BACHELOR THESIS

The Relationship between Skin Conductance and Self-Reported Stress

Does the relationship exist and, if so, does it differ across different types of stressors?

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Abstract

In current stress research it is well acknowledged that acute psychological stress activates the endocrine-, physiological-, and psychological system (e.g. Campbell & Ehlert, 2012). However, although this homeostatic process between these systems is often assumed, literature regarding this relationship is inconsistent. We proposed that these inconsistencies may be due to a lack of differentiation between different types of stressors. Therefore, the present study examined whether a relationship between the physiological-, and psychological system exists and, if so, whether this relationship differs, depending on whether a social-, environmental-, or cognitive stressor is used. 55 students took part in a single session experiment where they were confronted with the Sing-a-Song-Stress Test (SSST; social stressor), a Noise Test (environmental stressor) and the Beauty Contest Game (BCG; cognitive stressor) while their skin conductance response (SCR) and self-reported stress were measured. Results indicated no overall correlation between relative increase in mean amplitude SCR and difference scores of self-reported stress. The environmental stressor showed a significant correlation between these systems but this correlation did not significantly differ from the correlations of the SSST and the BCG. Therefore, it cannot be answered if the relationship between the physiological-, and psychological system exists. However, the study provides first evidence that this relationship does not seem to vary across different types of stressors. This insight can give a direction for future research and, hereby, help to further understand the complex mechanisms in the assumed homeostatic process between systems in stress.

Keywords: social stressor, environmental stressor, cognitive stressor, self-reported stress, skin conductance

Samenvatting

Tegenwoordig is in stressonderzoek erkend dat acute psychologische stress leidt tot activatie van het endocrien-, fysiologische- en psychologische systeem (bijv. Campbell & Ehlert, 2012). Hoewel deze homeostatische proces tussen deze systemen vaak wordt aangenomen zijn de bevindingen vanuit de literatuur hierover tegenstrijdig. We stelden dat deze tegenstrijdige bevindingen kunnen worden veroorzaakt door een gebrek aan differentiatie tussen verschillende soorten stressoren. Daarom heeft deze studie onderzocht of een relatie bestaat tussen het fysiologische-, en psychologische systeem en, zoals ja, of deze relatie verschilt, afhankelijk daarvan of er een sociale-, milieu-, of cognitieve stressor wordt gebruikt. 55 studenten namen deel aan een experiment waar ze werden geconfronteerd met de Sing-a-Song-Stress Test (SSST; sociale stressor), een Noise Test (milieu stressor) en de Beauty Contest Game (BCG; cognitieve stressor), terwijl hun huidgeleiding reactie (SCR) en zelf-gerapporteerde stress werden gemeten. De resultaten toonden over het algemeen geen correlatie tussen de relatieve stijging van de gemiddelde amplitude SCR en de verschil scores van zelf-gerapporteerde stress. De milieustressor toonde een significante correlatie tussen de systemen maar deze correlatie verschilde niet significant van de correlaties van de SSST en de BCG. Het kan niet worden beantwoord of een relatie bestaat tussen het fysiologische- en psychologische systeem. De studie geeft wel een eerste indicatie dat deze relatie niet lijkt te variëren tussen verschillende soorten stressoren. Deze inzicht kan een richting geven voor toekomstig onderzoek en helpt hierdoor om een beter beeld te krijgen van de complexe mechanismen die een rol spelen in het veronderstelde homeostatische proces tussen systemen in stress.

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1. Introduction

In current stress research it is well acknowledged that acute psychological stress activates three systems in the body, namely the hypothalamic-pituitary-adrenal axis (HPA; Hellhammer, Wüst & Kudielka, 2009), the sympathetic nervous system (SNS; Selye, 1950) and the psychological system (Lazarus, 1966; Lazarus & Folkman, 1984). Starting in 1936, Hans Selye first introduced the term “stress” and he found out that chronic stress can make one ill. In 1984, Lazarus and Folkman proposed a psychological component of stress, cognitive appraisal, and defined stress as the evaluation of a specific event as threatening to the stability of the individual’s endocrine, physiological and psychological homeostasis (Andrews, Ali, & Pruessner, 2013; Lazarus & Folkman, 1984). Nowadays, this definition is widely used and the term homeostasis, the balance between all three systems, is a core assumption in stress research (e.g. Andrews et al., 2013; Gaab, Rohleder, Nater, & Ehlert, 2005; Ursin & Eriksen, 2004). This assumed interplay of different systems is currently being used to, for example, measure stress through biological measures, such as cortisol, heart rate and skin conductance (Hellhammer et al., 2009). However, although the effect can be observed, there is a lack of understanding in how this interaction between the physiological-, endocrine-, and psychological systems works and what the exact relationship between these systems is. Studies regarding this topic showed mixed results in the correlations between these systems, ranging from moderate to non-existent (Campbell & Ehlert, 2012). This inconsistency makes it difficult to create a comprehensive model that describes the relationship and interaction between all three systems of stress (Andrews et al., 2013).

