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EFFECT OF ALEXITHYMIA ON THE RELATIONSHIP BETWEEN AFFECTIVE AROUSAL AND ADDITIONAL HEART RATE

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Abstract (Nederlands)

Emoties kunnen gecategoriseerd worden in twee dimensies: valentie en intensiteit. Emotionele valentie kan variëren van negatief tot positief. Emotionele intensiteit varieert van laag tot hoog en verschilt over tijd, zowel tussen als ook binnen individuen. Emotionele intensiteit kan gemeten worden door zelf-rapportage, gedrag of fysiologie. Individuen verschillen aanmerkelijk in de variatie van zelf gerapporteerde emotionele ervaringen. Een voorbeeld is het persoonlijkheidskenmerk alexithymie, dat bekend staat als verminderede capaciteiten in het ervaren, herkennen, verbeelden en beschrijven van eigen emoties en die van anderen. Een interessante maar nog niet uitvoerig onderzochte methode om emotionele intensiteit fysiologisch te meten is aanvullende hartslag. Aanvullende hartslag is het gewogen verschil in hartslag per minuut gedeeld door de gemiddelde maat van versnelling, om zo het effect van fysieke beweging op hartslag uit te sluiten. Emotionele intensiteit stimuleert het autonome zenuwstelsel die wederom de aanvullende hartslag laat toenemen. Het huidige onderzoek was een *experience sampling* studie op een binnen-proefpersoon niveau, gebaseerd op een *intensive longitudinal method* in het dagelijks level. Gedurende zeven dagen droegen dertien participanten een E4 armband die fysiologie mat en vulden elke twee uur een vragenlijst in over de intensiteit van ervaren emoties. Ten eerste werd verwacht dat aanvullende hartslag en zelf-gerapporteerde emotionele intensiteit positief correleren. Ten tweede werd verwacht dat alexithymie de relatie tussen aanvullende hartslag en zelf-gerapporteerde emotionele intensiteit negatief medieert. Beide hypothesen konden niet bevestigd worden. De huidige studie toonde een brede spreiding aan van correlaties tussen aanvullende hartslag en zelf-gerapporteerde emotionele intensiteit, en tussen alexithymie en de relatie tussen aanvullende hartslag en zelf-gerapporteerde emotionele intensiteit. Daarnaast toont de huidige studie nieuwe inzichten in de toepasbaarheid van een *intensive longitudinal experience sampling* design in het dagelijks leven. Deze kunnen interessant zijn voor toekomstig onderzoek naar de relatie tussen fysiologie en zelf-gerapporteerde emoties. Participanten waren bereid om elke twee uur een korte vragenlijst in te vullen. Er wordt aanbevolen om tijdens toekomstig onderzoek emotionele intensiteit over een langere periode te meten, waarbij het aannemelijk is dat emotionele gebeurtenissen ook aanwezig zullen zijn. Bijvoorbeeld tijdens de eerste weken van een nieuwe baan.

Abstract (English)

Emotions can be categorized into two dimensions: valence and arousal. Valence varies from negative to positive, whereas arousal varies from low to high. Affective arousal indicates the intensity of emotions and varies over time between and within individuals, which can be measured by self-report, behavior or physiology. Individuals differ markedly in the variability of their reports on different emotional experiences. An example is the personality trait alexithymia, which is known as reduced capabilities in experiencing, recognizing, imagining and describing of own emotions and those of others. An interesting but not yet well tested physiological measure of arousal is additional heart rate. Additional heart rate is the weighted heart rate difference per minute divided by the mean vector of acceleration, in order to rule out the effect of physical activity on heart rate. Affective arousal activates the autonomic nervous system which increases additional heart rate. The current study was an experience sampling study on within-subject level, based on an intensive longitudinal method in daily life. During seven days, thirteen participants wore an E4 wristband which measured physiology and filled out a questionnaire about the intensity of experienced emotions every two hours. First, it was hypothesized that additional heart rate and self-reported arousal correlate positively. Second, it was hypothesized that alexithymia negatively moderates the relationship between additional heart rate and self-reported arousal. Both hypothesizes could not be confirmed. This study demonstrated a wide spread of correlations between additional heart rate and self-reported arousal and between alexithymia and the relationship between additional heart rate and self-reported arousal. It provides new insights into the applicability of an intensive longitudinal experience sampling design in daily life. These could be of interest for future research on the relationship between physiology and self-reported emotions. Participants are willing to fill out questionnaires on a smartphone every two hours. It is recommended to measure affective arousal during a period of at least two weeks while emotional arousing events are likely to happen as well. For example during the first weeks at a new job.

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1 Introduction

At present, wearable technologies to monitor physiological measures (e.g. heart rate) become more and more available for customers (Statista, 2015). These wearable devices give the user insight into the personal emotional state by transforming measured heart rate into arousal or stress levels which are shown on the screen. However, several studies showed that drawing conclusions about emotional concepts such as stress, based on physiological measures, is not always reliable due to the complexity of the relationship between psychology and physiology (Barrett & Simmons, 2015; Evers et al., 2014; Fairclough, 2009). For instance, differences in emotional experiences between individuals and emotional episodes within individuals are not taken into account. It has been found that differences exist in experiencing, describing and recognizing emotions, both within and between situations and individuals (Chen, Xu, Jing & Chan, 2011; Russell, 2009). Reduced capabilities of the cognitive regulating and processing of emotions are known as the personality trait alexithymia which ten percent of the population have (Taylor & Bagby, 2004; Zimmermann, Rossier, Meyer de Stadelhofen, & Gaillard, 2005). The present study tries to consider these individual differences in experiencing emotions while examining the relationship between physiology and emotional concepts. Next to physiological measurement both an alexithymia questionnaire and an experience sampling design will be used to explore individual ways of experiencing emotions. The current study examines to what extent self-reported arousal predicts heart rate within individuals, captured by a wearable bio-sensor and to what extent this relationship is associated with an individual's way of experiencing, describing and recognizing emotions, expressed in an alexithymia score.

1.1 The Concept of Affective Arousal

According to the circumplex model of affect, developed by Russell (2009), emotions can be rated by the dimensions arousal and valence. Valence is used to rate emotions from positive (e.g. happy) to negative (e.g. sad), whereas arousal is used to rate the intensity of emotions from calm to exciting (Russell, 2009). Affective arousal is the intensity of an emotional response and thus signals emotional reactivity (van Rijn, Barendse, van Goozen, & Swaab, 2014; Mehl & Conner, 2012). The amount of arousal does not depend on the valence of emotions, high arousal can be caused by both extreme negative and extreme positive emotions (Russell, 2009).

Emotions, especially the emotional dimension arousal, fluctuate over situations and time, both between and within individuals (van Rijn, Barendse, van Goozen, & Swaab, 2014;

Mehl & Conner, 2012; Russell, 2009). Mehl and Conner (2012) concluded in a literature review that emotional experience differs at within-person and between person-level. At within-person level, affective experience is more complex than between-subjects (Mehl & Conner, 2012). Whereas emotions of the same valence do correlate high between subjects, at within-person level these correlations were low (Mehl & Conner, 2012). Further research is needed at within-person level and for the arousal dimension regarding individual differences in emotional experiencing (Mehl & Conner, 2012).

It has been found that affective arousal activates the autonomic nervous system (ANS), which controls and regulates functions of the internal organs (Russell, 2009). The level of affective arousal is associated with the level of physical arousal: the state of activity in both an individual's mind and body, which prepares the individual for taking action (Storbeck & Clore, 2008). Arousal is often measured by physiological markers of autonomic nervous system activity (Kop et al., 2011).

