Erschienen in: Experimental Psychology ; 67 (2020), 2. - S. 150-159
https://dx.doi.org/10.1027/1618-3169/a000483

The Opposite of Stress

The Relationship Between Vagal Tone, Creativity, and Divergent Thinking

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Abstract. Cognition is affected by psychophysiological states. While the influence of stress on cognition has been investigated intensively, less studies have addressed how the opposite of stress, a state of relaxation, affects cognition. We investigated whether the extent of parasympathetic activation is positively related to divergent thinking. Sixty healthy female participants were randomly allocated to a standardized vagus nerve massage (n = 19), a standardized soft shoulder massage (n = 22), or a resting control group (n = 19). Subsequently, participants completed the Alternative Uses Test (AUT), a measure of divergent thinking. Respiratory sinus arrhythmia (RSA), a vagally mediated heart rate variability component, was monitored throughout the experiment. The area under the curve with respect to the increase was calculated for RSA trajectories as an indicator of vagal tone during the relaxing intervention. Regressions tested the effect of vagal tone on AUT outcomes. We found an association between vagal tone and subsequent AUT outcomes. Yet, this association was no longer significant when controlling for the effect of the creative potential of an individual, which was strongly related to AUT outcomes. Being exploratory, we found a positive association between creative potential and vagal tone. These results imply that creative potential might be related to the capacity to relax.

Keywords: respiratory sinus arrhythmia, divergent thinking, creativity, relaxation, heart rate variability

The psychophysiological state of a person influences their cognition. Stress, for example, induces a state of high arousal, which can have impairing or facilitating effects on cognitive functions, depending on the timing of the stressor relative to the cognitive task, the stressor intensity, and the aspect of cognition that is put on focus (de Kloet, Oitzl, & Joëls, 1999; McEwen & Sapolsky, 1995; Sandi, 2013; Wolf, 2009).

Other aspects of cognition and their associations with different psychophysiological states have been less extensively investigated. One of these aspects is problem-solving, which can be categorized into convergent and divergent thinking. While convergent thinking is applied to closed questions, in which individuals search for a single, correct solution of a problem, divergent thinking describes the search for a variety of different (novel) solutions to an open question (Gilhooly, Fioratou, Anthony, & Wynn, 2007; Guilford, 1962). Although both convergent thinking and divergent thinking are essential components of problem-solving, divergent thinking is more strongly related to the generation of novel ideas and the concept of creativity (Carson & Runco, 1999).

From a meta-analysis of 76 experimental studies, one can conclude that stress might be related to creative task outcomes like divergent thinking in an inverted U-shaped pattern (Byron, Khazanchi, & Nazarian, 2010). The authors argue that situations including moderate stress can facilitate creative outcomes, while highly stressful situations can impair them. Since catecholamines, such as epinephrine, and glucocorticoids, such as cortisol, are generally believed to mediate the effect of stress on cognition (Carson & Runco, 1999), they could be considered the biological substrates behind the effect of stress on divergent thinking. This assumption is supported by pharmacological studies that indicate that the noradrenergic system affects cognitive outcomes related to divergent thinking, such as cognitive flexibility (Beversdorf, Hughes, Steinberg, Lewis, & Heilman, 1999; Silver, Hughes, Bornstein, & Beversdorf, 2004). Be that as it may, these findings suggest that divergent thinking is influenced by the psychophysiological state of an individual.

While many studies have focused on the effects of stress on cognition, less studies have looked into the reverse direction, namely, how the "opposite of stress" affects cognitive processes, and divergent thinking in particular. A state opposite to stress can be operationalized as a state of absent threat and increased relaxation, which is physiologically characterized by increased parasympathetic nervous system (PNS) activation. This regenerative state is especially important for the organism, since it allows for the restoration of resources, promotes growth, and has been shown to be a mediator of improved health (Kupari, Häring, Agirre, Castelo-Branco, & Ernfors, 2019; Laborde, Mosley, & Thayer, 2017; Thayer & Lane, 2009). Notions exist that state creativity can be promoted by using relaxation techniques (Krampen, 1997). While some studies concluded that relaxation sessions might have no or only little influence on subsequent divergent thinking outcomes (e.g., Khasky & Smith, 1999), other studies found a positive impact of relaxation techniques on divergent thinking (Hershey & Kearns, 1979; Krampen, 1997). These findings suggest that there is interest in the possible effect of relaxation on state creativity, but that results are so far inconsistent. This might be due to methodological differences in the aforementioned studies. While some used a one-time application of relaxation-inducing programs such as progressive muscle relaxation to induce a state of relaxation (Khasky & Smith, 1999), others engaged in practicing relaxation exercises over many weeks before assessing the effect on creative outcomes (Hershey & Kearns, 1979). Especially if a procedure requires the learning of a cognitive or behavioral approach, a one-time application with immediate testing of the creative outcomes appears problematic because an individual with prior exposure or experience with the procedure could then benefit much more from the intervention (Manzoni, Pagnini, Castelnuovo, & Molinari, 2008). On the other hand, when practicing the intervention over several weeks, variations in learning speed could create additional variation that might mask the true effect. Overall, diversity in relaxation interventions and variation in the intervention technique itself might explain the differences in results. As such, it is unclear whether the appropriate induction of *acute* relaxation which is independent of experience or learning can enhance state creativity. Furthermore, it is unclear which psychophysiological mechanism might underlie the proposed relationship. Since previous studies have not included physiological markers of relaxation, such as measures of PNS activity, it is unclear whether specific changes in vagal tone contribute to an improved performance in divergent thinking tasks following relaxation interventions.

