UNIVERSITY
OF TWENTE.

Exploring the relationship between self-reported stress and electrodermal activity in daily life

Lisa Kiel

University of Twente

Enschede, July 2018

Bachelor Thesis

Positive Psychology and Technology

Faculty of Behavioral Science

Department of Psychology, Health & Technology

1st supervisor: Dr. Matthijs Noordzij

2nd supervisor: Youri Derks

Abstract

Background: In recent years there was a significant increase of number of people who experienced stress. This can potentially lead to severe health problems. It is therefore of interest to have a device that could help detect ones stress levels. Laboratory studies have indicated the effectiveness of using electrodermal activity (EDA) to detect ones stress level. The current study aims to investigate this relationship in a real-life setting and by looking at the correlation of self-reported stress with skin conductance level (SCL) and number of skin conductance response (SCR), which data were measure continuously over the course of seven days in real life.

Methods: The 38 participants wore a wearable wrist-sensor, the Empatica E4, in order to measure their EDA. Their stress levels were acquired through the mobile application mQuest in which they indicated their stress level for the past minute and past 2 hours. The Pearson correlation coefficient of the stress and EDA variables was calculated for each participant to investigate their relationship.

Results: Only for very few of the participants a significant correlation between the variables could be found. The highest correlation yielded the correlation of the past minute stress variable with the past minute number of SCR, with seven significant correlations of which 6 were positive.

Discussion and Conclusion: The small number of significant results indicate that overall EDA cannot be used to indicate ones stress level in daily life. Further research should include measurements of the participants' introspection to investigate to what extent this affects the relationship between EDA and more research is needed about the relationship of EDA and stress in long-term stress situations.

Table of Contents

1. Introduction

In recent years, stress has become a growing concern in society. According to the American Psychology Association, in 2107 there was a significant increase in stress for the first time since 2007 (American Psychological Association, 2017). In their study, more than the half of the participants stated that they experience stress. Persistent stress can result in severe health problems, for example an increase of the risk for cardiac diseases (Ziegler, 2012), for an impaired immune system (Moynihan, 2003) or an increased likelihood for developing depression (Hassard et al., 2014). The impaired health due to stress can also result in decreased productivity or absence at work, which led up to $300 billion for healthcare costs, solely due to stress at the workplace (Eastern Kentucky University , n.d.). Besides the workplace, pollution, noises or interpersonal-conflicts can also be contributors to chronic stress (McEwen, 2006). So many people are potentially exposed to stressors that can trigger chronic stress, and with it its negative consequences. It is therefore of interest to be able to monitor ones stress level to recognize persistent and chronic stress in time, as an early detection may enable the individual to identify them and implement behavior to better cope with it (Bakker, Holenderski, Kocielnik, Pechenizkiy & Sidorova, 2012). Stress tracking has therefore become a favorable feature which some wearable technologies already intend to perform. This study aims to investigate whether physiological measurements can be used to give correct information about ones perceived stress level.

Stress is, according to Feuerstein, Labbé and Kuczmierczyk (1994) a complex pattern of reactions that can involve behavioral, physical as well as cognitive components. The physiological component consists, under more, out of the activation of the sympathetic nervous system (SNS) which is part of the autonomic nervous system. The activation of the SNS in turn involves gland secretion of the skin, blood pressure and the heart's electrical activity (Sun et al., 2012). The measurable physiological components of stress could therefore potentially be used to measure stress itself.

There already have been studies conducted who successfully used measurements of the ANS as indicator for perceived stress. For example, Sandulescu Andrews, Ellis, Bellotto and Mozos (2015) used a variable device to measure heart rate and electrodermal activity (EDA) to measure self-reported stress levels, while Sun et al. (2012) used electrocardiography (ECG) and galvanic skin response. It is important to note however, that because of the complex nature of stress, as Feuerstein et al. describe it, it may be problematic to draw conclusions on an individual's stress level, solely based on physiological measurements. Psychophysiology is usually seen as being a one-way and one-dimension relationship, so that one emotion can be linked to one certain physiological reaction and vice versa. However, it is for instance also possible that the very same physiological reaction can be due to many different emotions (Fairclough, 2009). Current empirical evidence for psychophysiology has also the flaw that most studies have been done in laboratory settings, which in few cases may tried to simulate real life, but simulation cannot reach the complexity and unpredictability of a real-life environment.. Although laboratory research may have its advantages, like more control over the variables and being able to compare the results with control groups, generalizations to real-life can be problematic, because the artificial nature lacks characteristics you have in real-life and possible bias could influence the results (McLeod, 2012).

The current study therefore aims to investigate the relationship between the physiological activity and self-reported psychological experiences with a wearable device in real life.

1.1 Physiological measurements

For the present study it is chosen to measure physiological activity on the basis of EDA. This is because EDA has an advantage above other physiological measurements. The sweat glands are, in contrast to for instance blood pressure or heart rate, not influenced by the parasympathetic nervous system but solely by the SNS, which makes the sweat glands „an ideal measure for sympathetic activation and therefore for the stress reaction“ (Setz et al., 2010). Another concern with using physiological measure is the possible confounding variable of physical activity. A higher skin conductance can also be caused by physical activity (Wilhelm, Pfaltz, Grossmann & Roth, 2006) and would therefore incorrectly indicate a higher stress level. However, there have also been several studies conducted that indicate the effectiveness of using EDA to measure stress, despite some physical activity. Collet, Salvia and Petit-Boulange (2012) measured workload with EDA and the results in their study show that EDA was well correlated with mental strain but not with the motor requirements necessary for a task. In another study of Sun et al. (2012), the participants were put under mental stress while they either had to sit, stand or walk. In this study, analysis of the data showed that the measurements of skin conductance were not influenced by the three different activity levels. The studies indicate that EDA can also be expected to be a reliable tool to measure stress, under regular physical activity in daily life.

Therefore, the current study focuses on the measurement of EDA, more particularly skin conductivity. EDA is an umbrella term for electrical phenomena on the skin (Boucsein, 2012). One of the most common studied forms of EDA is skin conductance. As the name suggests, it measures the conductivity of the skin by measuring the current flow of two electrical potentials which are applied on the skin (Braithwaite, Jones, & Rowe, 2015). As described above, a typical physiological response to stress is the activation of the sweat glands through the SNS. Because the skin conductivity is higher on damp skin, this measurement potentially be used to measure stress level. The responsiveness of the skin conductance also differs across the body. In a study by Van Dooren, de Vries and Janssen (2012) they compared 16 different location for its skin conductance responsiveness to emotional arousal. The fingers, feet and shoulders were found to be most responsive, while the arm, back and thigh where the least responsive.

There is usually distinguished between two components of the skin conductance signal: First (1), the *skin conductance level* (SCL) which is the slow changing part of which is assumed that it reflects autonomic arousal. The second (2) part is de *skin conductance response* (SCR) which is the faster changing part that is expected to occur after a stimulus. If no external stimuli are discernible, it is referred to be a *non-specific* SCR (NS.SCR) (Braithwaite et al., 2015). The study of Setz et al. (2010) indicates that the peak rate, respectively the SCR occurrences, and its height can give information about the subjective stress levels of a person. Therefore these two measurements will be used in the current study.

