beaty & Silvia, 2012, 2013)—enhance creativity.

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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. http://dx.doi.org/10.1016/j.biopsycho.2006.08.005

Beaty, R. E., & Silvia, P. J. (2012). Why do ideas get more creative across time? An executive interpretation of the serial order effect in divergent thinking tasks. *Psychology of Aesthetics, Creativity, and the Arts*, *6*, 309–319. http://dx.doi.org/10.1037/a0029171

Beaty, R. E., & Silvia, P. J. (2013). Metaphorically speaking: Cognitive abilities and the production of figurative language. *Memory and Cognition*, *41*, 255–267. http://dx.doi.org/10.3758/s13421-012-0258-5

Benedek, M., Franz, F., Heene, M., & Neubauer, A. C. (2012). Differential effects of cognitive inhibition and intelligence on creativity. *Personality and Individual Differences*, *53*, 480–485. http://dx.doi.org/10.1016/j.paid.2012.04.014

Benedek, M., Jauk, E., Fink, A., Koschutnig, K., Reishofer, G., Ebner, F., et al. (2014). To create or to recall? Neural mechanisms underlying the generation of creative new ideas. *NeuroImage*, *88*, 125–133. http://dx.doi.org/10.1016/j.neuroimage.2013.11.021

Benedek, M., Jauk, E., Sommer, M., Arendasy, M., & Neunauer, A. C. (2014). Intelligence, creativity, and cognitive control: The common and differential involvement of executive functions in intelligence and creativity. *Intelligence*, *46*, 73–83. http://dx.doi.org/10.1016/j.intell.2014.05.007

Benedek, M., Könen, T., & Neubauer, A. C. (2012). Associative abilities underlying creativity. *Psychology of Aesthetics, Creativity, and the Arts*, *6*, 273–281. http://dx.doi.org/10.1037/a0027059

Benedek, M., Mühlmann, C., Jauk, E., & Neubauer, A. C. (2013). Assessment of divergent thinking by means of the subjective top-scoring method: Effects of the number of top-ideas and time-on-task on reliability and validity. *Psychology of Aesthetics, Creativity, and the Arts*, *7*, 341–349. http://dx.doi.org/10.1037/a0033644

Benedek, M., & Neubauer, A. C. (2013). Revisiting Mednick's model on creativity-related differences in associative hierarchies: Evidence for a common path to uncommon thought. *Journal of Creative Behavior*, *47*, 273–289. http://dx.doi.org/10.1002/jocb.35

Berntson, G. G., Bigger, T., Jr., Eckberg, D. L., Grossman, P., Kaufmann, P. G., Malik, M., et al. (1997). Heart rate variability: Origins, methods, and interpretive caveats. *Psychophysiology*, *34*, 623–648. http://dx.doi.org/10.1111/j.1469-8986.1997.tb02140.x

Berntson, G. G., Lozano, D. L., Chen, Y., & Cacioppo, J. T. (2004). Where to Q in PEP. *Psychophysiology*, *41*, 333–337. http://dx.doi.org/10.1111/j.1469-8986.2004.00156.x

Brehm, J. W., & Self, E. A. (1989). The intensity of motivation. *Annual Review of Psychology*, *40*, 109–131. http://dx.doi.org/10.1146/annurev.ps.40.020189.000545

Brinkmann, K., & Franzen, J. (2013). Not everyone's heart contracts to reward: Insensitivity to varying levels of reward in dysphoria. *Biological Psychology*, *94*, 263–271. http://dx.doi.org/10.1016/j.biopsycho.2013.07.003

Carson, S. H., Peterson, J. B., & Higgins, D. M. (2005). Reliability, validity, and factor structure of the Creative Achievement Questionnaire. *Creativity Research Journal*, *17*, 37–50. http://dx.doi.org/10.1207/s15326934crj1701_4

Christensen, P. R., Guilford, J. P., & Wilson, R. C. (1957). Relations of creative responses to working time and instructions. *Journal of Experimental Psychology*, *53*, 82–88. http://dx.doi.org/10.1037/h0045461

Cybulski, G. (2011). *Ambulatory impedance cardiography: The systems and their applications*. Heidelberg, Germany: Springer.

