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Faculty of Behavioural, Management and Social Sciences (BMS)

Electrodermal Activity in relation to Self-reported Stress and Emotion Intensity in Individuals

An Exploration of Intra-subject Relations through Experience Sampling and Wearable Sensors

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Abstract

Stress is a common response for human beings, which, if chronic, can have detrimental effects on physical and mental well-being. While many laboratory studies have provided us with an association between physiological responses (e.g. electrodermal activity) and stress, little research has been done about this association in real life settings over longer periods of time. Additionally, most research focuses on general populations and their means, while wearable sensors increasingly available to the public demand individual applicability. This research's main aim was to explore the intra-subject relations between self-reported stress and arousal and electrodermal activity (momentary and retrospective) in real life through experience sampling. Therefore, 18 participants wore an Empatica E4 wristband for seven consecutive days, while reporting their stress level and emotion intensity (of the past two hours and past minute) every two hours using their smartphone (mQuest). Hypotheses suggesting positive intra-subject correlations could not be explicitly retained. Spearman's rank correlation coefficient analyses showed trends of more positive correlations, while strongly negative correlations were found as well. The large range of correlations imply the significance of individual differences in long-term ambulatory assessment of stress and electrodermal activity. Additional analyses testing for differences in inter-subject correlations between momentary and retrospective assessment of stress, showed no significant differences. Concluding, fluctuations in self-reported stress and arousal and their association with fluctuations in electrodermal activity in daily life in young adults rely on individual differences and that these differences must be considered when making predictions based on electrodermal activity and stress. Timeframe of measuring and lack of insight into stressful events were among the limitations of this study. General recommendations were to elaborate and expand long-term ambulatory assessment of electrodermal activity within individuals, so as to enable applicability of wearable sensors in modern society.

Table of contents

1. Introduction

With the world and technologies constantly changing, stress is a common response for human beings. According to Segerstrom and Miller (2004), stress is related to the evolution and survival of human beings, as stress induces physiological responses related to the 'fight-or-flight' system. Today's stressors are not per se a risk for our physical well-being, though the stress that is perceived still has physical consequences (Segerstrom & Miller, 2004). These physical consequences (e.g. decreased immune response, cardiovascular response) are a threat to the health of human beings when stress becomes chronic (Sharma & Gedeon, 2012). Myers (2017) for instance, states that stress and depressive illnesses can lead to cardiovascular diseases through autonomic imbalance, which is characterized by alterations in heart rate variability and baroreflex sensitivity. As heart rate and blood pressure are regulated by the autonomic nervous system (ANS), other bodily functions regulated by the ANS may very well be affected by stress and depression. For this reason, many experiments in laboratory settings have been performed, researching the relation between psychological events and physiological responses, specifically emotions and the autonomic nervous system (e.g. electrodermal activity; Boucsein, 2012). However, to be able to apply the research to real-life situations, laboratory experiments are not extensive enough. Research has generally focused on inter-subject correlations as to generalize results for the wider population (Molenaar & Campbell, 2009), while there are many individual differences regarding physiological responses to stress that may vary over time within individuals, which cannot be predicted from inter-subject (cross-sectional) research findings. With the development or wearable sensors, or bio-sensors, the experiments can be performed in real-life situations without being obtrusive, over a prolonged period of time. The aim of this study is to explore to what extent fluctuations in self-reported stress and arousal are associated with fluctuations in electrodermal activity, or skin conductance, in the daily life of individuals, through the use of momentary and retrospective assessment.

1.1. Theoretical background

Many wearable sensors are able to measure physiological responses, associated with stress and general arousal. These wearable sensors measuring physiological signals (e.g. mainly heart rate, blood pressure, some of them skin conductance) are becoming more and more available to the wider public (e.g. Embrace Watch, Apple Watch). Many of these devices report these measures in a simplified way and with this, claim that you can easily monitor your fitness and health through a combination with a smartphone application (Apple Inc., 2016). The feedback that the device gives to its users is of importance. Van Dijk, Westerink, Beute, and IJsselsteijn (2015) for instance, showed that in a study regarding heart rate, people who received no feedback on their stress level or heart rate showed little to no correlation between their heart rate and momentary stress.

In addition to the increasing availability of wearable sensors, the increasing number of smartphones available can give more specific data regarding self-reported stress. For instance, instead of retrospectively asking how a participant felt during the day through a computer or paper questionnaire, it is now possible to ask these same questions through the participant's smartphone in real time, through experience sampling, or so-called ambulatory assessment. According to Conner and Feldman Barrett (2012), traditional self-report techniques, such as retrospective assessment, rely on memory-based reports, or the remembering self, while ambulatory assessment relies on the experiencing self, or real time feelings and thoughts. Ambulatory assessment is thought to result in less biased measurements, as they are not based on reconstruction and recollection (Conner & Feldman Barrett, 2012). Robinson and Clore (2002) support this difference, as according to them, "an emotional experience can neither be stored, nor retrieved" (p. 395). Memories can generate emotions through re-enactment, but these emotions will be generated in that new moment, and not recalled (Robinson & Clore, 2002). Therefore, research suggests that the link between the bodily reactions and experiencing self is stronger than the link between bodily reactions and remembering self (Conner & Feldman Barrett, 2012; Robinson & Clore, 2002). Additionally, Conner and Feldman Barrett (2012) mention a number of examples (e.g. cessation of smoking, pain) where retrospective accounts revealed overestimations in comparison to momentary assessments: "This general pattern of overestimation in memory has since been replicated for a variety of emotions as well as physical pain" (p. 238).

Before we can research whether self-reported stress and arousal can be predicted by physiological responses in humans, we must define these elements separately. Arousal is a term often used in emotion or affect research. Affect is seen as the basic sense of feeling that is continuously present, while "emotion is a much more complex mental construction" which seems to be dependent on culture (Feldman Barrett, 2017). This affect is measurable as it, according to Russell (1980), consists of two dimensions; valence and arousal. "Valence is a subjective feeling of pleasantness or unpleasantness; arousal is a subjective experience of feeling activated or deactivated" (Feldman Barrett, 1998, p. 580). This report focuses on arousal, further referred to as emotion intensity, as it seems to incorporate the internal sensations associated with experiences (Feldman Barrett, 1998). It will also limit the scope of the research as it is measurable through self-report, and the lowers the burden for participants.

The definition of stress in psychology research consists of a wide range of phenomena and it is therefore difficult to grasp, according to Boucsein (2012). However, he states: "stress can be defined as a state of high general arousal and negatively tuned but unspecific emotion, which appears as a consequence of stressors (i.e., stress-inducing stimuli or situations) acting upon individuals" (Boucsein, 2012, p. 381). Meaning that stress should be seen as a form of emotion with high arousal, which is predominantly negative. But like any other emotion, stress seems to be overly generalized through common sense, as it depends on subjective experience. According to Russell (2009), the problem with subjective experience of emotions is that among self-report studies of emotions, there is a lack of factors corresponding to basic emotion. One may think of fear as an example, where fear in one person results in screaming and running away, while another person would quietly cower in a corner. The same applies for stress, while one person sees stress as a negative emotion, for another it may result in better outcomes as they are forced to take action. Boucsein (2012) also states this difference (distress vs. eustress), and reports that both result in similar physiological responses: "Both distress and eustress, i.e., negatively and positively experienced stress, come with hefty emotional responses and manifest most prominently in ANS [autonomic nervous system] measures and especially in the EDA [electrodermal activity]" (p. 369). This research will focus on the stressful events that the participants subjectively consider stressful, as these are measurable through self-report.

As for physiological responses, several have already been linked to stressful situations in laboratory studies, most of which pertain the autonomic nervous system (ANS; Boucsein, 2012; Sharma & Gedeon, 2012). According to Sharma and Gedeon (2012), these physiological responses include changes in electrodermal activity (EDA). EDA comprises electrical phenomena in relation to the skin (near sweat glands). These responses are measurable through skin conductance response (SCR) among others, described below. As stated earlier, stressful events induce an increase in the so-called fight-or-flight response. This response is regulated by the sympathetic nervous system (SNS), which is the part of the ANS regulating bodily functions unconsciously (e.g. heart rate, digestion). Stressful events have resulted in an imbalance of hormones, activating the SNS responsible for sweat secretion and heart rate, and inhibiting the parasympathetic nervous system (PSNS) responsible for digestion and salivation for instance. Therefore, we can conclude that stressful events can lead to an increase in EDA in the majority of people.

The question in this case however, is whether fluctuations in self-reported measures of experienced stress and emotions cohere with fluctuations in physiological measures within individuals over time. Russell (2009) states that “people who experience fear show a variety of ANS changes, engage in various behaviours, and so on” (p. 1272). From this we can conclude that people respond differently with instances of emotions. This raises the question whether there is a correlation between EDA and momentary self-reported stress and emotion intensity in individuals. Also, Conner, Tennen, Fleeson, and Feldman Barrett (2009) state that ambulatory assessment, or experience sampling allows for examination of these individual differences.