1.2 Psychological measurements

Self-reports are the common used methods to measure a participants experience or emotion (Schwarz, 2004). They can be distinguished between *retrospective* self-reports, where the participant reports how he felt in the past, and *current* self-reports, which is about how the participant feels at the moment. Retrospective reports have the disadvantage that they rely on the memory of the participant, which is prone to bias because emotions are poorly represented in our memory (Schwarz, 2004), which is why current study will focus on current self-reports.

1.3 Current Study

The aim of this study is to gain more insight into the relationship between electrodermal activity and psychological experience of an individual to get to know if a wearable device can help to detect stress and help to prevent associated health-problems. The hereby chosen design of continuous measurements over several days in a real-life environment is, according to the researcher's knowledge, rather innovative. Although the field-study nature of chosen design differs from the laboratory one of previously mentioned studies, the expectations for the current study are nonetheless based on those, because of a lack of studies about this issue that have a comparable design. Further it is chosen to look at the intra-individually relationship of the participants, because the ability of self-perception that is required may differ among them. Therefore, the research question for the current study is whether skin conductance positively correlates with the individual participant's self-reported stress levels. It is expected to find a moderate positive correlation.

2. Method

2.1 Participants

To participate in this study, sufficient knowledge of the English knowledge was required and the participants had to own a smartphone and have access to a computer with USB-port and an internet connection. The participants consisted out of two samples. For both samples, participants were removed when they did not finish the study or errors with the equipment occurred. The first sample was recruited in 2017 and consisted out of 18 participants who completed the study and additional three who had to be removed from the data. The remaining 18 participants had German, English or Dutch as their first language and were aged 19 to 27 years (*M* = 20.83). For the second sample 23 participants were recruited of which three were removed from the data. The remaining 20 were aged 19 to 45 years (*M* = 22.9) Taken together there were 40 participants, aged 19 to 45 years (*M* = 21.87, *SD* = 4.04). More detailed information about the participants can be found in Table 1. The study was further approved by the ethical commission of the University of Twente

Table 1.
Descriptive statistics of the study's used samples.

Sample	Women	Men	*N* Total	*M* Age (*SD*)	Age Range
2017	11	7	18	21.76 (2.56)	19-27
Current	12	8	20	22.04 (5.37)	19-45

Total	23	15	38	21.92 (4.30)	19-45

Note: Descriptive statistics after the exclusion of participants

2.2 Materials

The participants were provided with an E4 Empatica wristband, in order to unobtrusively measure the physiological data. The size of E4 wristband is comparable to modern Smartwatches, which enables the participants to wear it unobtrusively. It is equipped with an EDA sensor to measure the changes of the skin's electrical properties with a sampling frequency of 4 Hz, and a 3-axis Accelerometer which enables to capture motion-based activity with a frequency of 32 Hz (Empatica, 2018). It is further equipped with a Photoplethysmography sensor to measure the heart rate variability and a sensor to measure skin temperature, which both were not used in this study.

The wristband was handed to the participant together with a micro-USB to USB cable and a charging cradle, with which it can be connected to the computer and used to charge the wristband. Via the software “Empatica Manager”, which was installed on their computer of choice, the data of the wristband could be uploaded.

For the psychological measurements, the application for mobile devices “mQuest” was used, which the participants had to install on their smartphone. With this application, the participants received push-notifications to answer the questions in previously specified time-intervals. The questions were also provided through the application. The participants received questions about how much stress they experienced, how intense their emotions were and how pleasant their experiences were (see Appendix A). This was asked for their experiences during the past minute and the last two hours. For the first questions about their stress and arousal level, a scale from 0 (very low) to 10 (very high) was used and for the last questions regarding their perceived pleasure, a scale of 0 (very unpleasant) to 10 (very pleasant) was used. For the sample of 2017, the questions about their perceived pleasure were not used and they only received the ones about their perceived stress and arousal.

Additionally, the participants had to fill in the Toronto Alexithymia Scale (TAS-20) in the beginning and at the end of the study. This questionnaire was not used in the current study, but was administered for potential future studies.

2.3 Design & Procedure

The current field-study has an observational and within-subject design. The data of the participants were collected over the course of one week. Before the study started, the participants had to sign an informed consent and had to fill in the TAS-20. Then they were informed about the procedure and how they shall handle the equipment. The application and software were installed with them together and they got an instruction about how to upload the data and how the app is used.

The physiological data were collected continuously and passively through a wearable sensor in form of the E4 wristband. When they were awake, they also had to answer the questions for the psychological data on the mQuest application every two hours. They were further asked to upload the data every night and charge their wristband while they sleep.

After they had finished the seven days, they had to fill in the TAS-20 again and a brief interview was held with them, in which they were asked about problems they came across with and what they took into consideration when filling in the questions (see Appendix B for detailed description of the questions).

2.4 Data-analysis

Regarding self-reported stress variable, the data was derived through the CSV files of the mQuest application. For the physiological variables of the electrodermal activity, the CSV files that were provided by the Empatica E4 wristband were used. Moreover, the "Continuous

Decomposition Analysis" (Benedek & Kaernbach, 2010) was used for the physiological variables to obtain the SCL and SCR variables. This was done for both, the interval of the last two hours and the interval of the last minute. As the SCL can only have positive values, data below zero were removed. To evaluate the descriptive statistics, the data were averaged and aggregated before the descriptive analysis was being conducted. Lastly, a correlation analysis was being conducted with the different stress and EDA variables, to explore the relationship between those.

3. Results

3.1 Descriptive Statistics

Electrodermal activity. For electrodermal activity, SCL and SCR were measured for both timeframes, the last two hours and the last minute. The mean of the SCL for the last minute timeframe is 0.59 µS (*SD* = 0.56 µS) respectively 0.7 µS (*SD* = 0.85 µS) for the 2-hour time frame. This is less than the typical range of 2 µS to 16 µS (Braith et al., 2015). The mean number of SCR for the one minute interval is 2.59 and lies within the typical range, which according to Boucsein (2012) is considered to be 1 - 3 per minute in calm and over 20 per minute in high arousal situations. A complete overview of the descriptive statistics of these variables can be found in Table 2.

Table 2. *Descriptive statistics of the averaged EDA and stress variables*

Variable	Timeframe	*N*	Mean (*SD*)	Min	Max
SCL (µS)	last minute	36	0.59 (0.56)	0.03	2.71
	2 hours		0.7 (0.85)	0.06	4.51
SCR	last minute	36	13.68 (3.28)	6.78	19.45

	2 hours		1,601 (489)	357	2,324
Stress	last minute	36	2.59 (1.24)	0.17	4,86
	2 hours		4.03 (1.76)	1	7.28

3.2 Individual differences of the variables

EDA variables. Looking at the individual differences of the SCL between the participants, it is clearly visible that there are great variations present. For the past minute timeframe, participant 24 is especially to mention whose data have a great variation, with his upper quartile up to 12 and his lower quartile at nearly zero, which can be seen in Figure 1. Also noticeable is participant 6, who has a very low SCL with low variation. In the 2-hours interval, participant 24 and 38 have a higher SCL, with an upper quartile above 10. They and with more variation, in comparison to the other participants (see Figure 2). For both timeframes it is further visible that for the majority of the participants the variation of their SCL is below 1 μS and thereby clearly under the range that is typical expected.

