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# Retention of a standard operating procedure under the influence of social stress and refresher training in a simulated process control task

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**ABSTRACT**

In a simulated process control task, we investigated the effects of refresher training and acute social stress on performing a standard operating procedure (SOP) containing a production and monitoring task and knowledge recall after a retention interval of two weeks. In a $2 \times 2$ between-group design (Factor 1: induced social stress, Factor 2: refresher training), 76 engineering students performed an SOP at t1 in week 1 and at t2 in week 3. A MANOVA in week three (t2) indicated a main effect of the refresher training for the SOP execution containing a production and a monitoring task and an impairing effect of stress on the monitoring task. That means that after a retention interval, stress mainly affects the SOP's monitoring task. An additional correlational analysis showed that knowledge test performance is negatively associated with cortisol level and that retentivity is a strong predictor for knowledge test performance and production task performance, too.

**Practitioner Summary:** We investigated effects of social stress and refresher training on performing a standard operating procedure (SOP) after a retention interval of two weeks. The impact of social stress reduced the monitoring task performance as part of the SOP, but not the production outcome. Without refresher training, performance is significantly worse.

**Abbreviation**: SOP: Standard Operating Procedure; MANOVA: Multivariate Analysis of Variance; CSB: Chemical Safety and Hazard Investigation Board; TSST: Trierer Social Stress Test; P-TSST: Placebo Trierer Social Stress Test; WaTrSim: Water Treatment Simulation; HPA axis: hypothalamic pituitary adrenal axis; WIT-2: Wilde Intelligenztest – 2; SPSS: Statistical Package for the Social Sciences; ANOVA: Analysis of Variance.

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**KEYWORDS**
Stress hormones; cortisol; knowledge recall; start-up procedure

## Introduction

### *Infrequently executed standard operating procedures and retention intervals*

Most of the daily and routine work situations in process control are well handled by Standard Operating Procedures (SOPs) and rule-based behaviour under conditions without stress (Rasmussen and Jensen 1974; Rasmussen 1983; Reinartz 1993; Wickens and Hollands 2000). But some of the tasks become non-routine, as they are performed infrequently (Wickens and Hollands 2000; Kluge 2014), for example, the start-up and shutdown of a plant or a unit before and after a revision (Johansson 1989) or external weather conditions. To give an example: In August 2017, the U.S. Chemical Safety and Hazard Investigation Board (CSB) issued a safety alert urging oil and chemical facilities to take special precautions when restarting in the wake of shutdowns due to Hurricane Harvey.

The CSB stated explicitly that the startup of major processes at chemical facilities is a hazardous phase and facilities should pay particular attention to process safety requirements during this critical period to assure a safe and expeditious return to normal operations '(CSB, 2017)'. The CSB adds that restarting a complex petrochemical process requires a higher level of attention and care than normal processing, as numerous activities are occurring simultaneously and many automatic systems are run under manual control (news@csb.gov, CSB Issues Safety Alert Following Hurricane Harvey, email alert 28.August 2017).

In the present study, we argue that in non-routine situations, such as the above-described start-up of a plant, operators are additionally exposed to social

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stress. Their actions are closely observed by their supervisors and managers, who are keen to return to the normal situation and to re-achieve the production goals as quickly as possible. From the point of view of work and organizational psychology, this kind of stress based on a social-evaluative threat describes an unpleasant condition experienced from a subjective perspective, which results from the fear that one's own performance-related expectations or those of other persons or groups will not be met, although this is urgently required (Wegge and Bornewasser 2018). In that respect it is known from social psychology, social facilitation and inhibition research (e.g. Bond and Titus 1983) as well as from social monitoring research (e.g. Aiello and Kolb 1995), that performance varies under the influence of social presence, an audience and peer observation (Blascovich et al. 1999; Bond and Titus 1983; Wolf et al. 2015). Social facilitation refers to performance enhancement and impairment effects engendered by the presence of others typically as observers or audience (Blascovich et al. 1999). In terms of social inhibition, the presence of others impairs complex performance accuracy (Bond and Titus 1983), independent of observer status, and involves evaluative-cognitive mechanisms such as evaluation apprehension and attention (Blascovich et al. 1999). There is strong evidence that electronic social performance monitoring is linked to perceived stress (Aiello and Kolb 1995; Bernstein 2017).

In summary, there are two main influences in a situation described above: higher demands on attentional processes and resources and social facilitation or inhibition. Our study combines both aspects in an innovative manner as the objective of the present study is to combine applied research questions with basic research methods on physiological measures of social stress in a setting close to real operator tasks on process control and to show its potential for future ergonomics research.

## Work-related stress, the role of social stressors and their impact on cognitive performance

Work-related stress has many facets: There is a long list of potential work-related stressors discussed in the literature, for example, heat or cold as environmental stressors due to conditions of extreme environments, fatigue and sleep loss due to shift work or overtime, time pressure, conflicting goals (Dismukes, Goldsmith, and Kochan 2015; Driskell and Johnston 1998; Starcke, Brand, and Kluge 2016), social stress (Arora et al. 2010; Kluge 2014) and cognitive strain (e.g. see Moore, Mason, and Crow 2012; Raaijmakers 1990; Harris, Ross, and Hancock 2008).

Although research on the effects of stress on cognitive processes is not new with studies, for example, in domains such as aviation (e.g. Dismukes, Goldsmith, and Kochan 2015) or health care (LeBlanc 2009), there is less research on the effects of social stress in the domain of SOP performance as can be found in process control, e.g. in petrochemical or pharmaceutical plants, power plants or other production sites associated with process control, in which impaired cognitive processes can lead to severe accidents (Johansson 1989; Kluge, Nazir, and Manca 2014).

Laboratory research found that acute social stress, for example, induced by the Trier Social Stress Test (TSST), impairs memory retrieval (Kuhlmann, Piel, and Wolf 2005) and can be assumed to also affect the memory retrieval of SOPs. The effect on memory is mediated by the impact of the adrenal stress hormone cortisol on brain regions involved in memory retrieval (e.g. the hippocampus and the prefrontal cortex, see a review by Wolf (2017a, 2017b). It is particularly apparent when the task load is high (e.g. Schoofs, Wolf, and Smeets 2009; Shields, Sazma, and Yonelinas 2016), for example, due to additional attentive oversight and additional monitoring processes (Dismukes, Goldsmith, and Kochan 2015; Vedhara et al. 2000).

The impact of stress is mediated by underlying physiological alterations. Stress and the associated activation of the sympathetic nervous system (SNS) and the hypothalamic-pituitary-adrenal (HPA) axis,

- affects the execution of complex cognitive tasks (Raaijmakers 1990; Wetzel et al. 2006; Dismukes, Goldsmith, and Kochan 2015),
- has impact on cognitive efficiency (Eysenck et al. 2007),
- influences information processing capabilities such as working memory capacity (Dismukes, Goldsmith, and Kochan 2015; Harris, Ross, and Hancock 2008; LeBlanc 2009; Lupien et al. 2007; Shields, Sazma, and Yonelinas 2016),
- affects long-term memory retrieval (Wolf 2017a), and
- leads to riskier and less flexible decision making (Starcke and Brand 2012, 2016).
- Impairs top-down control and enhances bottom-up (stimulus-driven) influences (Arnsten 2009; Schwabe and Wolf 2013) to give some examples.

