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When One Kind Predicts Another: How Task-Induced Stress Influences Subjective and Objective Stress

Name: Thalia (S.T.) Schindler
Supervisor: Jop Groeneweg
Second reader: Guido Band
Cognitive Psychology
Thesis Msci Applied Cognitive Psychology

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Abstract

Psychological research desires to evaluate occupational stress, which is a major health problem in modern society. A stress-causing factor, namely task-induced stress, as well as the difference between subjective and objective stress were researched. The current study explored whether task-induced stress predicted subjective and/or objective stress. A field study was conducted with twenty-eight train traffic controllers (TTC´s) in Arnhem (The Netherlands). The biomarkers heart rate variability (HRV) and electro dermal activity (EDA) measured objective stress and a short questionnaire measured subjective stress. An expert panel of 6 people rated task-induced stress per individual task. The association between subjective, objective, and task-induced stress was more complex than expected. HRV and EDA were not correlated. Emotional and cognitive processing influenced HRV and EDA, but the degree of influence could vary per biomarker. Task-induced stress could correctly predict HRV-based stress and subjective stress, but not EDA-based stress. A higher task-induced stress predicted a lower HRV and, unexpectedly, a lower subjective stress value. A lower HRV could indicate a higher mental strain, but there is disagreement about this interpretation in the literature. The assessment of subjective stress had a design issue, because it was assessed per day instead of per task. More investigation is needed to elaborate which psychophysiological tool measures which aspect of stress.

1 Introduction

Occupational stress, or work stress has been a wide research area of growing interest for the last five decades. It describes the way society understands the interrelation of work environment, the individual mind, and the body with great emphasis on the distress causing incompatibility between these three elements (Kendall & Muenchberger, 2009). It has been considered one of the greater health problems of our modern western world although work conditions have been improving (Väänänen, Murray, & Kuokkanen, 2014; Föhr et al., 2015). Health consequences of occupational stress include psychological and physical symptoms such as mental fatigue (or tiredness), sleep alterations, emotional exhaustion, headaches, and signs of musculoskeletal disorders in the back and neck area (García-Herrero, Mariscal, García-Rodríguez, & Ritzel, 2012). These health problems often result in higher rates of absenteeism and sick leave, more turnover, and feelings of dissatisfaction with one's job (Väänänen et al., 2014).

The importance of field studies has gained acknowledgement in recent years. The aim of psychological research about occupational stress is to evaluate and eventually improve working conditions and worker's efficiency, capacity, productivity and satisfaction. As Vedhara, Hyde, Gilchrist, Tytherleigh, and Plummer (2000) stated, it is therefore important to assess naturally occurring stressors in their actual environment to gain a trustworthy, realistic picture of them. Furthermore, Föhr et al. (2015) recognised, that occupational stress interacts with and is influenced by factors such as emotions and recovery phases throughout the working day. Data obtained in those everyday life settings could therefore lead to better applications of improvement strategies.

Khoozani and Hadzic (2010) introduced a framework including most of the recent knowledge about occupational stress to gain a much-needed overview about the topic. In their ontology they illustrated various perspectives from which stress can be approached. One of these perspectives concentrates on differentiating between subjective and objective stress. Objective stress denotes the objectively measurable stress experienced by the human body, which can be quantified by psychophysiological instruments. Subjective stress refers to the individual experience and evaluation of stress.

Many studies used psychophysiological measurements to assess objective stress in laboratory settings. The advantage in this approach lies in the objectivity of the measurement, thus the independence from human judgement. Biomarkers such as heart rate (HR), heart rate variability (HRV) and electro dermal activity (EDA) are often used in these studies, because they can be assessed with non-invasive tools. This makes those biomarkers suitable for field studies and provides a comfortable use in real work settings. Most studies utilised various biomarkers at the same time, because there are suggestions, that different physiological effects are influenced in different ways by cognitive changes (Whang, Lim, & Boucsein, 2003).

HRV indicates the variability of the time intervals between consecutive heartbeats. To be more specific, each heartbeat has a R-wave, which peaks in the R peak. The time span of two consecutive R-peaks (RR interval) in a certain amount of time can vary. Those variations between RR intervals are defined as HRV (Niskanen, Tarvainen, Rabta-aho, & Karjalainen, 2004). A higher HRV value reflects a great variation of the RR intervals, whereas a lower HRV value indicates small variation. Those RR intervals are modulated by both parasympathetic and sympathetic activity of the autonomic nervous system (ANS). In stress situations an increased activation level of the body is associated with sympathetic activity dominating the ANS. During recovery phases a reduced activation level is associated with parasympathetic activation dominating the ANS (Föhr et al., 2015).

HRV is broadly accepted as a sensitive, non-invasive indicator for mental work load (Fercho, Peterson, & Baugh, 2016), an aspect of stress induced by cognitive (over)load (Feinberg & Murphy, 2000). The change in cognitive capacity due to mental strain is accompanied by changes in the physiological indicator HRV (Nickel & Nachreiner, 2003). Controlled information processing, thus conscious and active processing, leads apparently to suppression of HRV. Moreover, decreased HRV can indicate phases of activation of the cognitive system due to mental strain (Nachreiner, 1999). Finally, in high-demand job situations a decreased HRV value seems to indicate a higher mental load (Van Amelsvoort et al., 2000). Although some researchers raised the question whether HRV is really sensitive enough to detect small changes in mental workload (Nickel & Nachreiner, 2003), others consider it as a useful, sensitive tool for cognitive research (Van Amelsvoort, Schouten, Maan, Swenne, & Kok, 2000) and as an index of mental strain (Parker, Laurie, Newton, & Jimmieson, 2014).

The analysis of HRV is possible with various methods (time-domain, frequency-domain, non-linear, and time-varying) and different parameters within each method (Tarvainen et al., 2014). It is important to keep the design of the research and the researcher’s goal in mind when choosing the specific kind of analysis (Task Force, 1996). In the current research a time-domain analysis was chosen. Uusitalo et al. (2011) indicated this method as generally more stable and repeatable across non-stationary conditions compared to the other methods. Non-stationary conditions are an important criterion, because the current research will be conducted in an uncontrollable real life setting. A more detailed description of the HRV analysis follows in the section "Statistical Analysis".