Therefore, the current study investigated whether the extent of PNS activation during a relaxation intervention is facilitating creative thinking. For this purpose, we randomly assigned participants to one of three relaxing interventions (two different massage interventions and one resting control group [RCG]; see Meier et al., 2020) to induce varying degrees of relaxation and increase variability in respiratory sinus arrhythmia (RSA) – an index of PNS activation (vagal tone). Relying on a pure physiological effect, we assumed that the effect of these interventions is relatively independent of former experiences with massages. After the intervention, participants completed the Alternative Uses Test (AUT) as a measure of divergent thinking. We hypothesized that the extent of vagal tone would predict differential aspects of divergent thinking, such that higher PNS activation indicated by higher RSA values would be related to higher fluency, uniqueness, and flexibility scores in the divergent thinking test.

Methods

Participants

Sixty-three healthy female students were recruited at the University of Konstanz as part of a larger research project (Meier et al., 2020). Participant exclusion criteria were current or past orthopedic problems (e.g., scoliosis, discopathy, spinal fracture), whiplash, thyroid or cardiac disease, intake of blood-thinning or anticoagulant medication, smoking, and left-handedness, all of which might interfere with the relaxation paradigm/massage protocol. Participants were not allowed to consume caffeine-containing beverages 2 h prior to the laboratory session. The data of three participants were excluded (reasons: technical problems, n = 1; insufficient German language skills, n = 1; premature termination of the experimental procedure; n = 1), resulting in a final sample of 60 subjects. Descriptive statistics of the sample can be found in Table 1. All participants gave written informed consent and received financial compensation (10€), or experiment participation credits. The study was approved by the Ethics Committee of the University of Konstanz.

Procedure

Laboratory sessions were scheduled to start between 7:00 a.m. and 7:00 p.m. and lasted for approximately 50 min. Throughout the laboratory session, participants wore a heart rate sensor (Polar H7, Finland) to continuously monitor their heart rate (HR). After an introduction and an acclimatization period, during which participants completed demographic questionnaires and the Creative Achievement Questionnaire (CAQ; Khasky & Smith, 1999), participants sat quietly for 5 min to assess a physiological baseline. After that, participants were randomly allocated

Table 1. Descriptive statistics of the sample

Variable	VNM (n = 19)	SSM (n = 22)	RCG (n = 19)	Total sample (N = 60)
Age (years)	23.44 ± 3.37	22.46 ± 3.94	22.47 ± 2.89	22.76 ± 3.43[d]
RSA baseline[a]	5.50 ± 1.04	5.26 ± 1.04	5.22 ± 1.09	5.32 ± 1.05
HR baseline[b]	72.57 ± 11.98	79.95 ± 12.29	76.77 ± 8.85	76.61 ± 11.44
CAQ[c]	10.22 ± 3.90	8.27 ± 3.84	8.84 ± 4.40	9.05 ± 4.06[d]

Note. Data are expressed as *mean* ± *SD*. A one-way analysis of variance by experimental condition (VNM, SSM, and RCG) was calculated to test whether experimental groups differed in respect to the listed variables. There were no statistically significant differences between the groups in the listed variables. CAQ = Creative Achievement Questionnaire; HR = heart rate; RCG = resting control group; RSA = respiratory sinus arrhythmia; SSM = soft shoulder massage; VNM = vagus nerve massage.
[a]RSA baseline: mean of the first and second part of the heart rate variability baseline measurement.
[b]HR baseline: mean of the first and second part of the heart rate baseline measurement.
[c]CAQ: Creative Achievement Questionnaire.
[d]n = 59 due to one missing.