Next to physiological responses, affective arousal consists of other components: a behavioral response, and a psychological experience (van Rijn et al., 2014). The current study will examine both the physiological response and the psychological experience of affective arousal, which will be discussed in the following sections.

1.2 Experience Sampling as a Mean to Measure Arousal

The most common way to measure an individual's experienced emotional arousal is by using an experience sampling design (Mehl & Conner, 2012; Conner & Barret, 2012). According to Mehl and Conner (2012), emotional variability is best measured by observing individuals intensively over time in daily life. In the current study, respondents will be asked to answer questions in real time about experienced emotional arousal several times per day. However, individuals in general have poor access to physiological reactions of the own body (Robinson & Clore, 2002). Situation-specific and identity-related beliefs are used to draw conclusions about bodily processes such as arousal (Robinson & Clore, 2002). If an individual is asked to report on physiological symptoms and processes about arousal, situation-specific beliefs are used when the person noticed an intense environmental stimulus. Examples of situation-specific beliefs are the believe that insults are associated with anger, vacations are associated with happiness and birthdays are enjoyable (Robinson & Clore, 2002).

More specific, experiences measured by momentary self-reports are less biased than memory-based self-reports (Conner & Barrett, 2012; Robinson & Clore, 2002; Mehl & Conner, 2012). Robinson and Clore (2002) concluded in a literature review that when reporting on current emotions, people use experiential information from the current situation. These experiential details lack if people report on emotions from the past, because it is not possible to store and recall earlier experienced emotions. Then memory recall from either semantic or episodic memory is needed, but a delay between experiencing and reporting an emotion results in a decay of information which leads to a less accurate report. Thus, self-reports of emotions which are delayed from the experience are less likely to be valid than self-reports of current experiences (Robinson & Clore, 2002; Mehl & Conner, 2012). Conner and Barret (2012) stated that retrospective reports should be avoided when reporting on actual experiences. The present study only focusses on current experiences of arousal.

1.3 Alexithymia

It has been found that people differ in reporting on experienced emotions (Chen et al., 2011; Taylor & Bagby, 2004). Individuals differ in the extent of experiencing and being aware of one’s emotions (Chen et al., 2011). Individual differences exist in being able to identify and verbally describe experienced emotion as well. Reduced capabilities in experiencing, recognizing, imagining and describing of own emotions and those of others are known as the construct alexithymia (Taylor & Bagby, 2004). More specifically, individuals with high alexithymia suffer from deficits in cognitive regulation and processing of affective states (Zimmermann et al., 2005). For instance, high-alexithymia individuals are more likely to use external stimuli rather than internal stimuli while self-reporting on emotional constructs (Peasley-Miklus et al., 2016). Several studies showed that individuals with high alexithymia show inconsistencies between emotional response domains, for instance high self-reported arousal relative to low autonomic responses (Eastabrook, Lanteigne and Hollenstein, 2013; Peasley-Miklus, Panayiotou and Vrana, 2016; Roedema and Simons (as cited in Peasley-Miklus et al., 2016)).

An instrument which is often used to measure alexithymia is the Toronto Alexithymia Scale (TAS-20), a self-report scale developed by Parker and colleagues (as cited in Zimmermann et al., 2005) which consists of 20 items. The TAS-20 is a valid measurement for alexithymia across nonclinical and clinical populations (Zimmermann et al., 2005).

Researchers do not agree about the cause of alexithymia and whether alexithymia is a continuous personality factor, an affect-deficit disorder or an emotional instable cognitive state of externally oriented thinking (Chen et al., 2011; Taylor & Bagby, 2004). According to Chen and colleagues (2011) alexithymia is “a cognitive state of externally oriented thinking with an emotional instability and unsecure performance in controlling stressful situations” (p.

1). Research is still focussing on investigating possible sources of alexithymia, for instance by exploring relations between aspects of emotional processing and alexithymia, measuring physiological responses to emotion-inducing stimuli and using functional brain imaging techniques to investigate neural activity related to alexithymia (Chen et al., 2011; Taylor & Bagby, 2004).

Due to the fact that individuals with a high score on alexithymia experience difficulties identifying and describing of emotions, it is expected that these individuals experience difficulties with reporting on the intensity of arousal as well. More specifically, individuals who score higher on alexithymia experience emotions less intense than those with lower scores on alexithymia. For instance, Roedema and Simons (as cited in Peasley-Miklus et al., 2016) concluded that individuals with high alexithymia show lower ratings of self-reported emotional intensity in response to emotional images, while others repeated these findings only for sad emotions (Peasley-Miklus et al., 2016). In the current study it is expected that individuals with high alexithymia will report lower scores on experienced arousal than high-alexithymia individuals.

1.4 Physiological Activity as a Mean to Measure Arousal

Next to measuring affective arousal by self-reports, the current study uses physiology to determine physiological arousal. The autonomic nervous system (ANS) constantly controls and regulates states of the body in order to deal with internal and external stressors (Schneiderman, Ironson, & Siegel, 2005). The sympathetic part of the ANS mainly controls the fight-or-flight response: physiological responses which prepare the human body for taking action (Schneiderman et al., 2005). If muscles and organs need more oxygen and nutrients during physical effort, the sympathetic part of the ANS increases the heart rate by secretion of noradrenaline (Schneiderman et al., 2005). The parasympathetic nervous system regulates body states during physical inactivity, for instance by decreasing heart rate and increasing digestion activity (Schneiderman et al., 2005).

The level of physiological arousal can be determined by physiological indicators of autonomic nervous system activity, which will be discussed below (Russell, 2009; Schneiderman et al., 2005; Kop et al., 2011). Although it is commonly believed that emotions have their own ANS activity patterns, a literature review of Mauss and Robinson (2009) rejected this statement. Identifying specific emotions by ANS activity is not reliable, but for determining affective arousal it is (Mauss & Robinson, 2009).

The most common ways to measure activity of the autonomic nervous system are by measuring an individual's heart rate (HR) or skin conductance level (SCL) (Mauss & Robinson, 2009; Kreibig, 2010; Levenson, 2014). A not yet well tested but interesting physiological indicator for emotional arousal in particular is additional heart rate (Myrtek, Aschenbrenner, & Brügner, 2005). Additional heart rate is an adaption of heart rate, which indicates both sympathetic and parasympathetic activation of the autonomic nervous system (Kreibig, 2010; Levenson, 2014). In order to understand additional heart rate, heart rate in general will be discussed first.

1.4.1 Heart rate. The heart is the most important organ of the human body, because it pumps blood through the blood vessels to supply the body with nutrients and oxygen. In order to measure the speed of an individual's heartbeat, the number of contractions of the heart per minute (bpm) are measured, which is the heart rate (Levenson, 2014). The normal heart rate of a resting adult varies between 50 and 90 bpm. The current study measures heart rate by the photoplethysmography (PPG) sensor of a wearable bio-sensor. By measuring the relative absorption of infrared light over exposed skin, PPG determines the blood volume pulse. The relative oxygen saturation in the blood can be measured at two wavelengths, because de-oxygenated and oxygenated blood exhibit light absorption differently (Fletcher, Poh, & Eydgahi, 2010).