As discussed later, one possible explanation for this inconsistency may be the lack of differentiation between different types of stressors. We propose that if different stressors lead to variations in the relationship between the physiological system and the psychological system, this may explain the inconsistencies found in the literature regarding stress systems. Therefore, the current paper investigates whether a correlation between the physiological-, and psychological system exists and whether this correlation differs, depending on the type of stressors that is used.

1.1 Between-system correlations

When examining the relationships between the physiological-, endocrine-, and psychological stress systems, most studies adapt Lazarus' concept of 'response coherence' (Lazarus & Folkman, 1984). This concept suggests that the initial stressor is perceived and evaluated by the psychological system through first evaluating the significance or meaning of the stressor and then assessing the available resources and strategies to cope with it. After that, the psychological system imposes a coherent response across all systems through interaction between each other (Lazarus & Folkman, 1984). Therefore, according to Andrews et al., 2013, "one should expect that being exposed to a stressful event leads to a perception of that event, and the activation of both the SNS and the HPA" (p. 950). However, this is not what most studies found (Campbell & Ehlert, 2012). In a meta-analysis, Campbell and Ehlert (2012) reviewed 359 studies that used the Trier Social Stress Test (TSST; Kirschbaum, Pirke, & Hellhammer, 1993) and found that most of the studies did not find a relationship between the systems. Furthermore, evidence for this relationship is also absent for other systems that involve psychological systems such as emotional states, despite the centrality of this concept in these systems (Evers et al., 2014; Mauss, Levenson, McCarter, Wilhelm, & Gross, 2005.). This raises the question whether this correlation between the physiological-, and psychological system exists, and if it does exist, how can these inconsistencies between studies be explained.

According to Andrews et al. (2013), there are several possible reasons for these variations. First, the original perception of an event may be masked due to subjective appraisals of the own emotional reaction that may lead to cognitive and behavioral responses such as emotion regulation or avoidance which, in turn, may influence the perception. Secondly, specific characteristics of the individual's personality, such as denial, could distort self-reports by altering the awareness of his or her emotions.

Furthermore, as discussed in the next section, research findings may seem inconsistent because of different activations of the systems, depending on the type of stressor that is being used. Similar to the postulate of Evers et al. (2014), it is argued that, instead of always reacting in the same manner, different types of stressors, such as social-, environmental-, or cognitive stressors, could lead to different responses in the physiological and psychological systems.

1.2 Types of stressors

When sorting existing studies into different groups based on the stressor that was used in the study, study results seem to show more consistent findings. Studies that employed social stressors such as the Trier Social Stress Test (TSST) or the Sing-a-Song Stress Test (SSST; Brouwer & Hogervorst, 2014) found non-existent to moderate correlations between subjective experience and physiological response (Campbell & Ehlert, 2012; Kudielka, Buske-Kirschbaum, Hellhammer, & Kirschbaum, 2004; Lundberg & Frankenhaeuser, 1980). However, studies that employed cognitive stressors did not find these correlations (Elsesser, Freyth, Lohrmann, & Sartory, 2009). Rather, it is reported that physiological measures react more sensitively to cognitive stress than self-reports (Knaepen et al., 2015; Luque-Casado, Perales, Cárdenas, & Sanabria, 2016; Mehler, Reimer, Coughlin, & Dusek, 2009). This means that physiological responses to the cognitive stressor could be measured although the respondent did not report any perceived stress. However, this physiological response did not increase gradually with an increase in cognitive stressors but plateaued relatively quickly (Luque-Casado et al., 2016; Mehler et al., 2009), suggesting a rather fixed physiological increase, independent from the level of cognitive stress. Also, according to Mauss et al. (2005), emotions that involve a stronger cognitive component were found to have weaker correlations between physiological-, and psychological systems. Besides that, a third type of stressor, the environmental stressor, is rarely used in contemporary research. One study that did include an environmental stressor suggests that self-reports seem to be able to moderately predict physiological responses (Cohen, 1985). Thus, it seems that self-reported environmental stress and physiological response would moderately correlate with each other, yet it needs more evidence to safely make this assumption.