EDA measures sweat gland activity of the skin. Emotional sweating is particularly linked to increasing gland activity caused by stress situations (Boucsein, 2012). A general opinion is that human sweat glands receive only excitatory sympathetic nerve impulses, because there is only sympathetic innervation in this peripheral part. This peripheral activation is also found to react to hormonal stimuli. Management of EDA also takes place in the hypothalamic areas of the brain. Thus emerges the possibility that the part of the CNS involved in EDA could be under parasympathetic control. Only a few studies used EDA as indicator of occupational stress caused by non-physical workload in industrial and shift work research involving human-computer interaction. Influences on EDA recordings that can be ascribed to ambient temperature, gender, age, season, humidity, ethnicity, and their interactions are likely to occur, but are difficult to isolate. Nevertheless, EDA recordings are regarded as valuable tool in stress research and promising for future research. Studies report an EDA increase as work conditions become less comfortable, for example due to a small operating screen size (Ellis, Sims, Chin, Ellis, Upham, & Jannone, 2008). There is also a close connection between EDA and stages of higher information processing. For example, an indicator for the duration of an information registration process is the recovery time of elevated EDA values (Boucsein, 2012).

Most experimental studies, which investigated stress with psychophysiological measurements, ignored the subjective stress experience of human beings, although it would provide an additional facet to stress evaluation. Many field studies, in contrast, paid attention to subjective, individual stress experience using questionnaires and reports as tools for these studies (Föhr et al., 2015). The purpose of those field studies was to gain an as detailed a possible picture of the stress experience of the individual employee in the work situation. For example, Szalma et al. (2004) stated that workers with executive monitoring tasks experienced more stress the more time they spent looking at a task on the monitor. Then again, most of these non-laboratory studies disregard the added value of objective stress measures.

The utilisation of subjective and objective stress measurements in the same study would provide an additional aspect to stress evaluation. However, there is only a small number of studies regarding both subjective and objective stress. Unfortunately, the results of those studies display a most divergent picture (Khoozani & Hadzic, 2010). Teisala et al.

(2014) and Föhr et al. (2015) found a correlation between an increase in objective, HRV-based stress and an increase in self-reported stress symptoms in participants (who were all of working-age). A similar correlation was presented between a slight increase in electrodermal measures as subjective stress increased (Boucsein, 2012). Vedhara et al. (2000) found the exact opposite effect in their study. Higher self-reported stress levels where associated with lower levels of the stress-associated hormone cortisol in students during examination periods. Malarkey, Pearl, Demers, Kiecolt-Glaser, and Glaser (1995) in turn argued that only students with high self-reported stress levels had also increased levels of cortisol during examination periods.

Another approach to occupational stress is to study its causes (Khoozani & Hadzic, 2010). There are dispositional as well as situational factors causing internal stress states (Matthews & Falconer, 2000). Studies about dispositional factors have often used personality traits like regulatory focus (Parker et al., 2014) or core self-evaluation (Brunsborg, 2008) to explain differences between individual responses to stress. Studies regarding situational factors often focus on task features to predict individual stress reactions (Dickerson & Kemeny, 2004). One important feature is task-induced stress, which refers to the (perceived) mental, physical, and temporal demands of a task (Claypoole, Dewar, Fraulini, & Szalma, 2016). Task-induced stress is regarded as a major problem in the daily working life, which needs further investigation (Matthews & Falconer, 2000). Most studies focused on task-induced stress and its relation to performance (Helmick-Rich, Burke, Oron-Gilad, & Hancock, 2004) and influential factors, e.g. presence of a supervisory figure (Claypoole et al., 2016). For example, Wada and Ueda (2012) found a correlation between increasing psychophysiological measurements of HR and EDA and increasing task difficulty, which is only one aspect of task-induced stress.

However, there is relatively little research available about the relationship of subjective and objective stress in real life work settings. One interesting question to answer in this area is whether task-induced stress is a better predictor for subjective or objective stress. To answer this question, a field study with train traffic controllers (TTC´s) was conducted. The work demands of TTC's have shifted from active control to executive monitoring in the last two decades (Szalma et al., 2004). Like many modern jobs it requires successful completion of cognitive tasks together with computer interaction to avoid errors and risky situations (Fercho et al., 2016). A detailed description of the tasks and the work environment in question follows in the section "Method". The quantification of the current study included both objective stress measurements and subjective stress measurements. Objective stress was assessed in two forms, because a single indicator would include too few important aspects of the construct of occupational stress (Nickel & Nachreiner, 2003). The two measures for objective stress were HRV and EDA. A detailed description of the measurement tools will also follow in the section "Method".

Two hypotheses were formed. First, a significant, positive relationship between subjective and objective stress was expected. An increase in objective stress should occur together with an increase in subjective stress. The two objective indicators, moreover, were expected to positively correlate. Second, task-induced stress was expected to significantly predict the levels of subjective stress as well as objective stress. The expectation in detail was: Higher levels of task-induced stress should predict higher levels of subjective and objective stress (Figure 1).

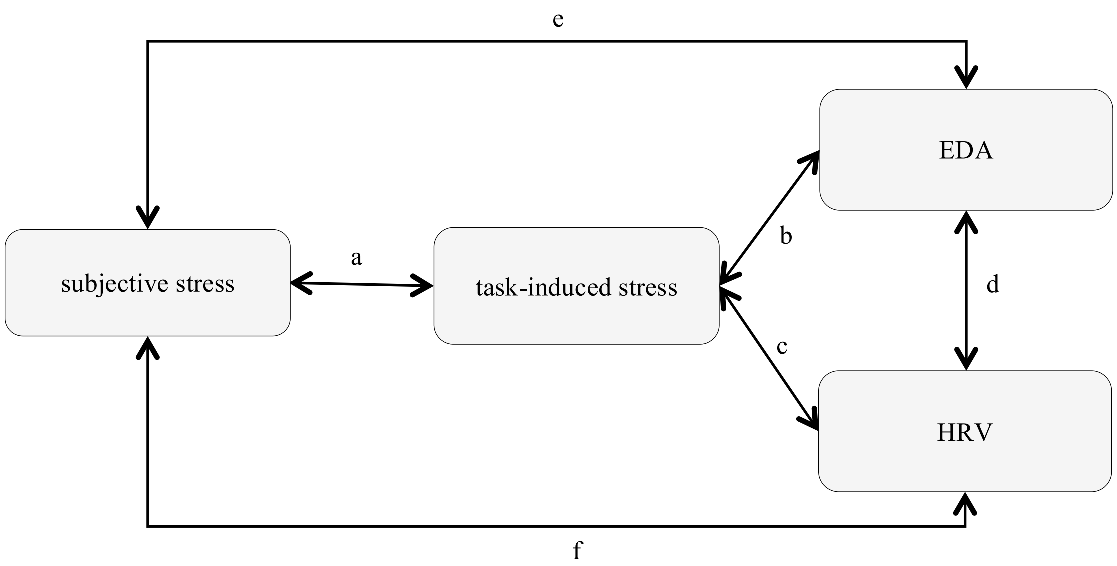

Figure 1. Model of the two hypotheses. Higher task-induced stress should predict higher subjective stress (a), higher EDA-based stress (b), and higher HRV-based stress (c). There should be a positive relationship between EDA-based and HRV-based stress (d), between EDA-based and subjective stress (e), and between HRV-based and subjective stress (f).