to either one of two massage intervention groups (vagus nerve massage [VNM], n = 19; soft shoulder massage [SSM], n = 22), or a RCG (n = 19) to induce varying degrees of relaxation and increase variability in vagal tone. Participants in the VNM group received a standardized 10-min massage in the head and neck area with moderate pressure applied to the skin. Participants in the SSM group received a standardized 10-min massage in the neck and shoulder area with light pressure applied to the skin (strokes and soft touch). The massages were operationalized with the help of two approved physiotherapists by defining the nature of contact, its intensity, duration, and order, and were applied by the female experimenters, who were trained by the physiotherapists prior to the study. The detailed standardized protocols for the VNM and the SSM can be obtained online at https://osf.io/4bwsj/ (Open Science Framework project DOI 10.17605/OSF.IO/4BWSJ). Participants in the RCG did not receive physical contact but remained seated and took the same body position as the other participants (head placed on a massage pillow on the desk in front of them, eyes closed). Conversations during the intervention phase were restricted to a minimum. After the intervention, participants completed the AUT for 3 min. During the succeeding recovery period, participants completed additional questionnaires. At the end of the laboratory session, participants were thanked and debriefed, and they received compensation for participation.

Heart Rate and Respiratory Sinus Arrhythmia

Throughout the experiment, RR intervals (temporal interval between two subsequent heart-beats in milliseconds) were measured using the Bluetooth low-energy Polar H7 heart rate sensor (sampling rate: 1,000 Hz) on a two-electrode chest strap (Polar, Finland) in combination with the application Heart Rate Variability Logger for iOS (Altini, 2013) running on an iPad (Apple Computer, Cupertino, CA, USA). The electrodes of the chest strap attached to the H7 heart rate sensor were moistened with water before use. To correct for artifacts caused by noise, or motion, RR intervals differing more than 20% from the previous interval were discarded by the Heart Rate Variability Logger. Ectopic beats were corrected after visual inspection, and missing data points were interpolated using an automated script (in house). Average HR and RSA (a natural logarithm of high-frequency HR variability) of the events of interest (baseline and intervention) were calculated using R version 3.5.3 (R Core Team, 2019), RStudio version 1.1.463 (RStudio Team, 2016), and the R package *RHRV* (Rodríguez-Liñares et al., 2011). RSA is a vagally mediated, frequency-domain HR variability component and is considered a reliable and pure marker of PNS activation (Berntson, Cacioppo, & Quigley, 1993; Denver, Reed, & Porges, 2007; Laborde et al., 2017; Thayer, Åhs, Fredrikson, Sollers, & Wager, 2012). RSA derives its name from the rhythmical oscillation in HR that is linked to respiration: While HR increases during the inhalation phase, it decreases during the exhalation phase (Berntson et al., 1993); nonetheless, any factor impacting on PNS activation also affects RSA.

RSA was calculated as the natural logarithm of high-frequency HR variability (fixed frequency bandwidth of 0.15–0.4 Hz) using 2.5-min segments from a 5-min window of each participant's baseline and a 10-min window of each participant's intervention. Splitting the windows this way allows for a higher temporal resolution. From the segments, instantaneous HR signal was extracted, and artifacts and values outside of the physiological range were detected and removed by the filter algorithm provided by the R package *RHRV* (Rodríguez-Liñares et al., 2011). Next, the HR signal was interpolated at a sampling frequency of 4 Hz. Average HR was calculated based on these calculations. Finally, mean RSA over the 2.5-min segments was calculated using 60-s segments with a time shift of 30 s.

Since both massage interventions induced a similar increase in RSA (Meier et al., 2020), we used a composite measure of *vagal tone* instead of the variable condition (VNM, SSM, RCG) for our main analysis. The area under the individual RSA curve with respect to the increase (AUCi; Prüssner, Kirschbaum, Meinlschmid, & Hellhammer, 2003) was calculated as a measure of RSA reactivity as a marker of vagal tone during the time of the intervention. The AUCi is a measure used to incorporate repeated measurement values by estimating the integral of the trajectory and correcting it for initial baseline differences. Here, high (positive) AUCi values indicate high RSA increases induced during the different interventions, which are indicative of high *vagal tone*. For descriptive statistics, we further calculated an *RSA baseline* by averaging the two RSA baseline values.