It is important to note that a stressor that provokes a higher absolute physiological response is more likely to be perceived as stressful by the participant which, in turn, could lead to a higher correlation between the physiological-, and psychological systems. Also, less noticeable increases in stress are more likely to be interpreted in an ambiguous way, leading to a lower correlation between the physiological-, and psychological system (Campbell & Ehlert, 2012).

Taken together, the differentiation of studies based on the stressor showed more consistent findings which suggests that there may be differences in correlations between physiological measurements and self-reports in stress, depending on whether a social-, environmental-, or cognitive stressor is used. Yet, there is no known study that compares the relationship between these systems across the types of stressors which leaves this proposition inconclusive. Therefore, the current study examines whether the correlation between physiological measurements and self-reports in stress differs, depending on the type of stressor that is used. In order to measure the individual's physiological response to stress, electrodermal activity (EDA) was used as an indicator of stress.

1.3 Electrodermal Activity

Besides heart rate and blood pressure, EDA is one of the most widely used measures to assess activity of the SNS in stress (Andrews et al., 2013; Boucsein, 2012). EDA is a common term for all electrical phenomena in the skin and it is recorded in skin conductance (SC) units. SC can be further divided into tonic (SCL = skin conductance level) and phasic (SCR = skin conductance response) phenomena (Boucsein, 2012). SCL indicates the response-free (e.g. baseline) level of skin conductance whereas SCR typically measures a rapid augmentation of skin conductance which is mostly the response to an external stimulus (Boucsein, 2012). The difference between the individual's response-free level (SCL) and his or her measured response to a stimulus (SCR) is called amplitude. In the present study, the relative increase of this amplitude in SCR will be used to measure participants' physiological response to stress.

1.4 The current study

In the present study, it was investigated whether a correlation between the physiological-, and psychological system exists and, if so, whether the correlation between these systems differs, depending on whether a social-, environmental-, or cognitive stressor is used. In order to answer these questions, participants completed three different stress tasks while their relative increase in mean amplitude SCR was measured and their self-reported stress was assessed. This results in the following research questions:

1. Does a significant correlation between relative increase in mean amplitude SCR and self-reported stress exist?

2. Does the correlation between relative increase in mean amplitude SCR and self-reported stress differ, depending on whether a social-, environmental-, or cognitive stressor was used?

2. Method

In order to answer the research questions, 55 students took part in a single session experiment where they were confronted with social-, environmental-, and cognitive stressors while their relative increase in mean amplitude SCR was measured and self-reported stress responses were obtained to investigate the relationship between the physiological- and psychological system.

2.1 Procedure

On arrival at the laboratory, participants were told that they would participate in a validation study for the Empatica E4 wearable (Empatica Inc.). After the informed consent was signed (see Appendix A) and all demographic questions were answered, the physiological sensors were attached and the participants indicated their baseline stress level. Then, the experiment started and the participants were instructed not to move and not to speak to the experiment leader since all information were shown on the monitor and any movements would alter the physiological measures. Next, all three (social-, environmental-, and cognitive-) stressors including baseline-, and recovery period were presented in one sequence on the monitor. Between the tasks, participants were asked to fill in the stress questionnaire on the computer using the trackpad of a laptop (see Appendix D). The whole experiment took around 30 minutes on average.

During the experiment, the participants were not able to see their own physiological response to the stressors. The experiment leader sat next to the participants and wrote down all movements of the participants, if the participants sang a song during the social stressor and which number the participants picked during the cognitive stressor. After the experiment, all participants got debriefed and it was explained that the experiment’s intention was to measure physiological responses- as well as their subjective perception of stress to examine the relationship between these systems.

Figure 1. Experiment design. BP = Baseline Period, RP = Recovery Period, N_1 = Neutral sentences of the SSST, N_2= Neutral sentences of the BCG, SQ = Stress Questionnaire

2.2 Apparatus

Skin conductance. Skin conductance responses measured using the SC-Flex/Pro skin conductance sensor (Model: SA9309M, Thought Technology Ltd.). Electrodes embedded in fastener bands were attached around the medial phalanges of the index and ring finger. Physiological data was processed by a ProComp Infiniti encoder. The sampling frequency for all signals was fixed at 256 samples/second.

Software. The experiment was programmed in Python 2.7 and ran with PsychoPy v1.8 (Source code available on request). All instructions of the experiment were presented on a 17-inch laptop display.