A relationship was found between heart rate and self-reported emotions (Peasley-Miklus et al., 2016). This relationship is negatively influenced by the construct alexithymia (Peasley-Miklus et al., 2016). Based on several within-person studies, it was concluded that individuals with high alexithymia show inconsistency between self-reported emotion and physiology, while individuals with low alexithymia do not (Peasley-Miklus et al., 2016). While an increase in heart rate was related to emotionally arousing pictures compared with neutral ones among low-alexithymia individuals, heart rate was not different for emotionally arousing images compared with neutral images among individuals with high alexithymia (Peasley-Miklus et al., 2016). Heart rate reactivity was reduced while self-reporting of emotions was intact within high-alexithymia individuals (Peasley-Miklus et al., 2016). This finding contradicts the research of Roedema and Simons (as cited in Peasley-Miklus et al., 2016), which stated that individuals with high alexithymia would report lower scores on experienced arousal, as discussed earlier. But both studies support the view that in individuals with high alexithymia physiological and cognitive responses on emotions are decoupled (Peasley-Miklus et al., 2016; Roedema and Simons (as cited in Peasley-Miklus et al., 2016). Further research on this topic is needed.

1.4.2 Additional heart rate. In order to determine if an increase in heart rate is really caused by affective arousal, physical activity needs to be excluded as a possible cause. An increase in heart rate shows increasing ANS activity, which could be caused by physical activity as well (Myrtek et al., 2005). Physical activity, which can be assessed by an accelerometer, causes an increasing demand in oxygen which increases sympathetic nervous system's activity and thus an increase in heart rate as well (Myrtek et al., 2005). Thus, an emotional event can be identified by an increasing heart rate without an corresponding increase in physical activity, caused by an increase in demand for oxygen. Such an acceleration of heart rate which is not accompanied by an increase in physical activity is called additional heart rate (Myrtek et al., 2005). It can be concluded that additional heart rate is an interesting but not yet well tested physiological indicator for emotional arousal.

A coherence between additional heart rate and emotional arousal has been found among widely varying situations. This can be stated according to several studies of Myrtek (as cited in Myrtek et al., 2005), which showed higher additional heart rate between subjects in high-risk situations versus low-risk situations, lower additional heart rate during social contact with peers versus strangers, higher additional heart rate when driving a car versus daily activities and higher additional heart rate watching an erotic movie versus comedy (Myrtek et al., 2005). Moreover, a within subject design showed that train drivers' additional heart rate was higher during starting and breaking than while driving. This difference in additional heart rate is due to an increase in emotional arousal caused by higher risk while leaving and driving in to a station (Myrtek et al., 2005). It is hypothesized that additional heart rate and self-reported arousal do correlate.

1.5 Current Study

The purpose of the current study was to determine to what extent self-reported affective arousal predicts additional heart rate within individuals, measured by a wearable bio-sensor, while taking into account the personality construct alexithymia. An increase in affective arousal will be associated with an increase in the activity of the autonomic nervous system and therefore an increase in additional heart rate as well. The first hypothesis is:

> "*Additional heart rate correlates positively with self-reported affective arousal across multiple points of measurements in time within individuals.*"

Due to the fact that individuals with a high score on alexithymia experience difficulties with identifying and describing of emotions, it was expected that these individuals experience difficulties with reporting on the intensity of arousal as well. Individuals who score higher on alexithymia experience emotions less intense than those with lower scores on alexithymia. The second hypothesis is:

"Scores on alexithymia correlate negatively with the relationship between self-reported affective arousal and additional heart rate."

2 Method

2.1 Participants

This study consists of a convenience sample of 18 students of the University of Twente (M_{age} = 20.8 years, age range: 19-27 years; 38,9 % female, 61.1 % male) who participated voluntarily in turn for course credits. Five participants were excluded who had less than 20% of 84 complete timeslots (Mehl, 2012), timeslots with values for both additional heart rate and self-reported arousal.

Participants were sampled from the direct environment of the researchers. Participants were included if they had the minimum age of 18 years, do not suffer from heart problems, understand and speak Dutch or English and owned a smartphone. Prior to participation, all participants gave written permission by signing an informed consent form. Permission for the conduction of the current research was requested and granted by the ethics committee of the faculty BMS of the University of Twente[1].

2.2 Materials

3.2.1 Toronto Alexithymia Scale. The Toronto Alexithymia Scale (TAS-20) was used in the current study (See appendix A for the TAS-20). This self-reported scale consisted of twenty items, divided over three subscales measuring difficulty describing emotions, difficulty identifying emotions and the tendency of individuals to focus attention externally. The items were rated using a 5-point Likert scale, whereby 1 = strongly disagree and 5 = strongly agree. To calculate an individual's TAS-20 score, the scoring for items 4, 5, 10, 18 and 19 were reversed. Then, scores of all twenty items were summed up, which is the Alexithymia score (Zimmermann et al., 2005). TAS-20 scores equal to or greater than 61

[1] The current study is part of a broader study about physiological measures, measured by a wearable biosensor, and self-reported stress and arousal. Five other students from the University of Twente worked on the study, each with an own research question. The method described below was commonly conducted, but each student used different data. With respect to the completeness of the method, parts which are irrelevant for the current study are (shortly) mentioned as well.

indicate high alexithymia, whereas scores equal to or less than 51 indicate low-alexithymia or non-alexithymia. Scores of 50 to 60 indicate possible alexithymia (Zimmermann et al., 2005).

3.2.2 Self-reported stress and arousal. For measuring self-reported stress and arousal the smartphone application mQuest Survey® version 11.7 (Cluetec, 2017) was used. Participants were asked to answer questions about perceived stress and arousal on their smartphone if the application gave a push notification. The questionnaire consisted of four items, which are inspired by Vansteelandt (as cited in Mehl & Conner, 2012): “How intense were your emotions during the last 2 hours?”, “How intense were your emotions during the last minute?”, “How much stress did you experience during the last 2 hours?” and “How much stress did you experience during the last minute?”. The items were rated using a 10-point scale, whereby 1 = the least and 10 = the most.

3.2.3 E4 wristband biosensor. For measuring real-time physiological measures, the wearable device Empatica E4 Wristband was used, including docking station and USB-cable. This device measured blood volume pulse by a photoplethysmograph, from which heart rate variability, heart rate and other cardiovascular features can be derived. A 3-axis Accelerometer measured motion-based activity. Events could be tagged by an Event Mark Button to correlate them with physiological signals. An Electrodermal Activity Sensor (EDA) measured sympathetic nervous system arousal and features related to stress, skin temperature was measured as well (Empatica, n.d.). Participants uploaded data of the E4 and charged the device by themselves, using the program Empatica Manager (Empatica, 2017) which was installed on the participant’s laptop.

2.3 Design and Procedure

3.3.1 Design. The current study is a quantitative experience sampling study with a within-subject design, based on an intensive longitudinal method in daily life. The present study used two sampling strategies. Self-reported experiences of stress and affective arousal were measured by an interval-contingent time-based sampling every two hours. Both momentary and interval reports were used to actively measure current experiences and experiences during the last two hours. Several physiological indicators, such as heart rate and skin conductance, were measured with a continuous sampling while participants were awake.

3.3.2 Procedure. The day before the measurements started each participant attended a briefing session, either in English or in Dutch based on the participant’s nationality. During the briefing, an instruction was given about the procedure of the research and the participant was asked to sign the informed consent (See Appendix B for the informed consent). Then, the participant was asked to fill out the TAS-20 questionnaire, either in German, English or Dutch depending on the native language of the participant. After the participant's approval, the researcher installed the Empatica software on the participant's laptop and the mQuest Survey application on the participant's smartphone and made it ready for use. Instructions were given about the mQuest Survey application, wearable biosensor E4 and the software Empatica Manager. Afterwards, these instructions were also sent to each participant by e-mail. The instructions received by the participants can be found in Appendix C (Wijk-Van Lier, personal communication, March 31, 2017).

