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Heart rate and self-reported stress: A real life measurement of the intra-individual relationship

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Bachelor Thesis

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Abstract

The feeling of being stressed and elevated heart rate (HR) are two indicators of stress. However, no studies directly assessed the psychophysiological relationship between these two. The present study is the first to explore the direct relation between perceived stress and HR. There are studies that indirectly suggest a potential positive one-to-one relationship (e.g. Brugnera et al., 2018; Sloan et al., 1994). While, Verkuil et al. (2016) could not support these findings. This study differs from previous studies in approaching the psychophysiological relation on an intra-individual level which is suggested in studies on subjective psychological constructs (e.g. Reisenzein, 2000). Participants wore a biosensor for seven days in order to measure heart rate and reported subjective stress levels on a smartphone application. Intra-individual correlations were calculated and data was split twice, in order to examine the consistency of correlations within individuals. The results reveal that the found intra-individual correlations are not significant and vary widely in strength and direction. In total, the correlations approximate a normal distribution which suggests no tendency for a positive or negative relationship. Also, correlations are not consistent within individuals meaning no pattern or tendency could be detected here either. The present paper is therefore not able to support a one-to-one relationship between perceived stress and HR and is in line with the findings of Verkuil et al. (2016). Explaining constructs such as unconscious stress or alexithymia are suggested to be included in future studies.

Keywords: Heart rate, self-reported stress, intra-individual correlation, real life measurement

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Introduction

The notion that psychological experiences and physiological responses, i.e. mental stress and higher heart rate (HR), are associated, is commonly shared and accepted among the majority of people (Barrett, 2006). Both lay people and scientists, assume a one-to-one relationship between subjective psychological experiences and bodily response meaning when we mentally feel stressed, our heart rate automatically increases. Recently, a newspaper reported that work related stress increases the risk of heart failure, stroke and other cardiovascular diseases due to higher HR when employees experience work pressure ("Work stress may lead to irregular heart rate," 2018). According to the authors, "people who feel stressed at work and have palpitations or other symptoms of atrial fibrillation [in terms of rapid heartbeat] should see their doctor and speak to their employer about improving the situation at work" ("Work stress may lead to irregular heart rate," 2018). This article exemplifies the common notion on the one-to-one psychophysiological relationship, in particular work related feeling of stress and a persons' HR.

Although there are some studies that provided insights in the relation between perceived stress and HR, mostly they use indirect measures and inter-individual research designs (see for exception: Verkuil et al., 2016). Since perceived stress is inherently an individual assessment and depended on someone's absorptive capacity, an intra-individual research design is likely to more adequately capture the psychological construct under concern. Herewith, we aim to address potential flaws in earlier works. Thus to address this gap, our research question is the following: *"To what extent do participant's HR and subjective stress level correlate intra-individually when measured in real life settings?".* This study aims to examine this relationship using an intra-individual data analysis, on 36 participants in real life settings. Since we did not find a relationship between self-reported stress and HR, we make a strong contribution both to theory as well as to practice. Hence, our findings suggest a more complex psychophysiological relationship. In the remainder of this paper we review literature on the relationship between persons' experienced stress and HR. Afterwards, we describe the method we used to test the relationship between stress and HR before we present our results. Finally, we conclude the paper with the discussion of the results and formulating implications for theory and practice.

Psychological Experience and Heart Rate as Indicators of Stress

Studies show that stress occurs when an individual's adaptive capacity is exceeded by external or internal stimuli, which are termed "stressors" (Cohen, Kessler, & Gordon, 1995). Stress is expressed in different ways such as by an elevated HR and subjective experience of perceived stress (Burns, Sun, Fobil, & Neitzel, 2016; Epel, et al., 2018; Folkman, 2013).