2.3 Materials

Social stressor. A modified version of the Sing-a-Song Stress Test was used as a social stressor (Brouwer & Hogervorst, 2014). The participants were asked to sit quietly and focus on their breathing for two minutes during the baseline period. Then, they were presented with four cognitive tasks such as: “Think of different animals that start with the letter P” (see Appendix B). Every task was presented for ten seconds and then a countdown was shown, counting down from 30 seconds. The fifth task told the participants to prepare a song that they could sing. After a 30 seconds countdown, the text:” Now sing a song aloud over the next 30 seconds and try to keep your arms still. Keep singing!” appeared and it was written down whether the participants sang or not. Then, the participants were again asked to sit quietly and focus on their breathing for two minutes during the recovery period.

Environmental stressor. After a two-minute baseline period, where participants were asked to sit quietly and focus on their breathing, participants were presented with 1000Hz beep sounds that lasted for 200ms each and appeared in a fixed random order. The total duration of the environmental stressor was five minutes with a total of 26 beep sounds and an average time of 11.38 seconds (SD = 2.87) between two sounds. After the five-minute period, the participants were asked to focus on their breathing for two minutes during the recovery period.

Cognitive stressor. In the current study a modified version of the Beauty Contest Game was used as a cognitive stressor (see Leder, Häusser, & Mojzisch, 2015). The participants were asked to sit quietly and focus on their breathing for two minutes during the baseline period. Then, two tasks were presented, namely: “Think of things you can find in a living room.” and “Think of different animals that start with the letter C” with a 30 second countdown after each sentence (see Appendix C). Next, the Beauty Contest Game was presented. It was explained that every participant would say a number between one and one hundred and that the average of all answers would be calculated. Then, this average would be multiplied by 2/3 and the participant whose number was closest to the result would win €25 as a gift card. The task description was presented for 40 seconds and the participant then had 30 seconds to choose a number. The participants were asked to say the chosen number out loud and not move during the task.

Stress Questionnaire. The stress questionnaire for reported stress consisted of the following four items: “How stressed were you BEFORE x?”, “How stressed were you DURING x?”, “How stressed were you RIGHT AFTER x?” and “How stressed are you at this moment?” whereby x was substituted with the specific task name (see Appendix D). All items were answered on a seven-point multi-item Likert scale (1 – not at all stressed, 7 – extremely stressed).

2.4 Design and Participants

The research design of this study was correlational as it studied the relationship between relative increase in mean amplitude SCR and self-reported stress across different types of stressors (see Fig. 2). The variables in this study were the relative difference between baseline and stressor in mean amplitude SCR, self-reported stress and the type of stressor which was either a social-, environmental-, or cognitive stressor. The study consisted of 55 participants (30,9 % female) with an age range between 19 years and 36 years (M = 24.16, SD = 4.4). All participants in this study were volunteers and they had the chance to win a €25 gift card. Most participants were students who were recruited from the Psychology Participants Pool by signing up online and by convenience sampling.

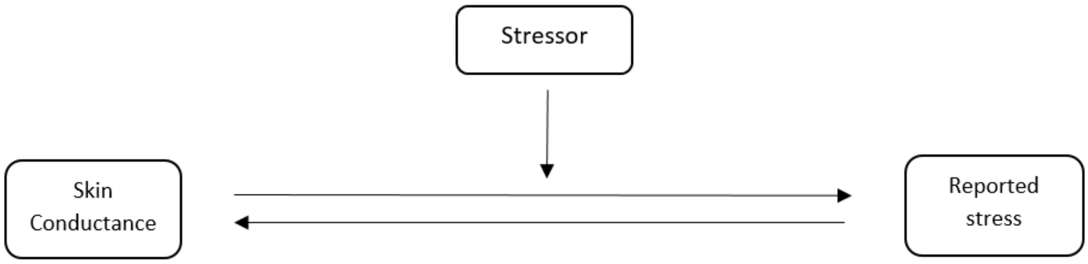

Figure 2. Illustration of the potential relationship between the physiological system (skin conductance) and psychological system (reported stress). It was argued that this relationship may differ, depending on whether a social-, environmental-, or cognitive stressor is used.

2.5 Plan of Analyses

All raw data files were first analysed in MATLAB (The MathWorks, Inc.) using Continuous Decomposition Analysis (CDA) in Ledalab. The amplitude of every skin conductance peak within a specific marker was computed and per marker and participant, a mean amplitude score was calculated.