2 Method

2.1 Participants and Location

This study was conducted at the train traffic control centre in Arnhem in The Netherlands. Twenty measurement sessions were scheduled for this purpose, spread out over

5 weeks. The focus lay on three workstations: Nijmegen (Nm), Arnhem (Ah), and Arnhem-Velperpoort Aansluiting (Ah-VA). Train traffic control centres are open 24 hours a day, thus TTC's work in three shifts labelled morning shift (from 07:30 a.m. to 14:30 p.m.), afternoon shift (from 14:30 p.m. to 22:30 p.m.), and night shift (from 22:30 p.m. to 06:30 a.m.). The emphasis of this study lay on the morning and afternoon shift because train traffic is enormously reduced during the night. In total, 28 TTC's volunteered to participate in this study, which made up nearly all of the post's employed TTC's. Twenty-five participants were men and three were women. Each TTC could be measured on all three work stations once, because there were not enough employees to measure every TTC only on one work station. The collected data was made anonymous to a maximum, because this study took place during actual work performances. It should be impossible to link stress data back to the individual employee. For this reason no demographical information (such as age, health state, education) is made available. Twenty-one HRV and 21 EDA sessions were analysed. Eleven of them were taken during morning shifts and ten were taken during afternoon shifts. The reason for this low number was complications with the measurement tools. The exact nature of these complications is described in the section "Discussion".

An expert panel of six people was established after the measurement sessions were completed. They judged the estimated task-induced stress per individual task that had occurred during the measurement sessions. Potential candidates for this panel were approached via e-mail. Everyone within the Dutch railway infrastructure (ProRail BV), who was familiar with the tasks of TTC’s but was not familiar with the current study counted as a potential candidate. Eventually, three people on the panel worked at the time of the rating as TTC themselves. The other three experts were in managing positions of ProRail BV.

2.2 Work Tasks

The core task of a TTC is to keep the train traffic on schedule. Schemed traffic has been automatised, but communication and occurring disturbances remain to be operated by the TTC. Human-computer interaction happens with several screens displaying the movements and planning of the train traffic. Communication with other TTC’s takes place in face-to-face interaction (if the TTC's work at the same control centre) or via telephone. At the post Arnhem there are five workstations, one supervisor, and three broadcasting spaces situated in one office.

Disturbances in train traffic range from delays to technical issues to accidents and vary in their time demands. Communication regards safety and logistic aspects about change of plans, information seeking, and, if present, scheduling the shunting yard logistics. Train traffic has a rush hour, too, thus the workload is not evenly distributed across the working day.

On a cognitive level the above-mentioned tasks involve complex information processing. First of all, it is essential to keep an overview of the schedule and traffic of the station, especially when calamities arise. TTC’s have to be flexible, because the information input can come from various sources regarding different issues. The density of tasks can increase within seconds, which can place great load on the short-term memory. Furthermore, communication has to be clear and unambiguous, which involves linguistic demands.

2.3 Measurement

The measurement sessions required a full workday (eight hours) with the TTC´s of workstations Ah, Nm, Ah-VA participating in the study. All three participants received two psychophysiological devices to measure objective stress. The first one was an Empatica E3 sensor, which quantified EDA. This device was applied like a wristwatch on the non-dominant hand. The second device was a BioHarness Chest Strap 3; a sensory device buckled around the chest at the height of the heart, which quantified an electrocardiogram (ECG). The HRV values were later calculated from this ECG data. Subjective stress was quantified by a questionnaire. At the end of the session all participating TTC’s were asked to answer a short questionnaire about their subjective stress experience during their shift (Appendix A). Consequently, subjective stress was only measured after the session and only once for each session. They could give a rating from "1" to "10" ("1" being the lowest stress experience, "10" being the highest). Furthermore, the researcher observed one TTC per session. All events, actions and tasks (summarised as "triggers") were registered in an observatory scheme the moment they occurred (Appendix A). All participating TTC’s received the same observatory scheme at the beginning of the session. The researcher observed and filled in the observatory scheme at one work station. The other two participating TTC's received the request to fill these schemes in by themselves. The researcher tried to evenly distribute her observations among the workstations and the shifts. Thus, an actual work task and the two psychophysiological measurements were co-registered at the same time (when the event actually occurred), but subjective stress experience was not registered at that time.

Task-induced stress was quantified by the ratings of the expert panel per task. The researcher identified 44 different tasks by analysing the observatory schemes and presented them subsequently to the expert panel for stress rating. Examples of the tasks were "communication with DVL", "lights brighter/dimmer", and "combining trains". A full list of all tasks can be found in Appendix B. These tasks were presented to the panel without any information about the context in which the tasks occurred during the sessions. All observatory schemes and questionnaires were in Dutch.

2.4 Procedure

The researcher arrived half an hour before the shift began. The TTC’s on the workstations Nm, Ah, and Ah-VA were guided to a separate room, where the purpose and the procedure of this study were explained. All measurement devices were introduced and applied. Each TTC received the observatory scheme for tasks, events, and actions. Everyone then returned to his or her workstation and the researcher took a seat at one of the workstations. All sensory devices were detached as soon as the TTC’s for the following shift arrived. The participating TTC's then filled in the above-mentioned questionnaire about subjective stress experience. All data from the sensory devices and the information from the questionnaires were transferred to the researcher’s laptop after each session. The observatory schemes were scanned and saved as a PDF document.

After the period of 20 measurement sessions the researcher made a list with all tasks the TTC’s were required to perform during the sessions. An expert panel of 10 people was asked to rate how stressful these tasks were according to them. The rating questionnaire was available online on the website thesis tools (http://www.thesistools.com). The specific link was sent to each panel member.

2.5 Design

This field study was a quasi-experiment with a between-subject design. Task-induced stress per task was the independent variable. HRV, EDA, and subjective stress experience were the dependent variables. All variables were of quantitative nature. To ensure a double-blind design the expert panel must not be familiar with the research or its purposes. This way, the researcher was able to individually examine each task's induced stress and its effects on subjective and objective stress. The project manager, the external supervisor, and the manager of the train traffic control centre in Arnhem granted the ethical approval for this study. All of them were supervising this research project. Their judgement was based on their experience from prior studies. Three main criteria were considered before granting approval: first, it was examined whether the measurement method was responsible to use without being inconsiderate towards the participants. The same consideration was applied for the questionnaires. Second, TTC's willingness to participate in the study was estimated considering the amount of information made public about them. Third, thorough discussion was held about the maximum level of anonymity that should be achieved to protect the privacy of the participants.