In respect to process control tasks and their subtasks, for example, executing and monitoring tasks, that need to be orchestrated (Kluge 2014), the results on the impact of stress is mixed. That is, there is some evidence that stress enhances prospective memory performance if this is the primary or sole task (Glienke and Piefke 2016; Nater et al. 2006) in less applied settings. In contrast, there is also evidence from experimental laboratory studies using dual task paradigms that stress enhances goal shielding, reduces cognitive flexibility (Plessow et al. 2011) and impairs secondary task performance (Yildiz, Wolf, and Beste 2014).

The requirement concerning attentional resources and cognitive resource management is important to consider, as longer retention intervals for infrequently executed SOPs lead to less automaticity with which an SOP is performed. Automaticity fades due to skill decay (Dismukes, Goldsmith, and Kochan 2015; Johansson 1989; Kluge and Frank 2014; Reinartz 1993; Schneider 1999) compared to a performance level directly after initial training. In order to monitor whether SOP performance is achieving the operator's objective, the use of more attentional resources, accompanied by at least some conscious control, is required (Vidulich, 2003) and may lead to a reduction of reserve capacity. These goal-directed, top-down and consciously controlled cognitive processes for performing SOPs after periods of non-use is affected by stress (Schwabe and Wolf 2013).

But so far, there is no research on stressors which contain a social-evaluative threat (Dickerson and Kemeny 2004) and impact on cognitive performance in a control room in a non-routine situation.

Based on the research and empirical finding on the effects of social stress on complex cognitive tasks, it is hypothesised that:

> H1: Social stress reduces the performance and recall of an SOP of operators compared to operators who perform and recall the SOP without the influence of social stress.

### *The role of refresher training to mitigate stress effects*

As stress is recognized as a significant factor affecting task execution when the task needs to be performed with a high level of accuracy, some preconditions have been identified on which the magnitude of the stress effects depend (Dismukes, Goldsmith, and Kochan 2015; Wetzel et al 2006). It is assumed that the magnitude of stress effects depends on training factors such as

- differences in training design (e.g. Stress Exposure Training, e.g. Driskell and Johnston 1998; Driskell et al. 2008),
- and training duration (e.g. overtraining, Orasanu and Backer 1996),
- quality and quantity of refresher training (Kluge and Frank 2014),
- person-related factors such as cognitive ability (e.g. working memory capacity, Dismukes, Goldsmith, and Kochan 2015),
- retentivity (Kluge et al. 2016) and
- individual cognitive resource management.

In the present study, we focus on the refresher training as consistent and regular training has been shown to make task performance resistant to the effects of stressors such as increased mental workload (Fisk and Scerbo 1987; Hancock 1984). Moreover, the refresher of fixed strategies for recurrent problems and the training of routine tasks have been found to counteract the negative effects of stress (Desaulniers 1997; Raaijmakers 1990; Shanteau 1987) also in process control tasks (Hockey, Sauer, and Wastell 2007). However, automatisation of skill after intensive initial training needs to be maintained by the use of refresher training (Kluge and Frank 2014; Kluge et al. 2016; Kluge, Burkolter, and Frank 2012, p. 2437). The empirical evidence shows that skill maintenance after periods of non-use can be enhanced by increasing the amount of training through task repetition both before and *after* task proficiency has been achieved (Colquitt, LePine, and Noe 2000; Patrick 1992; Hagman and Rose 1983), also in process control (Foss et al. 1989; Kluge and Frank 2014; Kontogiannis and Shepherd 1999; Mattoon 1994; Morris and Rouse 1985).

In summary, well-rehearsed tasks are less impaired by stress (Mendl 1999), but although this assumption would appear to be self-evident, it has not been investigated systematically with regard to acute social stress.

Based on the empirical evidence presented, we hypothesise that

> H2: Refresher training supports the performance and recall of an SOP of operators compared to operators that perform and recall the SOP without refresher training of skill.

Finally, we also hypothesise an interaction effect of stress and refresher training in the following sense:

> H3: Operators performing and recalling an SOP after refresher training are less affected by social stress than operators without a refresher.

## Method

An experimental $2 \times 2$ factorial (Factor 1: refresher training versus control group, Factor 2: Stress group