For further analyses, SPSS 22 (The International Business Machines Corporation, IBM) was used. Descriptive statistics such as frequencies, means and standard error of means were computed. Next, the mean amplitude scores of all baseline markers (baseline period and neutral sentences) of the SSST were computed into a single mean baseline score and this process was repeated to calculate a single mean baseline score for the BCG. Then, the mean amplitude scores of all markers of the noise test (beep sounds) were computed into a single mean amplitude score. This way, every stressor had a single mean baseline score and a single mean amplitude score. Subsequently, t-tests were carried out to examine whether the mean amplitude scores of the respective stressor significantly differed from the mean amplitude scores of the baselines.

After that, for every stressor and participant mean difference scores were calculated. These scores consisted of the difference between the mean baseline score and the mean amplitude score of the respective stressor. Furthermore, in order to account for individual differences in skin conductance response sensibility, a relative difference score ($\boldsymbol{d}$) was computed using the following formula:

$$\boldsymbol{d} = \frac{(\boldsymbol{y} - \boldsymbol{x})}{(\boldsymbol{y} + \boldsymbol{x}) \div \mathbf{2}}$$

Hereby, $\boldsymbol{y}$ equals the mean amplitude score of the respective stressor while $\boldsymbol{x}$ equals the baseline score of the stressor. Next, the relative mean amplitude difference scores of all stressors were checked for outliers. An outlier was defined as a score with a difference of at least two standard deviations from the mean and participants whose scores were identified as outliers were excluded from further analyses.

Then, the relative difference scores of every stressor was tested for normal distribution in order to determine which test should be most appropriate to use. If the data was normally distributed, then Pearson's correlation coefficient would be used. If the data was not normally distributed, then Pearson's correlation coefficient could not be used since it requires normal distribution. In this case, Spearman's rank correlation coefficient would be used to determine the correlation between participants' physiological responses and self-reports to stress. In order to test for normal distribution, the Shapiro-Wilks (S-W) test was used whereby $p > .05$ was used as an indication for normal distribution and $p \leq .05$ would indicate no normal distribution. Next, the scores on the stress questionnaire were used to calculate difference scores for every stressor and participant by subtracting participants' scores on the question "How stressed were you BEFORE x" from their scores on the question "How stressed were you DURING x" where x was substituted by the respective stressor.

After that, the appropriate test (either Pearson's correlation coefficient or Spearman's rank correlation coefficient) was used to calculate the correlation between the relative mean amplitude difference score and questionnaire difference score of the respective stressor. A correlation coefficient between |0.3| and |0.5| was considered weak, a correlation coefficient between |0.5| and |0.7| was considered moderate and a correlation coefficient greater than |0.7| was considered strong (Hinkle, Wiersma, & Jurs, 2002).

In order to examine whether the correlations significantly differ from each other, we used the following formula from Chen and Popovich (2002) to conduct a t-test for dependent rs:

$$\boldsymbol{t_{Difference}} = \left(\boldsymbol{r_{xy}} - \boldsymbol{r_{zy}}\right)\sqrt{\frac{(\boldsymbol{n}-\boldsymbol{3})(\boldsymbol{1}+\boldsymbol{r_{xz}})}{\boldsymbol{2}(\boldsymbol{1}-\boldsymbol{r_{xy}}^2-\boldsymbol{r_{xz}}^2-\boldsymbol{r_{zy}}^2+\boldsymbol{2}\boldsymbol{r_{xy}}\boldsymbol{r_{xz}}\boldsymbol{r_{zy}})}}$$

Hereby, $\boldsymbol{x}$ equals the respective relative mean amplitude difference score of a stressor, $\boldsymbol{y}$ equals the questionnaire difference score and $\boldsymbol{z}$ equals the relative mean amplitude difference score of a second stressor.

3. Results

Means and standard error of means of the baselines, stressors, difference scores and relative difference scores are shown in Table 1. T-tests showed significant differences in mean amplitudes between respective baseline and stressor when measuring social stress (SSST), *t*(54) = -3.56, p < .001, environmental stress (Noise test), *t*(54) = -3.88, p < .001, and cognitive stress, *t*(54) = -3.23, p < .003. The normality test showed that neither the SSST (Shapiro-Wilk = 0.96, p = .05), the Noise test (Shapiro-Wilk = 0.95, p < .05), nor the BCG (Shapiro-Wilk = 0.89, p < 0.05) showed normal distribution.