Psychological experience of stress is reflected in a person's intuitive internal feeling, such as anxiety (American Psychology Association, n.d.; Folkman, 2013), discomfort, overwhelm and losing control (Epel et al., 2018). The physiological response to stress includes a change in patterns of the cardiovascular system (Akselrod, Gordon, Ubel, Shannon, Berger, & Cohen, 1981), i.e. an increase in HR. When stress occurs, the so called 'autonomic nervous system' (ANS) is stimulated. This system activates the sympathetic nervous system, which in turn reduces activity of the parasympathetic nervous system. This physiological response to stress, results in the adrenal glands to release the hormones epinephrine – also termed "adrenaline"-, and norepinephrine. Finally, the release of these two hormones, elevates HR, increases blood pressures, muscle tension and vasoconstriction of blood vessels. This specific combination of physiological expression of stress is also called the "fight-or-flight" body response. In this state, the body anticipates harmful events, threat, pain or attack and is a characteristic bodily response to stress (Cacioppo, Tassinary, & Berntson, 2017). In the longer term, physiological response to stress can cause serious problems to people. In support, the meta-analysis of Palatini and Julius (2004) - consisting of 23 studies - clearly relates an elevated HR to cardiovascular diseases. In other words, it is likely that an elevated HR as psychosocial response to psychological experienced stress, can relate to a cardiovascular diseases, especially when experienced frequently.

The Relation between Perceived Psychological Stress and Elevated Heart Rate

To the authors best knowledge, there are no studies that specifically examine the direct relation between perceived stress level and HR. However, there are some studies that provide important insight in this relationship, while concentrating on different research topics and research settings. From literature, we derived three important implications for our study on the relation between perceived stress and elevated heart rate.

First, a recent study of Brugnera et al. (2018), measured HR before and after participant's exposure to three stress tasks, among which Montreal Imaging Stress Task. The study was

conducted in a controlled laboratory setting. The main findings of the study are that participant's HR went up during exposure to all of the stress tasks. While, HR decreased during the rest and recovery stage, i.e. stage after exposure to stress task. Also Elwess and Vogt (2005) used a similar technique to measure stress and HR, although they used a different research setting. They measured HR of college students during three situations; 1) attending a lecture; 2) taking an exam and; 3) waiting for the exam grades. The main findings are that taking an exam increased the HR with 35% in comparison to attendance of a lecture. While the studies of Brugnera et al. (2018) and Elwess and Vogt (2005) not specifically focus on the relation between perceived stress and HR, they did deliver important insights. It can be assumed that taking exams and exposure to a stressful task would let participants perceive stress on a subjective level. However, the two above mentioned studies assume relations between perceived stress and HR but no direct correlations were calculated to assess this association.

Second, another set of studies that did measure perceived stress, focus on a relationship with "heart rate variability" (HRV). HRV is different from the HR approach in that HRV measures intervals between heartbeats, while the HR approach measures the number of heart beats within a certain time period. An important study on the relation between perceived stress (measured through "negative affect") and HRV is the study of Sloan et al. (1994). They found an inverse relationship between perceived stress and HRV. More specifically, one unit increase on the stress scale, related to a reduction of 50ms on the intervals between heart beats. In support, Orsila et al. (2008) used the same variables in context of an electronic company. Participants' HRV was measured during one day and related to participants' perceived stress, reported in dairies. The study reveals a positive relationship between perceived stress and HRV. While these studies do focus on the relation between perceived stress and information about heart rate, these studies adopt the HRV approach. Although HRV seems to be a commonly used parameter, we pose to measure HR in direct sense during real life events. HRV is more sensitive to movement and could only provide reliable information when movement is reduced to its minimum. This, however, is problematic since the present study aims to collect data under real life conditions of participants. HR, therefore, seems to be a more robust and the more adequate parameter. Still, the two above mentioned studies give some insight due to the inverse relationship between HR and HRV. High HR is associated with low HRV and vice versa (Kazmi et al., 2014). Of course, HRV and HR are two different methods to represent coronary information and are not to be confused.

However, these studies allow for careful assumptions about a positive one-to-one relation between perceived stress and HR.