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. http://dx.doi.org/10.1016/0301-0511(95)05137-6

de Manzano, O., Theorell, T., Harmat, L., & Ullén, F. (2010). The psychophysiology of flow during piano playing. *Emotion*, *10*, 301–311. http://dx.doi.org/10.1037/a0018432

Drewes, D. W. (2000). Beyond the Spearman–Brown: A structural approach to maximal reliability. *Psychological Methods*, *5*, 214–227. http://dx.doi.org/10.1037/1082-989x.5.2.214

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. http://dx.doi.org/10.1017/S0048577299981003

Feist, G. J., & Barron, F. X. (2003). Predicting creativity from early to late adulthood: Intellect, potential, and personality. *Journal of Research in Personality*, *37*, 62–88. http://dx.doi.org/10.1016/S0092-6566(02)00536-6

Finke, R. A., Ward, T. B., & Smith, S. M. (1992). *Creative cognition: Theory, research, and applications*. Cambridge, MA: MIT Press.

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. http://dx.doi.org/10.1037/a0019742

Gendolla, G. H. E., Wright, R. A., & Richter, M. (2012). Effort intensity: Some insights from the cardiovascular system. In R. M. Ryan (Ed.), *The Oxford handbook of human motivation* (pp. 420–438). New York: Oxford University Press.

Ghacibeh, G. A., Shenker, J. I., Shenal, B., Uthman, B. M., & Heilman, K. M. (2006). Effect of vagus nerve stimulation on creativity and cognitive flexibility. *Epilepsy and Behavior*, *8*, 720–725. http://dx.doi.org/10.1016/j.yebeh.2006.03.008

Gilhooly, K. J., Fioratou, E., Anthony, S. H., & Wynn, V. (2007). Divergent thinking: Strategies and executive involvement in generating novel uses for familiar objects. *British Journal of Psychology*, *98*, 611–625. http://dx.doi.org/10.1111/j.2044-8295.2007.tb00467.x

Graziano, P., & Derefinko, K. (2013). Cardiac vagal control and children's adaptive functioning: A meta-analysis. *Biological Psychology*, *94*, 22–37. http://dx.doi.org/10.1016/j.biopsycho.2013.04.011

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. http://dx.doi.org/10.1016/j.biopsycho.2005.11.014

Grosul, M., & Feist, G. J. (2014). The creative person in science. *Psychology of Aesthetics, Creativity, and the Arts*, *8*, 30–43. http://dx.doi.org/10.1037/a0034828

Hancock, G. R., & Mueller, R. O. (2001). Rethinking construct reliability within latent variable systems. In R. Cudeck, S. du Toit, & D. Sörbom (Eds.), *Structural equation modeling: Present and future* (pp. 195–216). Lincolnwood, IL: Scientific Software International.

Heck, R. H., & Thomas, S. L. (2009). *An introduction to multilevel modeling techniques* (2nd ed.). New York: Routledge.

Hennessey, B. A. (2000). Rewards and creativity. In C. Sansone, & J. M. Harackiewicz (Eds.), *Intrinsic and extrinsic motivation* (pp. 55–78). San Diego: Academic Press.

Hennessey, B. A. (2010). The creativity–motivation connection. In J. C. Kaufman, & R. J. Sternberg (Eds.), *The Cambridge handbook of creativity* (pp. 342–365). New York: Cambridge University Press.

Hirsch, J. A., & Bishop, B. (1981). Respiratory sinus arrhythmia in humans: How breathing pattern modulates heart rate. *American Journal of Physiology: Heart and Circulatory Physiology*, *241*, H620–H629.