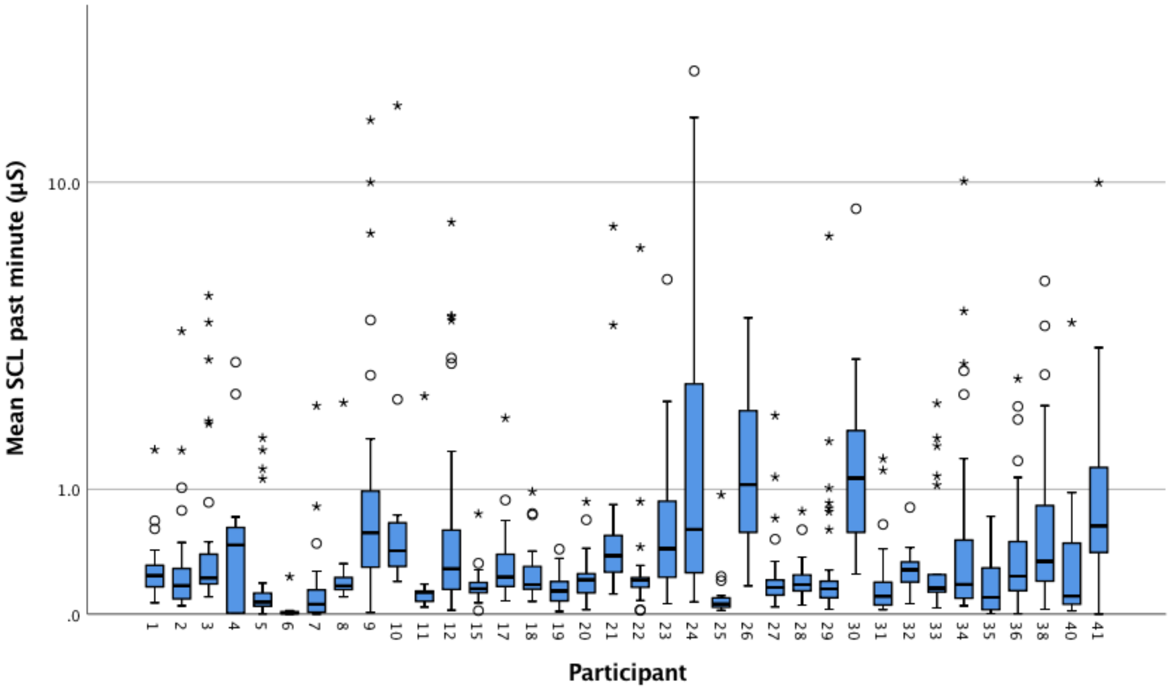

Figure 1. Mean skin conductance level (µSiemens) for the past minute per participant on a log scale with base 10.

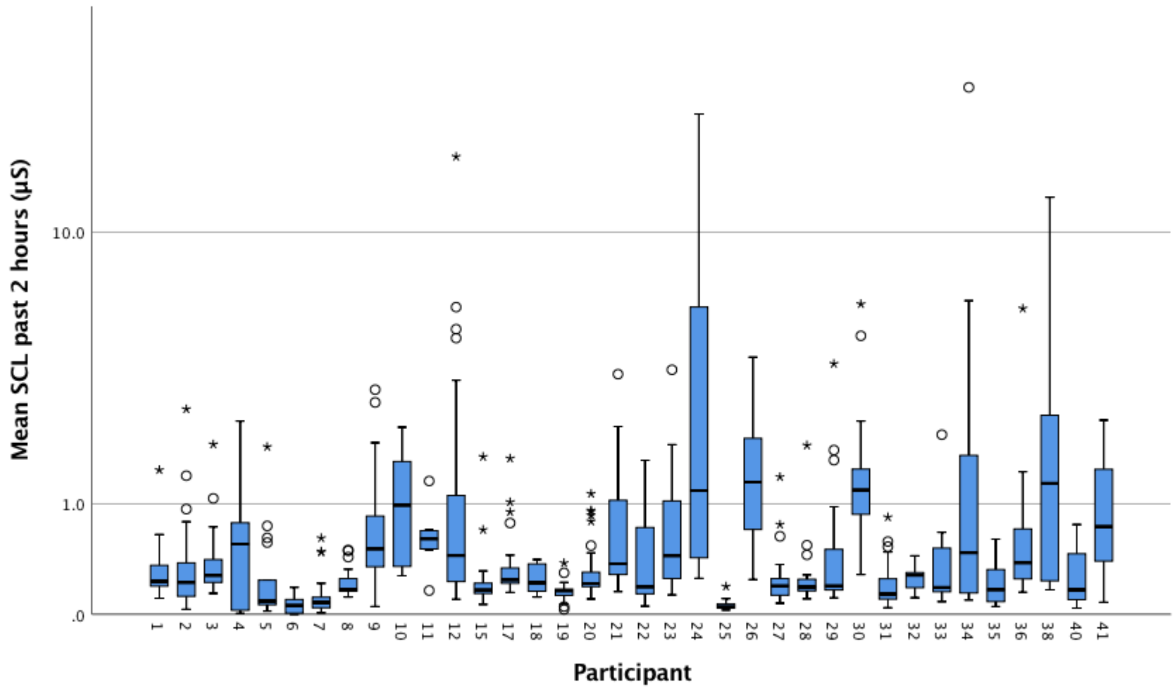

Figure 2. Mean skin conductance level (µSiemens) for the past two hours per participant on a log scale with base 10.

With regard to the SCR, there are also great individual differences visible. Overall, the participants showed highly different patterns of as well the amount of number of SCR, as the variation of it. For the two-hour interval, participant 6 is especially to mention, because he has a comparatively little number of SCR and the only one who’s upper quartile is under 1,000. There were no extreme differences between the 2-hours and one minute timeframe present.