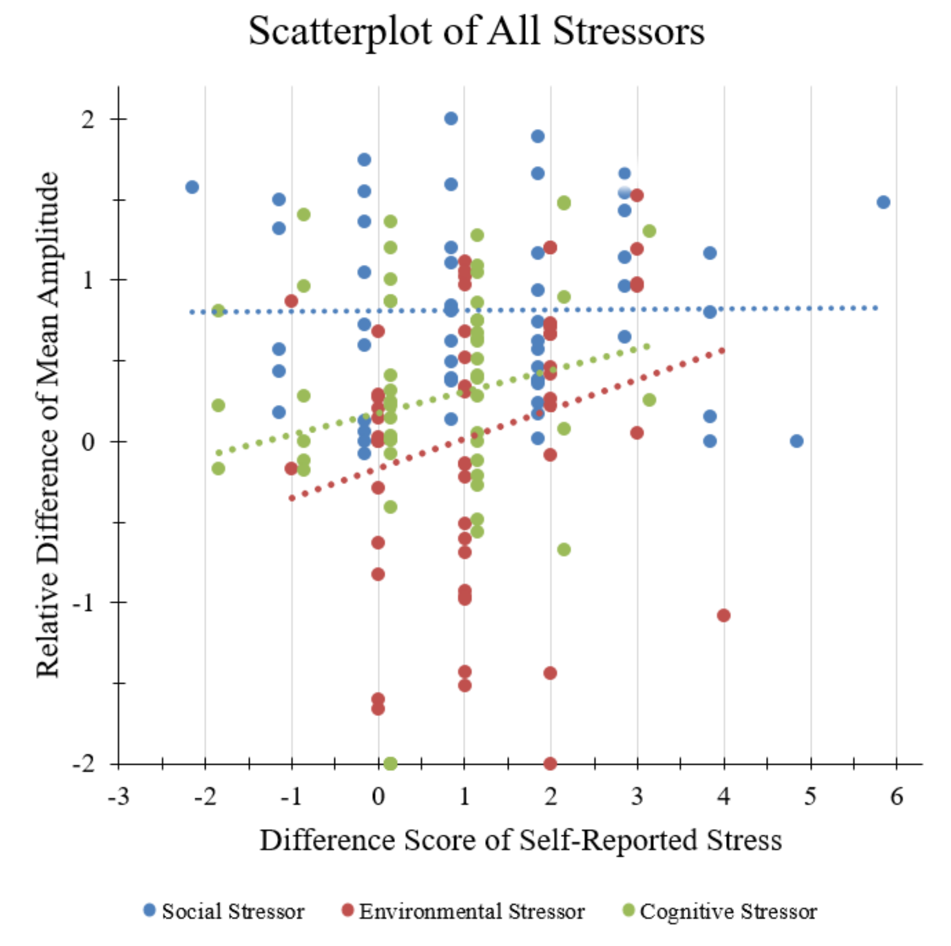

Figure 3. Participants' self-reported difference between baseline stress and event-related stress and the relative increase in mean amplitude SCR of all stressors.

Spearman's rank correlation coefficient was used to compute the correlation between the overall relative amplitude difference score and the overall difference score in self-reported stress and it showed no significant correlation, *r*(53) = .04, p = .77.

Furthermore, Spearman's r test was used to examine the correlation between the relative mean amplitude difference score and the difference score of the self-reports on the SSST (r(53) = 0.07, p = .65), Noise test (*r*(53) = .33, p < .05) and BCG (*r*(53) = .20, p = .16) and it only showed a significant relationship when using the Noise test.

In addition, t-tests were conducted to test whether the calculated correlations differed significantly from each other. It was found that the correlations of the social stressor and environmental stressor did not differ significantly, *t*(52) = -1.51, p > .05. Also, the correlations of the social-, and cognitive stressor as well as the correlations of the environmental-, and cognitive stressor did not significantly differ from each other, *t*(52) = -0.69, p > .05; *t*(52) = 0.68, p > .05.

Table 1

Means and standard error of mean of Baselines, Stressors, Difference Scores and Relative Difference Scores (N = 55)

Variable	**Baseline**	**Stressor**	**Difference Score**	**Relative Difference score**
Overall Amplitude	0.05 (0.01)	0.11 (0.25)	0.06 (0.02)	0.11 (0.02)
SSST Amplitude	0.04 (0.01)	0.14 (0.04)	0.09 (0.03)	0.85 (0.08)
Noise Amplitude	0.05 (0.01)	0.09 (0.02)	0.03 (0.01)	0.05 (0.12)
BCG Amplitude	0.05 (0.01)	0.10 (0.03)	0.06 (0.02)	0.26 (0.12)
Overall Self-Report	2.48 (0.12)	3.49 (0.13)	1.02 (0.10)	-
SSST Self-Report	2.44 (0.15)	3.87 (0.21)	1.44 (0.22)	-
Noise Self-Report	2.27 (0.13)	3.45 (0.19)	1.18 (0.15)	-
BCG Self-Report	2.73 (0.17)	3.16 (0.17)	0.44 (0.15)	-

4. Discussion

The present study attempted to examine whether a correlation between the physiological-, and psychological system in stress exists and if this correlation differs, depending on the type of stressor that is used. Although our findings cannot give a conclusive answer to the existence of a correlation between the physiological-, and psychological system, the study does demonstrate that this relationship does not seem to vary across different types of stressors.