During the next seven days the participants were asked to wear the E4 wristband during the whole day, except while sleeping or when taking part in activities were water was involved. The participants had to upload the data from the E4 wristband and to charge the E4 daily. Next to wearing the E4 wristband, the participants were asked to fill out a questionnaire on their smartphone every two hours, except while sleeping. A push notification was sent by the mQuest Survey application if a new questionnaire was available. In total, each participant received 84 questionnaires, the timeslots were the same for all participants (See Table 1). Each questionnaire was available during 30 minutes.

After seven days of wearing the E4 wristband and filling out a questionnaire every two hours, all participants attended a debriefing session. The participants were asked to fill out the TAS-20 questionnaire in their native language for a second time. Afterwards, the participants were asked to answer seven questions, for example concerning the usability of the E4 wristband and filling out the questionnaire every two hours (See Appendix D for the debriefing questions).

2.4 Data Analysis

All data analyses were carried out by means of Microsoft Excel (version 2016) and IBM SPSS Statistics (version 22). The mediation analysis was carried out by PROCESS for SPSS (version 2.16) (Hayes, 2016). The data was exported from the websites Empatica Connect, Qualtrics and the software Cluetec QuestAdmin (version 2017). For each participant, timeslots were excluded if values of additional heart rate were missing. Self-reported arousal questionnaires which have not been completed, were automatically removed from the dataset by the software mQuest and thus excluded. Concerning the reliability of the current study, five participants were excluded for the reason that they had completed less than 20% of 84 timeslots (Mehl & Conner, 2012), with both values of additional heart rate and self-reported arousal.

The variable Self-Reported Affective Arousal consisted of the scores on the item "How intense were your emotions during the past minute?" The internal consistency of both items "How intense were your emotions during the past minute?" and "How intense were your emotions during the past two hours?" was measured by Cronbach's Alpha, α of .70 or higher is acceptable (Cortina, 1993).

The variable Additional Heart Rate was the weighted heart rate difference per minute divided by the mean vector of acceleration, calculated with an algorithm (M.L. Noordzij, personal communication, May 22, 2017), which was an adaption of Myrtek and Foster (in Myrtek et al., 2005) (See Appendix E for the additional heart rate for every minute algorithm). This algorithm took into account the mean heart rate during the minute prior to filling in the arousal survey. First, heart rate (HR) change of minute i was computed by the current HR of minute i minus the average HR of the three minutes before the current minute. Second, physical activity was computed by a mean vector of acceleration of three axes. Third, the HR change in minute i should be at least 3 beats per minute (bpm) for counting as additional heart rate. In order to get an activity weighted reference value for HR, a minimal HR change in minute i was computed by adding value three to the physical activity of minute i. Finally, additional HR was computed by dividing the HR change of minute i by the minimal HR change in minute i. The possible additional heart rate value varies between zero and six.

The Alexithymia score of the pre-test TAS-20 was calculated for each participant according to the article of Zimmermann and colleagues (2005). The internal consistency of the TAS-20 scale and its subscales was measured by Cronbach's Alpha.

First, for each participant values on additional heart rate and self-reported arousal were analyzed using a Spearman rank correlation test. Second, a mediation-regression model (Hayes, 2016) was used to test the mediating effect of the pre-test scores on alexithymia on the relationship between additional heart rate and self-reported arousal. The mediation model consisted of four regression analyses: between additional heart rate and self-reported arousal, between additional heart rate and alexithymia, between alexithymia and additional heart rate in the presence of self-reported arousal and between additional heart rate and self-reported arousal in the presence of alexithymia. A Sobel test was conducted to test whether the mediation effect is statistically significant. Finally, the computed correlations within respondents were displayed in several graphs, in order to visualize the variability within and between subjects.

3 Results

3.1 Compliance and Overview of Collected ESM Data

Participants completed on average 30 out of 84 timeslots, were both heart rate and self-reported arousal were measured, a response rate of 36% (*SD* = 9,5%, range = 25,6-47,6%), after excluding five participants with a response rate less than 20%. Frequencies of the amount of completed timeslots within individuals, after excluding incomplete timeslots where either heart rate, arousal or both were missing, are shown in Figure 1. Notable is the difference between the total amount of measurements of additional heart rate (*n* = 380) and self-reported arousal (*n* = 536). The timeslots of the self-reported affective arousal questionnaire have been filled out the most at 2:00 PM (*n* = 78) and 6:00 PM (*n* = 75), and at 4:00 AM (*n* = 0) and 6:00 AM (*n* = 1) the least.

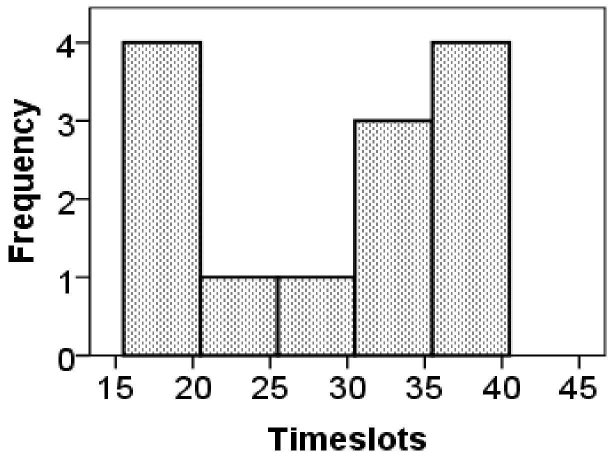

Figure 1. Frequencies of filled in timeslots where both values of heart rate and self-reported arousal were measured within subjects. The total possible amount of time slots was *n* = 84.

Notable is the finding that participants reported relative low amounts of affective arousal, the average was 2.6 (*SD* = 1.86) on a 10-point Likert scale. Figure 2 shows frequencies of average scores on self-reported affective arousal within individuals. Figure 3 shows frequencies of average additional heart rate. Additional heart rate is the weighted heart rate difference per minute divided by the mean vector of acceleration, as discussed earlier. The average additional heart rate within individuals was .62 (*SD* = 1.57) with possible values between 0 and 6. Scores (with standard deviations in parentheses) of the TAS-20 score conducted before the week of measuring and conducted afterwards, were 43.38 (7.57) and 41.92 (8.17), respectively. Figure 4 shows the frequencies of the scores of the TAS-20.

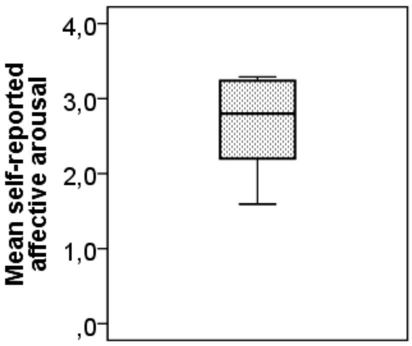

Figure 2. Frequencies of mean scores on self-reported affective arousal between subjects. Self-reported arousal was measured on a 10-item Likert scale.

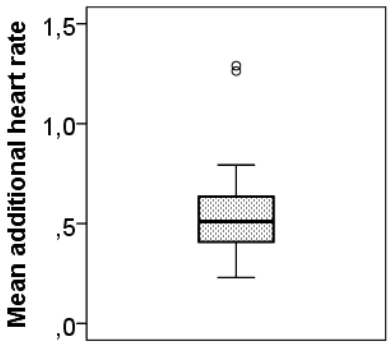

Figure 3. Frequencies of average additional heart rate between subjects. Additional heart rate is the weighted heart rate difference per minute divided by the mean vector of acceleration.