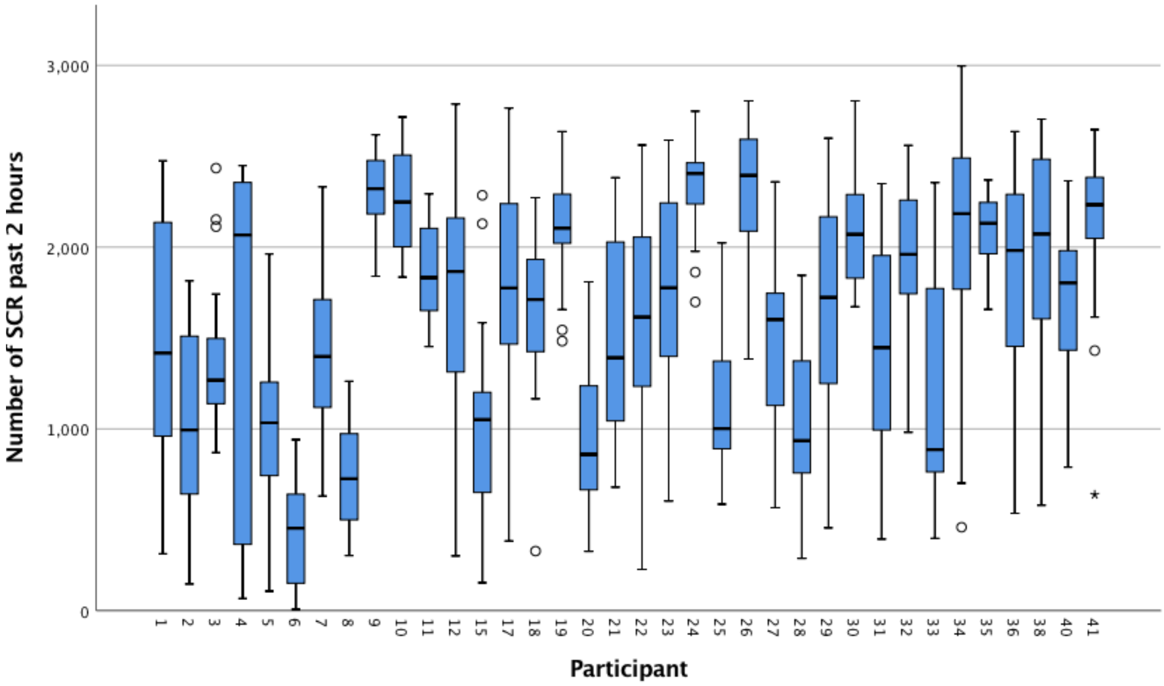

Figure 3. Number of SCR for the past 2 hours, per participant.

Self-reported stress levels. The mean of the self-reported stress level during the past two hours is with 4.12 higher than that of the past minute timeframe, which lies at 2.65 (see Table 1 for detailed descriptive statistics). Regarding the variation between each participant, there are clear differences visible. In the past-minute interval, participant 3 and 6 are with a median of zero especially to mention (see figure 4). Further, participant 3, 5, 11 and 38 have nearly no variation in their self-reported perceived stress. For the past two hours, there was a clear difference visible between the two samples that received slightly different material. As it can be seen in Figure 5, the group that received additional two questions (participant 22 - 41) show clearly a higher level of stress overall than the other sample. Moreover, the second sample also indicated a much higher stress level for the past two hours interval than for the past minute, whereas the difference was not as big within the first sample.

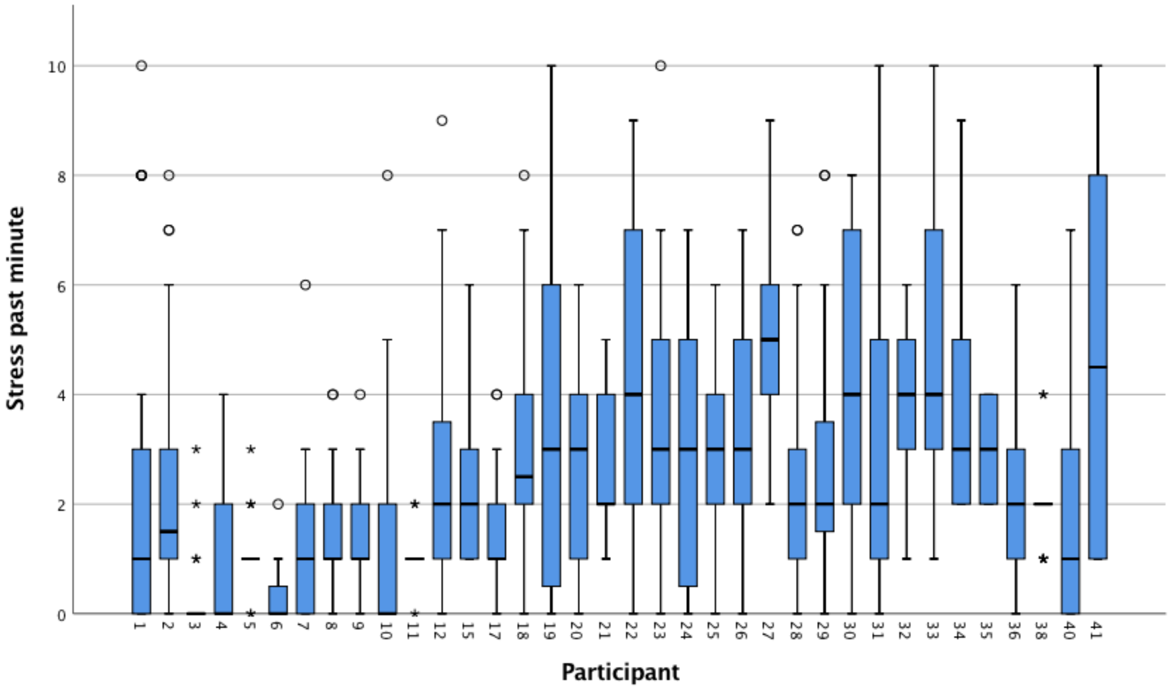

Figure 4. Self-reported stress level during the past minute per participant.

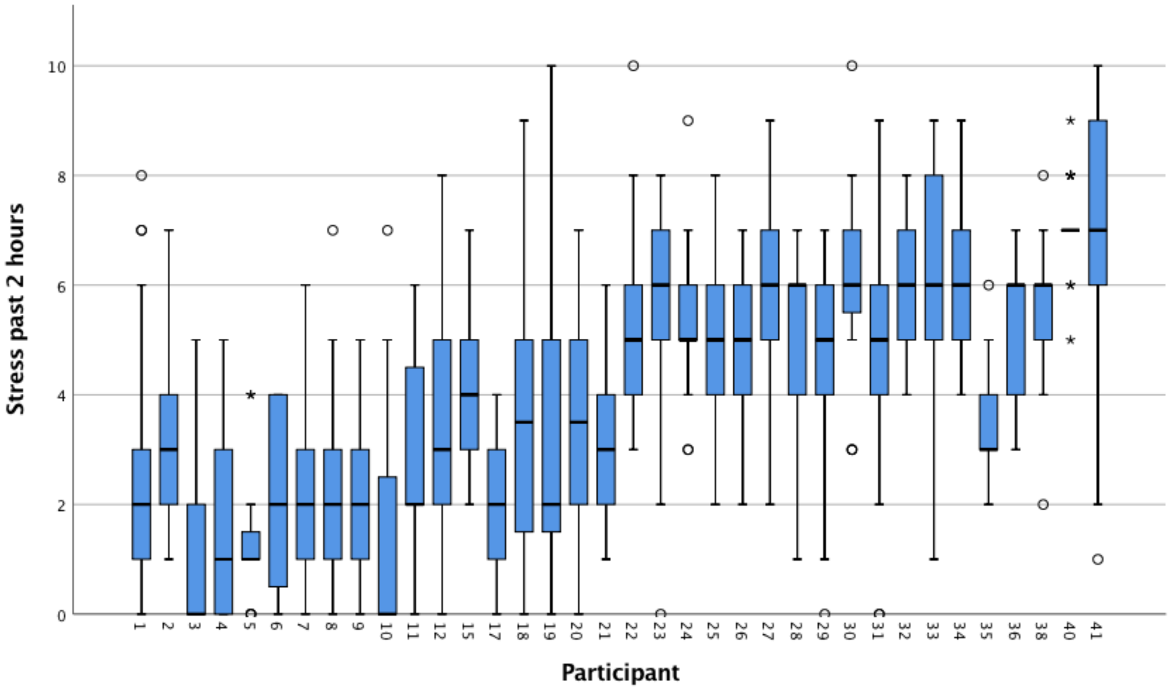

Figure 5. Self-reported stress level during the past two hours per participant.