This research aims to answer questions relating to the measurement of stress and arousal through both momentary and retrospective self-report and bio-sensors, and whether certain levels of perceived stress and emotion intensity can predict physiological response such as electrodermal activity within individuals.

1.2. The current study

Many studies establish a link between emotion, specifically stress and level of arousal, and the autonomic nervous system, of which most were performed in laboratory settings (Boucsein, 2012). This study focuses on this relation in real life and therefore, aims to explore to what extent fluctuations in self-reported stress and arousal are associated with fluctuations in electrodermal activity in daily life in young adults. For this research several hypotheses were formulated based on aforementioned literature.

First of all, it is hypothesized that higher EDA signals are associated with moments perceived as stressful in individuals. Also, it is believed that on average, momentary measures of stress and emotion intensity are more representative of EDA than retrospective measures. For this hypothesis, inter-subject correlations will be compared.

H1a: Positive intra-subject correlations can be found between self-reported levels of stress and EDA momentarily and retrospectively

H1b: Positive intra-subject correlations can be found between self-reported intensity of emotions and EDA momentarily and retrospectively

H2: Higher inter-subject correlations can be found between momentary reported stress levels and EDA than between retrospective reported stress levels and EDA.

2. Methods

2.1. Participants

The participants of this study were recruited through convenience sampling, or so-called self-selection, within the researchers circle of friends and family, and with the use of an online platform called 'SONA systems'. This is a platform the University of Twente uses where students can share their studies with other students, who in return receive credits for partaking in the studies (in this case 5 SONA credits). Inclusion criteria for the study included that participants were between the age of 18 and 35, had Dutch, English, or German as their native language, and had a sufficient mastery of the English language. Additionally, participants were required to own a smartphone (Android or iOS) and had to make use of a computer or laptop with an internet connection and a USB-port (Windows or macOS).

The total number of participants was 18 of which 7 were male. The average age of the participants was 20.83 years (N=18, SD=1.86, spread=19-27). 44.40 percent of the participants had Dutch as their native language, while 50.00 percent spoke predominantly German, and 5.60 percent were English native speakers. A little over one fourth (28%) of the participants received SONA credits for the study, while the majority of participants did not receive any reward. Initially, 21 participants started the study. However, 3 participants quit the study as it was either too burdensome or the E4 (described below), its accessories, or software did not function properly (when uploading the data).

This research was approved by the Ethics Committee of the faculty of behavioural sciences of the University of Twente (Commissie Ethiek Gedragswetenschappen) and all participants signed an informed consent before participation.

2.2. Materials and measures

2.2.1. Empatica E4 wristband

To measure EDA, several Empatica E4 wristbands and their accessories were provided to us by the BMS lab powered by Tech4People. The E4 contains several sensors; photopletysmolography (PPG) sensors for heart rate (BPM) and inter-beat-interval (IBI), EDA sensors, skin surface temperature, and a 3-axis accelerometer (Empatica Inc., 2014). The EDA is measured at a rate of 4 Hz and has a range from .01 – 100 µS (described below; Empatica Inc., 2014). The E4 wristband measures EDA through the use of dry electrodes and relies on natural skin hydration of the wrists, as this allows for ambulatory long-term measure in addition to being unobtrusive when compared to EDA measured through gelled electrodes, or electrodes placed on the palms or fingers (Picard, Fedor, & Ayzenberg, 2016). This allows for a constant output of data without interference of the researcher.

Every participant in the study received an E4 in its container along with a charging cradle and a Micro USB to USB cable, and instructions on the use of the wristband. The E4 has a streaming mode as well as a recording mode, however, for this research only the latter was used. The data recorded on the wristband was uploaded to the Empatica Connect server every evening before participant went to sleep through Empatica Manager (either version 1.0.2.1828, or version 1.1.0.2827), which was installed on the participant's laptop during the briefing. For the program to run properly, laptops must run Windows 7 or higher, or macOS, and have a standard USB connection port and internet connection for synchronisation.

2.2.2. Electrodermal activity

Electrodermal activity (EDA) can be expressed in several forms. According to Boucsein (2012), EDA can be measured in skin conductance (SC) units if the electrical current is constant, and can be divided into two categories, namely tonic phenomena (skin conductance level or SCL) and phasic phenomena (skin conductance responses or SCR's). The SCL can be seen as a baseline, as it indicates the "response-free recording" of the persons' EDA (Boucsein, 2012, p. 3). One can count the number of peaks that the EDA signal contains (number of SCR's), derive the SCR frequency, or measure the amplitude (difference from SCL) of every SCR and calculate the mean amplitude of SCR's over a set period of time, along with several other methods (Boucsein, 2012). EDA is expressed in microSiemens (µS). On average, the SCL ranges from 2 to 16µS (Braithwaite, Watson, Jones, & Rowe, 2013).

This study will focus on the mean amplitude of SCR's as well as the number of SCR's, as the output of the E4 will allow these measures. SCL was considered as a measure as well, however, SCL seems more sensitive to changes in outside temperature, especially within individuals, while participants wore the E4 inside and outside (Doberenz, Roth, Wollburg, Maslowski, & Kim, 2011; Hot, Naveteur, Leconte, & Sequeira, 1999).

2.2.3. mQuest

To measure the self-reported stress and emotion intensity, the smartphone application mQuest was used. For this, participants were required to own a smartphone running Android or iOS. The application was also installed during the briefing and the use of the application was explained.

2.2.4. Self-reported stress and emotion intensity

The self-reported measures of stress and emotion intensity consisted of the following four items: ‘how intense were you emotions during the last two hours?’, ‘how much stress did you experience during the last 2 hours?’, ‘how intense were your emotions during the last minute?’, and ‘how much stress did you experience during the last minute?’. Participants were asked to rate these constructs on a scale from 0 – 10 every two hours through a survey task on the mQuest application.

2.2.5. Exit interview

The exit interview consisted of seven questions relating to the burden of the experiment as well as the subjectivity of emotions and stress (Appendix E). It was semi-structured, so as to allow for follow-up questions and different interpretations of the questions. Some of the questions were very general, while others were very specific to the experiment. Two examples of the questions are: ‘How did it go this week?’, and ‘What things do you consider when judging your own level of stress?’.

This report is part of a larger project which included the measures heart rate and alexithymia (TAS-20). These measures do not lay within the scope of the current report, and are therefore not described in this paper.

2.3. Design

This study was conducted as an observational within-subjects design, so as to gather individual information needed for the intra-subject correlation analyses. To gather the self-report data, an active experience sampling method was used. The fixed time-based strategy allowed for momentary as well as retrospective assessments to be made, and allowed the subjective experience of the participants (Conner & Lehman, 2012). For the physiological data, a mainly passive continuous physiological sampling method was used. As participants were instructed to upload their physiological data themselves, this may be seen as an active sampling method (Conner & Lehman, 2012). However, during the day, participants needed not to intervene in the sampling.

2.4. Procedure

This research consisted of three parts, namely a briefing, data gathering, and debriefing. During the briefing, participants signed an informed consent and filled out the Toronto Alexithymia Scale (TAS-20). Also, participants of the study received the E4 wristband and instructions on how to use it and upload the data, as well as instructions on how to use the app 'mQuest' with which the data would be recorded, after it was installed on their smartphone. Additionally, they were informed of the twelve prompts (and their timeframe) they were to receive on their smartphone daily to answer a few questions relating to arousal and stress, and the fact that the researchers could not make any medical statements based on the data gathered in the study and that therefore, participants would not be shown the personal results of the study.

The data gathering took seven full days, weekends included, where participants would constantly wear an E4 wristband, as long as they were awake. The starting day of measurement was random as it was deliberated upon with every participant. During this time, participants would answer four scale questions relating to arousal and stress up to twelve times a day, at a set timeframe of every two hours, meaning they received 84 prompts in total of which 56 were practical data points (considering 16 hour days). As a reminder, they received notifications through their smartphone on which they answered aforementioned questions. The participants were required to upload the data from their wristband on a daily basis through their computer or laptop. If participants had any questions, they were to pose these to their contact person through their channel of preference.

The debriefing consisted of the handing in of the wristband after seven days of data gathering had passed. Additionally, in a recorded and transcribed exit interview, several open questions relating to the research, the wristband and app, and subjectivity of arousal and stress were be posed. The TAS-20 was also filled out again as a post-test. If applicable, participants would receive their credits through the SONA system of the University of Twente.

2.5. Data analysis

First of all, descriptive and frequency analyses were performed to have an overview of the data. Following this, participants who did not meet the threshold to fill out twenty percent of the total 84 data points of the self-reported measures while having reported measures of skin conductance were excluded from the dataset. To check for normality, the Shapiro-Wilk test was performed on the full dataset as well as per participant. Subsequently, to test the hypotheses

(H1a and H1b) of the intra-subject relations between self-reported stress and number and mean amplitude of skin conductance responses, and the intra-subject relations between emotion intensity and number and mean amplitude of skin conductance responses, Spearman's rank correlation coefficient analyses were performed with SPSS 23 for all participants separately. All tests were performed one-sided because the hypotheses suggest differences in one certain direction.