2.6 Statistical Analysis

Only sessions with complete measurements of both ECG and EDA data were included in the statistical analysis. First of all, the data from the sensory devices was converted and modulated. All psychophysical data was analysed beginning and ending on the hour, thus ranging from 7 o'clock to 14 o'clock and from 15 o'clock to 22 o'clock. This ensured the same length of all measurements and gave the participants the time to calm down from possible stress responses unrelated to their work (due to travelling, the study itself, private matters). Furthermore, the 30 minutes lunch break was not included in the analysis, because stress responses in this time frame are most probably not caused by work-related tasks.

The HRV values were calculated as follows: The ECG data from the BioHarness Chest strip was fed into the program Kubios, which converted the raw ECG data into various HRV parameters. Kubios also provides threshold based artifact correction in its standard version, which was used in the current research. Every RR interval value was compared against a local average interval. Depending on the chosen threshold for this difference, the RR interval was identified as an artifact. Kubios then corrected this artifact by replacing it, using cubic spline interpolation. The program offers threshold correction at five levels of sensitivity. A default medium artifact correction with a threshold of 25 ms was applied, because a "strong" or "very strong" correction would have increased the number of false detections without decreasing the number of missed detections (Kaufmann, Sütterlin, Schulz, & Vögele, 2011). A time-domain analysis was used for the recent analysis with the parameter of the root mean squared successive differences (RMSSD). This distinct parameter seems to be especially useful for short-term HRV quantifications (Tarvainen et al., 2014; Kubios Users Guide, 2017).

In contrast, the EDA values were easily derived from the Empatica E3 data. The Empatica E3 device sent all obtained measurements to the Empatica website. The EDA data can then be downloaded from there (http://www.empatica.com/connect). The website also provides a graph to illustrate the values better. The downloaded EDA data came in form of an Excel sheet; each column represented an individual measurement with four values measured per second.

In a next step, all moments in which a task had emerged were extracted from the observation papers. All moments for which a task definition, HRV, EDA, and subjective stress values was available, were listed. This procedure resulted in 874 individual moments from the 21 measurement sessions. For each of those moments the matching psycho-physiological value was determined with the above-mentioned programs. Both of them could pinpoint the HRV and EDA measures to a minimum interval of 30 seconds. Any time span less than half a minute could not be analysed. The succeeding steps in the statistical analysis were executed with the *IBM SPSS Statistics 24* program.

First of all, the distributions of the dependent variables were calculated by the Kolmogorov-Smirnov normality test. Subsequently, correlations were calculated between the scores of subjective experienced stress, EDA-based stress, and HRV-based stress. The correlation between EDA and HRV values was an indicator for the association between objectively measured kinds of stress. At last, three simple linear regression analyses were conducted to examine whether task-induced stress can accurately predict objective and/or subjective stress. An individual regression analysis was executed for each dependent variable (subjective stress, HRV-based stress, and EDA-based stress).

3 Results

The first hypothesis of a correlation between objective and subjective stress was partly supported. The HRV scores expressed in RMSSD had a wide range, $M = 43.69$ms, $SD = 23.97$, $N = 874$; the median was 39.3ms, the 3rd quartile was 53.03ms, and the maximum was 436.6ms (Figure 2). EDA scores, too, had a wide range ($M = 1.57$ µS, $SD = 1.73$, $N = 874$) with a maximum at 10µS (Figure 3). However, the median was 0.76µS and the 3rd quartile was 2.37µS. The subjective stress was not higher than 7 on the scale ($M = 4.34$, $SD = 2.17$, $N = 874$) (Figure 4). The inter rater reliability with regard to the expert panel's stress rating of the tasks was of moderate degree. The average measure ICC was .59 with a 95% confidence interval from .37 to .76 ($F(43, 215) = 3.27$, $p < .01$).

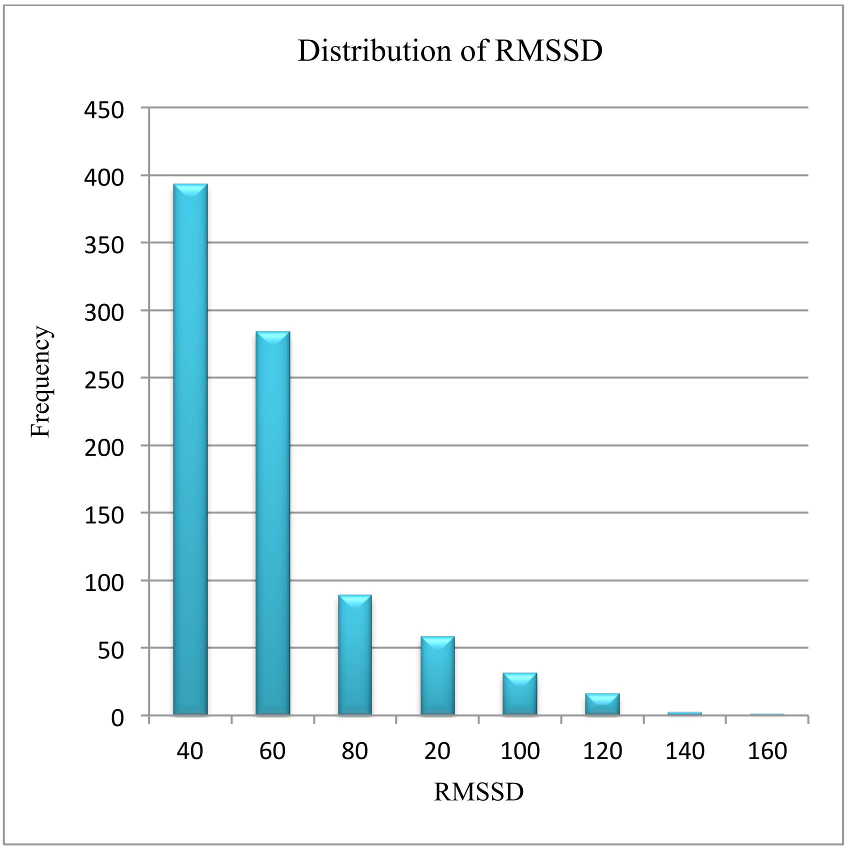

Figure 2. Histogram of the right-skewed distribution of RMSSD scores.