3.3 Correlation between self-reported stress with number of SCR and SCL

In order to examine the correlation of both stress variables with the EDA variables, a correlation analysis with Person's correlation coefficient was being conducted for each participant. Overall, only for very few of the participants, a significant correlation could be found. The frequency of found correlations, including the non-significant results, were relatively equally distributed among the negative and positive correlation, with the majority around a correlation of 0 (see Appendix D).

Correlation with SCL. The correlation analysis between the stress variable and the SCL yielded the least number of significant results. For the two hours timeframe there was found only one significant result, with a moderate positive correlation for participant 31, r (31) = -.44, p = .013. The correlation of the past minute stress variable with the past minute SCL, yielded three significant correlations. All of them were positive, whereby one was weak with r (42) = ,017, p = .368. The other two were found to be moderate, with the highest correlation of participant 34 (r (34) = .553, p = 0.001).

Correlation with number of SCR. The correlation analyses between stress and the number of SCR during the last two hours, yielded a significant correlation for three of the 36 participants. Participant 4 had a strong negative correlation with r (13) = -.60, p = .02. The other two significant correlations were positive and found to be moderate, with r =.46 , respectively strong with r = .53.

For the correlation with the number of SCR during the past minute, the most significant results were found, with seven significant correlations (see Figure 6). One of those was negative with a moderate correlation (r (32) = -.35). The other six correlations were positive, whereby five were moderate with all r's between .31 and .49, and one, of participant 5, was found to be strong (r (23) = .52, p = 0.12).

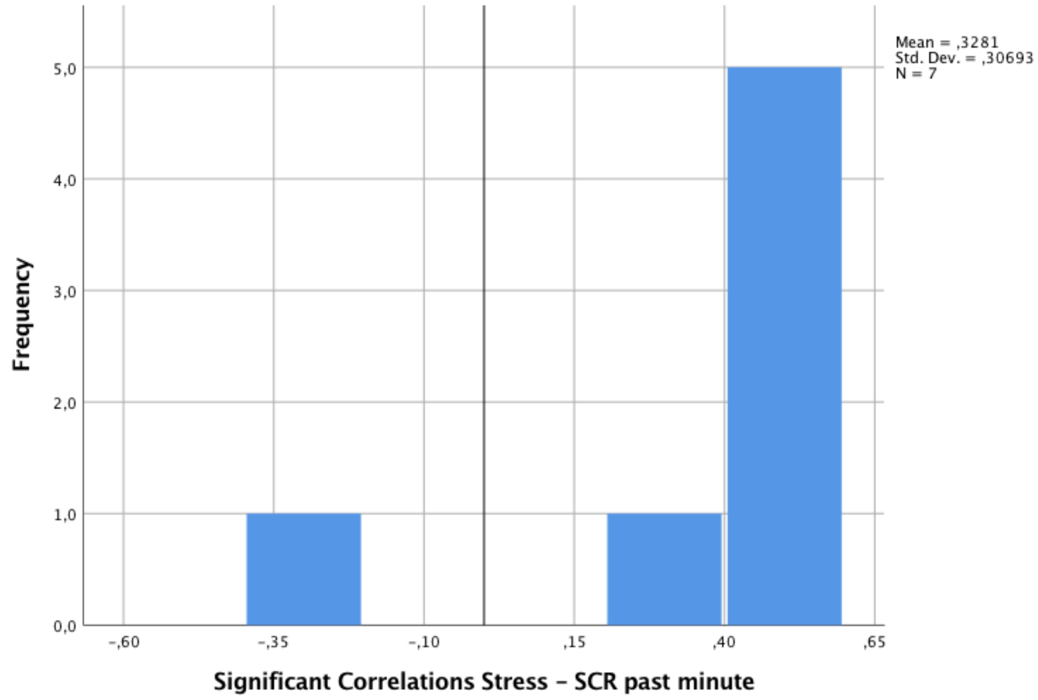

Figure 6. Frequency distribution of the significant correlation coefficients of the variables stress past minute and SCR past minute, with base line.

4. Discussion

The aim of this study was to investigate the relationship of self-reported stress levels and measurements of electrodermal activity in daily life. The results were against previous expressed expectations, to find a moderate positive correlation between the stress and EDA variables. The very low number of significant results, taken together with the presence of some negative correlations indicate that overall there could not be found a relationship between EDA and self-reported stress in this study. Noticeable is, however, that the correlation between the number of SCR and stress during the last minute yielded more than twice as much significant correlations than for the other variables. A possible explanation is that the number of SCR better reflect ones stress level than the SCL. In the study of Setz et al. (2010), they also found that only the number of SCR but not the SCL gave information about the participants stress levels. In addition the past minute interval might be less prone to biases than the two hours interval. To ask the participants how they felt for two hours requires them to make an accurate mean of this period and it is likely that they over or underestimate certain events, while they only have to indicate what they are feeling at the very moment to reflect over the past minute. This could also be reflected in the variation of the participants stress level; Especially the second sample that was used in this study indicated a much higher stress level for the two-hours interval than for the past minute, which could reflect a bias and overestimation of their stress levels for the longer timeframe. It is unclear however, why the second sample overall differed so remarkably in their stress levels. It could be possible that the two additional questions about their perceived pleasure could have influenced it, because they were rated differently. For stress and arousal, the 0 of the scale indicated a very low level and 10 a very high level. The scale for the perceived pleasure however was from 0 (very unpleasant) to 10 (very pleasant). The “neutral” of this scale is therefore not 0 but 5, so some participants could have confused these ratings.

Nevertheless, the found results differ from these of previously introduced studies which all successfully used EDA to indicate ones stress level (Setz et al., 2010; Collet et al., 2012; Sandulescu et al., 2015; Sun et al, 2012). There are several aspects to mention in which these studies differ from the current one, which could give some explanation for those different results. First, the methodological setup was very different. All cited studies were conducted in a laboratory set-up, regardless that some attempt to mimic real-life stress situations (Collet et al., 2012; Setz et al., 2010), while the current one has been done in a real-life setting. There was usually a clear distinction between a base condition and a stress condition, while this will not necessarily occur in daily life. Participants therefore may find it difficult in daily life to indicate their stress level, if it for example slowly increased over a longer period of time or is subtle. The little variation some participants show in the levels they indicated further supports this assumption. Another difference to previous studies is the study’s length. Previous studies had stress conditions which were usually under or around ten minutes long (Sandulescu et al., 2015; Sun et al, 2012), while current study measured several hours per day for a whole week. It is therefore possible that the physical reaction to a novel stress situations is high first, but declines over a longer period of time, while the situation itself is perceived as being stressful the whole time. One could think hereby on the experiences during an exam. The first minutes the palms are sweaty and the heart is racing, but after some time one gets adapted to the situation and calms down, although the situation is still far away from relaxing.