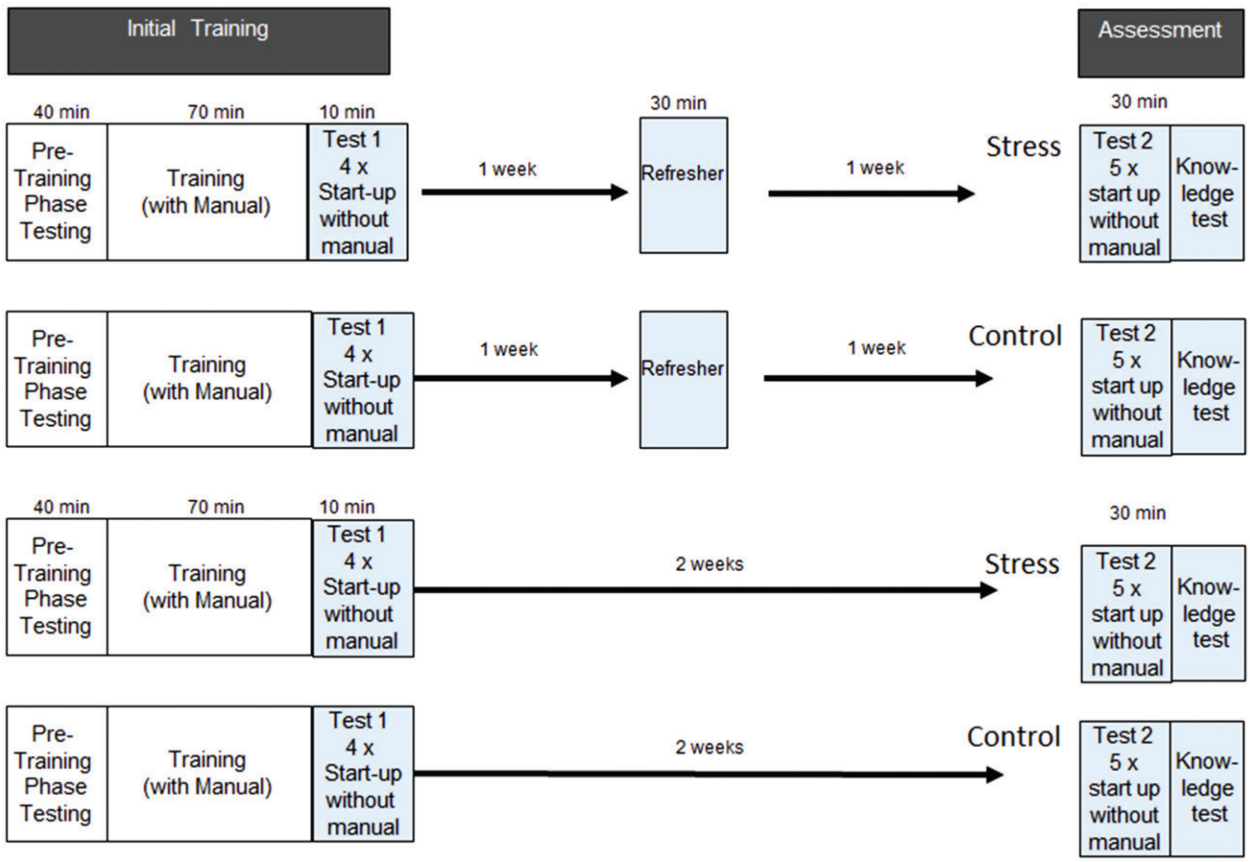


Figure 1. General experimental 2 × 2 between-group design with Factor stress/control and Factor refresher training/no refresher training.

versus control group) between-group design was applied, as displayed in Figure 1.

To test our hypotheses, we chose a laboratory study in which an SOP has to be performed and recalled in the context of a simulated process control task. The advantage of this approach lies in the experimental control of the relevant variables (e.g. cortisol) under investigation and the direct observation of the stress response using biomarkers. In this respect, we controlled for the stressor (by experimentally inducing stress using a well-validated psychosocial laboratory stressor, see below) and the standardized timing of the stressor in relation to the timing of the performance measure.

Moreover, we were able to measure the stress response by using a biomarker (measuring the stress hormone cortisol as the end product of the HPA axis) while including participants who did not differ in their initial performance before the stressor was applied and who did not differ in their physical preconditions, which might affect the stress response. Previous work by us and others has demonstrated that elevated cortisol concentrations impair declarative memory retrieval and we wanted to use a highly similar design and timing in order to test the impact of stress on the WaTrSim.

Cortisol needs about 20–30 minutes after stress onset to reach peak concentrations (Dickerson and Kemeny 2004). For this reason, the stressor was applied first and the WaTrSim task had to be executed afterwards (at times of peak cortisol concentrations).

## Sample

Eighty students from engineering departments at the Ruhr-University of Bochum took part in the study (18 female, age $M = 22.11$, $SD = 3.72$). Four participants (all male) were excluded due to the selection criteria as their production outcome of purified gas in all four trials in the initial training phase was <200l (see Method section describing the criteria for exclusion). Thus, 76 data sets were used for statistical analysis. To ensure a basic understanding of the technical processes represented in the process control simulation Waste Water Treatment Simulation (WaTrSim), only students from faculties of engineering were recruited by postings and flyers. Participants, who were all novices in learning the process control task, received 30€ for

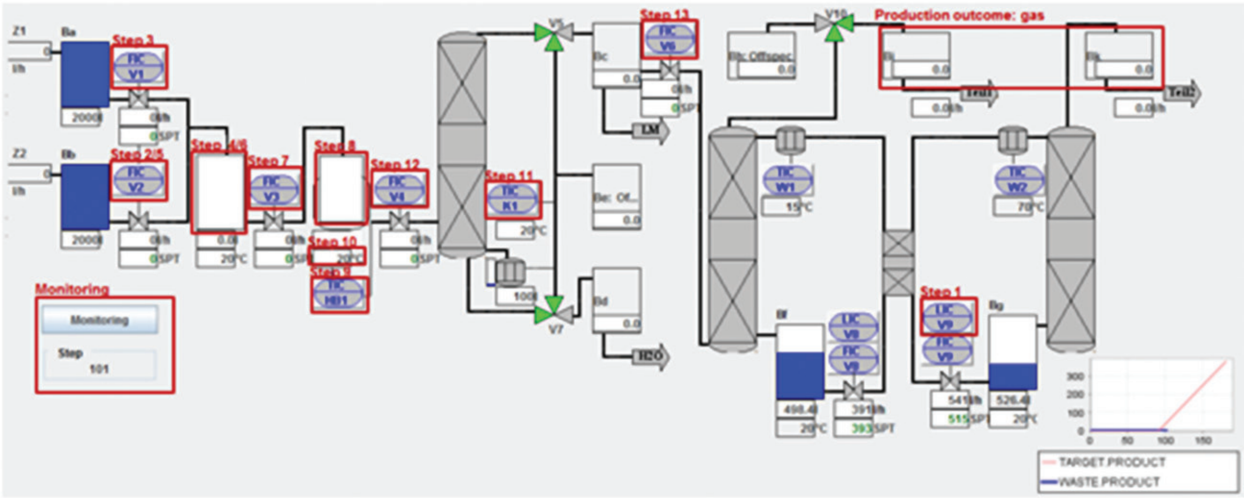


Figure 2. WaTrSim interface with valves (V1–V9), heaters (HB1, K1, W1, W2) and tanks (Ba, Bb, R1, HB1, Bc, Be, Bd, Bh, Bj, Bk, Bf, Bg). The production task is indicated by red boxes with the labels "step 1–13" and the monitoring (secondary) task is indicated by the label "monitoring".

Table 1. The SOP to start up the plant (Frank and Kluge, 2017) and description of the production (primary) and monitoring (secondary) tasks.

| Step | Production task<br>Execute start-up procedure<br>Objective: Production outcome | Seconds | Monitoring Task<br>Monitor tank level of tank BA every 50 seconds<br>Objective: Monitoring |
|---|---|---|---|
| 1 | LIC V9: Flow rate 500 l/h | 0–49 | Monitor tank level of tank BA |
| 2 | V2 deactivate follower control | 50 | Report tank level of tank BA:<br>Click on button Monitoring<br>and set number of tank level |
| 3 | Valve V1: Flow rate 500 l/h | 51–99 | Monitor tank level of tank BA |
| 4 | Wait until R1 > 200 l | 100 | Report tank level of tank BA:<br>Click on button Monitoring<br>and set number of tank level |
| 5 | Valve V2: Flow rate 500 l/h | 101–149 | Monitor tank level of tank BA |
| 6 | Wait until R1 > 400 l | 150 | Report tank level of tank BA:<br>Click on button Monitoring<br>and set number of tank level |
| 7 | Valve V3: Flow rate 1000 l/h | 151–180 | – |
| 8 | Wait until HB1 > 100 l | – | – |
| 9 | Activate heating HB1 | – | – |
| 10 | Wait until HB1 > 60 °C | – | – |
| 11 | Activate column K1 | – | – |
| 12 | Valve V4: Flow rate 1000 l/h | – | – |
| 13 | Valve V6: Flow rate 400 l/h | – | – |

participating in the refresher intervention group (3 hours in total) and 25€ for participating in the control group (2.5 hours in total). This research complied with the American Psychological Association Code of Ethics and was approved by the Institutional Review Board at the Faculty of Psychology, Ruhr-University Bochum. Informed consent was obtained from each participant. Participants were informed about the purpose of the study and told that they could discontinue participation at any time.