To test hypothesis 2 of the comparison of momentary and retrospective inter-subject correlations of stress, the data was be aggregated with SPSS accordingly. After correlations were calculated, through the Fisher z-transformation, the correlations were ready to be compared through an Independent-Samples T test, as the transformation allows for parametric testing (Doberenz et al., 2011; Fisher, 1915). The transformation and comparison were performed with Excel 2013, see Appendix F for calculations and formulas.

3. Results

Descriptive and frequency analyses show that in both the conditions 'past minute' and 'past two hours', the mean scores on self-reported stress and arousal were quite low. See Table 1 for a full overview of this data. The threshold to stay included in the dataset was set at 20 percent of 84 data points, meaning that participants who had a response rate lower than 17 were excluded from further testing. This resulted in exclusion of two participants for momentary assessment, and five participants for retrospective assessment; N=16 and N=13, respectively.

Most distributions were not normal. Although a few normal distributions were found (particularly relating the number of SCR), as to be able to compare the data, non-parametric tests were performed as they are more robust.

3.1. Intra-subject correlations

3.1.1. Self-reported stress

Overall, when looking at the momentary correlations of self-reported stress and EDA, the strongest and weakest correlations were both negative (r_S = -.44, p = .01 and r_S = -.01, ns, respectively). Both correlations were found between self-reported stress and amplitude of SCR's. For retrospective assessment on the other hand, both the strongest and weakest correlations of self-reported stress and EDA were positive (r_S = .60, p = .00 and r_S = .01, ns, respectively). Additionally, these strongest and weakest correlations were found between retrospective assessment of self-reported stress and number of SCR's as well as amplitude of SCR's, and occurred in the same participants. A full overview of correlations per participant

Table 1

General overview of measured variables (N=18)

Measure	*N*	*M*	*SD*	Range
Past minute				
Self-reported stress	673	1.87	1.94	0-10
Self-reported arousal	673	2.53	1.91	0-10
Number of SCR per minute	547	5.41	3.99	0-19
Mean amplitude of SCR's (μS)	547	.04	.08	.00-.69
Past two hours				
Self-reported stress	673	2.54	1.95	0-10
Self-reported arousal	673	3.43	1.87	0-10
Number of SCR per two hours	414	585.45	333.80	5-1484
Mean amplitude of SCR's (μS)	414	.05	.05	.01-.47

concerning self-reported stress can be found in Table G1, Appendix G.

Figure 1 shows the frequencies of the momentary correlations between self-reported stress and EDA (number and mean amplitude of SCR's), while Figure 2 represents the correlation frequencies of retrospective assessment, both derived from Table G1, Appendix G. Both figures show that correlations mainly lie between -.20 and .20, which can be considered weak to non-existent correlations (Haslam & McGarty, 2003). Both figures do show a trend of more positive correlations (momentary = 11/16 and 7/16; retrospective = 10/13 and 12/13), however, this trend seems more apparent in Figure 2 regarding retrospective assessment as the retrospective correlations have a higher minimum as well as a higher maximum. This trend is also supported by the values of the medians, as they are positive values, except for momentary self-reported stress versus mean amplitude of SCR's.

In addition to this trend, valid response rates of participants were at an average of 58 percent of the 56 practical data points (considering 16 hour days; M_n=32.63; *SD*=8.45; range=17-47). Considering the significance of the correlations, for momentary assessment of self-reported stress and number of SCR's, 3 significant positive correlations in contrast to 1 significant negative correlation were found. For amplitude of SCR's, 1 positive significant correlation contrasted 2 significant negative correlations. For retrospective assessments, significant positive correlations contrasted with significant negative correlations as 3 to 0 and 2 to 0 for number of SCR's and amplitude of SCR's, respectively (α = .05, one-tailed).

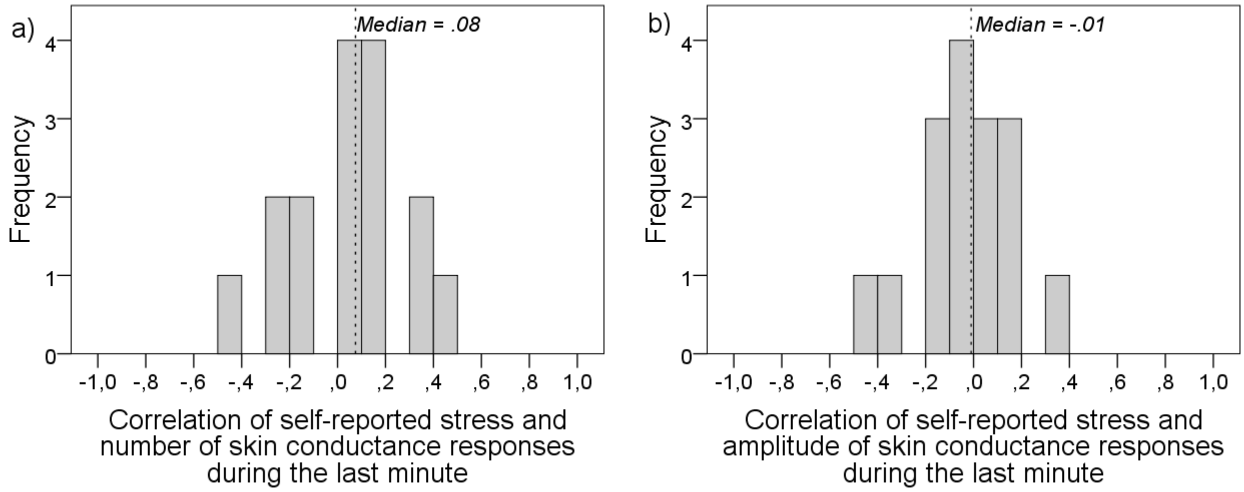

Figure 1. Histograms of Spearman correlation frequencies between self-reported measures of stress and (a) number and (b) amplitude of skin conductance responses during the last minute.

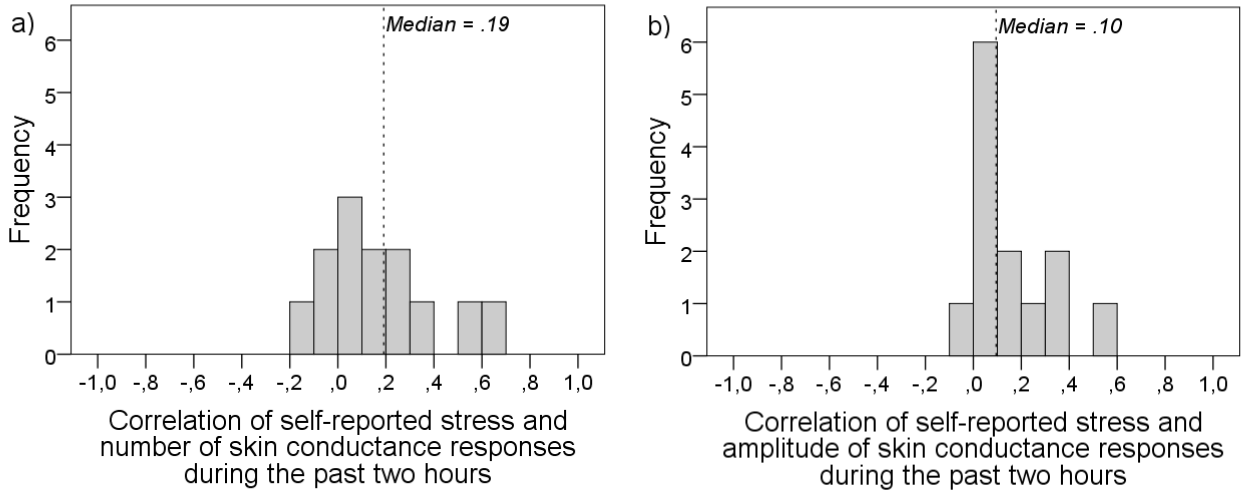

Figure 2. Histograms of Spearman correlation frequencies between self-reported measures of stress and (a) number and (b) amplitude of skin conductance responses during the last two hours.

3.1.2. Self-reported emotion intensity

Generally, when looking at the momentary correlations of self-reported emotion intensity and EDA, the strongest and weakest correlations were r_S = .52 (p = .01) and r_S = -.01 (ns) respectively. The strongest correlation was found between self-reported emotion intensity and amplitude of SCR's, while the weakest correlation was found between self-reported emotion intensity and number of SCR's. For retrospective assessment on the other hand, both the strongest and weakest correlations of self-reported emotion intensity and EDA were positive

(r_S = .62, p = .00 and r_S = .02, ns, respectively). Both these correlations were found between retrospective assessment of self-reported emotion intensity and amplitude of SCR's. A full overview of correlations per participant concerning self-reported emotion intensity can be found in Table G2, Appendix G.