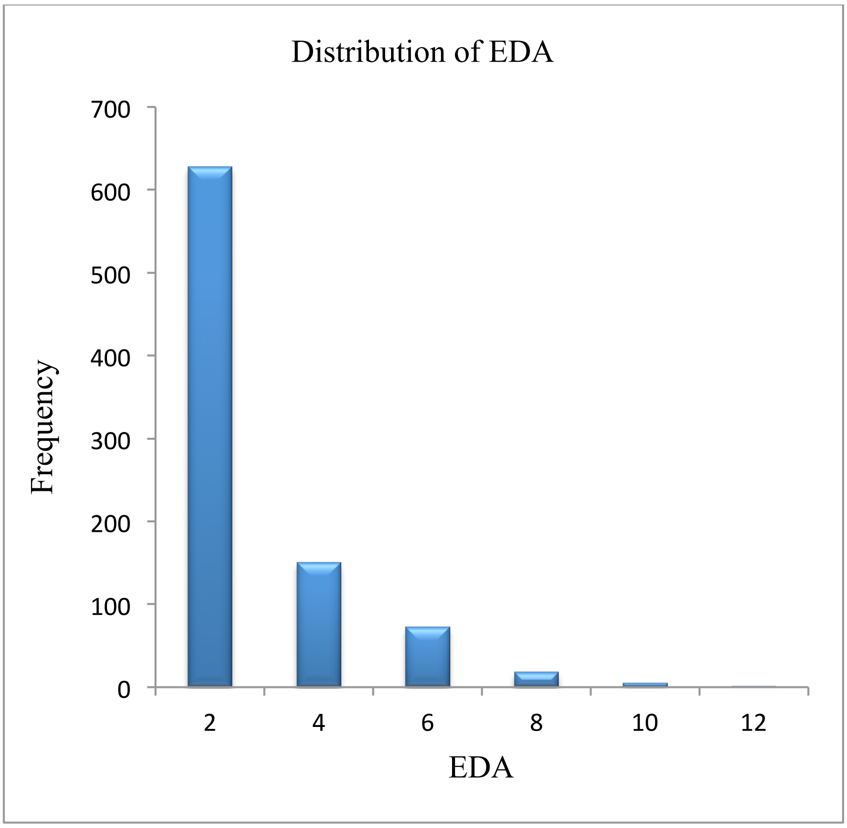

Figure 3. Right-skewed distribution of EDA scores.

All dependent variable had a non-normal distribution. A log transformation was therefore applied to the raw data to achieve a more normal distribution. The following correlations between the variables' scores were found: EDA and HRV (r = .008, p = .82) had a non-significant correlation (Figure 5). EDA and subjective stress (r = .18, p < .01) had a significant, positive correlation as well as HRV and subjective stress (r = .23, p < .01) had. This correlation indicates a tendency of those variables to increase in the same direction.

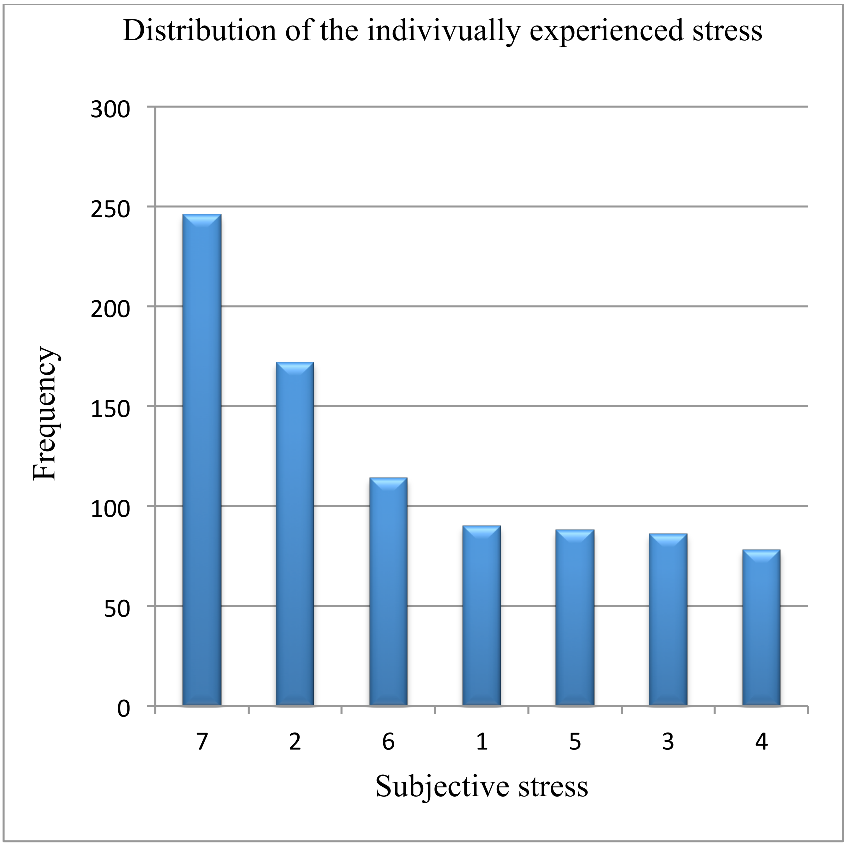

Figure 4. Right-skewed distribution of subjective stress scores

The second hypothesis of this research was, that task-induced stress predicts subjective stress experience as well as objective stress. The results supported this assumption only for subjective stress and HRV-based stress.

A first simple linear regression was calculated to examine whether task-induced stress could predict subjective stress. Heteroscedasticity (non-constant variance of the residuals) of this variable was detected when plotting the residuals against the predicted value. Therefore, a weighted least squares (WLS) regression was applied. A significant WLS regression was found, F(1,872) = 36.11, p < .01, R^2 = .04. Task-induced stress accurately predicted subjective stress (b = -0.18) and explained 4% of its variance.

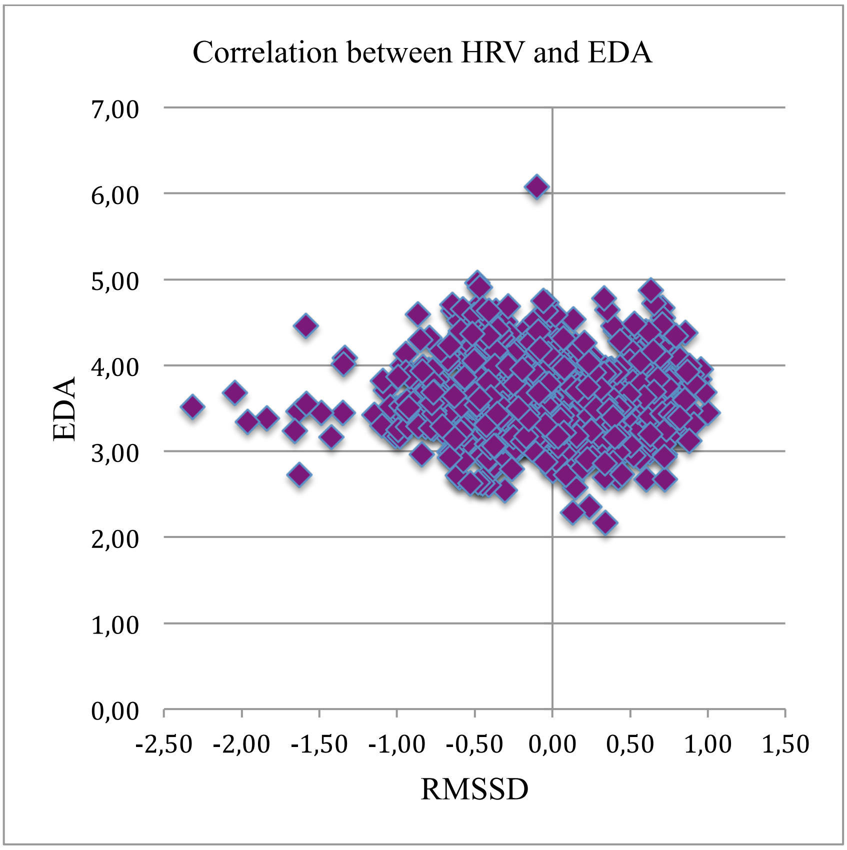

Figure 5. Correlation between transformed values of HRV (which was reflected in RMSSD) and EDA.