Participants had to be between 18 and 35 years old, healthy and medication-free. Regular smoking, a Body Mass Index (BMI) out of the normal range (below 19 or above 30 kg/m$^2$) and acute or chronic diseases led to exclusion. In addition, we excluded potential participants who had previously participated in the TSST.

### The standard operation procedure (SOP)

Using the WaTrSim (Figure 2; Kluge and Frank 2014; Kluge et al. 2016; Frank and Kluge 2017), participants had to execute a 13-step standardized operating start-up procedure (SOP, described in Figure 2 and Table 1), a fixed sequence (Ormerod, Richardson, and Shepherd 1998). The SOP consists of a production task (primary task) and monitoring task (secondary task) that proved it's validity and reliability in several experiments (e.g. Kluge and Frank 2014; Kluge et al. 2016; Frank and Kluge 2017). For a general understanding of WaTrSim and the procedure please see the video on http://www.aow.rub.de/fue/gazeguiding.html.de

The production task: In WaTrSim, the operator's primary task is to separate wastewater into fresh water and gas by starting up, controlling and monitoring the plant (Kluge and Frank 2014; Frank and Kluge 2017). The operation goal is to maximize the amount of purified gas and to minimize the amount of wastewater by executing the 13 steps start-up procedure in a correct order while considering the right timing for execution. The time permitted to start up the plant is 180 seconds.

The separated purified gas outcome is used for the primary task calculations, as this shows that the participants performed step 13 (the final step) of the start-up procedure correctly (Frank and Kluge 2017, see Figure 2). Executing the WaTrSim fixed sequence start-up procedure correctly leads to a production outcome of a minimum of 200 litres of purified gas. The minimum amount of purified gas in initial training was predefined as a selection criterion (> =200 litres).

The monitoring tasks (secondary task) require the operators to check the level of tank BA (see Figure 2, Table 1) every 50 seconds and to report the tank level of tank BA by clicking the button 'Monitoring' and set the number of tank level.

## Independent variables

### Stress and control treatment

To experimentally induce social stress, the TSST was applied (Kirschbaum, Pirke, and Hellhammer 1993). After a five-minute preparation period, participants have to perform an oral presentation (a simulated job interview) and an arithmetic task (counting backwards in steps of 17) for a total of ten minutes. They are evaluated by a panel (one woman and one man dressed in white coats), who act in a cold and reserved manner and deliberately refrain from providing any sort of feedback. Additionally, participants are videotaped. The TSST is known to reliably activate the SNS and the HPA axis (Dickerson and Kemeny 2004). The non-stressful control condition, called the Placebo-TSST (P-TSST; Het et al. 2009), also consists of an oral presentation and an arithmetic task, but participants do not perform in front of an audience and are not videotaped. It thus lacks the stressful components of the TSST (social-evaluative threat and uncontrollability) and does not elicit an HPA axis response (Het et al. 2009).

### Refresher training

The refresher training was varied by separating groups into a refresher training and a control group. The refresher training applied in the present study is based on the theoretical assumptions regarding skill proceduralisation (Anderson 1983; Kluge and Frank 2014; Schneider 1985; Sun, Merrill, and Peterson 2001; Sun, Slusarz, and Terry 2005). Participants from the refresher training group executed the start-up procedure of the plant four times one week after initial training and were allowed to consult the description of the procedure (see Figure 1).

## Dependent variables

The SOP production performance was measured by the *produced amount of purified gas* in the first trial at t2 (see Figure 1). To demonstrate successful SOP acquisition at t1, the minimum production outcome at initial training was 200 litres of purified gas.

The SOP's *monitoring task* (called 'Monitoring' task, see Figure 2) is a prospective memory task and mental workload measure. It requires that the operator remembers by him/herself to type in the filling level of a specific tank (Tank BA, see Figure 2) in an input box. Participants have to click on the monitoring button that opens up to type in the numbers (of the tank level). The monitoring task has to be executed three times (which means every 50 seconds) parallel to the production task (score 0-3, max. of 3 tank level recordings every 50 sec. in the 180 sec of the start-up phase). The monitoring task is independent of the production task and requires memory for an action (reading a tank level and type it into an input box) to be carried out in the future (every 50 sec., Matthews et al. 2000).

*SOP Knowledge test performance*: At the end of the assessment in week 3 (t2), participants underwent a knowledge test addressing declarative and procedural knowledge of the SOP as prior studies showed that knowledge is partially independent of performance (e.g. Kluge and Frank 2014). It is of interest to test skill performance and knowledge retrieval since the effects of stress could be selective (Schwabe and Wolf 2013).

The test was also used in a previous study by Kluge et al. (2016) and includes clozes, questions and graphics about WaTrSim and background knowledge about wastewater treatment. Questions included 'What are the goals in the start-up procedure in WaTrSim?', 'Which gadget is shown in the graphic?' 'Is it correct

Table 2. Experimental procedure and applied tests.

| Session Week 1 (t1) | Session Week 2 | Session Week 3 (t2) |
|---|---|---|
| Initial Training;<br>120 min | Refresher training group only<br>30 min | Assessment<br>30 min |
| Pretraining Test<br>• Socio-demographic data<br>• Retentivity (WIT-2, learning phase)<br>• Explaining and Introducing WaTrSim<br>• Retentivity (WIT-2, reproduction phase) | Practice<br>• - 4× Start-up with help of manual (refresher training group only) | Cortisol measurement 1(Base line)<br>TSST / Control TSST (10 min)<br>Cortisol measurement 2, +10 min (compared to end of TSST) |
| Initial Training<br>• 2× Exploration of WaTrSim<br>• 4× Start-up with manual<br>Test 1<br>• 4× Start-up without manual (performance of last trial and average of last two trials were used to compare groups before the intervention of stress and refresher training) | | Test 2<br>• 5 × Start-up without manual (performance of first start-up trial was used, additional analysis of average of last two trials )<br>• Knowledge test<br>• Cortisol measurement 3, + 40 min (compared to end of TSST) |

*Note*: WIT: Wilde Intelligence Test; TSST: Trierer Social Stress Test, Cortisol Measurement explained in Text.

that tank R1 has to be filled with at least 100 litres so that the heating HB1 can be turned on?' (total score 0–54 points).