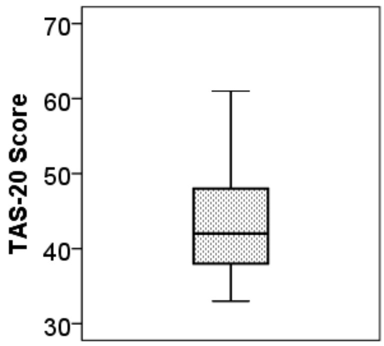

Figure 4. Frequencies of average TAS-20 scores between subjects. Scores ≥ 61 indicate high alexithymia, scores ≤ 51 indicate low alexithymia**.** Scores of 50 to 60 indicate possible alexithymia (Zimmermann et al., 2005).

3.2 Self-reported Arousal and Additional Heart Rate

In order to answer the first hypothesis, for each individual a Spearman's rank-order correlation was calculated between the scores on self-reported arousal and additional heart rate over all completed timeslots. Figure 5 shows the frequencies of correlations between self-reported arousal and additional heart rate within subjects. According to Cortina (1993), who recommended a minimal of $\alpha = .70$, the internal consistency of the self-reported arousal scale is acceptable ($\alpha = .70$).

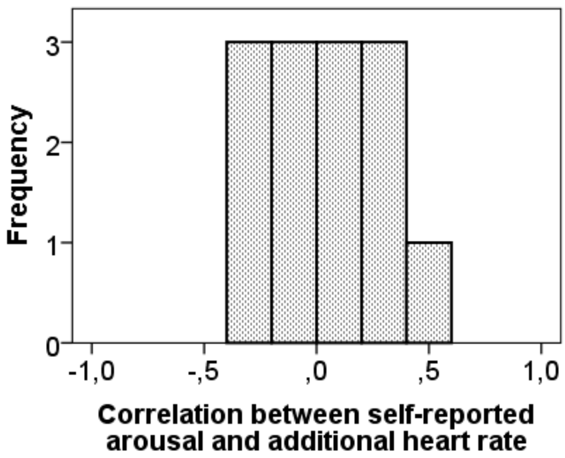

Figure 5. Frequencies of correlations between self-reported arousal and heart rate within subjects. Additional heart rate is the weighted heart rate difference per minute divided by the mean vector of acceleration

A moderate, positive monotonic correlation was found between scores on self-reported arousal and additional heart rate within 1 out of 13 participants, which was not significant at a level of .05 (r_s = .40, n = 18, p = .10). This means that self-reported arousal non-significantly slightly increases if additional heart rate increases, without the presence of a linear relationship. Weak, positive monotonic correlations were found within 3 out of 13 participants, which were not significant (r_s = .37, n = 20, p = .11; r_s = .37, n = 19, p = .12; r_s = .22, n = 37, p = .19) and non-significant, weak, negative monotonic correlations were found within 3 out of 13 participants (r_s = -.31, n = 31,p = .09; r_s = - .28, n = 26, p = .17; r_s = -.21, n = 24, p = .33)[2]. All other participants, 6 out of 13, participants showed very weak positive or negative monotonic correlations between scores on self-reported arousal and additional heart rate, which were non-significant as well. Figure 6 shows graphical representations of the correlations between self-reported arousal and additional heart rate, within four different individuals from the current sample.

[2] Within the excluded five participants who completed less than 20% of the timeslots, the following correlations were found: A significant strong positive monotonic correlation (r_s = .62, n = 12, p = .03), at the specified 0.05 level. Next, a strong positive monotonic correlation (r_s = .62, n = 7, p = .14), a moderate positive monotonic correlation (r_s = .48, n = 12, p = .11) and two moderate negative monotonic correlations (r_s = -.46, n = 9, p = .21; r_s = .36, n = 15, p = .19), which were all non-significant.

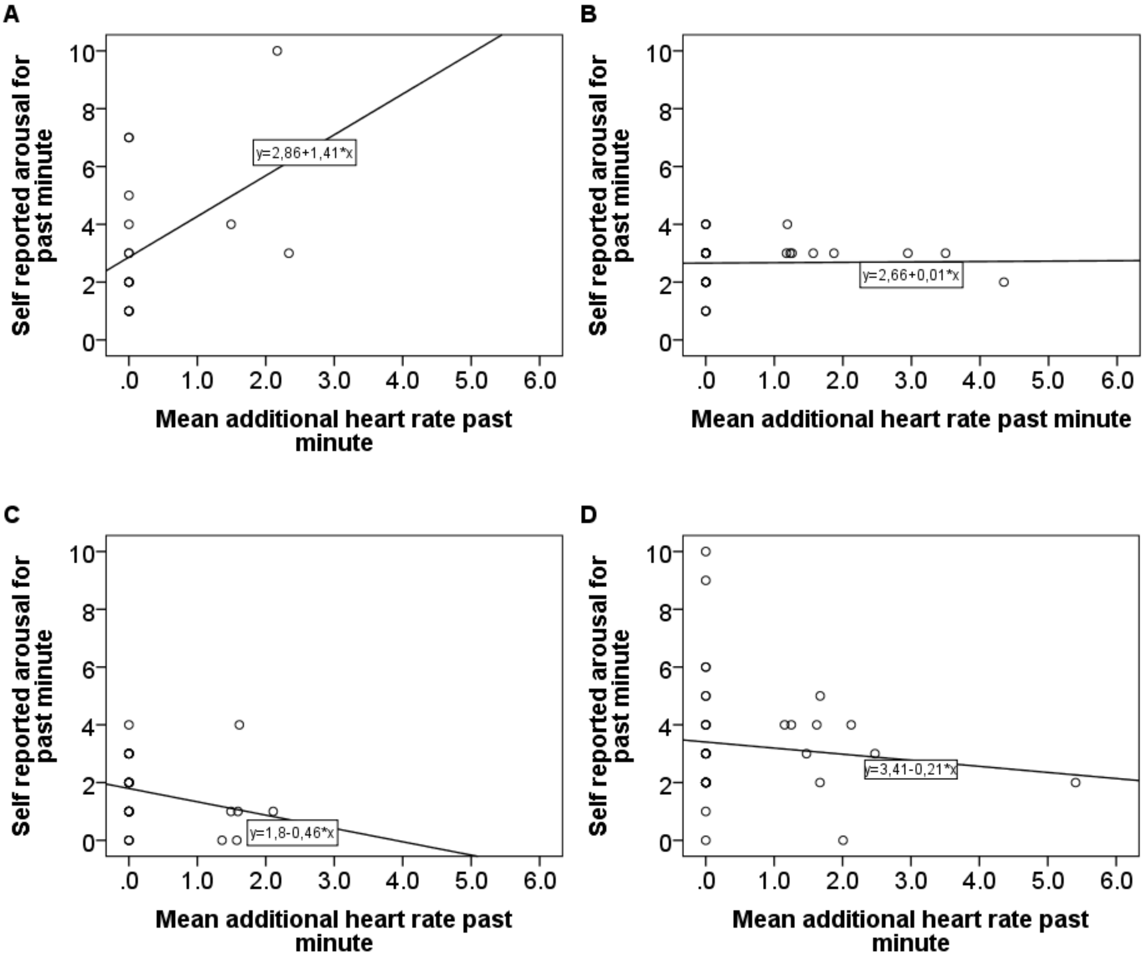

Figure 6. Visualization of correlations within individuals between scores on self-reported arousal and heart rate: *(A)* Moderate positive monotonic correlation (r_s = .40, *n* = 18, *p* = .10). (*B)* Weak positive monotonic correlation (r_s = .22, *n* = 37, *p* = .19*). (C)* Weak negative monotonic correlation (r_s = -.31, *n* = 31, *p* = .09). *(D)* Very weak neutral monotonic correlation (r_s = .04, *n* = 38, *p* = .83).