A second simple linear regression was calculated to examine whether task-induced stress could predict EDA. Heteroscedasticity was detected, too. Therefore, a weighted least squares (WLS) regression was applied. A non-significant WLS regression was found, $F(1{,}872) = 2.55$, $p = .111$, $R^2 = .003$. Task-induced stress did not accurately predict EDA values.

A third simple linear regression was calculated to examine whether task-induced stress could predict HRV reflected in RMSSD. Heteroscedasticity was detected, too. Therefore, a weighted least squares (WLS) regression was applied. A significant WLS regression was found, $F(1{,}872) = 13.05$, $p < .001$, $R^2 = .015$. Task-induced stress accurately predicted HRV expressed in RMSSD ($b = -.08$) and explained 1.5% of its variance.

To summarise, the recent results indicated a predictive value of task-induced stress for HRV-based stress and subjective experience stress. The negative regression weights of the variables indicated a slight decline in both the HRV values and subjective stress values as task-induced stress increased. The objective stress measures were not significantly correlated.

4 Discussion

The current study examined the predictive value of task-induced stress for objective and subjective stress experience as well as the relationship between objective and subjective stress in a sample of Dutch TTC's throughout the working day. The association between subjective, objective, and task-induced stress was more complex than expected. The two objective stress measures were not correlated. Task-induced stress could correctly predict HRV-based stress and subjective stress experience in the current research. It could not predict EDA-based stress (Figure 6. Subjective stress experience had no high rankings. Half of all scores were below the indicator for moderate stress experience. Apparently, the measured working days were not experienced as extremely stressful.

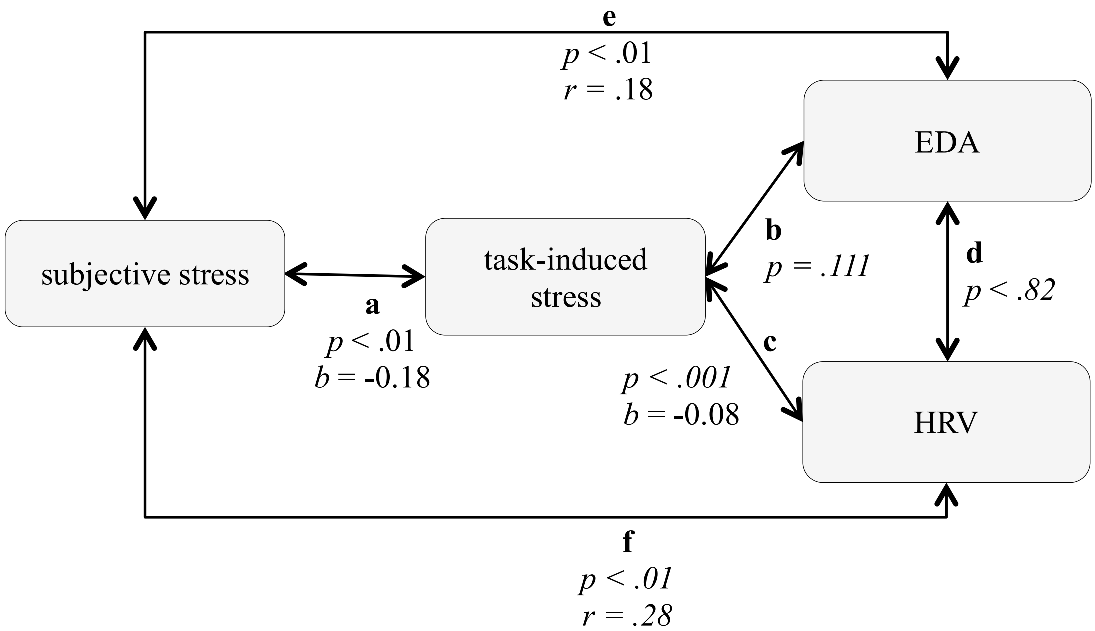

Figure 6. Model of results of statistical analysis. Task-induced stress predicted subjective stress, but in opposite direction than expected (a); it did not predict EDA-based stress (b). Higher task-induced stress predicted higher HRV-based stress (c). There was no relationship between EDA-based and HRV-based stress (d). There was a positive relationship between EDA-based and subjective stress (e) and between HRV-based and subjective stress (f)

The first hypothesis predicted a significant, positive relationship between the two objective stress measures and between subjective and objective stress. The two objective stress measures (HRV- and EDA-based stress) had no relationship. At the core of this non-existing correlation could be a difference in stress processing, although they both fall into the same research category, namely *measurement of stress feelings* (Khoozani & Hadzic, 2010). HRV-based stress and EDA-based stress are both influenced by emotional as well as cognitive processing of stress, but the exact ratio of those kinds of processing could vary. Whang et al. (2003) argued, that EDA values reflect a more affective response to stress whereas HRV values reflect the more cognitive response (like increased mental strain) to a stressful task. Thus, EDA-based stress could be more influenced by emotional processing and HRV-based could be more influenced by cognitive processing of stress. Another assumption gives a possible explanation for the current findings. It could be, that electrodermal and cardiovascular measures, in general, have different domains of validity with regard to their function as indicator on the arousal and stress continuum (Boucsein, 2012).

The correlation that was found between subjective stress and HRV supports earlier results of subjective stress and HRV-based stress increasing together most of the time throughout the working day (Föhr et al., 2015). The current results indicated, that those two measures of stress also co-increase over short time spans such as a single task.

The correlation that was found between EDA and subjective stress also supports earlier research. As Boucsein (2012) stated in his book, subjective stress and electrodermal measures increased together slightly in various previous studies. Previous studies also indicated, that EDA and perceived stress increase together as a result of uncomfortable work environment (Ellis et al., 2008). Circumstance that elicit a subjective stress response seem to elicit an electrodermal response as well.