### *Control variables*

Cortisol concentrations: For the assessment of salivary cortisol, participants were instructed to refrain from drinking anything except water and from brushing their teeth for one hour before testing. After collecting three saliva samples (see Table 2) using Salivettes®, samples were deep-frozen at -18 °C and analyzed at our local biochemical laboratory using the *DEMEDITECs Cortisol Free in Saliva enzyme-linked immunosorbent assay (ELISA) Kit* according to the manufacturer's manual. A coefficient of variation (CV %), expressed as the percentage deviation from the mean of ≤15% to retain any given duplicate sample, was used. Intra- and inter-assay coefficients of variation (CV) were below 10%. Since cortisol release follows a circadian rhythm, testing took place in the afternoon between 2 and 6.30 pm (TSST-stress and control intervention took place between 2 and 4.30 pm).

As prior studies showed the strong incremental influence of retentivity on skill retention (Frank and Kluge 2017; Kluge et al. 2016), we measure retentivity as a person–related control variable using the Wilde Intelligence Test-2, which requires the memorization and recall of verbal, numerical and figural information (Kersting, Althoff, and Jäger 2008; Kluge et al. 2016; Lang et al. 2010). Following a four-minute memorization period at t1, information concerning WaTrSim was presented for approximately 17 minutes (disruption phase). In the subsequent reproduction test, participants were required to distinguish between details, with the correct solution to be chosen from a series of six alternatives. The total score varies between 0-21. Retentivity measured by the WIT-2 is assumed to be low when the score is between 0 and 12, medium when it is between 13 and 14, and high when it is between 15 and 21 (see test manual by Kersting, Althoff, and Jäger 2008).

### *Procedure*

The participants in the refresher training groups attended three times (initial training, refresher and assessment, see Figure 1 and Table 3) while the control group participants attended twice (initial training and assessment, Table 2).

The initial training (week 1, t1) took 120 minutes and was identical for all four groups. After completing the WIT-2 to measure retentivity, participants explored the simulation twice and received instructions and information about the start-up procedure. Subsequently, they trained the start-up procedure by referring to a manual. The training objective was to perform the start-up procedure four times without help and to produce a minimum of 200 litres of purified gas at least once.

In week 3, at the assessment and 2 weeks after the initial training, the participants were welcomed and first provided a saliva sample (cortisol measurement 1). Next, the TSST or the control condition was applied (about 10 min) and cortisol was measured a second time (cortisol measurement 2, + 10 min). Then, the participants were asked to start up the plant up to five times in succession without help (the first trial was used to assess the SOP performance) and the knowledge test was administered. The testing at t2 took approximately 30 min. Finally, the cortisol level was measured for the third time (cortisol measurement 3, + 40 min)

## Results

Descriptive statistics are displayed in Table 3. Four participants were excluded as their production outcome

Table 3. Descriptive statistics mean and standard deviations (in Brackets).

| | Refresher and Stress | Refresher and Control | No Refresher and Stress | No Refresher and Control |
|---|---|---|---|---|
| *N* | 19 | 17 | 20 | 20 |
| Age | 23.40 (3.32) | 23.00 (3.22) | 21.90 (2.57) | 20.60 (5.07) |
| Sex | 5 female/14 male | 4 female/13 male | 6 female/14 male | 3 female/17 male |
| Prior knowledge (scores 0- 7) | 5.55 (1.19) | 6.06 (0.97) | 6.25 (1.00) | 5.90 (1.07) |
| Retentivity (scores 0- 21) | 13.85 (3.22) | 14.76 (2.77) | 14.45 (1.70) | 14.40 (3.76) |
| Initial Training (t1) | | | | |
| IT Production outcome last trial | 342.27 (61.28) | 359.61 (34.02) | 356.84 (52.38) | 360.42 (42.62) |
| IT Production outcome last two trials average | 322.74 (74,56) | 319.03 (67,67) | 317,07 (76,67) | 349.04 (42.83) |
| IT Secondary task (scores 0- 3) | 2.63 (0.60) | 2.94 (0.24) | 2.85 (0.37) | 2.90 (0.31) |
| IT Start-up mistakes (scores 0-15) | 2.55 (3.32) | 2.12 (3.22) | 3.10 (4.06) | 2.60 (4.60) |
| IT Start-up time (scores 0- 180) | 96.21 (12.93) | 91.24 (10.54) | 91.15 (13.50) | 90.90 (10.99) |
| Assessment (t2) | | | | |
| Production outcome (first trail) | 276.33 (110.31) | 256.95 (110.23) | 149.79 (107.81) | 126.76 (129.08) |
| Production outcome last two last trials average | 335.15 (77.85) | 332.60 (53.35) | 277.09 (131.42) | 305.25 (98.16) |
| Secondary task (scores 0- 3) | 2.42 (0.96) | 3.00 (0.00) | 1.55 (1.28) | 2.05 (1.19) |
| Knowledge Test Performance (Scores 0- 54) | 25.15 (7.26) | 28.00 (4.72) | 24.73 (7.13) | 26.35 (7.30) |
| Cortisol Basis | 10.70 (4.21) | 10.86 (9.95) | 16.64 (12.42) | 12.10 (8.43) |
| Cortisol + 10 min | 25.56 (13.89) | 13.26 (13.48) | 34.50 (19.07) | 11.61 (6.91) |
| Cortisol + 40 min | 18.63 (8.88) | 9.36 (6.50) | 26.06 (17.46) | 9.70 (6.46) |

*Note*: IT: Initial Training; cortisol +10 min: 10 minutes after the stressor was applied; cortisol +40 min: 40 minutes after the stressor was applied.

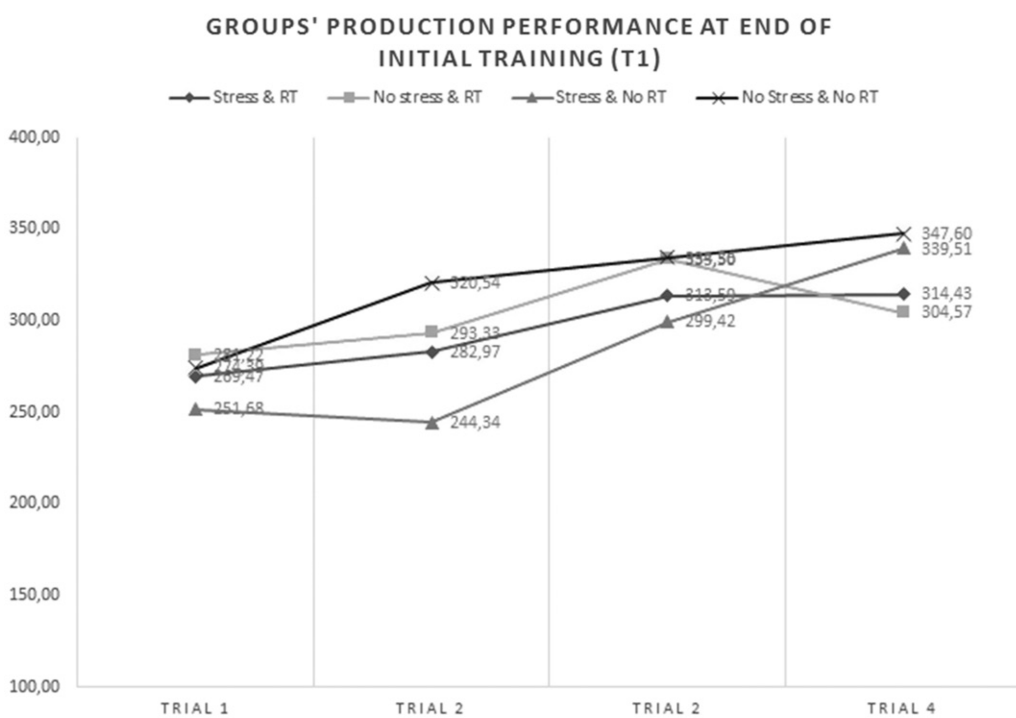


Figure 3. Production outcome performance (in litres) over four trials at initial training (t1).

of purified gas in all four trials in the initial training phase was <200 l (see Sample and Method section). Thus, 76 participants remained for statistical analysis.