Besides RSA as a marker of vagal tone, low-frequency (LF) HRV and the ratio between LF and high-frequency (LF/HF) HRV are frequently used to describe sympathovagal balance of the autonomic nervous system (Laborde et al., 2017). In the course of the processing described above, both markers were calculated in addition to RSA. As we have shown previously, both massage interventions (VNM, SSM) induced a significant increase in *vagal tone* compared to the RCG (Meier et al., 2020). Considering AUCi of RSA during the intervention, the experimental groups differed significantly in their magnitude of vagal tone, $F(2, 57) = 11.09$, $p < .001$, partial $\eta^2 = .28$. Furthermore, the experimental groups differed in respect to AUCi of LF HRV during the intervention, $F(2, 57) = 3.17$, $p = .049$, partial $\eta^2 = .10$, and in respect to AUCi of LF/HF HRV during the intervention, $F(2, 57) = 3.22$, $p = .047$, partial $\eta^2 = .10$. Since the effects were most pronounced for RSA in terms of effect size, we will focus on the effects of *vagal tone* in the following. The LF and LF/HF HRV data can be obtained online at the Open Science Framework project associated with this work (https://osf.io/d4s6q/; DOI 10.17605/OSF.IO/D4S6Q).

Alternative Uses Test

The AUT (Gilhooly et al., 2007) was used as a measure of divergent thinking, or state creativity. The AUT is a prototypical test with proven reliability and validity (Müller, Gerasimova, & Ritter, 2016) in which subjects are asked to find as many different uses as possible for a familiar object beyond the common use (Heilman, 2016). In this study, participants were asked to list as many alternative uses for a paper clip as possible within 3 min. For the analysis, the qualitative solutions of each participant were rated on three different subscales. The total amount of produced solutions represents the subscale *fluency*. The subscale *uniqueness* represents the originality of the different solutions in comparison to the other participants' solutions. For this rating, the frequency of each solution in the complete sample was determined (naming frequency). After that, the naming frequencies of all solution of an individual were averaged to represent the *uniqueness* score, with higher values indicating generally less unique solutions. The amount of different solution categories represents the subscale *flexibility*. The classification of the solutions was based on keywords and categories used in a previous report (Dippo & Kudrowitz, 2013).

To avoid effects of repeated performance through exercise, the AUT was performed once after the intervention without assessing preintervention performance.

Creative Achievement Questionnaire

As has been proposed by Colzato and colleagues (Colzato, Ozturk, & Hommel, 2012), the CAQ (Carson, Peterson, & Higgins, 2005) was used to assess participant's previous creative accomplishments in different contexts and their experience with creativity to control for potential baseline differences in creative potential. The CAQ is a self-report measure that is considered an indicator of past creativity. The CAQ includes questions concerning former achievements in various creative areas and the existence of objective evidence of those in the form of awards and press articles. The questionnaire shows good test–retest reliability ($r = .81$), and a good (albeit very high) internal consistency (*Cronbach's* $\alpha = .96$) (Carson et al., 2005). Higher CAQ values indicate more creative experiences and consequently a higher overall creative potential. One participant did not fill out the CAQ; therefore, the analyses for this questionnaire relied on $n = 59$ subjects.

Statistical Analysis

Statistical analyses were conducted in JASP version 0.11.1 (JASP Team, 2019). Graphs were created in R version 3.5.3 (R Core Team, 2019) using RStudio version 1.1.463 (RStudio Team, 2016) with the package *ggplot2* (Wickham, 2016).

The assumptions for linear regression models were checked visually by evaluating Q–Q plots (normality and linearity assumption) and residual plots (homoscedasticity). Additionally, for regressions including covariates (multiple regressions), the assumption of collinearity was checked using the variance inflation factor and tolerance estimates. Finally, case-wise diagnostics (e.g., Cook's distance) were applied to detect potential influential cases and outliers. If not reported otherwise, all assumptions were met and no influential cases were detected.

In a first step, the effect of the experimental manipulation (induced relaxation) on cognition was quantified