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. http://dx.doi.org/10.1016/j.ijpsycho.2005.02.003

Hurwitz, B. E., Shyu, L. Y., Lu, C. C., Reddy, S. P., Schneiderman, N., & Nagel, J. H. (1993). Signal fidelity requirements for deriving impedance cardiographic measures of cardiac function over a broad heart range. *Biological Psychology*, *36*, 3–21. http://dx.doi.org/10.1016/0301-0511(93)90076-k

Jauk, E., Benedek, M., & Neubauer, A. C. (2014). The road to creative achievement: A latent variable model of ability and personality predictors. *European Journal of Personality*, *28*, 95–105. http://dx.doi.org/10.1002/per.1941

Jausovec, N., & Bakracevic, K. (1995). What can heart rate tell us about the creative process? *Creativity Research Journal*, *8*, 11–24. http://dx.doi.org/10.1207/s15326934crj0801_2

Kaufman, J. C., Plucker, J. A., & Baer, J. (2008). *Essentials of creativity assessment*. Hoboken, NJ: Wiley.

Kaufman, S. B. (2013). Opening up openness to experience: A four-factor model and relations to creative achievement in the arts and sciences. *Journal of Creative Behavior*, *47*, 233–255. http://dx.doi.org/10.1002/jocb.33

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

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. http://dx.doi.org/10.1017/S0048577298001310

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. http://dx.doi.org/10.1111/j.1469-8986.2007.00544.x

Lee, C. S., & Therriault, D. J. (2013). The cognitive underpinnings of creative thought: A latent variable analysis exploring the roles of intelligence and working memory in three creative thinking processes. *Intelligence*, *41*, 306–320. http://dx.doi.org/10.1016/j.intell.2013.04.008

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. http://dx.doi.org/10.1097/01.PSY.0000107886.51781.9C

Lozano, D. L., Norman, G., Knox, D., Wood, B. L., Miller, B. D., Emery, C. F., et al. (2007). Where to B in d*Z*/d*t*. *Psychophysiology*, *44*, 113–119. http://dx.doi.org/10.1111/j.1469-8986.2006.00468.x

Mednick, S. A. (1962). The associative basis of the creative process. *Psychological Review*, *69*, 220–232. http://dx.doi.org/10.1037/h0048850

Meijer, J. H., Boesveldt, S., Elbertse, E., & Berendse, H. W. (2008). Method to measure autonomic control of cardiac function using time interval parameters from impedance cardiography. *Physiological Measurement*, *29*, 383–391. http://dx.doi.org/10.1088/0967-3334/29/6/s32

Nusbaum, E. C., & Silvia, P. J. (2011a). Are intelligence and creativity really so different? Fluid intelligence, executive processes, and strategy use in divergent thinking. *Intelligence*, *39*, 36–45. http://dx.doi.org/10.1016/j.intell.2010.11.002

Nusbaum, E. C., & Silvia, P. J. (2011b). Are openness and intellect distinct aspects of openness to experience? A test of the O/I model. *Personality and Individual Differences*, *51*, 571–574. http://dx.doi.org/10.1016/j.paid.2011.05.013

Nusbaum, E. C., Silvia, P. J., & Beaty, R. E. (2014). Ready, set, create: What instructing people to "be creative" reveals about the meaning and mechanisms of divergent thinking. *Psychology of Aesthetics, Creativity, and the Arts*, http://dx.doi.org/10.1037/a0036549 (in press)

Obrist, P. A., Light, K. C., James, S. A., & Strogatz, D. S. (1987). Cardiovascular responses to stress: I. Measures of myocardial response and relationship to high resting systolic pressure and parental hypertension. *Psychophysiology*, *24*, 65–78. http://dx.doi.org/10.1111/j.1469-8986.1987.tb01864.x

Raudenbush, S. W., & Bryk, A. S. (2002). *Hierarchical linear models: Applications and data analysis methods*. Thousand Oaks, CA: Sage Publications.