Further, all mentioned studies used sensors on the fingers to measure the skin conductivity, while for this one the wrist was used, which is less obtrusive for the participants and more convenient to use in daily life. However, the skin conductance of the fingers were found to be very responsive to emotional arousal whereas the arm was found to be the least responsive location (Van Dooren et al, 2012), which could be a reason for the deviant results. The lower responsiveness of the wrist could also explain that the means of the SCL in this study where relatively low. Another possibility for the low SCL levels could be that the equipment did not work as intended.

In addition, some participants noted that they were unsure about what exactly counts as being stressed, for instance if positive stress should be classified as stress or not. This uncertainty could have affected the results and could also explain the presence of the few negative correlations. Taken together, there are some reasons why there (wrongly) may not have been found any significant results, but the results could also just support what has already been mentioned; that the relationship between physiological and psychological phenomena may be more complex than one would expect them to be (Fairclough, 2009).

4.1 Strengths and Limitations

A clear strength in comparison to previous done studies is that the present study was a field study instead of a laboratory one. This gave the opportunity to see how EDA and stress relate over the course of many hours and over many different kind of situations. The long measurement time also yielded a high amount of data for each individual. A field-study further eliminates possible biases that can be expected in a laboratory set-up. Although a field study has mentioned advantages, it also has its flaws. Its uncontrollable nature makes it impossible to check for biases or to control whether the participant executes the tasks as expected.

Despite of the very low number of significant correlations within the participants between stress and EDA, the present study gave valuable insight for future research. First, it could be interesting to see how different levels of introspection could have influenced the results. The current study already made a first step for this by starting to collect data of the TAS 20 which could be used for future research. Moreover, it could be helpful to give the participants a briefing with a definition and examples about stress and which emotions are considered to fall under stress or arousal and if they should make a distinction between them. This could eliminate some uncertainties that were noted by some participants, that they were unsure which emotions they should classify as stress. Another possibility to prevent such uncertainties could be to use a more elaborate or standardized questionnaire, like the Perceived Stress Questionnaire by Levenstein et al. (1993). This however could be difficult to implement in daily life as it would require much more time to fill they in than the questions that were used in the current study. It would also be important to investigate to what extent the different scaling of the questions could have affected the results, before the study is conducted another time. In addition it would also be interesting for a laboratory study, to investigate what extent biases may influence the correlation with EDA and stress, for example by preparing one group before the experiment that it is going to be stressful and demanding, while encouraging another group that it will be easy to do. Lastly, little is known so far about the relationship of EDA with long-term stress periods, so further research in this direction could give valuable insight.

4.2 Conclusion

The current study examined the relationship between perceived stress and EDA through continuous measurements over the course of one week. Against expectations, there were only few positive correlation found between those variables, which overall indicate that EDA cannot reliably used to indicate ones stress levels in a real-life environment. Nonetheless, the study yielded some recommendations for further research and the notion that psychophysiology might be too complex to correctly indicate ones stress levels in daily life.

References

American Psychological Association (2012). S*tress in America: Coping with Change.* Retrieved from: http://www.apa.org/news/press/releases/stress/2016/coping-with-change.pdf

Bakker, J., Holenderski, L., Kocielnik, R., Pechenizkiy, M., & Sidorova, N. (2012). Stess@Work: from measuring stress to its understanding, prediction and handling with personalized coaching. *Proceedings of the 2nd ACM SIGHIT symposium on International health informatics - IHI '12*. doi:10.1145/2110363.2110439

Benedek, M., & Kaernbach, C. (2010). A continuous measure of phasic electrodermal activity. *Journal of Neuroscience Methods, 190*(1), 80-91. doi:10.1016/j.jneumeth.2010.04.028

Boucsein, W. (2012). *Electrodermal Activity* (2nd ed.). New York, NY, USA: Springer Science + Business Media. https://doi.org/10.1007/978-1-4614-1126-0

Braithwaite, J.J., Watson, D.G., Jones, R., & Rowe, M. (2015). A Guide for Analysing Electrodermal Activity (EDA) & Skin Conductance Responses (SCRs) for Psychological Experiments. Retrieved from: https://www.birmingham.ac.uk/documents/college-les/psych/saal/guide-electrodermal-activity.pdf

Collet, C., Salvia, E., & Petit-Boulanger, C. (2012). Measuring workload with electrodermal activity during common braking actions. *Ergonomics*, *57*(6), 886-96. doi: 10.1080/00140139.2014.899627

Eastern Kentucky University, (n.d.). *Work Related Stress on Employees Health.* Retrieved from: https://safetymanagement.eku.edu/resources/infographics/work-related-stress-on-employees-health/

Empatica (2018). E4 wristband user’s manual. Retrieved from https://empatica.app.box.com/v/E4-User-Manual

Feuerstein, M., Labbé, E.E., & Kuczmierczyk, A.R. (1994). Health Psychology: A Psychobiological Perspective. (pp. 99-125). New York, NY, US: Plenum Press.

Fairclough, S. H. (2009). Fundamentals of physiological computing. *Interacting with Computers*, *21*(1–2), 133–145. https://doi.org/10.1016/j.intcom.2008.10.011

Hassard et al. (2014). *Calculating the cost of work-related stress and psychosocial risks.* doi: 10.2802/20493

Levenstein, S., Prantera, C., Varvo, V., Scribano, M. L., Berto, E., Luzi, C., & Andreoli, A. (1993). Development of the perceived stress questionnaire: a new tool for psychosomatic research. *Journal of Psychosomatic Research*, *37*(1), 19–32.

McEwen, BS. (2006). Physiology and Neurobiology of Stress and Adaptation: Central Role of the Brain. *Physiol Rev 87*(3), 873–904. doi:10.1152/physrev.00041.2006.

McLeod, S. (2012). Experimental Methods in Psychology. Retrieved from https://www.simplypsychology.org/experimental-method.html

Moynihan, J. A. (2003). Mechanisms of stress-induced modulation of immunity. *Brain, Behavior, and Immunity, 17*(1), 11-16. doi:10.1016/s0889-1591(02)00060-0

Sandulescu, V., Andrews, S., Ellis, D., Bellotto, N., & Mozos, O. M. (2015). Stress Detection Using Wearable Physiological Sensors. *Artificial Computation in Biology and Medicine,* 526-532. doi:10.1007/978-3-319-18914-7_55

Schwarz, N. (2004). Retrospective and Concurrent Self-Reports: The Rationale for Real-Time Data Capture. In Stone, A., Shiffman, S.S., Stienza, A., & Nebeling, L. (eds). *The science of real-time data capture: Self-reports in health research* (pp. 11-26). New York, NY: Oxford University Press.