The second hypothesis expected task-induced stress to significantly predict levels of both subjective stress and objective stress. Higher task-induced stress should predict higher levels of both subjective and objective stress, because earlier research indicated that psycho-physiological measurements tend to increase with task-induced stress (Malarkey et al., 1995; Dickerson & Kemedy, 2004). However, although task-induced stress did accurately predict HRV values, a higher score on task-induced stress predicted a lower score on HRV. Several ideas and possible inferences of the current results are presented, because there is quite some discussion about the implication of HRV values.

Those current results are in line with the hypotheses and some previous studies. Earlier studies implied, that acute stress is reflected in a lowered HRV value (Föhr et al., 2015).

Furthermore, decreased HRV was associated with facilitation of activating the cognitive system in case of mental strain and stress (Nachreiner, 1999). The current results support these assumptions. An increase in task-induced stress is associated with an increase in objective stress (due to a lowered HRV). Additionally, this lowered HRV could suggest a preparation of the human cognitive system to meet the task demands and to facilitate its activation. A slightly different perspective follows this line of reasoning; Appelhans and Luecken (2006) defined HRV as a marker for the degree to which cardiac activity can be modulated to meet changing situational demands. A lower HRV indicated a faster adaption to the task demands. An association with increased task-induced stress could also mark a faster adaption of the human cognition. Thus, the more demanding the task became, the faster the cognitive system adapted to the situation. Another perspective is, that HRV is an indicator for the amount of mental strain but with incorporation of emotion's effect on tasks (Whang, Lim, & Boucsein, 2003). They argued, that the HRV value depends on the employee's emotional attitude towards complex and simple tasks; thus, it depends not purely on the objectively, isolated task-induced stress.

In contrast, the current findings also contradicted earlier research. Van Amelsvoort et al. (2000) also considered HRV as indicator for mental strain, but they argued that HRV decreases during relaxation and increases in times of mental strain due to task demands. However, they categorised the tasks in their experimental study along the low-high demands and low-high control spectrum, thus into four categories. The current research did not categorise the tasks, neither before or afterwards, according to a validated cognitive model.

Furthermore, a presumption was based on earlier studies, that task-induced stress elicits a subjective experience of distress (Dickerson & Kemeny, 2004). Task-induced stress correctly predicted subjective stress experience in the current study, too. However, the direction of the predictive value found was opposite to what was expected. As task-induced stress increased, the subjective stress experience tended to decrease.

This contradicts earlier research, where received stress enlarged due to higher task-induced stress (Szalma et al., 2004). It also contradicts Claypoole et al. (2016), who indicated an increase in subjective stress as mental and temporal task demands grew. A possible explanation for those contradictions lies in the use of unconscious compensatory strategies. Fercho et al. (2016) associated higher task-induced stress (caused by task difficulty in their study) with prolonged reaction time, but not with higher subjective stress. This way, no impairments of accuracy, time, or strategy of task solving had to be made by the operator. Those compensatory processes during magnified task demands could then balance out fatigue and stress experience. TCC's might also have used a compensatory mental strategy to compensate effects of high temporal and spatial task demands, which let them experience less stress. Another possible explanation is based on the research design. First of all, subjective stress experience is most probably a multidimensional construct (Boucsein, 2012), but the current study only assessed it by asking one question. Furthermore, subjective stress rankings were only given for a whole session instead of rankings per occurring task, as was done in earlier research (Claypoole et al., 2016). A short period with high task-induced stress in an otherwise relaxed session would therefore not be reflected in the overall judgement, although the task-induced stress in this short period was experienced as high. In contrast, a session with many short, but not utterly stressful tasks could be remembered as more stressful afterwards than it was actually experienced at the time.

Taken together, these results deliver the possibility, that subjective and objective stress do not always increase in the same direction during a stressful event.

Lastly, no predictive value of task-induced stress was found in the current study for EDA. This contradicts most earlier research. The current results contradicted the assumption, that high EDA values in a group of train drivers originated in elevated task-induced stress (Wada & Ueda, 2012). However, this study pointed out, that EDA was a moderator between task-induced stress and higher error rate. In particular, the moderation occurred, because EDA influenced cognitive processing, which resulted in a higher error rate. Ellis et al. (2008) also reported an increase in EDA as task comfort of the environment decreased (e.g. small operating screens). Yet, the current study examined the influence of task-induced stress and not the effects of the task environment. The different research focus could be the reason that the findings differ to such a degree. In general, not all acute psychological stressors in operational situations provoke a physiological response. The physiological effect depends on specific characteristics of the stressor (Dickerson & Kemedy, 2004). It is therefore possible, that some of the task demands in interaction with the task conditions did not elicit a change in EDA in the current study. Boucsein (2012) concluded in his review of previous studies, that EDA is most suitable as an indicator of anticipatory stress. Form this assumption follows the possibility, that task-induced stress did not cause a state of particular emotional tension and/or involvement, which in turn would cause an elicit EDA response in the current study. However, those assumption are drawn with caution, because the exact mental, physical, and temporal demands and effects of the tasks in the current research are not unraveled yet.

There were five major limitations of this study. First, the above-mentioned conclusion regarding subjective stress should be drawn with caution. As stated in the section "Method", subjective stress experience was measured as a score for a whole session (8 hours). The analysis, however, was carried out per task, thus the actual subjective stress experience per task may not be correctly reflected. Additionally, to save time and keep the participants motivated to fill in the final questionnaire, the subjective stress experience was measured using one question and one scale (Appendix A). Earlier research utilised questionnaires like the NASA Task Load Index (Claypoole et al., 2016; Ellis et al., 2008) to self-assess subjective stress experience. The incorporation of a more detailed, validated questionnaire would be beneficial. The challenge with such self-measurements is, however, the application in real-work settings. The discussion of this specific difficulty would exceed the range of this study.

A second limitation regarded the analysis of the HRV-values. The program Kubios could only analyse samples at least 30 seconds in length. The actual duration of many events was shorter, so the values used for the statistical analysis were not always pinpointed to the event itself.

A third limitation concerned the availability of measurement tools. Only one Empatica E3 device was available during the first half of the study, a second device was available throughout the second half of the study. Both the Empatica E3 and the BioHarness Chest strip malfunctioned several times during the sessions. Consequently, there was considerable less data collected than initially planned.

A fourth, theoretical limitation regarded the observations. Those were made without sufficiently categorising the tasks into cognitive, or mental, categories. An extended task analysis in the field of TCC's would help to interpret the results in a more detailed manner. One could accordingly place them better in the broader, theoretical context.

The last, most extensive limitation of this study pointed towards more general issues in the field of real-life work stress. There were many additional variables, which possibly influenced people's stress levels and their stress perception (Kendall & Muenchberger, 2009). The members of the expert panel therefore referred to the difficulty to rate the exact task-induced stress as there are many influential factors such as tasks occurring at the same time, number of tasks in a consequence, duration to preceding task, etc. The exact nature of the factors' influence on and interaction with task-induced stress remains mostly unknown in field studies. They were neglected in the current study. The current study is also one of the few to investigate the influence of different kinds of stress on each other. In general, research mostly focused on the interconnection between kinds of stress or its influence on performance and health.