Using SPSS 22, a MANOVA was applied with groups as independent variables and production outcome, monitoring task and knowledge test performance in week 3 (t2) as dependent variables.

As displayed in Table 3, performing a MANOVA and a chi-Square Test, the groups did not differ at t1 with regard to age, $F_{(3,72)} = 2.28$, $p = .087$, sex $\chi^2 = 1.349$ (3 df) $p = .718$ (Pearson), prior knowledge, $F_{(3,72)} = 1.41$ $p = 0.248$, and retentivity, $F_{(3,72)} = 0.31$, $p = .819$, as control variables.

An ANOVA (using SPSS 22) for difference between trails was calculated to test for difference between groups during initial training (Figure 3). There were no significant difference between groups during initial training found during trial 1 ($F_{(3,72)} = .25$, $p = .86$),

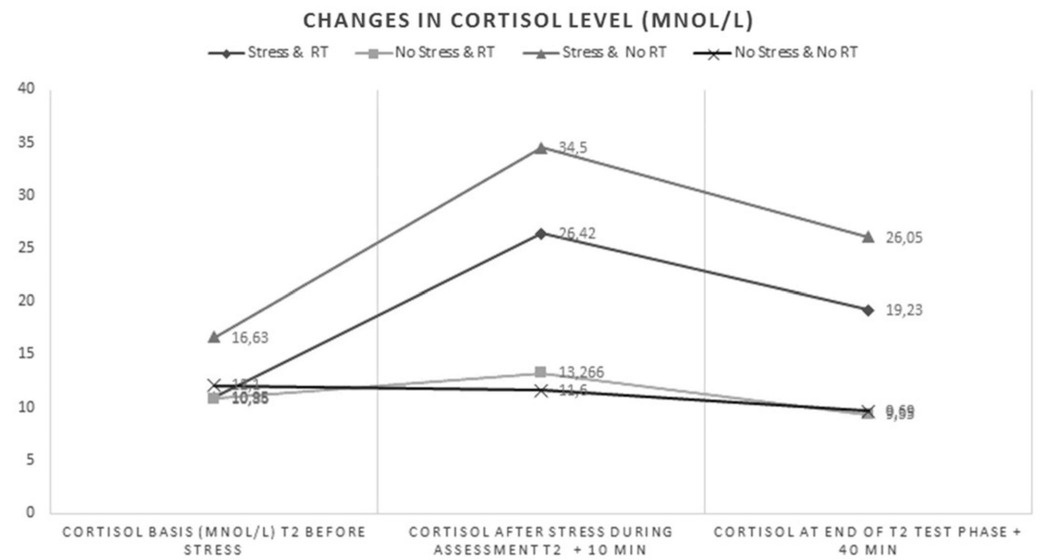


Figure 4. Changes in cortisol levels (in nmol/l = nanomol per liter) of the two stressed groups and two groups without stress during the assessment at week 3 (t2) (RT = refresher training).

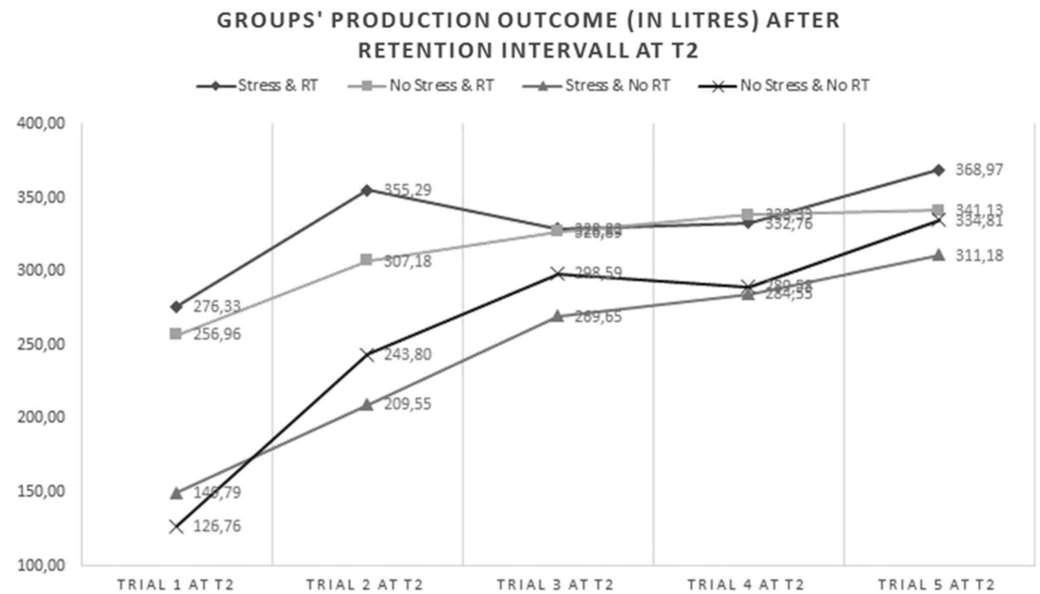


Figure 5. The production outcome at t2 at the first trial of the assessment and at the subsequent trials.

trial 2 ($F_{(3,72)} = 1.86$, $p = .145$), trial 3 ($F_{(3,72)} = .76$, $p = .517$), and trial 4 ($F_{(3,72)} = 1.10$, $p = .352$). An additional analysis of the average of the last two trials (trial 3 and 4, also see Table 3) at t1 showed no significant differences between groups ($F_{(3,72)} = .938$, $p = .427$).

Treatment Check: Cortisol level changes in the stress and control groups in Week 3 (t2)

In the stress groups, significant medium to large changes in salivary cortisol levels were observed over the three measurement points by applying a repeated measures ANOVA for cortisol changes at t2 in the two groups which experienced the TSST. By contrast, cortisol levels remained stable over time in the control groups (see Table 3 and Figure 4), cortisol x Stress Group $F_{(2,72)} = 31.59$, $p < .000$, $\eta_p^2 = 0.464$. This indicates that the laboratory stressor successfully activated the HPA axis.