3.3 Alexithymia, Self-Reported Arousal and Additional Heart Rate

The TAS-20 in the current sample consisted of 20 items (α = .75) divided over three subscales. The Difficulty Identifying Emotions subscale consisted of 7 items (α = .78), the Difficulty Describing Emotions subscale consisted of 5 items (α = .60), and the Externally-Oriented Thinking subscale consisted of 8 items (α = .73). The internal consistency of the TAS-20 scale is acceptable, according to Cortina (1993), who recommended a criterium of α ≥ .70.

To test the hypothesis whether an individual's TAS-20 score negatively mediates the relationship between self-reported arousal and additional heart rate within individuals, an regression analyse was conducted. In step 1 of the mediation model, the regression of self-reported arousal on additional heart rate, ignoring the mediator, was non-significant, *b* = .04, *t*(11) = .32, *p* = .75. This means that self-reported arousal does not influence additional heart rate. Step 2 of the mediation analyses showed that the regression of self-reported arousal on the mediator alexithymia, was also non-significant, $b = 1.95$, $t(11) = .71$, $p = .49$. Step 3 of the mediation analyses showed that the mediator, alexithymia, controlling for self-reported arousal, was non-significant too, $b = .02$, $t(10) = 1.22$, $p = .25$. Step 4 of the mediation analyses showed that, controlling for the mediator alexithymia, self-reported arousal was not a significant predictor of additional heart rate, $b = .01$, $t(10) = .07$, $p = .95$. A Sobel test was conducted and found no mediation in the model ($z = .50$, $p = .62$). It was found that alexithymia did not mediate the relationship between self-reported arousal and additional heart rate. [3]

In addition, individual differences of the mediating effect of alexithymia on the relationship between additional heart rate and self-reported arousal were visualized. For each individual a Spearman's rank-order correlation was calculated between the correlations between scores on self-reported arousal and additional heart rate over all completed timeslots, and the pre-test scores on the TAS-20 scale. Figure 5 shows the correlations between the TAS-20 score and the correlation between additional heart rate and self-reported arousal between individuals.

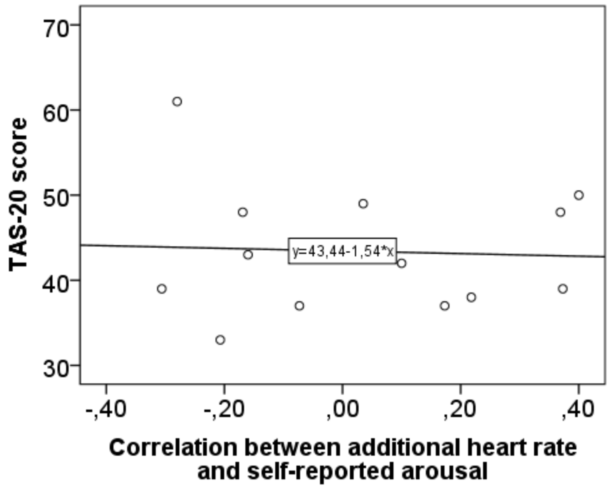

Figure 7. Visualization of correlations between the average TAS-20 score and the correlation between self-reported arousal and additional heart rate between individuals.

[3] Without excluding five participants who completed less than 20% of the timeslots, the following non-significant results were found: Step 1: $b = .05$, $t(16) = .74$, $p = .47$; Step 2: $b = .81$, $t(16) = .45$, $p = .66$; Step 3: $b = .01$, $t(15) = .59$, $p = .56$; Step 4: $b = .04$, $t(15) = .59$, $p = .33$; Sobel test: $z = .35$, $p = .73$. It was found that alexithymia did not mediate the relationship between self-reported arousal and additional heart rate.

4 Discussion

It has been found that today's wearable devices, which transform physiological measures into personal emotional states, are not always able to manage the complex relationship between psychology and physiology (Barrett & Simmons, 2015; Evers et al., 2014; Fairclough, 2009). Most of the time, differences in capabilities in experiencing emotions between individuals are not taken in to account, for example the personality trait alexithymia which is characterized by difficulties with identifying and describing emotions (Chen et al., 2011).

The aim of the current study was to study the mediating effect of an individual's score on the personality trait Alexithymia on the relationship between self-reported arousal and additional heart rate within individuals. Two hypothesizes were formulated. First, it was hypothesized that additional heart rate correlates positively with self-reported affective arousal across multiple points of measurement within individuals. Against what was expected, none of the 13 respondents showed a significant correlation between additional heart rate and self-reported arousal over several measurements in time. Second, it was hypothesized that the score on alexithymia negatively moderates the relationship between additional heart rate and self-reported arousal within individuals. However, no significant correlation was found between subjects.

4.1 Additional Heart Rate and Self-Reported Affective Arousal

It was notable that within several participants, most of the values of additional heart rate were zero, whereas the corresponding self-reported arousal values varied between zero and six. The non-alexithymia individuals did report higher levels of experienced arousal, while additional heart rate did not indicate the presence of arousal. This finding is the opposite of previous research (Peasley-Miklus et al., 2016; Roedema and Simons (as cited in Peasley-Miklus et al., 2016)), were a decoupling of physical and emotional responses was found only among high-alexithymia individuals. More specifically, Eastabrook and colleagues (2013) found that high-alexithymia individuals showed higher levels of self-reported self-consciousness relative to physiological arousal (heart rate) than low-alexithymia individuals. Eastabrook and colleagues (2013) measured heart rate and galvanic skin response among high and low-alexithymia individuals, determined by the TAS-20 as well, who hold a short speech. Self-reported and observer-rated feelings of self-consciousness were used to determine levels of self-consciousness (Eastabrook et al., 2013). The current study measured the intensity of experienced emotions in particular, but only non-alexithymia individuals were examined.

In contrast, Lang (as cited in Myrtek et al., 2004) stated that emotional cognitions could be generated without autonomic arousal among individuals in general. Myrtek and colleagues (2004) confirmed and specified this conclusion. More specifically, participants showed no differences in reporting on emotions during events with and without the presence of additional heart rate (Myrtek et al., 2005). Supposed was that emotional events, indicated by additional heart rate, could be too weak to become consciously perceived (Myrtek et al., 2005). In contrast, the current study showed being conscious of emotions but no presence of additional heart rate. Myrtek and colleagues (2005) measured heart rate and physical activity among female students during two days in daily life. Among other questions, feelings of excitement were asked on a device either when additional heart rate was present or random without additional heart rate. As in the current research, emotions were measured in real daily life of participants.

At first glance, it looked like more measurements were available for self-reported arousal then for additional heart rate, as displayed in the results. However, minutes with measures of self-reported arousal were used as starting values for further analyses. Values of additional heart rate were only included if a corresponding value of self-reported arousal was available as well. The amount of values of additional heart rate used in the current study was either the same or less than the amount of self-reported arousal values, whereas much more minutes of additional heart rate were available. This explains the notable difference between the amount of self-reported arousal values and additional heart rate values. Overall it can be stated that participants are willing to wear a wristband and to fill out questionnaires every two hours for a week, which affirms the usability of the sampling design of the current study.

Despite the lack of finding a relationship between additional heart rate and self-reported arousal within participants, correlations varied widely between participants. The correlations between additional heart rate and self-reported arousal were almost randomly distributed around zero. A possible explanation could be that participants differed in reported values of experienced affective arousal. Some participants reported relatively low scores, whereas others reported higher scores on self-reported arousal. During the debriefing, one participant believed that negative emotions hold more weight than positive emotions: “I assigned value two to being very happy, whereas a higher value was assigned to the same intensity of being angry.”. Another participant took positive and negative emotions equally in to account while determining the intensity of current emotions.