While a significant correlation between physiological-, and psychological system was measured when using an environmental stressor, the other two stressors did not show a significant correlation which also led to a non-significant overall correlation. Thus, the research question whether a relationship between physiological-, and psychological system exists cannot decisively be answered. Furthermore, although the environmental stressor was the only one to show a significant correlation, the differences between the correlations were not significant. This finding suggests that the relationship between physiological-, and psychological system may not differ across different types of stressors and, hence, the second research question has to be rejected.

This result is in line with the meta-analysis of Campbell and Ehlert (2012) which found that most conducted studies on this topic failed to show significant relationships between the systems. As discussed in Campbell and Ehlert (2012) as well as in Andrews et al. (2013), a possible reason for these findings may be that most studies try to find a linear correlation between the systems. Instead, it was argued that the relationship between physiological-, endocrine-, and psychological systems may not be linear or monotonic in nature but more complex, such as curvilinear (Campbell & Ehlert, 2012) or complementary (Andrews et al., 2013). However, although it is beyond the scope of this study to investigate the exact interaction between the systems, scatter plots of our dataset did not support such an interpretation.

Furthermore, since the correlation between physiological-, and psychological system was significant in the environmental stressor but not in other stressors, this raises the question which variables may have led to this finding. One could argue that differences in absolute SCRs between the stressors may be a contributing factor to this inconsistent finding. However, all three stressors did elicit significantly higher SCRs compared to their respective baselines and while the SSST showed the strongest absolute increases in skin conductance, it did not demonstrate a stronger correlation than the Noise Test and BCG. In contrary, the environmental stressor, which did show a significant correlation between physiological-, and psychological system, elicited significantly lower (absolute) mean amplitude SCR than the other two stressors. Therefore, absolute differences in SCRs between stressors cannot explain this finding.

Another possible reason may be that cognitive engagement in a task may influence the participant's awareness of the own stress level. According to Mauss et al. (2005), a stronger cognitive component in emotions were found to have weaker correlations between physiological-, and psychological systems. Thus, while participants were cognitively engaged during the SSST and BCG, they were not cognitively engaged during the Noise Test which, in turn, may have led to higher awareness of the participant's perceived stress. Also, the environmental stressor is the only type of stressor that elicits stress based on an external stimulus whereas the stimulation of social-, and cognitive stress is largely based on the participant's appraisal of the stimulus (e.g. anticipating negative consequences) (Lazarus & Folkman, 1984). This appraisal process may lead to more ambiguous interpretations of the stressful event and, therefore, may lead to lower correlations between the physiological-, and psychological system.

Taken together, although a relationship between the physiological-, and psychological system and its' differences across several types of stressors could not be confirmed, the study demonstrates that the interaction between the different systems involved in stress may be more complex than initially assumed.

4.1 Limitations and Future Research

The findings should be considered in light of a number of limitations. First, measures of HPA-axis activity were not included in the study. Since homeostasis is a process that involves the physiological-, psychological- as well as the endocrine system, the implementation of HPA-axis measures (e.g. cortisol) could be beneficial for a more complete understanding of the response system. However, since these measures peak twenty to thirty minutes after exposure to the stressor, it is reasonable to assume that the endocrine system may play a significant role in long-term stress (e.g. chronic stress) while exposure to short and acute stressors would mainly affect the fast changing nervous system and the psychological system (Andrews et al., 2013).

Besides that, self-reported stress measures to indicate participants' stress level during a task were assessed during brakes between the stressors. This may have altered participants' stress level responses since rapidly changing emotional states may interact with parts of the psychological system, such as cognitive appraisal processes that, in turn, may lead to different results (Campbell & Ehlert, 2012).

Since the main objective of the present study was to investigate the relationship between the physiological-, and psychological system in stress, it was chosen to take mean scores of the physiological data and self-reports. However, through this method individual differences between participants were neglected. Therefore, for future research it would be interesting to combine the present experiment design (i.e. every participant gets exposed to several different types of stressors) with an analysis of individual correlations per participant. This way, patterns (e.g. clusters) may become visible which could reveal new insights in how individuals differ in their overall as well as stressor-specific perception of stress. Eventually, this approach may help to explain the inconsistencies in the literature regarding the interaction between all three systems in stress.