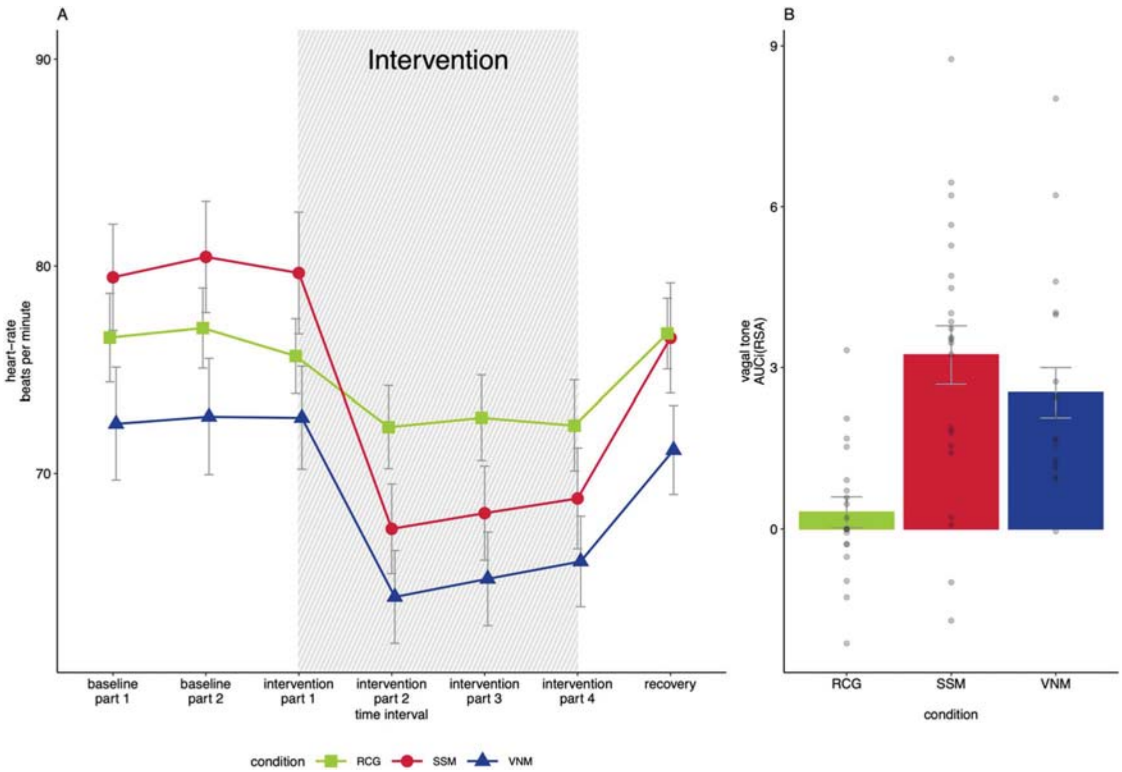

Figure 1. (A) Changes in heart rate across the experiment in the three different experimental groups: vagus nerve massage (VNM), soft shoulder massage (SSM), and resting control group (RCG). The shaded area covers the time of the intervention. (B) The effect of the three different experimental groups on vagal tone. Values are depicted as means ± *SE*. AUCi(RSA) = Area under the respiratory sinus arrhythmia curve with respect to increase.

using three linear regression models to estimate the effect of *vagal tone* on the different measures of *divergent thinking (fluency, uniqueness, flexibility)*.

In a second step, we recalculated the three regressions to confirm the results, while controlling for the effect of potential covariates. To estimate the significance of covariates, we calculated bivariate Pearson's correlations between the criterium variables (divergent thinking as indicated by the *fluency*, *uniqueness*, and *flexibility* scores of the AUT) and the variables *age* (in years), *creative potential* (CAQ score), and *RSA baseline* (the mean of the two RSA baseline values). Variables that were significantly correlated with the criterium variables were statistically controlled for in the recalculation of the linear regressions.

Finally, we compared the results of the linear regression models with and without controlling for the effect of covariates.

Results

For descriptive purposes, the average HR during the specific segments of the experiment split for the three experimental interventions (VNM, SSM, and RCG) and the effect of the three different experimental groups on *vagal tone* are depicted in Figure 1.

The linear regression model indicated a significant effect of *vagal tone* on *fluency*, with the model explaining 6.7 % of total variance (R^2), $F(1, 58) = 4.19$, $p = .045$. The variable *vagal tone* contributed significantly to the model ($\beta = .26$, $T = 2.05$, $p = .045$).

Furthermore, *vagal tone* did not significantly predict the divergent thinking aspect *uniqueness*, with the model explaining 5.9% of total variance (R^2), $F(1, 58) = 3.65$, $p = .061$. The variable *vagal tone* did not contribute significantly to the model ($\beta = -.24$, $T = -1.91$, $p = .061$).

The regression predicting *flexibility* from *vagal tone* was not statistically significant, with the model explaining 6.1% of total variance (R^2), $F(1, 58) = 3.74$, $p = .058$. The variable *vagal tone* did not contribute significantly to the model ($\beta = .25$, $T = 1.94$, $p = .058$).

Overall *creative potential* (as indicated by the CAQ score) was linearly correlated with all measures of divergent thinking (*fluency*: $r = .33$, $p = .011$; *uniqueness*: $r = -.30$, $p = .020$; *flexibility*: $r = .27$, $p = .037$). Therefore, this variable was included as a covariate in the subsequent analyses. The variables age and RSA baseline were