Thirdly, although using a variety of research designs, empirical settings and variables, all of the above mentioned studies indicated a positive one-to-one psychophysiological relationship (Cacioppo, Tassinary and Bernston, 2017). This suggest that whenever participants perceive stress, heart beat tends to elevate which could possibly cause longer term health problems, such as cardiovascular diseases. In contrast, Verkuil et al.'s (2016) findings suggest no one-to-one relation between perceived stress and HRV. We pose that the findings contrast earlier work, because Verkuil et al. (2016) are first to make use of an intra-individual design. Consequently, the scholars calculated correlations for each participant in the study and not one correlation for the entire sample or experimental group, which was done by the other mentioned studies. Calculating correlation using intra-individual or inter-individual methods can yield in different results. As with other subjective psychological constructs, perceived stress is an individual assessment and relates to someone's absorptive capacity which is likely to fluctuate per person. Approaches that are not taking an individual assessment in account, but aggregate them to an entire sample, can thus yield in different and unreliable results (see also: Committee on Metabolic Monitoring for Military Field Applications, 2004; Reisenzein, 2000; Ruch; 1995).

This can be explained by the model of Donaldson and Grant-Vallone (2002). They determined four factors that influence self-report bias, namely dispositional characteristics, true state of affairs, sensitivity of construct and situational characteristics. One factor that is considered as important is "sensitivity of construct" meaning that every individual is biased on its own due to dispositions and experience. In the current context this would mean that every individual has an own style of rating and experiencing situations as stressful. Everyone has own baselines and sensibilities to stress which makes calculating inter-individual means in order to conduct statistical analysis difficult and unreliable. When a participant is especially sensitive to stress, he or she could experience stress at a low HR already whereas other would feel this level of stress at a higher HR. This cannot be taken into account when measuring the correlation of a sample or experimental condition since data of several participants would be grouped together.

The present study

It appears, that the design and methodology of Verkuil et al. (2016) fits ideally for the relationship this study aims to examine. Therefore, design and style of data analysis of the

present study will be similar to the one used by Verkuil et al. (2016) except that the present study expanded the period of data collection to seven instead of one day in order to catch a wider variety of different situations. Measurements of the present study happened during participant's everyday life. This, on the one hand, means that there is less control for mediating or monitoring variables. On the other hand, measurements under real life conditions enhance ecological validity. Correlations found under real life settings enable more general conclusions since they are not manually stimulated but occur naturally (Cacioppo, Tassinary, & Berntson, 2017). In addition to that, the present study makes use of an intra-individual design. Rating styles of stress could differ per individual due to sensitivity of construct. An inter-individual design would be considered as an inaccurate measurement method and is a possible source for error (Reisenzein, 2000).

The present study aims to explore the direct correlation between raw physiological data (HR) and experienced psychological stress. HR is measured by means of Empatica E4 wristbands. Subjective stress level is self-reported by a one-item-questionnaire on a smartphone application. While previous studies used a variety of research designs and variables, it is difficult to formulate prediction about the relationship between perceived stress and HR. Some studies indicate a positive relation between perceived stress and HR. That is, in situations of high perceived stress, HR tends to go up. Meanwhile, other scholars (Verkuil et al., 2016) found no relation between perceived stress. As our study takes possible flaws of earlier studies in account, we predict that there is no one-to-one relationship between perceived stress and HR (see also: Verkuil et al., 2016).

Method

Participants

This study comprised convenience sample of 41 participants (male=16, female=25). The age ranged from 19 to 45 (*M*= 21.9, *SD*=4.25). In this study we applied the following exclusion criteria. First, participants must be in the possession of a smartphone and a laptop. Second, participants should be willing to participate voluntarily and sign an informed consent before participating in the study. We requested permission to the Ethics Committee of the Behavioural Management and Social Sciences (BMS) faculty of the University of Twente, which was granted. Due to technical issues, we had to remove five participants out of our total sample of 41.