Figure 3 shows the frequencies of the momentary correlations between self-reported arousal and SCR (number and mean amplitude), while Figure 4 represents the correlation frequencies of retrospective assessment, both derived from Table G2, Appendix G. Figure 3 shows that momentary correlations lie between -.50 and .60, which can be considered quite a large range. Figure 4 also shows large ranges of correlations (Figure 4a: -.10 – .70; Figure 4b: -.40 – .60). Both figures show a trend of more positive correlations (momentary = 10/16 and 11/16; retrospective = 12/13 and 8/13), however, this trend seems more apparent in Figure 4 regarding retrospective assessment.

In addition to this trend, response rates of participants were at an average of 49 percent (M_n=27.54; SD=5.08; range=17-35). The ratios of significant positive correlations in contrast to significant negative correlations were 2 to 2 and 3 to 3 for momentary assessment of self-reported emotion intensity and number of SCR's and amplitude of SCR's, respectively. While for retrospective assessment, 5 positive and 0 negative significant correlations were found between self-reported emotion intensity and number of SCR's, and 3 positive to 1 negative significant correlations were found for self-reported emotion intensity and amplitude of SCR's (α = .05, one-tailed).

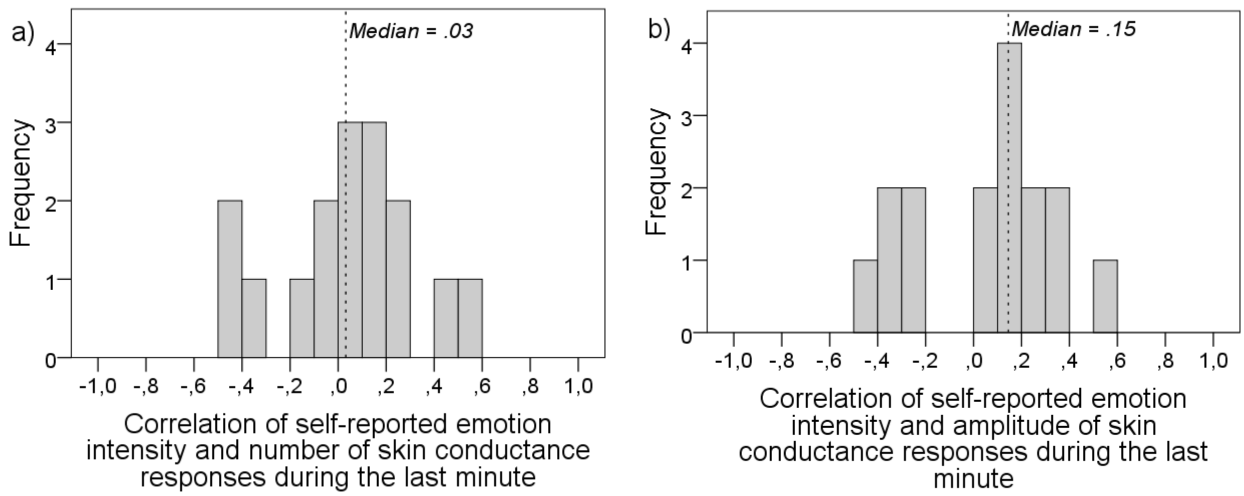

Figure 3. Histograms of Spearman correlation frequencies between self-reported measures of emotion intensity and (a) number and (b) amplitude of skin conductance responses during the last minute.

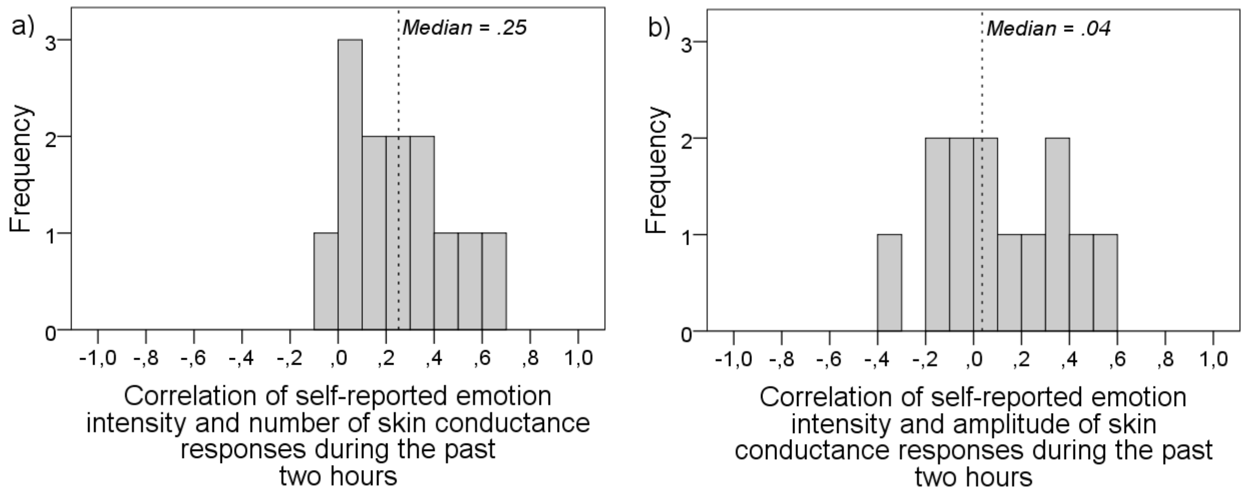

Figure 4. Histograms of Spearman correlation frequencies between self-reported measures of emotion intensity and (a) number and (b) amplitude of skin conductance responses during the last two hours.

3.2. Inter-subject correlations

Table 2 shows the inter-subject correlations for comparison. As can be seen, the strongest correlation is r_S = -.51 (p = .02). This negative correlation may be considered moderately strong and concerns the momentary assessment of self-reported stress and amplitude of SCR's (Haslam & McGarty, 2003).

Self-reported stress was neither significantly correlated with number of SCR's in momentary assessment (r_S = .07, ns), nor in retrospective assessment (r_S = -.05, ns). The difference between these correlations was not statistically significant (*Z* = .29, ns). Although self-reported stress was significantly correlated with the amplitude of SCR's in momentary assessment (r_S = -.51, p = .02), they were not significantly correlated in retrospective assessment (r_S= -.39, ns). The difference between these correlations was not statistically significant (*Z* = -.36, ns) either.

3.3. Exploratory analyses

Analyses showed that one participant in particular had strong and significant correlations throughout the data set, namely Participant D (Table G1 and Table G2, Appendix G). As per curiosity, several exploratory analyses were performed which resulted in the following. What is apparent from Table G1 and Table G2, is that for both self-reported stress and emotion intensity, correlations with EDA are negative for momentary assessment in this participant, while they are positive for retrospective assessment. With the weakest correlation still

Table 2

Inter-subject Spearman correlations between momentary and retrospective measures of self-reported stress and emotion intensity and number and amplitude of SCR

	Momentary assessment (*N* = 16)		Retrospective assessment (*N* = 13)	
	Number of SCR	Amplitude SCR	Number of SCR	Amplitude SCR
Self-reported stress	.07	**-.51***	-.05	-.39
Self-reported emotion intensity	**.48***	.01	-.09	-.28

*. $p < .05$ (one-tailed).

considered moderately strong at $r_S = -.41$ ($p = .01$) and the strongest correlation being $r_S = .62$ ($p = .00$; Haslam & McGarty, 2003). Overall, Participant D had a total of 25 valid data points. At 45 percent, this can be considered low in comparison to the average response rate. As can be seen in Table 3, Participant D reported low levels of stress and emotion intensity in general. Additionally, in comparison to the means of the whole sample (Table 1), the EDA of this participant seems to be low as well.

The exit interview of Participant D revealed that the participant most of times filled in the self-report questionnaires quite low and often gave similar answers. After finishing the questionnaire, the participant sometimes felt that they had had a frustrating meeting, but did not consider that when filling in the questionnaire as they were not consciously thinking about the past two hours: “maybe, I was not always as consciously answering the questions to actually think about the past two hours” (Participant D, personal communication, n.d.). Additionally, Participant D felt that it was difficult to separate emotion intensity from stress and that they associated emotions with something more unpleasant or negative. On the other hand, this participant did feel cheerful at times, but filled in low emotion intensity as this was more in line with the answer to the questions relating to stress. To this, the participant added their meaning of stress as something negative resulting from mental events, e.g. frustration with a co-worker, or work pressure, more than physical events, e.g. playing sports. Mental events were taken into account when scoring their level of stress. The participant concluded with the fact that they would be interested in the feedback the wristband provides, as they might be able to infer their own conclusions from it, as not every individual regularly checks their heart rate.