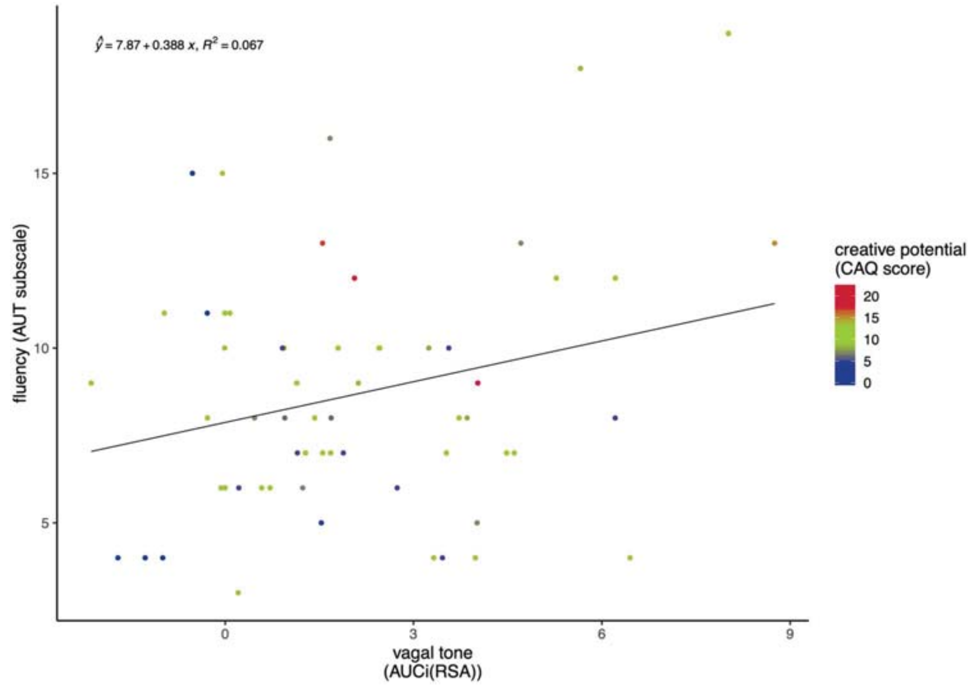

Figure 2. The regression model predicting the subscale fluency of the Alternative Uses Test (AUT) as a function of vagal tone during the relaxing intervention. The covariate creative potential is displayed as color of the scatterplot. AUCi(RSA) = Area under the respiratory sinus arrhythmia curve with respect to increase; CAQ = Creative Achievement Questionnaire.

not significantly related to the criterium variables (all $p >$ .05).

When controlling for significant covariates and recalculating the analyses, *fluency* was significantly predicted from the model. Overall, the regression explained a total of 13.4% of total variance (R^2), $F(2, 57) = 4.32$, $p = .018$. In this model, the variable *vagal tone* ($\beta = .16$, $T = 1.28$, $p = .206$) was not a significant predictor of *fluency*, but *creative potential* ($\beta = .28$, $T = 2.10$, $p = .041$) significantly contributed to the model. The relationship between the three variables is depicted in Figure 2.

Furthermore, *uniqueness* was significantly predicted by the model controlling for the effects of *creative potential*. The model explained 11.6% of total variance (R^2), $F(2, 57) = 3.66$, $p = .032$. Neither the variable *vagal tone* ($\beta = -.17$, $T = -1.24$, $p = .219$) nor *creative potential* ($\beta = -.25$, $T = -1.88$, $p = .065$) significantly predicted the criterium.

Finally, a separate regression model did not include a significant effect of *vagal tone* on *flexibility*, when controlling for the effects of *creative potential*, with the model explaining 10.1% of total variance (R^2), $F(2, 57) = 3.15$, $p = .051$. The variables *vagal tone* ($\beta = .17$, $T = 1.29$, $p = .202$) and *creative potential* ($\beta = .22$, $T = 1.62$, $p = .110$) were no significant predictors of *flexibility*.

In sum, the results of the regression models without covariates indicated a significant influence of vagal tone on specific aspects of divergent thinking, namely, *fluency*. However, when controlling for creative potential, *vagal tone* was no longer a significant predictor of different aspects of divergent thinking. Based on these analyses, our data do not support the hypothesis "The degree of vagal tone predicts different aspects of divergent thinking."

Since *creative potential* seemed to have some effect on the relationship between divergent thinking outcomes and *vagal tone*, we further conducted an exploratory analysis focusing on the relation between *creative potential* and the variables *vagal tone*, and *RSA baseline*. For this purpose, we calculated Pearson's correlations between the variables. We found a significant positive correlation between *creative potential* and *vagal tone* ($r = .32$, $p = .013$), but no association between *creative potential* and *RSA baseline* ($r = .05$, $p = .729$). The association between *creative potential* and *vagal tone* is depicted in Figure 3. Thus, the results suggest that creative potential is not only related to divergent thinking but also to vagal tone during a relaxation intervention.