Materials

Participants were provided with an Empatica E4 wristband that can measure physiological signals, such as HR. Specifically, HR is compiled using photplethsmography (PPG) techniques that measures the participant's blood volume pulse (BVP), sampled at 64 Hz. The participants were also provided with a user manual and cables to transfer collected data to a computer. For this purpose, we asked participants to install "Empatica Manager" software on their computers. In order to determine subjective stress levels the participants filled in a questionnaire on their smartphone. This was done through an app called "mQuest". Questionnaires were sent to the participants every two hours. The items of the questionnaire were self-developed. An example item is 'How much stress did you experience during the last two hours?'. The participants indicated a score from 1 to 10, ranging from very low to very high.

Design and Procedure

This study had a longitudinal, repeated-measures, single-subject design. Data from every participant about HR was collected as unobtrusively as possible and continuously for seven days. In order to gather information about subjective stress level this study made use of an Experience Sampling Method, also called daily diary method, like it was used by Berkel, Ferreira and Kostakos (2017). Participants were triggered to fill out a 6-item questionnaire every two hours where only one question asking about perceived stress for the last two hours is relevant for the present study. Asking participants every two hours, however, minimized reliance on the subject's long-term memory to remember experienced stress during the day.

First, there was a briefing. The participant signed the informed consent and filled in the Toronto Alexithymia Scale (TAS-20) (Bagby, Parker & Taylor, 1994). After that the participants were provided with the E4 wristband, the cable and the short manual provided by Empatica. Moreover, the participant got verbal instructions on how to use the wristband and the application after it was installed on the participant's smartphone. The participant was asked to wear the E4 wristband continuously, to upload the gathered data every night through the Empatica software on their computers, and to charge the wristband during the time they were asleep. After this briefing, the data collection started. For seven days, the participants received push-notifications on their smartphone every two hours in order to fill out the questionnaire. When the seven days were over, a debriefing took place. The participant returned the wristband and its belongings and again filled in the TAS-20. Also a semi-structured feedback conversation was conducted about

whether the participants ran into any problems and how the participant experienced the data collection. Example questions are ‘Were you able to upload the data from the E4?’, ‘Did you receive notifications from the mQuest app every two hours?’ or ‘How did you experience wearing the E4 this week?’.

Data analysis

Information about participant’s HR was provided by zip files that were created from the data of the E4 wristband. In order to determine the HR of the past two hours, the average HR for that period was calculated. Self-reported stress was stored in comma-separated values (CSV) files and could be downloaded from the mQuest webpage. The data was sorted by participant. All measurements have a timestamp which made it possible to combine data from the E4 with information about self-reported stress levels. The data of these two parameters were put into one dataset, suitable for the IBM SPSS software. However, since three participants stopped with the data collection, their data was not included in the current data set. Furthermore, it appeared that HR data from participant 37 and 39 was missing. Data of those two participants could therefore not be considered in the analysis and participants were dropped out of the sample. But also the remaining data was sorted and reduced. When a value was missing, the whole row of the data set file was deleted. Also, errors in HR measurements were filtered out. The resting HR of a female athlete is 54 bpm or higher whereas athletic men display HR of 49 bpm or higher (Golding, Myers, & Sinning, 1982). Data below these values was deleted since HR below these thresholds seemed unrealistic and erroneous. After sorting out missing and falsified values, from 1424 measurement points, 871 remained and were involved in the following data analysis.

To calculate intra-individual correlations, this study made use of the IBM SPSS software. First of all, a bivariate correlation of HR and self-reported stress was calculated for each individual to maintain a within-subject design. This made up 36 correlations, for each individual one. In order to determine whether correlations are consistent within individuals, it was chosen to split the data of every participant in two halves of approximately the same size. This was done two times. The first split was randomization based. Participants were randomly assigned to one of two halves by the SPSS software and intra-individual bivariate correlations within those groups were calculated. The second split was time based in order to explore possible time related (in)consistency of intra-individual correlations. For this, the first three days of every participant’s measurement were taken into the first group. The second group formed the last four days. This

was done due to the aspect that on the seventh day the least measurement points were taken (see Appendix A for the frequency of measurement points per day of data collection).