### *Hypothesis testing*

H1: Social stress reduces the performance and recall of an SOP of operators compared to operators that perform and recall the SOP without the influence of social stress.

The production outcome at t2 at the first trial of the assessment and at the subsequent trials is displayed in Figure 5.

Table 4. Pairwise comparisons between groups.

| Dependent Variables | Mean Difference | Standard Error | Sig. | Confidence interval | |
|---|---|---|---|---|---|
| | | | | Lower limit | Upper limit |
| Stress/No Stress | | | | | |
| Production outcome | 21.20 | 26.42 | 0.42 | −31.47 | 73.87 |
| Monitoring task | −0.53 | 0.23 | 0.02 | −1.00 | −0.07 |
| Knowledge test performance | −1.99 | 1.54 | 0.20 | −5.07 | 1.08 |
| Refresher Training/No Refresher Training | | | | | |
| Production outcome | 128.36 | 26.42 | 0.00 | 75.69 | 181.01 |
| Monitoring task | 0.91 | 0.23 | 0.00 | 0.444 | 1.37 |
| Knowledge test performance | 1.27 | 1.54 | 0.41 | −1.80 | 4.35 |

*Note*: Mean Difference: Difference between Mean Stress Group and No Stress Group and Refresher Training and No Refresher Training.

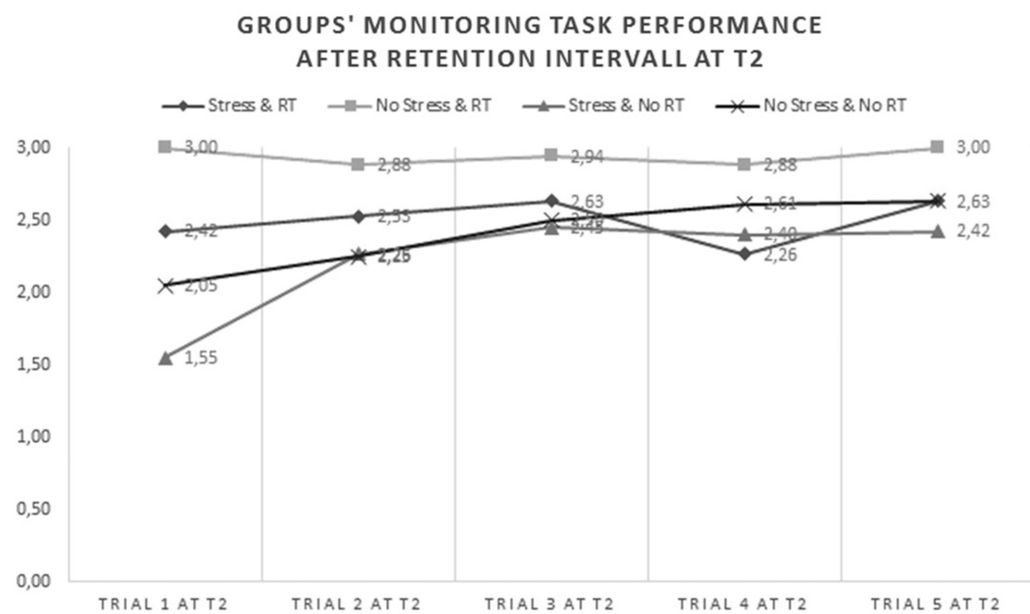


Figure 6. The monitoring task performance at t2 at the first trial of the assessment and the subsequent trials.

Regarding the SOP performance the results of a 2 × 2 MANOVA for production task, monitoring task and knowledge test performance showed no main effect of stress (see Table 4). Regarding the *monitoring task*, results showed (see Figure 6) a small impairing effect of stress, $F_{(3,68)} = 5{,}31$, $p = .024$, $\eta_p^2 = 0.069$. There was no effect of stress on knowledge test performance. This means that H1 is confirmed for the monitoring task only.

Additionally, we looked at the changes and possible increase in production performance due to relearning over the five subsequent trials. An ANOVA (using SPSS 22) for groups as independent variable and production outcome performance as dependent variable was calculated to test for difference between groups during the five trials at t2. There were significant difference between groups found in trial 1 ($F_{(3,72)} = 8.16$, $p <$ .001), in trial 2 ($F_{(3,72)} = 7.29$, $p < .001$) but *not* between trial 3 ($F_{(3,72)} = 1.15$, $p = .33$), trial 4 ($F_{(3,72)} = 1.16$, $p = .329$), and trial 5 ($F_{(3,72)} = 1.10$, $p = .352$). An additional analysis of the average production outcome of the last two trials 4 and 5 at t2 showed no significant differences between groups anymore ($F_{(3,72)} = 1.50$, $p = .220$) . That means that after some trials of relearning the production performance aligns.

An ANOVA (using SPSS 22) for groups as independent variable and secondary task performance as dependent variable was calculated to test for difference between groups during the five trial at t2. There were significant difference between groups found in trial 1 ($F_{(3,72)} = 6.65$, $p < .001$), but not in trial 2 ($F_{(3,72)} = 1.93$, $p < .13$), not in trial 3 ($F_{(3,72)} = 1.30$, $p = .27$), not in trial 4 ($F_{(3,72)} = 1.74$, $p = .16$), and not trial 5 ($F_{(3,72)} = 1.51$, $p = .21$).

Testing H2: Refresher training supports the performance and recall of an SOP of operators compared to operators that perform and recall the SOP without refresher.

Regarding the production outcome the results showed a small to medium effect of refresher training, $F_{(3,68)} = 23.60$, $p = .000$, $\eta_p^2 = 0.247$ (see Table 4).

Table 5. Correlation between person-related and performance-related variables.

| Variables | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| (1) prior knowledge | 1 | | | | | | | |
| (2) retentivity | 0.14 | 1 | | | | | | |
| (3) prodcution outcome best trial at t1 | −0.30** | −0.14 | 1 | | | | | |
| (4) monitoring task at t1 | 0.26* | 0.18 | −0.20 | 1 | | | | |
| (5) cortisol at t2 after social stress | −0.07 | −0.12 | 0.09 | −0.16 | 1 | | | |
| (6) production outcome first trial at t2 | 0.16 | 0.37** | −0.18 | 0.11 | −0.11 | 1 | | |
| (7) monitoring task score at first trial t2 | 0.21 | 0.17 | −0.05 | 0.16 | −0.10 | 0.49** | 1 | |
| (8) knowledge test performance at t2 | 0.34** | 0.38** | −0.16 | 0.17 | −0.25* | 0.52** | 0.36** | 1 |

*Note*: *Significant with $p < .05$; **Significant with $p < .01$.