Setz, C., Arnrich, B., Schumm, J., La Marca, R., Troster, G., & Ehlert, U. (2010). Discriminating Stress From Cognitive Load Using a Wearable EDA Device. *IEEE Transactions on Information Technology in Biomedicine, 14*(2), 410-417. doi:10.1109/titb.2009.2036164

Sun, F., Kuo, C., Cheng, H., Buthpitiya, S., Collins, P., & Griss, M. (2012). Activity-Aware Mental Stress Detection Using Physiological Sensors. *Lecture Notes of the Institute for Computer Sciences, Social Informatics and Telecommunications Engineering*, 211-230. doi:10.1007/978-3-642-29336-8_12

Van Dooren, M., De Vries, J., & Janssen, J. H. (2012). Emotional sweating across the body: Comparing 16 different skin conductance measurement locations. *Physiology & Behavior*, *106*(2), 298-304. doi:10.1016/j.physbeh.2012.01.020

Wilhelm, F.H., Pfaltz, M.H.,Grossman, P., & Roth, W.H. (2006). Distinguishing emotional from physical activation in ambulatory psychophysiological monitoring. *Biomedical Sciences Instrumentation*, 42:458–63.

Ziegler, M. G. (2012). Psychological Stress and the Autonomic Nervous System. *Primer on the Autonomic Nervous System*, 291-293. doi:10.1016/b978-0-12-386525-0.00061-5

Appendix

Appendix A: mQuest survey questions

1. How much stress did you experience during the last two hours?
2. How much stress did you experience during the last minute?
3. How intense were your emotions during the last two hours?
4. How intense were your emotions during the last minute?
5. How pleasant were your experiences during the last two hours?
6. How pleasant were your experiences during the last minute?

Appendix B: Interview questions.

Ask the participant for age, gender, and nationality.

General impression

- *How did it go this week?*
- *Did you run into any problems?*
- *What was the burden of the experiment [on a scale from 1 (very low)-10 (very high)*

E4

- *Were you able to upload the data from the e4?*
- *How did you experience wearing the e4 this week?*
- *Were you able to get used to the device?*

mQuest

- *Did you receive notifications from the mQuest app every two hours?*
- *How did you go about filling in the survey every two hours?*
- *Were you able to fill in the questionnaire in the mQuest app?*
- *Did you miss many opportunities to fill in the survey?*

Level of stress

- *What things do you consider when judging your own level of stress?*

Appendix C:

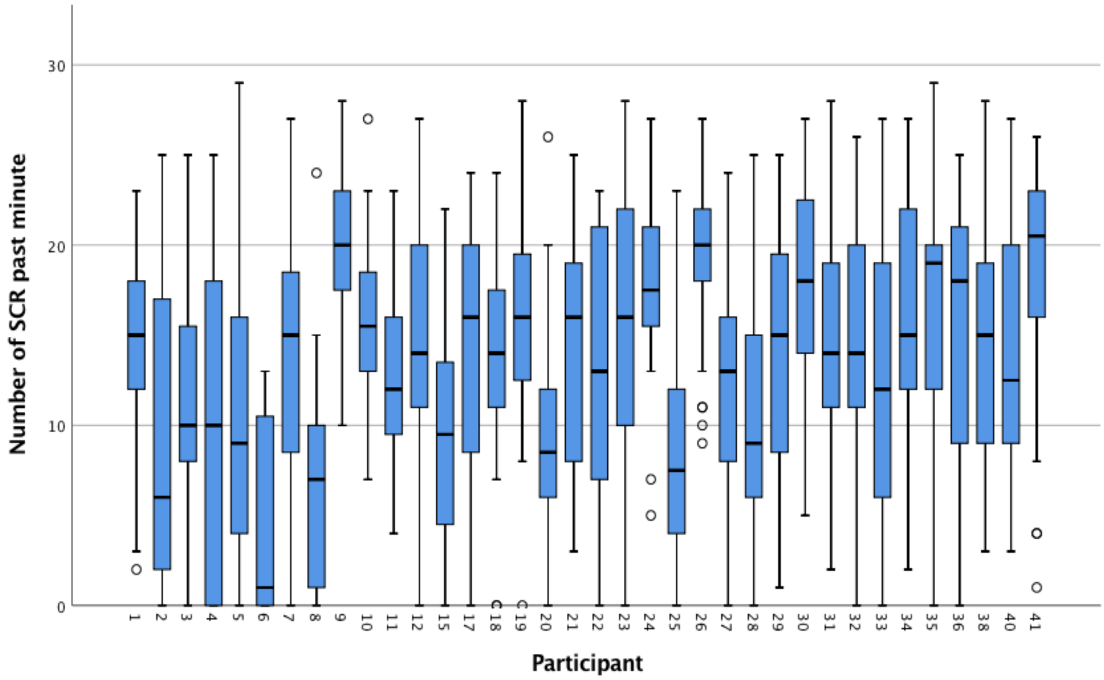

Figure C1: Number of SCR for the past minute per participant.

Appendix D: Frequency distribution of all correlation between the stress and EDA variables.

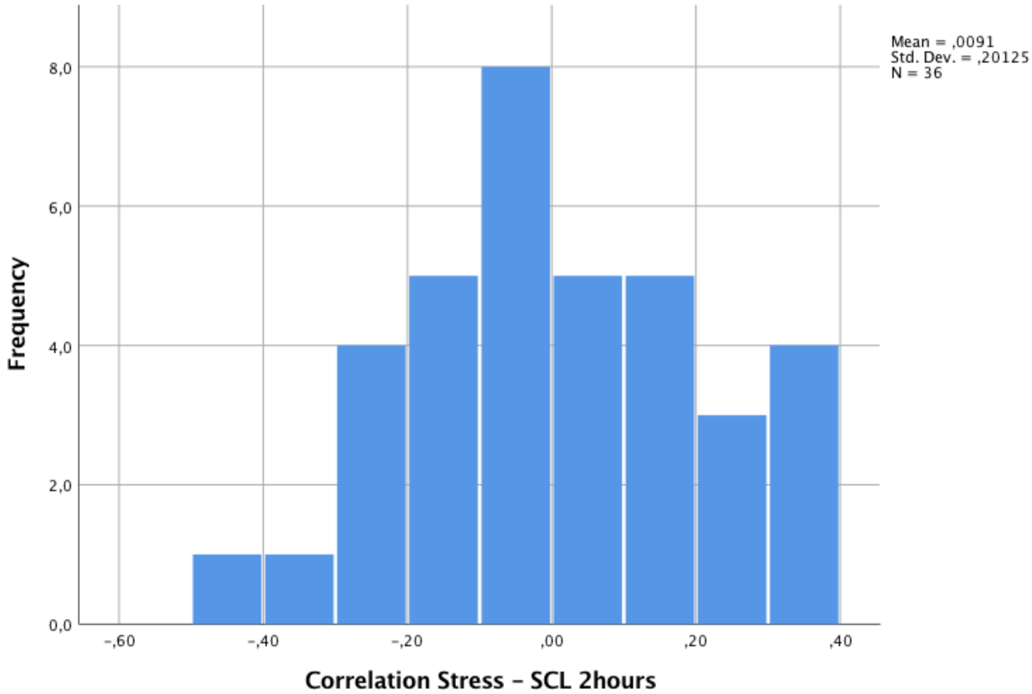

Figure D1. Frequency distribution of all correlations between stress and SCL during the last 2 hours.