5. Conclusion

The present study could not give a conclusive answer to the existence of a correlation between the physiological-, and psychological system. However, the study does provide first evidence that this relationship does not seem to differ when differentiated based on different types of stressors. Future research is needed to uncover the underlying reasons for these inconsistencies found in literature regarding the interaction between the involved systems in stress. These insights can help to further understand the complex mechanisms in the assumed homeostatic process between systems in stress.

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Appendices

Appendix A: Informed Consent

Informed consent

Titel: a validation study: how does your body respond?

Introduction

We are Tabea, Daniel and Daniela, all students of the University of Twente, and we are doing research on the validity of the E4 wristband. The Empatica E4 wristband is a new device to monitor physiological signals in real-time and it is being used in all kinds of research topics that involve physiological measures such as epilepsy and alcoholism. As part of this validity research we will ask you to do four different tasks, while being attached to some measurement devices: the E4 wristband, a skin conductance sensor and a heart rate monitor. The tasks you will have to do are presented on the computer screen and we ask you to move as little as possible in order to get flawless data.

We will give you an opportunity at the end to review your remarks, and you can ask to modify or remove portions of those, if you do not agree with our notes or if we did not understand you correctly.

If you have any questions, you can ask them now or later. If you wish to ask questions later, you may contact any of the following:

Tabea Bonus: t.r.bonus@student.utwente.nl

Daniel Lutscher: d.lutscher@student.utwente.nl

Daniela Guddorp: d.guddorp@student.utwente.nl

Informed consent

I explain that I am informed about the nature, method, and goal of the research. I know that the data and the results are being used anonymously and confidential and will solely be used for scientific analysis and presentation. My questions about the research have been answered satisfactorily.

Participation in this research is completely voluntary and you can ask questions or stop with your participation at any time. You do not have to take part in this research if you do not wish to do so

I have read the foregoing information, or it has been read to me. I have had the opportunity to ask questions about it and any questions I have been asked have been answered to my satisfaction. I consent voluntarily to be a participant in this study

Print Name of Participant__________________

Signature of Participant ___________________

Date ___________________________

Appendix B: Screen Instructions during SSST

Screen instruction	Time
Sit quietly, try to relax and focus your attention on your breathing while you see the countdown.	2 Minutes
Think of different animals that start with the letter P.	30 Seconds
Think of things you can find in a kitchen.	30 Seconds
Think of several things that are important if you want to organize a wedding.	30 Seconds
Think of as many team sports practiced without a ball as you can.	30 Seconds
The next task will be to sing a song aloud - think of a song you can sing.	30 Seconds
Now sing a song aloud over the next 30 seconds and try to keep your arms still. Keep singing!	30 Seconds
Sit quietly, try to relax and focus your attention on your breathing while you see the countdown.	2 Minutes

Appendix C: Screen Instructions during BCG

Screen instruction	Time
Sit quietly, try to relax and focus your attention on your breathing while you see the countdown.	2 Minutes
Think of things you can find in a living room.	30 Seconds
Think of different animals that start with the letter C	30 Seconds
Please work on the following decision task: Each participant of this study will write down a number between zero (0) and one hundred (100). Zero and one hundred are also possible. We will calculate the average, which is the mean of all numbers picked. Then we will multiply the mean with 2/3. The resulting number will be the target number. To win the game, you should pick a number that is as close as possible to this target number.	40 Seconds
The participant whose picked number is closest to the target number, 2/3 of the mean, will win the game and receives a 25 Euro voucher. Please say your chosen number out loud when the countdown has expired. Please do not move.	60 Seconds
Please say your chosen number out loud. Do not move.	10 Seconds

Appendix D: Questions of the Stress Questionnaire

Before starting the SSST:

1. *How stressed are you at this moment?*

After the recovery period of the SSST:

1. *How stressed were you in the minute BEFORE singing the song?*
2. *How stressed were you WHILE singing the song?*
3. *How stressed were you RIGHT AFTER singing the song?*
4. *How stressed are you at this moment?*

After the recovery period of the Noise Test:

1. *How stressed were you BEFORE the Noise Test?*
2. *How stressed were you DURING the Noise Test?*
3. *How stressed were you RIGHT AFTER the Noise Test?*
4. *How stressed are you at this moment?*

After the BCG:

1. *How stressed were you BEFORE choosing a number?*
2. *How stressed were you WHILE choosing a number?*
3. *How stressed were you RIGHT AFTER choosing a number?*