To gain additional insight into these interrelationships, the same analyses were further performed using the variable *condition* (VNM, SSM, RCG) instead of *vagal tone*. The detailed results of this analysis can be obtained online at the Open Science Framework project associated with this work (https://osf.io/d4s6q/; DOI 10.17605/OSF.IO/D4S6Q). Summing up the findings, the AUT scores (*fluency*, *uniqueness*, *flexibility*) did not significantly differ between the three experimental conditions (VNM, SSM, RCG) when using analysis of variances. Including *creative*

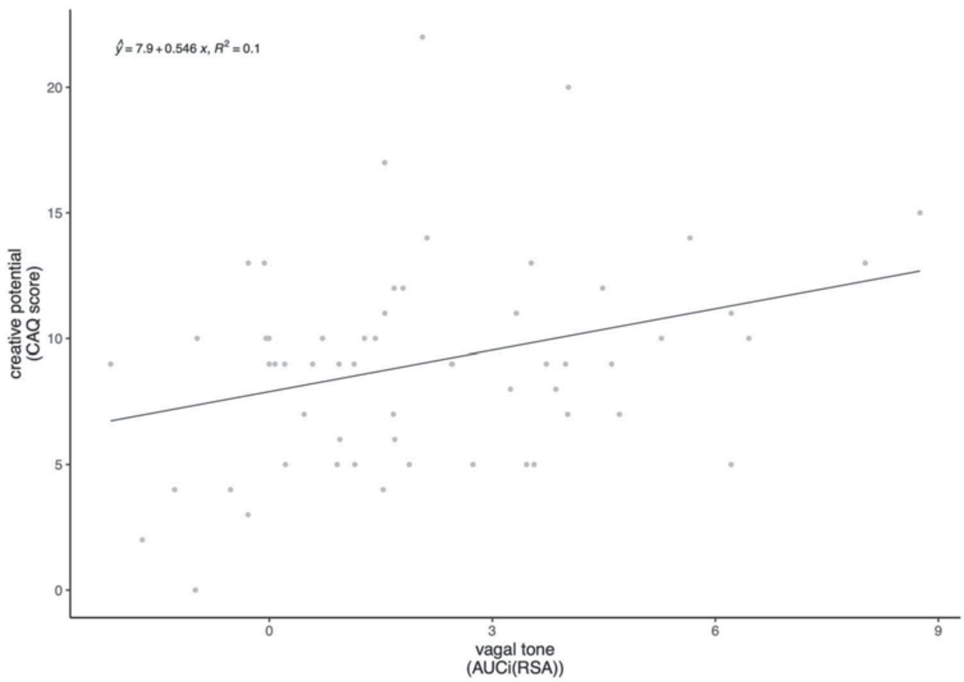

Figure 3. The significant association between vagal tone during the relaxing intervention and creative potential. AUCi(RSA) = Area under the respiratory sinus arrhythmia curve with respect to increase; CAQ = Creative Achievement Questionnaire.

potential as a covariate did not change the results but again showed that creative potential was a significant predictor of the AUT outcomes *fluency* and *uniqueness*.

Discussion

This study investigated whether the extent of PNS activation during a relaxation intervention can facilitate aspects of divergent thinking (state creativity) directly after the intervention. Using a sample of 60 female participants, we found an association between vagal tone during the relaxation intervention and *fluency* in the divergent thinking task. However, when controlling for creative potential as a covariate, which was associated with both vagal tone and performance on all three measures of divergent thinking, this effect was no longer significant. In the models including creative potential as a covariate, vagal tone neither predicted the number of produced solutions (*fluency*), nor the originality of the produced solutions (*uniqueness*), nor the number of different solution categories (*flexibility*). In conclusion, the opposite of stress, or vagal tone – operationalized through the vagally mediated HR variability component RSA – was not a predictor of creative aspects of cognition in this study when controlling for creative potential.