Results

The subjects displayed an average intra-individual mean of HR of 80.16 bpm (*SD*=10.85), ranging from 60 to 120 bpm. Figure 1 illustrates the average of HR per participant over the time period. The averaged intra-individual self-reported stress level was 4.18 (*SD*=2.3) with values ranging from 0 to 10. This is illustrated in Figure 2.

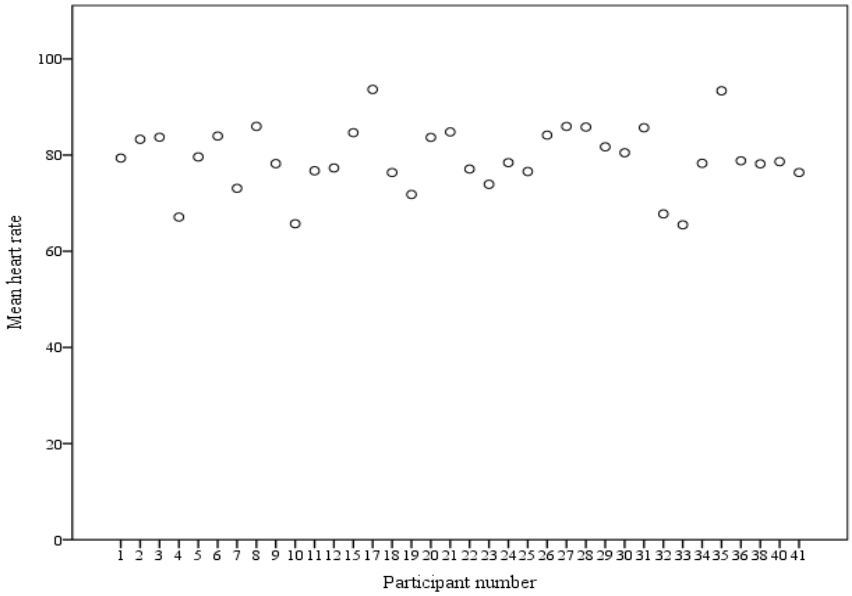

Figure 1. Average heart rate per individual over study period.

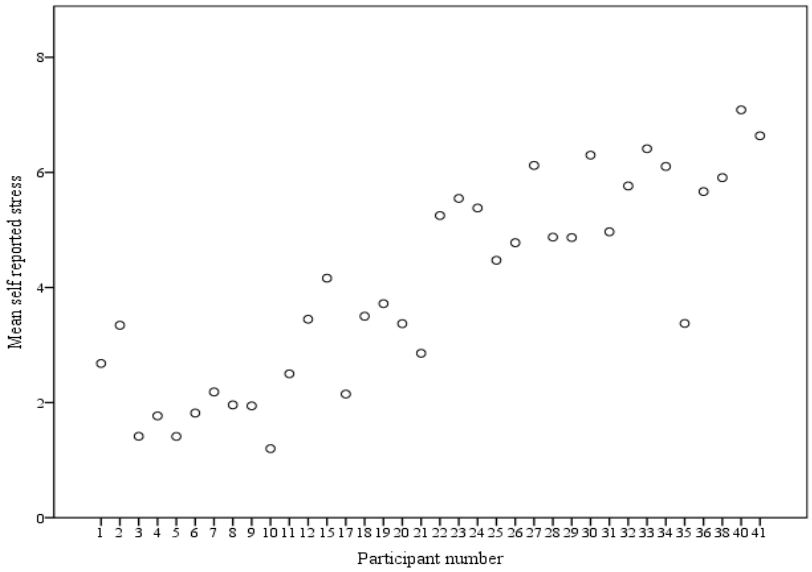

Figure 2. Average self-reported stress level per individual over study period.

The 36 participants displayed an average intra-individual correlation of *r*=.07 (*M*=.07, *SD*=.26), ranging from *r*=-.42 to *r* =.67. Both positive and negative intra-individual correlations had been found. However, 69% of these correlations were positive and 11 of the 35 correlations negative as can be seen in Figure 3.