These individual differences in reported arousal values are in line with previous research (Chen et al., 2011; Barrett, 2004), who found that individuals differ in experiencing and reporting emotions from which the construct alexithymia is an example(Taylor & Bagby, 2004). More specifically, Barrett (2004) found that people differ in the extent of emphasizing on arousal and valence while verbally reporting on experienced emotions. In Barrett’s study (2004), participants reported on experienced emotions during three parts, including experimental induced positive and negative emotional experiences, affective-related words and evocative slides on a computer. Especially, differences in the extent of verbally reported activation and deactivation of experienced emotions were found (Barrett, 2004). Focusing on arousal in self-reported experienced emotion was also related to better interoceptive sensitivity (Barrett, 2004). In contrast, the current study measured experienced emotions induced in real life, which could have been less emotional arousing than Barret’s (2004) experimental elicited emotions. This possible shortcoming of the current study will be discussed later.

However, Myrtek and colleagues (2004) clarified that studies conducted in laboratory and in real life do not always correspond due to different measuring circumstances. Results of ambulatory monitoring studies where the perception of emotions were studied in everyday life, differed a lot from laboratory studies (Myrtek et al., 2004). In laboratory experiments, participants are aware of coming situations which could strengthen the relationship between self-reported states and physiological activation (Myrtek et al., 2004). In contrast, this effect does not occur in field studies (Myrtek et al., 2004). Identification of affective arousal is more complex in real life than in laboratory, due to subjective hypothesizes and subjective schemata (Myrtek et al., 2004). According to Myrtek (2004) it is not unusual that the current study does not confirm results from studies conducted in controlled laboratory settings.

4.2 Alexithymia, Additional Heart Rate and Self-Reported Affective Arousal

The lack of finding a significant correlation between subjects could be due to the fact that no relationship was found between additional heart rate and self-reported arousal, as discussed before. In contrast, a study of which 50% of the sample consisted of participants with high alexithymia showed that the relationship between heart rate and emotional arousal was stronger as alexithymia decreased (Peasley-Miklus et al., 2016). Individuals with low alexithymia showed an increase in heart rate during affectively arousing compared to neutral imagery scripts, while heart rate of individuals with high alexithymia did not differ during affectively arousing compared to neutral imagery scripts (Peasley-Miklus et al., 2016). The study of Peasley-Miklus and colleagues (2016) was conducted in a controlled lab environment with elicited emotions, while the current study took place in real life and with real events and therefore real experienced emotions. In the former study all participants received the same positive and negative stimuli, while participants in the current study experienced different events with different dimensions of arousal and valence. The current study measured multiple times a day during seven days, while the study of Peasley-Miklus and colleagues (2016) was conducted during a few hours. Thus, the most importance difference is that Peasley-Miklus (2016) was assured of the presence of arousing experiences and being able to control these, while the current study was not. It might be that participants in the current study did not experience high-arousing events, while those of Peasley-Miklus (2016) certainly did. This possible limitation of the current study will be discussed later.

Findings of the current study do contradict earlier evidence, but inconsistency was found among studies whether higher alexithymia is related to deviations in heart rate reactivity or in self-reporting on emotions, compared to lower alexithymia. Roedema and Simons (as cited in Peasley-Miklus et al., 2016) concluded that individuals with high alexithymia show lower ratings of self-reported emotional intensity in response to emotional images, while Mantani (as cited in Peasley-Miklus et al., 2016) presented these findings only for sad emotions. However, a literature review on within-subject studies concluded that the majority of these studies showed that heart rate reactivity is reduced while self-reporting of emotions was intact within higher alexithymia (Peasley-Miklus et al., 2016). All between-subject studies mentioned above have in common that emotion-eliciting methods have been used, such as videos, mental task games and imagery, whereas the current study did not elicit any emotions but took advantage of already existing situations in respondent's daily life.

According to a literature review of Mehl and Conner (2012), emotions are structured differently at within-person versus between-person level. For example, correlations between same valence emotions were low within-subjects, but high among between-subjects according to Larsen (as cited in Mehl & Conner, 2012). The same was found between emotions of different valences (Mehl & Conner, 2012). Emotional experiences could be more complex at within-person level than at between-person level, but few is known about this topic (Mehl & Conner, 2012). Differences between emotions at within- and between-subject level could relate to the differences between findings of earlier between-subject studies and the current within-subject study, but this difference needs to be investigated further.

4.3 Limitations of the Study

The current study had some design limitations that could have influenced the results. First of all, events experienced by the participants in daily life could have been too less emotional arousing, which could explain the relative low values of self-reported experienced arousal and additional heart rate. As discussed earlier, previous studies who did research on emotions, elicited emotions experimentally and succeeded at increasing self-reported arousal (Peasley-Miklus et al., 2016; Barret, 2004). In contrast, in the current study nothing but self-reported arousal is known about emotions experienced by participants and factors eliciting these emotions. The missing or low availability of highly arousing events during the measuring period could have influenced the lack of finding a relationship between self-reported arousal and additional heart rate. If experienced events were too less emotional arousing, it is less likely that these events caused a change in heart rate intense enough to count as additional heart rate (Myrtek et al., 2005). The relative low values of self-reported arousal and additional heart rate could indicate the low amount of highly arousing events.

Second, the amount of timeslots including both values for additional heart rate and self-reported arousal were relatively low within several participants. Five out of 18 participants were excluded due to a very low response rate. Additional heart rate values lack if values of heart rate, acceleration or both are missing. The most likely causes of missing additional heart rate in the current study were malfunctions of the photoplethysmograph and/or the accelerometer, not wearing the wristlet the right way or not wearing it at all. For instance, some participants reported forgetting to turn the device on again after taking it off or wearing the wristband looser due to discomfort after a while. Other participants reported having a week off without much activities and waking up in the afternoon, which could have influence both self-reported arousal and additional heart rate values. Some participants reported not being able to fill in questionnaires while being at work, having important meetings or driving a car. Due to the low amount of useful data between and within participants, the representativeness and generalizability of the results could be negatively influenced.

4.4 Further Research

Despite not being able to draw conclusions about the moderating effect of alexithymia on self-reported arousal and heart rate in the current sample, this study demonstrated a wide spread of correlations between these variables. It can be concluded that most of previous research on the current topic is either done by lab experiments or in real life with few measure points. In contrast, the current study took place in daily life with real emotions and several measure points during seven days. Thus, the current study is one of the first ones to demonstrate the possibility of using an intensive longitude experience sampling design for examining self-reported emotions, physiology and alexithymia. In general, it is recommended to keep checking if the technologies function properly, in order to detect sudden malfunctioning of the Empatica E4 or the questionnaire's software. Just as important is to check if all participants understand and use these technologies the right way as well. Two more specific recommendations were made in order to support further research on this topic.

Firstly, since low values on self-reported arousal and additional heart rate were found, it is recommended to include high-arousing emotional events in the measuring period of further research. By measuring self-reported arousal and additional heart rate in a week with more emotional arousing events, it becomes more likely to find increases in self-reported heart rate and to find an effect of arousal on the autonomic nervous system. Further research could implement criteria for measuring periods, for example measuring among first year students during their first week at university or among students during examination weeks.

Secondly, it is recommended to increase the amount of data by extending the measuring period. For instance, by measuring two weeks instead of one, more data will be obtained to draw conclusions on which increases reliability. The chance of capturing highly emotional arousing situations in daily life which elicit emotions will increase as well. By increasing the duration of the measuring period, daily life could be represented more accurate and reliable.

4.5 Conclusion

This study provides new insights about the applicability of an intensive longitudinal experience sampling design in daily life to future research on (the effect of alexithymia on) the relationship between physiology and self-reported emotions. For instance, participants are willing to wear an E4 wristband and to fill out a short questionnaire every two hours. For further research it is recommended to measure affective arousal during a period of several weeks while emotional arousing events are likely to happen as well. For example during the first weeks at a new job.