We did not expect that vagal tone would have specific effects on certain aspects of divergent thinking, but rather an overall effect, leading to improvements in all aspects of divergent thinking, or state creativity. These assumptions were based on theoretical considerations as well as the results from past studies, showing small but promising effects of relaxation interventions (Hershey & Kearns, 1979; Krampen, 1997) and transdermal stimulation of the vagal nerve (Colzato, Ritter, & Steenbergen, 2018). These previous findings are paralleled by a discussion by Heilman (2016) arguing that decreased release of norepinephrine from the locus coeruleus might be related to increased creative outcomes during states of resting or relaxation (Heilman, 2016). In other words, reduced cortical arousal may facilitate unusual associations. However, findings in animals and humans also suggest that direct vagal stimulation activates the locus coeruleus, which results in an increase in HR through adrenergic pathways (Follesa et al., 2007; Ghacibeh, Shenker, Shenal, Uthman, & Heilman, 2006). These findings seem contradictive at first sight and in conflict with findings of the present study. Since we observed a significant increase in RSA during the intervention phase (Meier et al., 2020), we can speculate that we induced a decrease in norepinephrine levels that resulted in the observed increase in HR variability. Apart from that, researchers have discussed that creativity might be associated with the default mode network (DMN) (Beaty et al., 2014; Kühn et al., 2014; Raichle, 2015). This complex neural network comprises structures that are active in the resting state and whose activity decreases as soon as attention-intensive tasks are being solved or as soon as an activity has to be performed (Raichle, 2015). Even though the neuroanatomical structures underlying creativity do not exactly match the DMN, this approach seems promising (Jung, Mead, Carrasco, & Flores, 2013). It is possible that the activation of the DMN is necessary to foster creative outcomes and that physical arousal is a moderator of this relationship. However, as massages might also trigger other than purely physiological effects that facilitate relaxation, such as receiving attention by the massage therapist, we cannot be certain that the effects observed are purely due to vagal stimulation. In fact, while other studies investigating the effect of vagal stimulation on cognitive processes used electric impulses to stimulate the vagal nerve directly (e.g., Martin, Denburg, Tranel, Granner, & Bechara, 2004; Schevernels et al., 2016) or transdermally (e.g., Colzato et al., 2018; Jacobs, Riphagen, Razat, Wiese, & Sack, 2015), the standardized massage protocols used in this study may be considered a first attempt to stimulate the vagal nerve through transdermal, but manual stimulation that included a psychologically relaxing component. Interestingly, transdermal stimulation of the vagal nerve seems to have similar increasing effects on HR variability (Clancy et al., 2014), which resembles our results. Overall, we cannot exclude the possibility that the form of stimulation of the vagal nerve has an influence in its impact on HR variability. Further research has to determine whether these potential differences also exert different effects on cognitive processes.

Interestingly, in an exploratory analysis, we found a positive association between the creative potential, or experience, of an individual and the increase in vagal tone during a relaxing intervention. Here, it seemed that higher creative potential of an individual was associated with a higher capacity to relax. This observation that vagal tone is related to creative potential might hold some rescue potential for our initial assumption, although it is strictly correlational. Vagal tone comprises state and trait components, and the ability to relax under a given situation might be related to the ability to generate creative solutions to a given task on the spot (state creativity). However, we can further only speculate on which other variables might underlie this relationship. One possible factor that might play a role here is personality. It has been argued in the past that neuroticism is positively related to creativity (Perkins, Arnone, Smallwood, & Mobbs, 2015). Also, it has been shown that the effectiveness of relaxation paradigms is related to personality traits (Peciuliene, Perminas, Gustainiene, & Jarasiunaite, 2015). Since personality was unfortunately not assessed within the current study, it might be interesting to consider when studying the link between creative potential and the capacity to relax in future studies. Overall, our results and the small number of studies that have investigated this subject encourage to further research on these relationships by means of experimental study designs.

Although certain strength of this study, including the objective measure of PNS activity, should be highlighted, some limitations also merit discussion. Here, the limited generalizability of the results due to the homogeneous, young, and physically and mentally healthy sample should be pointed out in particular. Related to this, potential effects of hormonal status on our results cannot be excluded since menstrual cycle phase was neither assessed nor controlled for in this study. This also accounts for other potentially confounding variables like time of day, chronic stress levels, or levels of physical activity and fitness, which are known to influence the functioning of the PNS in particular. Besides that, the still relatively small sample size raises potential power issues. This is why these results need to be confirmed in replication studies using a more heterogeneous sample with bigger sample size. Nevertheless, we think that this study is an important contribution to encourage studies testing the effects of relaxation on cognition.

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Acknowledgment
The authors thank the University of Konstanz for funding support.

Conflict of Interest
The authors declare no competing interests.

Publication Ethics
The study was approved by the Ethics Committee of the University of Konstanz, Germany.

Authorship
M. Meier, J.C. Prüssner, A. Benz, U.U. Bentele, E. Unternaehrer, M. Wenzel, and S. Schorp contributed to the conception and design of the study. M. Wenzel and S. Schorp acquired the data. M. Meier, E. Unternaehrer, S.J. Dimitroff, and J.C. Prüssner analyzed the data and interpreted the results together with A. Benz, U.U. Bentele, and B. Denk. M. Meier drafted the manuscript together with J.C. Prüssner and E. Unternaehrer. All authors read, revised, and approved the final version of the manuscript.

Funding
The study has been supported by an institutional resaerch funding from the University of Konstanz to Jens C. Prüssner.

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