Table 3

General overview of measured variables for Participant D (N_D=25)

Measure	*M*	*SD*	Range
Past minute			
Self-reported stress	1.68	1.11	0-4
Self-reported arousal	1.68	1.15	0-4
Number of SCR per minute	2.08	2.25	0-7
Mean amplitude of SCR's (μS)	.01	.03	.00-.11
Past two hours			
Self-reported stress	1.96	1.49	0-7
Self-reported arousal	2.00	1.50	0-7
Number of SCR per two hours	222.84	63.49	134-328
Mean amplitude of SCR's (μS)	.03	.03	.01-.11

4. Discussion

This research' purpose was to explore the relations between the self-reported stress and arousal and the physiological response that is often associated with this, electrodermal activity, in real life settings. Instead of focusing on the general population by calculating averages, this study aimed to identify relations between psychological and physiological variables within individuals over time. Hypothesis 1a – 'Positive intra-subject correlations can be found between self-reported levels of stress and EDA momentarily and retrospectively' – may be retained to a certain extent, as well as hypothesis 1b – 'Positive intra-subject correlations can be found between self-reported intensity of emotions and EDA momentarily and retrospectively' –. Almost all medians are above zero (range = -.01 – .25), implying a trend of weak positive correlations in general. Not many correlations proved significant. However, this does not imply that non-significant correlations must be ignored, as they are existent. Although a trend is visible, not all correlations are positive. Additionally, the erratic pattern of medians, when comparing number and mean amplitude of SCR's across the different correlations, implies a large difference between individuals. These results do not correspond with the general idea that higher levels of stress and arousal lead to an increase in EDA posed by Boucsein (2012). It does, however, coincide with the differences between intra-subject and inter-subject correlations measured by Van Dijk et al. (2015). Also, they support the relevance of individual testing as suggested by Molenaar and Campbell (2009) for the applicability of research in individual contexts.

The wide range of results on intra-subject level may be explained by other factors, e.g. skin type (amount and dispersion of sweat glands), age, sex, physical activity, ambient temperature, as described in Doberenz et al. (2011). None of these features were controlled for in the current study, though the effects of age on EDA may have been accounted for by the inclusion criteria for participants. Additionally, psychological health was not within the scope of this study, while mental conditions may play a key role in the elicitation of physiological responses (Doberenz et al., 2011).

As for the last hypothesis (H2) regarding the comparison of momentary and retrospective inter-subject correlations of self-reported stress and electrodermal activity, this may be rejected. The analyses showed no statistically significant difference between the momentary and retrospective correlations when looking at either self-reported stress and number of SCR's, or self-reported stress and mean amplitude of SCR's. The correlations with number of SCR's may be considered non-existent, which has caused no difference to be visible in the first place. While on the other hand, the correlations with amplitude of SCR's were moderately strong, the sample size may have caused for the lack of significant difference. Interestingly, these results are not in line with suggestions made by and Conner and Feldman Barrett (2012) who state that when retrospectively assessing certain behaviours and emotions, participants tend to overestimate these behaviours and emotions are therefore considered more biased than momentary assessments. It is confirmed that momentary assessment relies on the experiencing self, while retrospective assessment relies on the remembering self (Robinson & Clore, 2002; Conner & Feldman Barrett, 2012). However, Conner and Lehman (2012) state that both methods provide different types of information, and that it depends on the research question whether momentary of retrospective is relevant. Precisely because of these different types of information these methods provide, it may be up for discussion whether comparing them in the first place is relevant. Overall, we may conclude that for predictions and statements about individuals, which was the general aim of the current study, experience sampling is a proper measure as it gives insight in individual thoughts, and behaviour (Conner et al., 2009).

It is interesting to see that Participant D, who scored quite low on all measures, had such diverging correlations. It seems that, although hypothesis 2 was rejected on both accounts (number of SCR's and mean amplitude of SCR's), Participant D would show a great difference between momentary and retrospective assessment. It is striking to see that for this participant, a low level of stress or emotion intensity is associated with a (relatively) high level of EDA in momentary assessments, while in retrospective assessments the opposite occurs, i.e. high level of stress or emotion intensity are associated with a high level of EDA. These results support the idea that individual differences matter when looking at the relations between psychological and physiological events and is exactly the reason this study focuses on individuals: "data analysis of psychological processes has mainly been conducted using methods that focus on variation between subjects" (Molenaar & Campbell, 2009, p. 112). The large range and existence of moderately strong negative and positive correlations in the current study support the statement of Molenaar and Campbell (2009) that inter-subject research is not always applicable at the individual level. One may consider the idea that a person with high correlation (say, .80) does not necessarily score high on EDA and stress. A different individual may score high on EDA and stress all the time, and still have the same correlation coefficient. When calculating the general correlation, these individual differences will be lost.

Participant D also gave rise to the question what would happen if participants received feedback on the physiological measures. As mentioned before, Van Dijk et al. (2015) showed that feedback from wearable sensors are important for people's ability to reflect on their stress level. With the use of intra-subject correlations they conclude that when participants receive feedback (either heart rate or supposed stress level), "their estimates of their stress level become more in tune with their heart rate", that is, show higher correlations, than when receiving no feedback at all (Van Dijk et al., 2015, p. 8). As the study involved participants performing "several short tasks, while they were either shown visual feedback about their heart rate or not" in the lab, it does not seem comparable to the current report (Van Dijk et al., 2015, p. 1). Its method does not compare to the long-term experience sampling performed in the current study. They do incorporate the difference between momentary and retrospective scores, however they do not compare these measures to each other. It may be of interest to combine aspects of both studies for further studies, as the wearable sensors available to the public are capable of giving real-time feedback. The advantages given by the feedback, may help people better understand their own levels of stress and in turn be able to do something to lower this for better health. However, one must take into account that most wearable sensors available to the wider public do not measure electrodermal activity yet.

4.1. Limitations

One must consider that the participants' daily life differs a lot, for a participant may be a student, a working person, or both. These individual differences may result in different interpretations of the general concepts stress and emotion intensity. For instance, for one person a schedule full of meetings is stressful, while another person deals with those meetings daily and does not consider this stressful. Also, when rushing for a meeting because you are almost late, you may be considered not stressed as you know you'll make it in time if you hurry, but still show high physiological response as you are hurrying along. Even though physical activity did not affect EDA on the inter-subject level, it did affect EDA on the intra subject level (Doberenz et al., 2011). These are some of the limitations of this study, as it is based on different interpretations of stress and emotions and varying baselines (usually very stressed, or physically active).

As there are many differences between participants' daily lives, one must in turn consider that even within one participants' daily life, one week may differ vastly from another. Imagine a student, for instance, his one week may be filled with exams, while the next week he is off on holiday. As this study measured one week per participant, it is not clear whether the same results will appear in a subsequent week. The time frame of measurement is a limitation for this reason. Recording what happened on a daily basis, through a diary of sorts, may provide a solution for this variance in weekly schedules. However, one must keep in mind the burden of the experiment for the participants as the more lengthy or extensive experiments require more input from participants, and perhaps more incentives for them as well (Conner & Lehman, 2012). It is difficult to keep participants motivated for longer periods of time without increasing the incentives handed to them.

4.2. Recommendations

Not much research has been done on long-term ambulatory assessment of electrodermal activity, while it may be useful for people with mental conditions as well as healthy people, e.g. there seems to be a difference in electrodermal response between subjects with depression (lower electrodermal response) and subjects with anxiety disorders (higher electrodermal response; Doberenz et al., 2011). Individuality is often overlooked in psychological research, as personal experiences are measurable through introspection only and this is thought to be too biased. However, to be able to apply research to the individual, intra-subject research is a necessity. As to include both these aspects, the following recommendations were made:

As this paper provided an exploration of the use of wearable sensors in long-term ambulatory assessment, future research may expand the current sample, while adding an open-ended question to the prompts relating to specific stressful events during the past two hours, as it may explain variance within the subjects experience of stress. This may also instigate the participant to more actively think back on the past two hours, resulting in different uses of the experiencing and remembering self.

As for the market of wearable sensors, as mentioned before, Van Dijk et al. (2015) showed that feedback from wearable sensors are important for people's ability to reflect on their stress level. It may be of interest to further study this, as the wearable sensors available to the public are capable of giving real-time feedback. The advantages given by the feedback, may help people better understand their own levels of stress and in turn be able to do something to lower this for better health. One could focus on expanding the research by adding a group who will receive feedback on their physiology, so as to make clearer statements about the requirements for wearable sensors (e.g. whether more generally available wearables should include EDA).

Eventually, one may think about the applicability of these wearable sensors in the psychological, or psychiatric field. For instance, one may consider certain target groups as participants for this study, e.g. borderline patients or people with depression, as they may have different physiological responses to stress (Argyle, 1991; Doberenz et al., 2011).

4.3. Conclusion

In the end, we may state that fluctuations in self-reported stress and arousal and their association with fluctuations in electrodermal activity in daily life in young adults rely on individual differences and that these differences must be considered when making predictions based on electrodermal activity and stress. Long-term ambulatory assessment of electrodermal activity within individuals must be further explored and elaborated upon, as to enable applicability of wearable sensors in modern society.

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6. References

Apple Inc. (2016, Dec 6). *Your heart rate. What it means, and where on Apple Watch you'll find it*. Retrieved from https://support.apple.com/en-us/HT204666.

Argyle, N. (1991). Skin conductance levels in panic disorder and depression. *The Journal of Nervous and Mental Disease, 179*(9), 563-566. https://dx.doi.org/10.1097/00005053-199109000-00008.