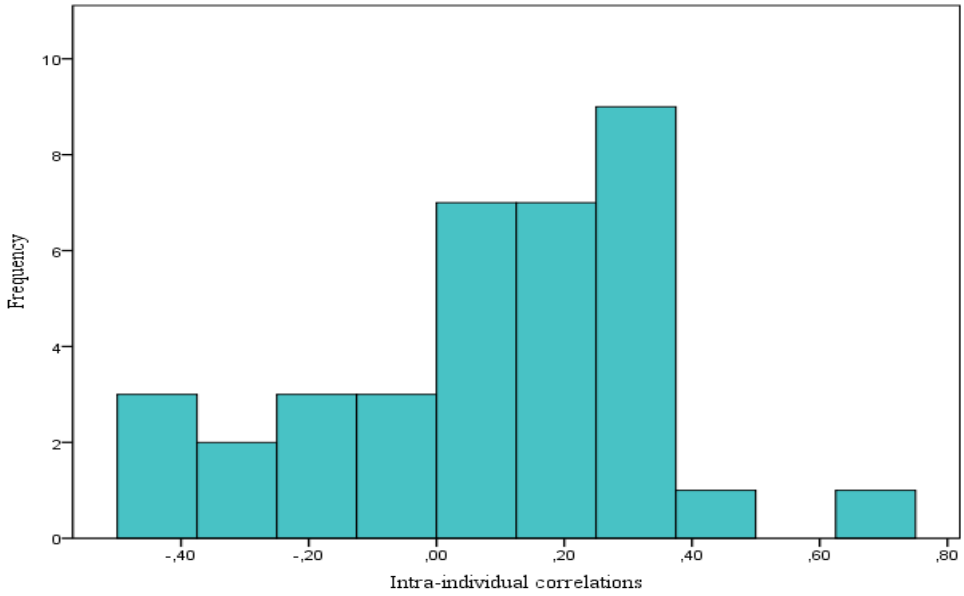

Figure 3. Histogram of intra-individual correlations.

Also, bivariate correlations of all participants were examined after the measurement points were split twice. It appears that the correlation between HR and perceived stress level differed within individuals for both split techniques, the random and for time-based assignment. Figure 4 and Figure 5 illustrate this. Points that are in the second or fourth quadrant of the scatterplot display correlations that differ across the split halves in direction and show inconsistent correlations within one individual. The line diagonal to the axes is a reference line that displays perfectly consistent intra-individual correlations between the two halves. For the first split, intra-individual correlations ranged from *r*=-.54 to *r*=.84 for the first half and from *r*=-.68 to *r*=.74 for the second half. Illustrations reveal that 40% of the intra-individual correlations are not consistent in direction, whereas 60% of the correlations show no change in direction. Also it appeared that some intra-individual correlations not only varied in degree but also in strength when comparing them to the reference line. Similar results could be found for the second time-

based split. Here, the correlations ranged from *r*=-.71 to r=.98 for the first three days and from *r*=-.64 to *r*=.95 for the remaining days. 48.6% of the intra-individual correlations showed a change in direction when comparing correlations from the first three days with the last four days. Also, there were intra-individual correlations that showed inconsistent strength when compared to the reference line.