New questions arose through this study. Information was lost about the individual, specific context of stressfulness of the same tasks. The expert panel rated the tasks without any context information. Therefore, it is difficult to draw a valid assumption about the relative change and variability in psychophysiological measures per individual task. It would be interesting to register the exact context and investigate alterations of stress level of the same task with different influential factors.

Furthermore, a precise conclusion about which facets of stress are reflected by HRV values and EDA values has proven to be difficult (Nickel & Nachreiner, 2003). Previous researchers concentrated on ascertaining how psychophysiological measures can be confidently coupled to mental states and cognitive processes (Nachreiner, 1999; Van Amelsvoort et al., 2000). Needless to say, it is important to obtain an overview of stress-specific pattern of psychophysiological responses. Detailed investigation about this matter is crucial for meaningful results in future studies. The current study did not examine possible moderation, mediation, or modulation effects of the biomarkers as earlier research did (Wada & Ueda, 2012). The implication of those effects would add a helpful perspective to gain a more complete picture about the processes of occupational stress.

Furthermore, incorporation of cortisol measurement would add value to the understanding of biomarkers and their association to stress. The relationship between cortisol, cognitive processes and subjective stress is a complex one, but it also delivers crucial insights into the nature and mechanism of occupational stress (Malarkey et al., 1995; Vedhara et al., 2000;). Thus, the relationship between subjective stress and objective stress seems to be complex and not mono-directional. A further complex aspect is the feasible presence of various facets of objective stress with no clearly examined interconnection yet. To conclude, the current field study presented some unexpected results regarding the question whether task-induced stress could predict subjective and/or objective stress. As the results showed, task-induced stress predicted HRV-based stress correctly, just as expected. Subjective stress was predicted correctly, too, but in the other direction as anticipated. Unexpectedly, task-induced stress did not predict EDA. Another unexpected finding was that there was no correlation between the two objective stress measurements. This indicated possibly different kinds of influences measured by different psychophysiological tools. The current research marked a gap in the area of stress research in field studies. More investigation is needed to elaborate which psychophysiological tool measures which aspect of stress. Furthermore, major factors influencing subjective and objective stress experience throughout a working day should be mapped by future research. A lot of questions remain open in the area of work stress, although the recent research indicated influence of task-induced stress on two aspects of stress. The object of future studies should be to gain a reliable overview over different facets of occupational stress and its consequences for the individual stress experience.

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Appendices

Appendix A
Observation scheme and questionnaire for all work stations during sessions

Wp: Nm - Ah - Ah(VA)
Datum:
Trdl-code:
Ploeg: vroeg - laat - nacht
Begintijd empatica meeting:

Tijd	Trigger/signaal	Betekenis	Handeling

Datum: ___:___:___
Dienst:
Trdl-code:
Wp:

- o Welke cijfer geeft u de werkdruk algemeen?*

  ____

- o Welke cijfer geeft u de werkdruk vandaag?* ________________________

**op een schaal van 1 t/m 10, 1 = heel lage werkdruk en 10 = heel hoge werkdruk*

Appendix B

Tasks identified by the researcher after the sessions

Code	task	specification
1	dienstovergave	Nvt
2	vertraging kwiteren	Nvt
3	vertraging verwerken	Nvt
4	voorwaardelijke vertraging invoeren	Nvt
5	alg (veiligheid & logistiek) communicatie buurtrdl	over vertraging planning volgorde treinen trein onder verkeerde nr i materieelwijziging doorgeven goederentrein voor roestrijden bijzondere trein (10 bakken)
6	alg (veiligheid & logistiek) communicatie trdl andere VL post	te vroeg vertrokken trein calamiteit (hond bij/op spoorweg)
7	wijziging materiaal aanbrengen	Nvt
8	VKL-bericht verwerken; inleggen	Nvt
9	VKL-bericht verwerken; opheffen	Nvt
10	aanwijzing aki/ahob/aob opmaken	Nvt
11	weco opmaken	Nvt
12	weco afsluiten	Nvt
13	veilig. communicatie LWB	alle communicatie met LWB
14	log. communicatie MMP	trein naar wasspoor materieelrelatie doorgeven
15	alg. commun. MMP	over spoorwijziging bijzondere trein (lengte 10 bakken) trein splitsen politie bij calamiteit betrekken
16	handmatig rijweg instellen	Nvt
17	klaarmelding aanbrengen	Nvt
18	klaarmelding wijzigen	Nvt
19	veilig. commun.	buitendienststelling spoor

	Arriva/Veolia regie	
20	logist. commun. Arriva/Veolia regie	Planregel ontbreekt
21	logist. commun. KnoCo	stilstaande trein (terwijl deze zou moeten rijden)
22	alg. commun. KnoCo	verkeerde treinlengte trein staat stil na verzoek optrekken naar sein
23	communicatie rond rangeerbeweging	
24	veilig. communicatie SMC	
25	spoorwijziging invoeren	Nvt
26	ABT voorstel invoeren	Nvt
27	aanbrengen verhingering bij overwegstoring	Nvt
28	sein herroepen	Nvt
29	commun. omroep NS/MRI	Nvt
30	schema roestrijden invullen	Nvt
31	seinverlichting omhoog/omlaag zetten	Nvt
32	monitoring invoeren	Nvt
33	veilig. commun. Procesleider	Persoon in spoor duidelijkheid situatie
34	logist. commun. Procesleider	trein moet nog met personeel worden voorzien trein naar wasspoor
35	alg. commun. Procesleider	over rangeerbeweging sein herroepen vanwegen treinsplitsing
36	LOA uitvoeren	Nvt
37	LOA afwijzen	Nvt
38	trein splitsen	Nvt
39	trein combineren	Nvt
40	veilig. commun. machinist	aanwijzing STS alarmoproep aan machinist
41	logist. commun. machinist	over onduidelijkheid in plan wachten ivm geen beschikbaar spoor door vertraging eerdere trein informatie vertrek tijden verzoek vervoerder wachten ivm geen beschikbaar spoor door vertraging eerdere trein

42	alg. commun. machinist	inlichten ABT storing over rijweg wijziging storing overweg verkeersbord in spoor (geen hindering treinverkeer) over normale/afwijkende seinbeelden spoorbezetting informatie wijziging materiaal relatie Toestemming geven voor optrekken naar sein
43	veilig. commun. DVL	WECO inleveren
44	alg. commun. DVL	planwijziging/ rijwegwijziging treinlengte & treinvolgorde dubbele spoorbezetting