Boucsein, W. (2012). *Electrodermal activity*. Springer Science & Business Media.

Braithwaite, J. J., Watson, D. G., Jones, R., & Rowe, M. (2013). *A guide for analysing electrodermal activity (EDA) & skin conductance responses (SCRs) for psychological experiments*, 1-43. Retrieved from https://www.birmingham.ac.uk/Documents/college-les/psych/saal/guide-electrodermal-activity.pdf

Conner, T. S., & Feldman Barrett, L. (2012). Trends in ambulatory self-report: the role of momentary experience in psychosomatic medicine. *Psychosomatic medicine, 74*(4), 327. https://dx.doi.org/10.1097/PSY.0b013e3182546f18.

Conner, T. S., & Lehman, B. J. (2012). Getting started: launching a study in daily life. In M. R. Mehl & T. S. Conner (Eds.), *Handbook of Research Methods for Studying Daily Life* (pp. 89-107). Retrieved from https://www.ebscohost.com

Conner, T. S., Tennen, H., Fleeson, W., & Feldman Barrett, L. (2009). Experience sampling methods: A modern idiographic approach to personality research. *Social and personality psychology compass, 3*(3), 292-313. https://dx.doi.org/10.1111/j.1751-9004.2009.00170.x.

Doberenz, S., Roth, W. T., Wollburg, E., Maslowski, N. I., & Kim, S. (2011). Methodological considerations in ambulatory skin conductance monitoring. *International Journal of Psychophysiology, 80*(2), 87-95. https://dx.doi.org/10.1016/j.ijpsycho.2011.02.002.

Empatica Inc. (n.d.). *Embrace: monitor seizures, sleep and physical activity*. Retrieved on 6 March 2017 from: https://www.empatica.com/product-embrace.

Empatica Inc. (2014, Nov 19). Empatica E4 [technical specification document]. Retrieved on 24 March 2017 from: https://box.empatica.com/documentation/20141119_E4_TechSpecs.pdf.

Feldman Barrett, L. (1998). Discrete emotions or dimensions? The role of valence focus and arousal focus. *Cognition & Emotion, 12*(4), 579-599. https://dx.doi.org/10.1080/026999398379574.

Feldman Barrett, L. (2017). *Affect vs. emotion*. Retrieved on 7 July 2017 from: https://how-emotions-are-made.com/notes/Affect_vs._emotion.

Fisher, R. A. (1915). Frequency distribution of the values of the correlation coefficient in samples from an indefinitely large population. *Biometrika, 10*(4), 507-521. https://dx.doi.org/10.2307/2331838.

Haslam, S. A., & McGarty, C. (2003). *Research methods and statistics in psychology*. London, England: Sage.

Hot, P., Naveteur, J., Leconte, P., & Sequeira, H. (1999). Diurnal variations of tonic electrodermal activity. *International Journal of Psychophysiology, 33*(3), 223-230. https://dx.doi.org/10.1016/S0167-8760(99)00060-4.

Molenaar, P. C., & Campbell, C. G. (2009). The new person-specific paradigm in psychology. *Current Directions in Psychological Science, 18*(2), 112-117. https://dx.doi.org/10.1111/j.1467-8721.2009.01619.x.

Myers, B. (2016). Corticolimbic regulation of cardiovascular responses to stress [Review]. *Physiology & Behavior. 172*, 49-59. https://dx.doi.org/10.1016/j.physbeh.2016.10.015.

Picard, R. W., Fedor, S., & Ayzenberg, Y. (2016). Multiple arousal theory and daily-life electrodermal activity asymmetry. *Emotion Review, 8*(1), 62-75. https://dx.doi.org/10.1177/1754073914565517.

Robinson, M. D., & Clore, G. L. (2002). Belief and feeling: evidence for an accessibility model of emotional self-report. *Psychological bulletin, 128*(6), 934-960. https://dx.doi.org/10.1037//0033-2909.128.6.934.

Russell, J. A. (1980). A circumplex model of affect. *Journal of Personality and Social Psychology, 39*, 1161-1178. https://dx.doi.org/10.1037/h0077714.

Russell, J. A. (2009). Emotion, core affect, and psychological construction. *Cognition and Emotion, 23*(7), 1259-1283. https://dx.doi.org/10.1080/02699930902809375.

Segerstrom, S.C., & Miller, G.E. (2004). Psychological Stress and the Human Immune System: A Meta-Analytic Study of 30 Years of Inquiry. *Psychological bulletin, 130*(4), 601-630. https://dx.doi.org/10.1037/0033-2909.130.4.601.

Sharma, N., & Gedeon, T. (2012). Objective measures, sensors and computational techniques for stress recognition and classification: A survey. *Computer methods and programs in biomedicine*, *108*(3), 1287-1301. https://dx.doi.org/10.1016/j.cmpb.2012.07.003.

van Dijk, E. T., Westerink, J. H., Beute, F., & IJsselsteijn, W. A. (2015). In sync: the effect of physiology feedback on the match between heart rate and self-reported stress. *BioMed research international, 2015*, 1-9. https://dx.doi.org/10.1155/2015/134606.

Zaiontz, C. (n.d.). Two sample hypothesis testing for correlation. Retrieved on 25 June 2017 from: https://www.real-statistics.com/correlation/two-sample-hypothesis-testing-correlation/.

7. Appendix

Appendix A. Briefing protocol

Afspraak maken, mailcontact met respondent	- Standaard mail opstellen voor afspraak maken
Van te voren herinneringsmail respondent	Gestandaardiseerde herinneringsmail sturen met afspraak voor briefing en aandachtspunten: ● Neem laptop en telefoon mee ● Laptop: installeer Java op www.java.com ● Smartphone: zorg dat je genoeg ruimte opslag hebt voor downloaden app: 200 mb.
Voorbereiding	Voorbereiding: ● E4 opladen en werking controleren ● Handleiding onderzoek op usb zetten ● Alexithymia vragenlijst printen ● Informed consent printen ● Voorbeeld vragenlijst klaar zetten die tijdens uitleg gesprek als voorbeeld ingevuld kan worden in de mQuest app. ● Aanmaken account voor mQuest app Meenemen: ● Laptop met vragenlijst Alexithymia ● E4 + oplader ● Alexithymia vragenlijst en informed consent ● Procedure op papier ● Pennen ● Usb-stick met software empatica manager
Gesprek 1: Introductie + informed consent	Tijdens eerste gesprek: ● Respondent verwelkomen, voorstellen en bedanken voor deelname Uitleg onderzoek ● *Wij zijn tweede- en derdejaars studenten Psychologie.* ● *Wij doen onderzoek naar stress en emoties. Daarvoor meten we met behulp van een e4 sensor en een app waarbij u elke 2 uur 4 korte vragen beantwoord.* ● *U hebt vrijwillig gekozen om deel te nemen aan dit onderzoek, u heeft dan ook het recht om deelname op elk moment op te zeggen, indien gewenst.* ● *Uw persoonsgegevens en onderzoeksdata zullen niet verstrekt worden aan derden, ze zijn alleen zichtbaar voor onze projectgroep en onze begeleider. Mochten wij uw data willen gebruiken in ons*

<table>
<tr><td></td><td>onderzoeksrapport, dan zal dit altijd anoniem gebeuren, zodat niemand kan achterhalen dat het van u afkomstig is.
● Wanneer u vragen hebt of als er onduidelijkheden zijn kunt u dit altijd aangeven en dan zullen we kijken tot in hoeverre wij deze kunnen beantwoorden/verduidelijken zonder dat er sprake kan zijn van beïnvloeding van het onderzoek.
Informed consent tekenen</td></tr>
<tr><td>Alexithymi vragenlijst + downloaden software + app</td><td>Stap 1. Uitleg software en vragenlijst invullen
Om de data van de E4 sensor te uploaden, zal er een programma geïnstalleerd moeten worden op uw laptop. Als het goed is, heeft u Java geïnstalleerd. Ook zal er een app op uw telefoon geïnstalleerd moeten worden.
Het installeren van de software en de app zal de onderzoeker voor u doen, gaat u hiermee akkoord?
In de tussentijd krijgt u een vragenlijst, zou u deze willen invullen?
Stap 2. Respondent Alexithymia vragenlijst laten invullen op laptop.
Laat proefpersoon vragenlijst in eigen taal invullen:
Wachtwoord vragenlijst:
Nederlands: link
Duits: link
Engels: link
Stap 3. Ondertussen software en app installeren.
https://www.empatica.com/empatica-manager-download
Stap 3a. Mquest app installeren op smartphone
Android:
1. Download de app mQuest in de google play store
2. Start de mQuest app door te klikken op het mQuest icoon in het algemene menu van je telefoon.
3. Wanneer “welcome to mQuest” verschijnt, kies dan Questserver Manual Configuration
4. Wanner “mQuest Preferences” verschijnt, verander dan “Profile” in “manual”
5. Verander “Mandator/Project ID” naar [mandator]
6. Verander QuestServer host in [server]
7. Verander username en wachtwoord.
8. “SSL”, “Auto-sync” en “Receive push notifications” aanzetten/controleren.</td></tr>
</table>