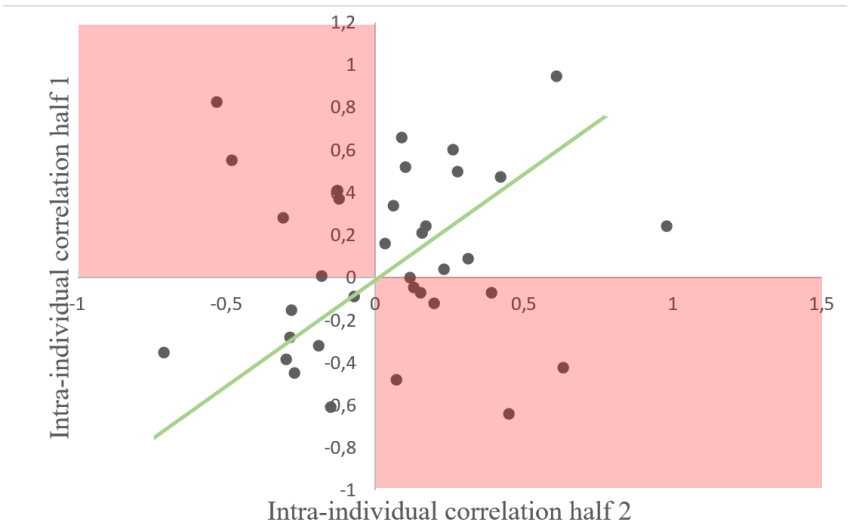

Figure 4. Scatterplot of intra-individual correlations of a randomization-based split.

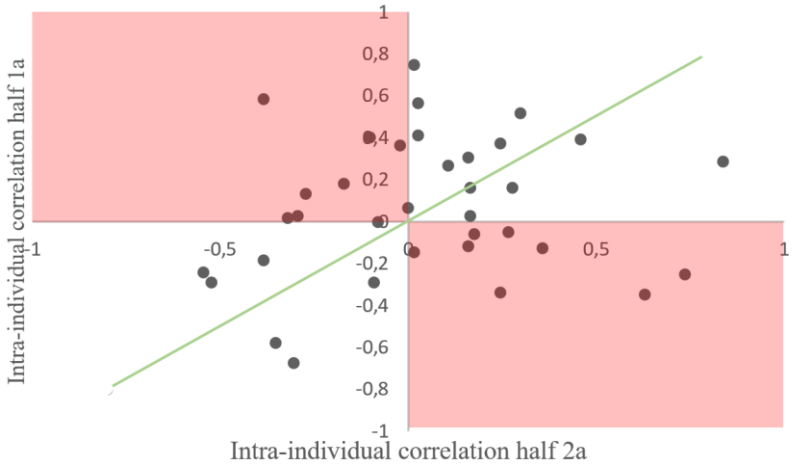

Figure 5. Scatterplot of intra-individual correlations of a time-based split.

Discussion

The purpose of the present study was to explore intra-individual correlations between participant's perceived stress and HR in real life settings. Since no studies directly assessed this relationship, or used potentially inadequate research designs, we adopted an intra-individual research approach and used a repeated-measure, single subject design among 36 participants for a period of seven days. In demonstrating the association between perceived stress and HR, we found no consistent intra-individual correlations. Rather, we found the intra-individual correlations to be relatively normally distributed which indicates that there is no tendency for a strong positive or negative relation between perceived stress and HR. Furthermore, using randomization- and time based split, we found no consistency within individuals either. Correlations varied widely in strength and direction, so that no clear pattern or tendency could be detected. These findings suggest that there is no one-to-one relation between perceived stress and HR. In other words, HR seems not to be directly associated with either high or low levels of perceived stress.

While the findings are in line with our prediction (see also: Verkuil et al., 2016), we contrast earlier works that indirectly assessed the relation between perceived stress and HR (Brugnera et al., 2018; Elwess and Vogt, 2005; Sloan et al.,1994; Orsila et al., 2008). Thus our findings put additional challenges to theory, by suggesting a more complex relation between perceived stress and HR. We argue that there are two main factors that are likely to influence the relation between perceived stress and HR and, could explain our findings to a certain extent. First, stress could be experienced unconsciously and consequently self-reported stress does not adequately capture actual individuals' stress levels. For instance, Brosschot et al. (2010) argues that people are not always aware of stress-related cognitive processes since a great part of cognitive processing operates unconsciously. In addition, they argue that unconscious stress increases cardiovascular activity for long periods of time (even during sleep) and consequently increase HR while individuals' do not experience stress consciously. In support, Brosschot et al. (2014), from their experiment, formulated comparable suggestions. In their study, they asked participant to count backward from 9000 in steps of seven. In the experimental condition, participants were exposed to harassing comments which aimed to induce stress. The control condition, exposed participant to encouraging comments. Measuring stress through "implicit affect", they found a positive relation with the period of cardiovascular recovery. This implicitly

suggest the possible influence of unconscious stress on HR. In addition, another important factor that can play a role in the relation between stress and HR lays in the assessment of perceived stress. People can have difficulties in identifying and describing subjective feeling and have different abilities in distinguishing between feeling and physiological sensations, termed "alexithymia" (see: Nemiah, 1977). Therefore, individuals that reported stress may not adequately capture their actual perceived stress levels and therewith influence measures of the relation between stress and HR. We encourage future studies to control for this potential cofounder, for instance, by taking into account the TAS-20 scale (Bagby et al., 1994).