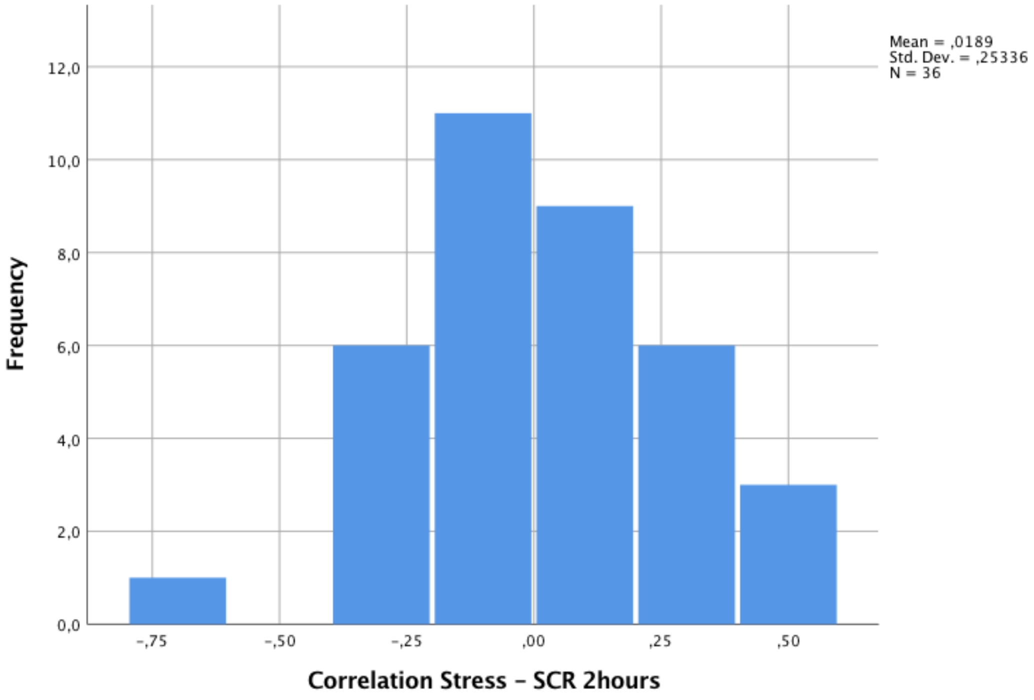

Figure D2. Frequency distribution of all correlations between stress and number of SCR during the last 2 hours.

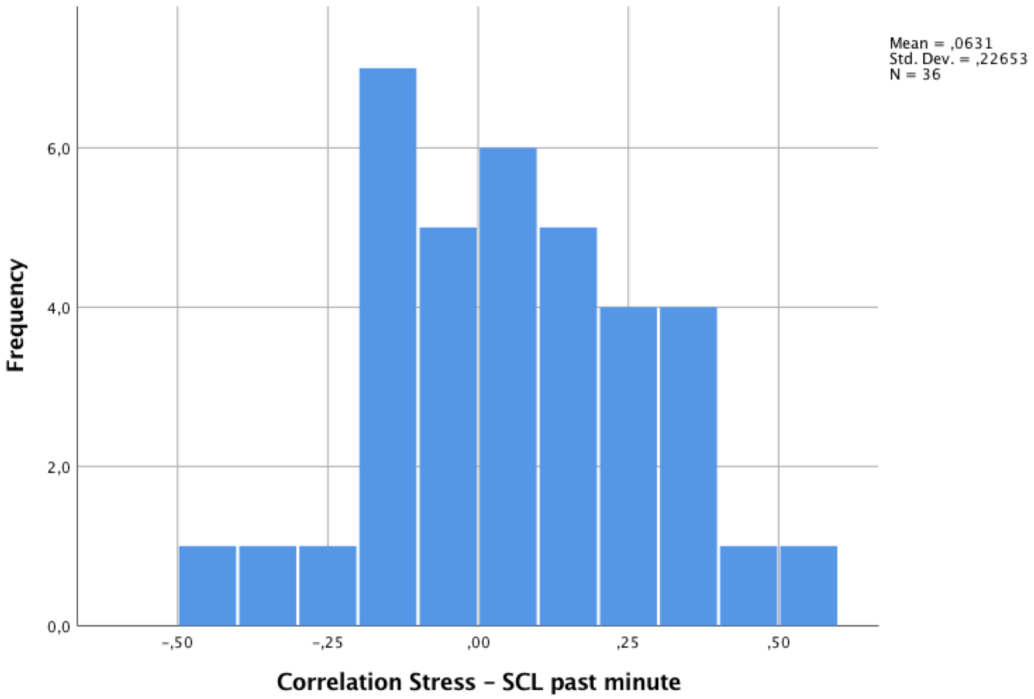

Figure D3. Frequency distribution of all correlations between stress and SCL during the last minute.

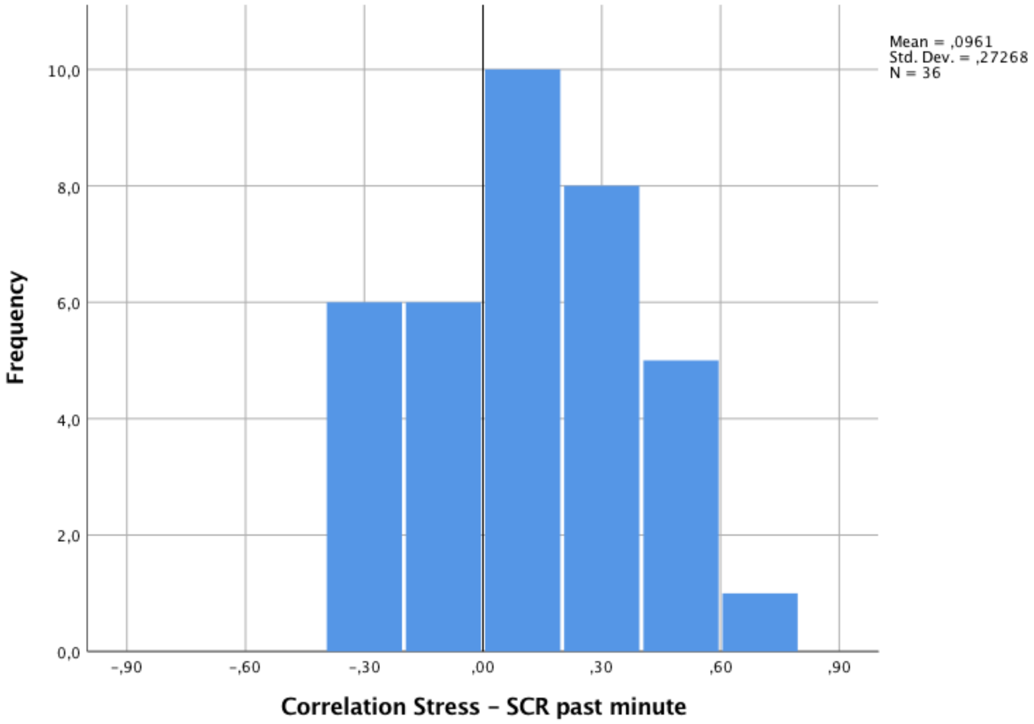

Figure D4. Frequency distribution of all correlations between stress and number of SCR during the past minute.