	9. Klik op "test server settings" 10. Ga terug, klik op "OK" 11. Klik op de "refresh" knop Apple: 1. Download de app mQuest in de apple store. Start de app door te klikken op het mQuest icoon in het algemene menu van je telefoon 2. Kies het menu icon 3. Kies "settings" 4. Kies "QuestServer preferences" 5. Verander "Profile" in: "Custom configuration" 6. Verander "Mandator/project ID" in [mandator] 7. Verander "QuestServer host" in [server] 8. QuestServer port moet op '443' staan 9. Verander username en wachtwoord. 10. Ga terug door op "settings" of "instellingen" te klikken links bovenin. 11. Zet de knopjes "Auto-sync after a survey" en "Receive push notifications" op aan. 12. Klik op "Back" links bovenin. 13. Klik op de synchronisatieknop rechts onderin 14. Klik op "OK" na melding "finished synchronization" 15. Klik op "OK" voor pushbericht **Stap 3b. Empatica installeren vanaf usb stick** ● Installeer vanaf stick ● Wachtwoord: … ● Gebruikersnaam: …
Uitleg E4	- Controleren of er zilveren knopjes aan het bandje zitten om band dicht te doen en huidgeleiding te kunnen meten Stap 4. Uitleg Sensor: *1. E4 om de pols doen van de linkerhand, het knopje aan de bovenkant ter hoogte van (en aan dezelfde kant als) de knokkel.* *2. De E4 moet strak om de pols zitten zodat er geen lucht onder komt, maar ook niet zo strak dat het pijn doet.* *3. Om de sensor te starten moet u 2 seconden de knop indrukken. De sensor gaat eerst 1 minuut groen knipperen, u moet dan even wachten. Daarna gaat de E4 automatisch in de opnamestand, het knipperlichtje gaat dan uit.* *a. Om te checken of de polsband aan het opnemen is kunt u de onderkant van de polsband bekijken, hier hoort dan groen licht uit te komen. Het groene licht mag tijdens het dragen niet aan de zijkanten te zien zijn, dan zit de polsband te los.*

b. *Door de button 2 seconden in te drukken, kunt u de E4 ook weer uitschakelen.*

Stap 5. Uitleg data uploaden: Leg dit uit aan hand van de software op de laptop van de respondent.

NB: Sluit nóóit de sensor aan de laptop aan als er géén empatica manager software is geïnstalleerd!

1. *De Empatica Manager wordt gebruikt om de data van de polsband te uploaden. Daarvoor moet je de software starten en je inloggen met*

Wachtwoord: …
Gebruikersnaam: …

2. *Zet de sensor uit. Sluit dan de polsband aan met de houder op de onderkant van de sensor (luister of de houder en sensor in elkaar klikken, zo niet, dan zit de sensor waarschijnlijk niet goed aangesloten). Stop het usb snoer in de laptop/computer. De upload gaat dan automatisch en wordt bevestigd door een kort berichtje.*
3. *We vragen u dit elke avond te doen.*

Stap 6. Uitleg opladen sensor: leg dit uit aan hand van de software op de laptop van de respondent:

1. *De sensor moet elke dag opgeladen worden. Het liefst op momenten dat u slaapt ('s nachts, minstens 2 a 3 uur.)*
    a. *Het is gemakkelijk om dit te doen wanneer u de data geupload hebt, omdat de sensor dan toch al aangesloten is.*
2. *Sluit daarvoor de polsband aan met de houder en usb snoer in een laptop of computer die aan staat. Niet aan een stopcontact opladen!*

Stap 7. Uitleg opmerkingen sensor

1. *De E4 kan niet tegen water of hevige regen.*
2. *De E4 NIET aan het stopcontact opladen!!!*
3. *De E4 gaat tijdens het opladen uit. Zet de E4 na het opladen weer aan door de knop 2 seconden ingedrukt te houden, kijk naar het groene licht.*
4. *Er een kans is dat de E4 stuk gaat zonder reden, neem dan zo snel mogelijk contact met de onderzoeker op voor een nieuw apparaat.*
5. *De E4 is verzekerd, maar bij bewuste schade of bewust verlies kan dit wel op de deelnemer verhaald worden.*
6. *Als u even niet meer weet wat u moet doen, of wanneer er iets onverwachts gebeurt, kunt u kijken in de handleiding.*

Uitleg mQuest	Stap 8. Uitleg mQuest 1. *Elke 2 uur staat er een vragenlijst klaar in de app, u wordt gevraagd om deze te beantwoorden als u wakker bent. Hier krijgt u een melding van. Als u slaapt kunt u deze melding negeren, u hoeft de vragenlijst dan niet in te vullen.* Laten zien hoe de app werkt. Er staat een voorbeeldvraag klaar in de app zodat de respondent samen met de onderzoeker kan kijken naar de vragenlijst. 2. *Na het invullen van de vragenlijst dient u elke keer op "OK" te drukken en daarna de app af te sluiten. Anders worden antwoorden niet goed opgeslagen.*
Vragen	*Heeft u nog vragen of zijn er onduidelijkheden?*
Uitleg contact + contactgegevens geven	● Contactpersoon: degene die brieft ● Nummer: ● *Als u toch nog een vraag heeft of als er problemen zijn kunt u altijd bellen of een berichtje sturen via sms of What's App naar +31 / +49 . Ook kunt u mailen naar [email].*
Afspraak maken voor debriefing	Afspraak maken voor debriefing (zie debriefing protocol)
Registratie	Onderzoeker noteert serienummer van de E4 en id van respondent. Ook leeftijd en geslacht wordt genoteerd na toestemming

Appendix B. Debriefing protocol

Stap 1	Afspraak maken tijdens briefing / reminder mail	❑ gestandaardiseerde mail sturen herinnering afspraak ❑ inleveren E4 ❑ alexithymia ❑ exit interview
Stap 2	Voorbereiding / meenemen	❑ vragenlijst 'alexithymia' NL, EN en DU digitaal ❑ laptop mee ❑ vragenlijst 'alexithymia' NL, EN en DU papier ❑ vragen 'exit interview' meenemen ❑ opname apparatuur / telefoon mee ❑ pennen
Stap 3	Opening	❑ participant bedanken, en vragen of alles gelukt is. ❑ uitleggen dat ze data niet te zien krijgen, en dat hun data vertrouwelijk behandeld zal worden.
Stap 4	Innemen E4	❑ noteren serienummer E4 en ID van respondent ❑ controleren of zilveren knopjes aan het bandje zitten ❑ controleren of lader en kabeltje erbij zitten ❑ controleren of de E4 nog aangaat / uitgezet moet worden ❑ controleren of de E4 nog data heeft opgeslagen (door aan laptop te leggen) ❑ controleren op zichtbare beschadigingen
Stap 4	Alexithymia	❑ participant vragenlijst 'alexithymia' laten invullen op laptop in moedertaal (NL/EN/DU) (papieren versie als reserve)
Stap 5	Exit interview	❑ vragen of exit interview opgenomen mag worden ❑ vragen 'exit interview' stellen
Stap 6	Afsluiting	❑ participant bedanken ❑ participant gedag zeggen

Appendix C. Informed consent (EN)

Informed consent

Title of the research: What self-reported experience of people is the best predictor of fluctuations in heart rate and skin conductance in daily life?

Responsible researchers: Liselotte Eikenhout, Marlise Westerhof, Kirsten Rupert, Jeremias Wenzel, Lukas Beinhauer en Mathijs de Ruiter.

To be completed by the participants

I declare in a manner obvious to me, to be informed about the nature, method, target and [if present] the risks and load of the investigation. I know that the data and results of the study will only be published anonymously and confidentially to third parties. My questions have been answered satisfactorily. [If applicable] I understand that film, photo, and video content or operation thereof will be used only for analysis and / or scientific presentations. I voluntarily agree to take part in this study. While I reserve the right to terminate my participation in this study without giving a reason at any time.

Name participant: ……………………………………………………………………………………………………..

Date: ……………………………………… Signature participant: …………………………………………………………

To be completed by the executive researchers

I have given an spoken and written explanation of the study. I will answer remaining questions about the investigation into power. The participant will not suffer any adverse consequences in case of any early termination of participation in this study.

Name researcher: ……………………………………………………………………………………………………..

Date: ………………………………… Signature researcher: ……………………………………………………….

Appendix D. User manual for participants

Manual for Participants

Login Data:

Empatica Manager

Login:

Password:

mQuest

Login:

Password:

First of all thank you very much for your participation in this research.

This manual should consist of everything you need to know in order to take part in this research. Take your time to read all the information and should there be any questions coming up go ahead to contact the researcher.

What is to be expected during the research?

Every 2 hours, if you're awake you will be asked to answer a couple of question via an app on your mobile phone. Whenever you're asleep you can ignore all notifications, so set your phone on silent. Every evening/night you will be asked to upload the E4 data, to recharge the wearable and synchronize the E4.

How does the E4 work?