This study has a number of limitations. First, a limitation of this study is the relatively simple measurement of HR as parameter. Verkuil et al. (2016) differentiate between 1) psychologically induced HR and; 2) physiologically induced HR. To measure psychological induced HR, data needs to be corrected for the effect of movement on HR. For instance, Verkuil et al. (2016) achieved this through certain calibration techniques where participants were asked to carry out certain physical activity while measuring HRV. Although acceleration was measured by the E4 too, no universally used algorithm could be found yet since this technique to control for movement became popular recently and requires further research. The current study did not use means to correct for physiologically induced levels of HR which is a factor that could influence the data. In order to rule this out, future studies could determine an algorithm that filters out physiologically induced HR reliably in order to produce more valid measurements. After that, future research should make use of corrected HR in order to correct gathered data about HR for acceleration. Another limitation the term "stress" as it was used by the questionnaire. Stress actually consists of several emotions, such as anger, irritability, anxiety and depression (American Psychology Association, n.d). It is not defined to what extend participants were able to differentiate experience of stress from feelings of anxiety or anger, for example. "Feeling stressed" might be something different for every individual. If every participant defines stress differently, it will not be possible to measure this relationship. Future studies could give a clear definition in their briefing. Then, every participant would be more conscious of a distinction between pure anxiety and stress and be more aware of how they might really feel. Alternatively, future studies could make use of stress scale - for example the PSS-10 (Taylor, 2015) - instead of a one-item-questionnaire as it was used in the present study. These questions require less interpretation of the participant and could provide more reliable and valid data.

To the authors best knowledge, this study is the first to explore the direct relation between perceived stress and HR with an adequate intra-individual design. This study collected data during real life settings which enhances ecological validity since it catches naturally stimulated occurrence of emotions instead of laboratorically induced ones (see: Brugnera et al., 2018). This approach can provide conclusion that reflect and are more applicable to everyday life. Furthermore, our study contributes by concentrating on intra-individual correlations and the consistency of those correlations within subjects, which has been overlooked by earlier works (e.g.: Elwess & Vogt, 2005; Sloan et al., 1994). While scholars argue that this can seriously impact the results of studies using self-reported measures (e.g. Reisenzein, 2000; Ruch, 1995). Finally, our third contribution lays in the period of study. We examined perceived stress and HR for seven days, which is likely to enhance reliability of findings. Hence, it is likely that within a seven day time span, participants experience different levels of perceived stress since there is a wider variety of situations that participants were exposed to and consequently our findings are more applicable to real life. Next to the theoretical implications, the study suggest some practical implications. First, no clear association between perceived stress and HR was found. Thus, we found no indication for an association between perceived stress and cardiovascular disease, often caused by elevated HR levels. This implies that whenever people feel stressed frequently, the risk of cardiovascular dysfunctions is not necessarily higher. Not every time our mind feels stressed, our body notices this.

Conclusion

This study examined intra-individual correlations of HR and self-reported stress. The present study could not find consistent intra-individual correlations between or within individuals and confirms that there is no one-to-one relationship. Due to that there must be either variables that influence this relationship or there is simply none so that the found correlations were random. Several possible influencing variables such as unconscious stress were discussed above. Future studies should aim at testing these constructs to a more detailed extent than this study could do. Although the findings of the current study should be interpreted carefully due to the above mentioned limitations, it is the first found study that correlated self-reported subjective stress levels and HR.

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Appendix A

Frequency of measurement points per day of data collection