Richards, R., Kinney, D. K., Benet, M., & Merzel, A. P. (1988). Assessing everyday creativity: Characteristics of the Lifetime Creativity Scales and validation with three large samples. *Journal of Personality and Social Psychology*, *54*, 476–485. http://dx.doi.org/10.1037/0022-3514.54.3.476

Richter, M. (2010). Pay attention to your manipulation checks! Reward impact on cardiac reactivity is moderated by task context. *Biological Psychology*, *84*, 279–289. http://dx.doi.org/10.1016/j.biopsycho.2010.02.014

Richter, M. (2012). Cardiovascular response to reward. In R. A. Wright, & G. H. E. Gendolla (Eds.), *How motivation affects cardiovascular response: Mechanisms and applications* (pp. 79–91). Washington, DC: American Psychological Association.

Richter, M. (2013). A closer look into the multi-layer structure of motivational intensity theory. *Social and Personality Psychology Compass*, *7*, 1–12. http://dx.doi.org/10.1111/spc3.12007

Richter, M., & Gendolla, G. H. E. (2009). The heart contracts to reward: Monetary incentives and preejection period. *Psychophysiology*, *46*, 451–457. http://dx.doi.org/10.1111/j.1469-8986.2009.00795.x

Sawyer, R. K. (2012). *Explaining creativity: The science of human innovation* (2nd ed.). New York, NY: Oxford University Press.

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

Segerstrom, S. C., & Nes, L. S. (2007). Heart rate variability reflects self-regulatory strength, effort, and fatigue. *Psychological Science*, *18*, 275–281. http://dx.doi.org/10.1111/j.1467-9280.2007.01888.x

Silvia, P. J. (2011). Subjective scoring of divergent thinking: Examining the reliability of unusual uses, instances, and consequences tasks. *Thinking Skills and Creativity*, *6*, 24–30. http://dx.doi.org/10.1016/j.tsc.2010.06.001

Silvia, P. J. (2012). Mirrors, masks, and motivation: Implicit and explicit self-focused attention influence effort-related cardiovascular reactivity. *Biological Psychology*, *90*, 192–201. http://dx.doi.org/10.1016/j.biopsycho.2012.03.017

Silvia, P. J., & Beaty, R. E. (2012). Making creative metaphors: The importance of fluid intelligence for creative thought. *Intelligence*, *40*, 343–351. http://dx.doi.org/10.1016/j.intell.2012.02.005

Silvia, P. J., Beaty, R. E., & Nusbaum, E. C. (2013). Verbal fluency and creativity: General and specific contributions of broad retrieval ability (Gr) factors to divergent thinking. *Intelligence*, *41*, 328–340. http://dx.doi.org/10.1016/j.intell.2013.05.004

Silvia, P. J., Beaty, R. E., Nusbaum, E. C., Eddington, K. M., Levin-Aspenson, H., & Kwapil, T. R. (2014). Everyday creativity in daily life: An experience-sampling study of "little c" creativity. *Psychology of Aesthetics, Creativity, and the Arts*, http://dx.doi.org/10.1037/a0035722 (in press)

Silvia, P. J., Eddington, K. M., Beaty, R. E., Nusbaum, E. C., & Kwapil, T. R. (2013). Gritty people try harder: Grit and effort-related cardiac autonomic activity during an active coping challenge. *International Journal of Psychophysiology*, *88*, 200–205. http://dx.doi.org/10.1016/j.ijpsycho.2013.04.007

Silvia, P. J., Kaufman, J. C., & Pretz, J. E. (2009). Is creativity domain-specific? Latent class models of creative accomplishments and creative self-descriptions. *Psychology of Aesthetics, Creativity, and the Arts*, *3*, 139–148. http://dx.doi.org/10.1037/a0014940

Silvia, P. J., & Kimbrel, N. A. (2010). A dimensional analysis of creativity and mental illness: Do anxiety and depression symptoms predict creative cognition, creative accomplishments, and creative self-concepts? *Psychology of Aesthetics, Creativity, and the Arts*, *4*, 2–10. http://dx.doi.org/10.1037/a0016494

Silvia, P. J., Martin, C., & Nusbaum, E. C. (2009). A snapshot of creativity: Evaluating a quick and simple method for assessing divergent thinking. *Thinking Skills and Creativity*, *4*, 79–85. http://dx.doi.org/10.1016/j.tsc.2009.06.005

Silvia, P. J., & Nusbaum, E. C. (2012). What's your major? College majors as markers of creativity. *International Journal of Creativity and Problem-Solving*, *22*, 31–43.