Regarding the monitoring task, results show a small effect of refresher training, $F_{(3,68)} = 15.15$, $p = .000$, $\eta^2_p = 0.174$. There was no effect of refresher training on knowledge test performance (see Figure 6). H2 is supported for the production outcome and the monitoring task but not for the knowledge test performance.

H3: Operators performing and recalling an SOP after refresher training are less affected by social stress than operators without refresher.

We found no interaction between stress × refresher training regarding production outcome ($F_{(3,72)}$= 0.005, $p = .94$), monitoring task ($F_{(3,72)}$= 0.02, $p = .86$) or knowledge test performance ($F_{(3,72)}$= 0.05, $p = .81$). H3 needs to be rejected.

### *Post hoc correlation analysis between person related and performance variables*

Independent of groups ($N = 76$), we analyzed the correlation (Pearson) between person-related and performance related variables (see Table 5).

Increased cortisol after the social stress is associated with a lower knowledge test result ($r = -0.25$, $p < .05$). No significant correlation between cortisol and production outcome ($r = -0.11$, $p = .34$) and cortisol and monitoring task performance ($r = -0.10$, $p = .392$) were found. This indicates that the social stress-induced increase of cortisol generally was associated with knowledge recall negatively, but did not affect primary task execution and secondary task of the SOP performance significantly in the complete group.

Independent of groups it can be seen that the strongest predictor for production outcome at the first trail at t2 is retentivity ($r = 0.37$, $p = .001$), which also predicts knowledge test performance ($r = 0.38$, $p = .001$), but not monitoring task performance ($r = 0.176$, $p = .128$).

In general, strong intercorrelations are found between production outcome of the first trial at t2, monitoring task performance and knowledge test performance. That means that participants who performed well in executing the production task performed also well in monitoring task and the knowledge test.

## Discussion

The objective of the study was to combine applied research and a psychoneuroendocrine perspective to investigate the effects of social stress on the recall and execution of a standardized operating procedure (SOPs) after a retention interval. To our knowledge, this is the first study to implement a standardized stressor at the time point of skill and knowledge recall, examining the physiological reaction which is assumed to affect skill and knowledge recall, as was outlined in the introduction.

Descriptive and inferential statistics show that performance in the production outcome differs significantly due to refresher training in a first attempt to execute the SOP after a retention interval, while monitoring task performance differs significantly between stress groups. With subsequent trials and relearning performance between groups aligns. That performance outcome aligns is good news, nevertheless, it also shows the importance of refresher training if the first attempt matters.

Nevertheless, although a robust stress response was introduced as indicated by a significant increase in cortisol, contrary to our hypothesis, we did not find evidence of effects of stress on production outcome performance and knowledge recall. This supports findings that well trained cognitive tasks are less sensitive to stress (Schwabe and Wolf 2013).

Although we replicated the strong impact of refresher training demonstrated in previous studies (e.g. Kluge and Frank 2014, Kluge et al. 2016), the impact of stress was only shown in the monitoring task. This supports findings that stress reduces cognitive efficiency (Dismukes, Goldsmith, and Kochan 2015; Eysenck et al. 2007; Harris, Ross, and Hancock 2008; LeBlanc 2009; Lupien et al. 2007) and affects mental workload by reducing the reserve capacity for performing the secondary task, also for the refresher training groups. While the refresher training group without stress showed more or less perfect secondary task performance, secondary task performance was reduced in the refresher training group exposed to stress. An explanation for this finding might be found in experimental laboratory studies using dual task paradigms in which stress enhanced goal shielding for the primary task, reduces cognitive flexibility (Plessow et al. 2011) and impairs response selection in action cascading (Yildiz, Wolf, and Beste 2014). Moreover, goal-directed behaviour is impaired by stress. In contrast, attention and action is more stimulus-driven (bottom up, Arnsten 2009, Schwabe and Wolf 2013). These effects combined can explain why secondary task performance is often impaired under stress as in the current experiment.

Although stress per se had no strong impact on experimental groups' performance as expected, we found a small to medium negative correlation between increase in cortisol and knowledge test performance which supports findings by Schwabe and Wolf (2013) and Wolf (2017a, 2017b). However, these previous studies typically tested the retrieval of words or pictures and implemented a shorter delay (hours to days). There is evidence that procedural tasks and older memories are less susceptible to the impairing effects of stress on retrieval (e.g. Wolf 2017a; Wolf et al. 2002).

A further reason for the lack of effects of stress might be that the knowledge test was performed after the five trials to measure retention assessment. It can be assumed that the primary task execution, which required the use of knowledge about the procedure, facilitated knowledge recall in the knowledge test. To test this assumption, future studies should administer the knowledge test before production task execution and swap the sequence of performance execution and knowledge recall.

An additional explanation might be that in the present study, the knowledge items were embedded in a meaningful context, and sequence and knowledge elements did not 'stand alone', as was the case in many other basic research studies, which required participants to recall lists of words or pictures. In the present study, by contrast, knowledge elements were linked and had the potential to be derived logically. This means that findings of impaired knowledge under stress from basic research cannot be directly transferred to applied settings (Wolf and Kluge, 2017).

From a methodological perspective, and in terms of internal and external validity, the presented study attempted to combine the advantages of a laboratory study, for example, to induce social stress and measure cortisol (applying controlled stressors and controlled measurements of the stress response using biomarkers), with the advantage of a simulated process control task and by investigating participants who do not differ in their initial performance. Of course, while these are ideal conditions for research, they are not easily found in applied settings. We are aware of the fact that a laboratory setting and a sample of engineering students differ from a real plant setting and operators with years of experience on the job. In our research we constantly face the challenge of balancing internal and external validity issues, for example, by controlling for person-related variables such as age, tenure, work experience and number of times of facing a non-routine situation as potential confounding variables on one side and statistical power based a calculated sample size on the other side and external validity and generalisability of findings on the other side. Nevertheless, experimentally induced stress and the measurement of biomarkers have also been shown to be of added value to Human Factors Research.

Further research in the applied process context, for instance in full-scope control room simulators or virtual reality training facilities, could shed additional light on the external validity of the laboratory results for 'real life'. Additionally, applying the stressor while performing the SOP and not before is a valuable follow up study.

From the perspective of internal validity, further studies might explore the effect of stress on knowledge recall by using two measurement times for knowledge recall rather than only one. Finally, as we only looked at one particular type of SOP, future studies should explore different types of sequences, such as parallel and contingent sequences, which are assumed to be more challenging and more susceptible to stressors, as suggested by initial findings from Frank and Kluge (submitted).

In conclusion, it can be summarised that although the main hypothesis on stress was only partially supported in the monitoring task and in the correlation between cortisol and knowledge test performance, we found further interesting contributing factors on performance after a retention interval: refresher training and the person-related variable retentivity predict performance after a retention interval better than the influence of stress. These findings could have an impact on Human Resource practices, for example, in High Reliability Organisations and addresses issue like personal selection and training policies. Especially personnel selection and staffing issues were so far not that much in the centre of organizational practices in process control.

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