5 Acknowledgement

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7 Appendices

7.1 Appendix A. TAS-20

1. For Researcher: fill in USER number for respondent:……..
2. For Researcher: briefing or debriefing
   - Briefing: gesprek 1
   - Debriefing: gesprek 2
3. Using the scale provided as a guide, indicate how much you agree or disagree with each of the following statements by circling the corresponding number. Give only one answer for each statement.

	Strongly disagree	Moderately disagree	Neither agree nor disagree	Moderately agree	Strongly agree
1. I am often confused about what emotion I am feeling. 2. It is difficult for me to find the right words for my feelings.	❍	❍	❍	❍	❍
3. I have physical sensations that even doctors don't understand.	❍	❍	❍	❍	❍

	Strongly disagree	Moderately disagree	Neither agree nor disagree	Moderately agree	Strongly agree
4. I am able to describe my feelings easily	❍	❍	❍	❍	❍
5. I prefer to analyze problems rather than just describe them.	❍	❍	❍	❍	❍
6. When I am upset, I don’t know if I am sad, frightened, or angry.	❍	❍	❍	❍	❍
7. I am often puzzled by sensations in my body.	❍	❍	❍	❍	❍
8. I prefer to just let things happen rather than to understand why they turned out that way.	❍	❍	❍	❍	❍

	Strongly disagree	Moderately disagree	Neither agree nor disagree	Moderately agree	Strongly agree
9. I have feelings that I can't quite identify.	❍	❍	❍	❍	❍
10. Being in touch with emotions is essential.	❍	❍	❍	❍	❍
11. find it hard to describe how I feel about people.	❍	❍	❍	❍	❍
12. People tell me to describe my feelings more.	❍	❍	❍	❍	❍
13. don't know what's going on inside me.	❍	❍	❍	❍	❍
14. I often don't know why I am angry.	❍	❍	❍	❍	❍

Using the scale provided as a guide, indicate how much you agree or disagree with each of the following statements by circling the corresponding number. Give only one answer for each statement.

	Strongly disagree	Moderately disagree	Neither agree nor disagree	Moderately agree	Strongly agree
15. I prefer talking to people about their daily activities rather than their feelings.	❍	❍	❍	❍	❍
16. I prefer to watch “light” entertainment shows rather than psychological dramas.	❍	❍	❍	❍	❍
17. It is difficult for me to reveal my innermost feelings, even to close friends.	❍	❍	❍	❍	❍
18. I can feel close to someone, even in moments of silence.	❍	❍	❍	❍	❍

19. I find examination of my feelings useful in solving personal problems.	❍	❍	❍	❍	❍
20. Looking for hidden meanings in movies or plays distracts from their enjoyment.	❍	❍	❍	❍	❍

7.2 Appendix B. 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: ……………………………………………………..

7.3 Appendix C. Participant Instruction (H.G. Van Dijk-Van Lier, personal communication, March 31, 2017)

Login Data:
Empatica Manager
Login: experiencesamplingnoordzij@gmail.com
Password: emp2017
mQuest
Login: USER..
Password: user..

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, either by texting, WhatsApp, calling or sending an email.

1. What is to be expected during the research?

The next seven days, starting from tomorrow, you will be asked to wear a wearable device called E4 when you are awake. Every 2 hours you will be asked to answer a couple of question via an app on your mobile phone. Whenever you’re asleep you don’t have to wear the E4 and you can ignore all notifications of the app, 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.

In order to upload the data from the E4, software needs to be installed on your laptop. The application for the questionnaire needs to be installed on your phone. Do you give permission that the researcher will install both the app and the software on your devices?

While the researcher installs the software, you are asked to fill out an online survey.

2. mQuest Application

During the next seven days, starting from tomorrow, your phone will give you notifications if a new questionnaire is available every two hours. An example questionnaire is now available in the app mQuest. You can open the app and fill out the questionnaire now.

3. How does the E4 work?

3.1 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.

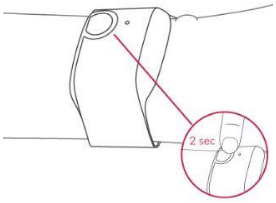
3.2 Upload data and recharge the E4

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!

3.3 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.



4. 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.

5. 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.

6. 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.

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

7.1 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)

7.2 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

7.4 Appendix D. Questions during Debriefing

- How did it go this week?
- What was the burden of the experiment (on a scale from 1 (very low)-10 (very high))
- Were you able to get used to the device?
- Did you miss many opportunities to fill out the survey?
    - If yes, what were the main reasons you missed those moments?
- Did you anticipate the notifications?
- How did you go about filling in the survey every two hours?

7.5 Table 1.

Timeslots for Stress & Arousal Questionnaires in an Experience Sampling Design

Timeslot	Start time	Timeslot	Start time	Timeslot	Start time	Timeslot	Start time
1	08:00	22	02:00	43	20:00	64	14:00
2	10:00	23	04:00	44	22:00	65	16:00
3	12:00	24	06:00	45	00:00	66	18:00
4	14:00	25	08:00	46	02:00	67	20:00
5	16:00	26	10:00	47	04:00	68	22:00
6	18:00	27	12:00	48	06:00	69	00:00
7	20:00	28	14:00	49	08:00	70	02:00
8	22:00	29	16:00	50	10:00	71	04:00
9	00:00	30	18:00	51	12:00	72	06:00
10	02:00	31	20:00	52	14:00	73	08:00
11	04:00	32	22:00	53	16:00	74	10:00
12	06:00	33	00:00	54	18:00	75	12:00
13	08:00	34	02:00	55	20:00	76	14:00
14	10:00	35	04:00	56	22:00	77	16:00
15	12:00	36	06:00	57	00:00	78	18:00
16	14:00	37	08:00	58	02:00	79	20:00
17	16:00	38	10:00	59	04:00	80	22:00
18	18:00	39	12:00	60	06:00	81	00:00
19	20:00	40	14:00	61	08:00	82	02:00
20	22:00	41	16:00	62	10:00	83	04:00
21	00:00	42	18:00	63	12:00	84	06:00

7.6 Appendix E. Algorithm for calculation of additional heart rate for every minute (M. L. Noordzij, personal communication, May 22, 2017; adaption of Myrtek & Foster, in Myrtek et al., 2005)

Current heart rate of minute i:

$$HR_i$$

Heart rate level for minute i:

$$HRL_i = \frac{1}{3} \left(\sum_{1}^{3} HR_{i-1} \right)$$

Heart rate change of minute i:

$$HRC_i = HR_i - HRL_i$$

Physical activity of minute i (mean vector of acceleration):

$$ACT_i = \frac{1}{60 \times SR} \sum_{j=1}^{j=60 \times SR} \sqrt{x_{ij}^2 + y_{ij}^2 + z_{ij}^2}$$

Minimal heart rate change in minute i to get an activity weighted reference value for the heart rate following the standard value chosen by Myrtek for a minimum value of 3 for the HRPLUS:

$$HRPLUS_i = \frac{ACT_i}{30} + 3$$

Additional heart rate for a given minute is then defined as the factor of the Current Heart rate change divided by the HRPLUS:

$$AHR\_value_i = \frac{HRC_i}{HRPLUS_i}$$

The final decision rule to log only those AHR values greater or equal than 1 :

$$AHR_i = \begin{cases} 0, & AHR\_value_i < 1 \\ AHR\_value_i, & AHR\_value_i \geq 1 \end{cases}$$