Silvia, P. J., Nusbaum, E. C., Berg, C., Martin, C., & O'Connor, A. (2009). Openness to experience, plasticity, and creativity: Exploring lower-order, higher-order, and interactive effects. *Journal of Research in Personality*, *43*, 1087–1090. http://dx.doi.org/10.1016/j.jrp.2009.04.015

Silvia, P. J., Nusbaum, E. C., Eddington, K. M., Beaty, R. E., & Kwapil, T. R. (2014). Effort deficits and depression: The influence of anhedonic depressive symptoms on cardiac autonomic activity during a mental challenge. *Motivation and Emotion* (in press).

Silvia, P. J., Wigert, B., Reiter-Palmon, R., & Kaufman, J. C. (2012). Assessing creativity with self-report scales: A review and empirical evaluation. *Psychology of Aesthetics, Creativity, and the Arts*, *6*, 1–16. http://dx.doi.org/10.1037/a0024071

Silvia, P. J., Winterstein, B. P., Willse, J. T., Barona, C. M., Cram, J. T., Hess, K. I., et al. (2008). Assessing creativity with divergent thinking tasks: Exploring the reliability and validity of new subjective scoring methods. *Psychology of Aesthetics, Creativity, and the Arts*, *2*, 68–85. http://dx.doi.org/10.1037/1931-3896.2.2.68

van der Meer, B. J. M., Noordegraaf, A. V., Bax, J. J., Kamp, O., & de Vries, P. M. J. M. (1999). Non-invasive evaluation of left ventricular function by means of impedance cardiography. *Acta Anaesthesiologica Scandinavica*, *43*, 130–134. http://dx.doi.org/10.1034/j.1399-6576.1999.430203.x

van Lien, R., Schutte, N. M., Meijer, J. H., & de Geus, E. J. C. (2013). Estimated preejection period (PEP) based on the detection of the R-wave and d*Z*/d*t*-min peaks does not adequately reflect the actual PEP across a wide range of laboratory and ambulatory conditions. *International Journal of Psychophysiology*, *87*, 60–69. http://dx.doi.org/10.1016/j.ijpsycho.2012.11.001

Wallach, M. A., & Kogan, N. (1965). *Modes of thinking in young children: A study of the creativity–intelligence distinction*. New York: Holt, Rinehart, Winston.

Weisberg, R. W. (2006). *Creativity: Understanding innovation in problem solving, science, invention, and the arts*. Hoboken, NJ: Wiley.

Wilde, S. W., Miles, D. S., Durbin, R. J., Sawka, M. N., Suryaprasad, A. G., Gotshall, R. W., et al. (1981). Evaluation of myocardial performance during wheelchair ergometer exercise. *American Journal of Physical Medicine*, *60*, 277–291.

Wright, R. A. (1996). Brehm's model of motivation as a model of effort and cardiovascular response. In P. M. Gollwitzer, & J. A. Bargh (Eds.), *The psychology of action* (pp. 424–453). New York: Guilford.

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. http://dx.doi.org/10.1111/j.1751-9004.2008.00093.x

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. http://dx.doi.org/10.1111/1469-8986.3920188

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

Zabelina, D. L., Felps, D., & Blanton, H. (2013). The motivational influence of self-guides on creative pursuits. *Psychology of Aesthetics, Creativity, and the Arts*, *7*, 112–118. http://dx.doi.org/10.1037/a0030464