Setting the E4 on and off

In order to start the sensor you will have to press the button for 2 seconds. The light will blink blue for a minute which you will have to wait for. Afterwards the E4 will start the recording automatically. Check the underside if you want to make sure the wearable is recording, you should be able to see a green light. Again by pressing the button for 2 seconds you will be able to switch off the E4.

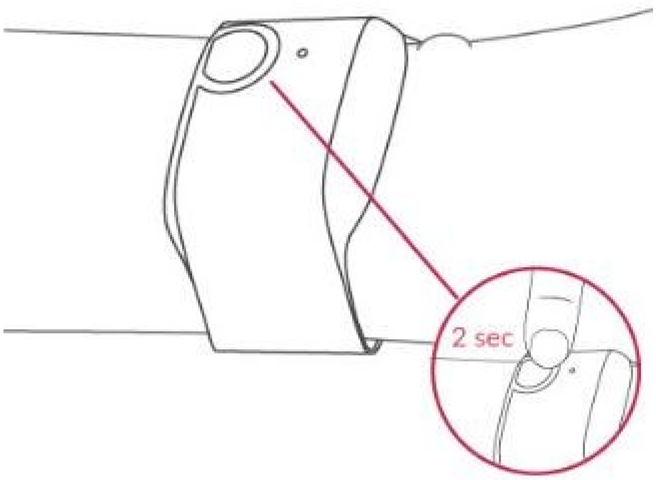
Upload data and recharge the E4

The Empatica Manager is used to upload the data from the wearable. To do so you have to start the software and login using email and password mentioned above. Now connect the wearable with the container and the cable to the laptop/computer. The upload will happen automatically and will be confirmed by a short message. We ask you to do this every evening/night before you go to sleep.

To recharge the wearable connect it to your laptop/computer following the same steps as mentioned above. Do not recharge it using a wall socket or a laptop/computer without Empatica Manager!

Wearing the E4

PLace the E4 wristband top-down on a surface. Wrap the band around the wrist while making sure that the button is on the outside of your wrist. For reference look at the picture below. The E4 should be worn behind the knuckle. Make sure it is fixed and can't wriggle back and forth.



What do the notifications of MQuest mean?

"Start synchronizing"

The app is synchronizing, wait for a moment.

"Loading projects"

The projects are being loaded.

"Checking for questionnaire update questionnaire .."

The app is checking if new information for questionnaire is ready.

"Finished synchronization while updating/loading a project questionnaire."

Something is not working while synchronization, multiple things can cause this. Try restarting your mobile phone and synchronize again.

"The task is now available. Please start it"

A new questionnaire arrived, go to the MQuest app to complete it.

"More tasks will be displayed as soon as the corresponding start-time or location has been reached"

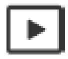
Whenever a new questionnaire is waiting for your completion will you be notified. If no questionnaire is displayed there's nothing you have to do.

What do I have to do when…?

I can't open the questionnaire, but instead only see information

regarding the questions.

You probably did not press to start button. Go back and try pressing .



I can’t start the E4 anymore?

Contact the researcher as fast as possible. Use the personal information you received with the E4.

I can’t find the E4 in the Empatica Manager?

Pull the E4 out of the usb-port, restart the Empatica Manager and reconnect the E4. If this doesn’t help call the researcher using the personal information you received with the E4 (You can easily do this the following day if that works better for you). It will recharge as long as the green light is there when you connect the E4 to the laptop/computer.

The push notifications annoy me during the night?

This can be modified. If this or other things annoy you during the research, go ahead and contact the researcher. We can check whether we are able to change things.

Remember that…

- The E4 cannot handle rain or other bigger water stream.
- The E4 will switch off while recharging. Restart it and check for the green light whenever you use it.
- It might happen that the E4 stops working for no apparent reason.

In that case make sure to contact the researcher as quickly as possible. (Use the personal information you received with the E4)

- The E4 may be insured, but should it be broken or lost consciously the costs will be transferred to the participant.

I removed mQuest, how do I install the app again?

New installation of mQuest for iPhone

1. Remove the app from your mobile phone
2. Download the app mQuest from the Apple App Store
3. Start mQuest by pressing the mQuest icon the your phone's menu
4. Chose "QuestServer manual configuration"
5. Change profile in "Custom configuration"
6. Change Mandator/project ID: 403010
7. Change QuestServer host: qs3.mquest.de
8. Change login and password. Login and password can be found in the beginning of this manual
9. Go back by pressing "settings" or "instelling" on the upper left side
10. Synchronization?
11. Ok?
12. Press OK for push-notifications (this is the notification you get when there is a new questionnaire ready for you)

New installation of mQuest for Android

1. Remove the app from your mobile phone
2. Download the app mQuest from the Google Play Store

3. Start the app by pressing the mQuest icon in your phone's menu
4. Chose "QuestServer manual configuration"
5. Press OK
6. GO to "setting" by pressing the 3 dots in the upper right corner
7. Chose Settings
8. Chose QuestServer preferences
9. Change profile in "Manual"
10. Changer Mandator/project ID: 403010
11. Change QuestServer host: qs3.mquest.de
12. Change login and password. Login and password can be found in the beginning of this manual
13. Go back (triangle/arrow, normal "back"-button for android)
14. Press OK

Appendix E. Exit interview questions

1. How did it go this week?
2. What was the burden of the experiment (on a scale from 1 (very low)-10 (very high))
3. Were you able to get used to the device?
4. Did you miss many opportunities to fill in the survey?
5. Did you anticipate the notifications?
6. How did you go about filling in the survey every two hours?
7. What things do you consider when judging your own level of stress?

Appendix F. Comparison calculations Excel

Formulas below are adapted from Zaiontz, C. (n.d.):

For correlations of stress and number of SCR's momentary assessment versus retrospective assessment:

H_0: $\rho_1 = \rho_2$

H_a: $\rho_1 > \rho_2$

r'_1 = FISHER(r_1) = FISHER(.07) = .070

r'_2 = FISHER(r_2) = FISHER(-.05) = -.050

s = SQRT(1/(n_1 – 3) + 1/(n_2 – 3)) = SQRT(1/13 + 1/10) = .421

$z = (r'_1 - r'_2)/s$ = (.070 – -.050) / .421 = .286

p-value = 1 – NORMSDIST(z) = 1 – NORM.DIST(0.286; 0; 1; TRUE) = .39

p-value = .39 > .05 = α

For correlations of stress and mean amplitude of SCR's momentary assessment versus retrospective assessment:

H_0: $\rho_3 = \rho_4$

H_a: $\rho_3 > \rho_4$

r'_3 = FISHER(r1) = FISHER(-.51) = -.563

r'_4 = FISHER(r2) = FISHER(-.39) = -.412

s = SQRT(1/(n_1 – 3) + 1/(n_2 – 3)) = SQRT(1/13 + 1/10) = .421

$z = (r'_1 - r'_2)/s$ = (-.563 – -.412) / .421 = -.359

p-value = 1 – NORMSDIST(z) = 1 – NORM.DIST(-0.359; 0; 1; TRUE) = 0,64

p-value = .64 > .05 = α

Appendix G. Spearman correlations per participant

Table G1

Spearman correlations per participant for self-reported stress

	Momentary assessment of stress		Retrospective assessment of stress	
Id	Number of SCR	Ampl. of SCR	Number of SCR	Ampl. of SCR
A	.07	.04	-.02	-.03
B	**.31***	-.04	**.56****	.02
C	**.37***	**.38***	.27	.14
D	**-.41****	**-.44****	**.60****	**.60****
E	.02	-.18	.20	.03
F	-.20	-.14	.19	.18
F	**.43***	.09	.22	.33
G	.16	.03	.08	.20
H	.11	.14	**.33***	.10
J	-.13	-.03	.04	.03
K	.02	-.01	-.10	**.39***
L	.10	.12	.01	.01
M	.17	.13	-.16	.08

P	-.20	-.20
Q	.08	**-.38***
R	-.20	-.01

*. $p < .05$ (1-tailed).
**. $p < .01$ (1-tailed).

Table G2

Spearman correlations per participant for self-reported emotion intensity

	Momentary assessment of emotion intensity		Retrospective assessment of emotion intensity	
Id	Number of SCR	Ampl. of SCR	Number of SCR	Ampl. of SCR
A	**-.31***	-.27	.10	-.11
B	.13	.22	**.53****	.24
C	**.40***	**.52****	**.48***	.34
D	**-.45****	**-.47****	**.62****	**.58****
E	-.01	**-.32***	-.04	**-.37***
F	.03	.17	**.34***	**.44****
F	-.09	.16	.25	-.04
G	.21	**.32***	.09	.04
H	**.50****	**.39***	**.37***	**.34***
J	.03	.08	.18	.15
K	.16	.25	.13	.02
L	.22	.12	.27	-.05
M	.14	.05	.10	-.14
P	-.42	-.28		
Q	.03	**-.34***		
R	-.14	.15		

*. $p < .05$ (1-tailed).
**. $p < .01$ (1-tailed).