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Human and machine-induced social stress in complex work environments: Effects on performance and subjective state

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ABSTRACT

Social stress at work can lead to severe consequences. As a result of technological developments, social stress will increasingly be induced by machines. It is therefore crucial to understand how machine-induced social stress affects operators. The present study aimed to compare human and machine-induced social stress with regard to its effect on primary and secondary task performance, and on subjective state (e.g., self-esteem, mood and justice). 90 participants worked on a high-fidelity simulation of a complex work environment, on which they had received extensive training (2h15). Social stress was induced by a human or a machine using a combination of negative performance feedback and ostracism. Results indicate that social stress did not affect performance, affect or state self-esteem. Machine-induced and human-induced social stress overall had similar effects, except for the latter impairing perceived justice. We discuss implications of these results for automation at the workplace and outline future research directions.

1. Introduction

The workplace can be a stressful environment in a number of different ways. In addition to environmental aspects, stress may arise from social interactions in the workplace. Social stress has recently been gaining interest the field of ergonomics and human factors (e.g. Gerhardt et al., 2021; Kluge et al., 2019; Sauer et al., 2022). Social stress may appear in different forms such as negative performance feedback, ostracism or illegitimate tasks (see for an overview e.g. Sauer et al., 2019). Exposure to social stress has a serious impact on operators at psychological, physical and behavioural levels (Semmer et al., 2019), which eventually may impair well-being or work performance (Gerhardt et al., 2021).

In the wake of the rapid technological advancement, humans work increasingly in hybrid teams together with technology (i.e. robots, intelligent agents etc.). Machines and algorithms are increasingly prevalent in the workplace (Meijerink et al., 2021; Ravid et al., 2020) and taking over functions of leadership (Quaquebeke and Gerpott, 2023; Wesche and Sonderegger, 2019), decision-making (Langer and Landers, 2021) and other management tasks (Lee et al., 2015). This can lead to situations where the technological agent is the source of social stress (Sauer et al., 2022). However, empirical understanding of the consequences of machine-induced social stress is still scarce. The present study addressed this gap by comparing the effects of human-induced and machine-induced social stress on subsequent performance and subjective state.

1.1. Social stress at work

A number of different social stressors may be present at the workplace (see for a list e.g. Gerhardt et al., 2021; Sauer et al., 2019). This diversity of stressors might explain the relatively high prevalence of social stress at work. Indeed, in a Swiss sample, 22% reported being exposed to at least one social stressor in the last 12 months (Grebner et al., 2011). According to the 'Stress as Offense to Self' approach (SOS; Semmer et al., 2019), social stress threatens the self, and self-esteem in particular. A distinction is made in the SOS approach between personal self-esteem (i.e. self-evaluation of intrinsic and aspired qualities) and social self-esteem (i.e. degree to which one feels valued by others). According to the SOS model, both types of self-esteem will be threatened by social stress, with possible consequences on several levels.

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1.2. Consequences of social stress: performance and subjective state

1.2.1. Effects on performance

A crucial outcome of social stress is subsequent performance. At the theoretical level, three mechanisms have been postulated to explain how performance may be affected by social stress (Sauer et al., 2019). The 'blank-out' mechanism allows protecting performance, the 'rumination' mechanism leads to impaired performance, and the 'increased motivation' mechanism causes improved performance. A meta-analysis found social stress to be negatively correlated with performance ($r = -0.22$ Gerhardt et al., 2021). It has to be noted that research on social stress, such as the one used in the cited meta-analysis, has mainly been performed as field studies or using methodologies such as vignettes or interviews. Such methodological approaches do not allow for an objective assessment of indicators of performance.

When focusing the literature review on lab studies of specific stressors, rather mixed results can emerge. This is the case for example for negative performance feedback, which is used in the present study. Human negative feedback impaired subsequent performance in several studies (Alder, 2007; Alder and Ambrose, 2005; Nease et al., 1999; Raver et al., 2012). However, performance improvement has also been found (Alder, 2007), as well as nil effects (Peifer et al., 2020; Thuillard et al., 2022). We also reviewed studies for the stressor ostracism, which was used in the present study as well. Lab studies on the effect of ostracism on subsequent performance are extremely scarce in the literature. Some studies found human-induced ostracism to decrease performance in a working memory task (Fuhrmann et al., 2019), in a word-search task (Lustenberger and Jagacinski, 2010) and on an eye-movement task (Jamieson et al., 2010). However, performance decrease could be restricted to some age groups (Fuhrmann et al., 2019), and ostracism could also lead to an increase in performance in some conditions (Jamieson et al., 2010). Overall, the current state on experimental research in this domain is inconsistent, with a majority of studies however indicating that human ostracism is linked with decreased subsequent performance.

When measuring performance, a crucial distinction has to be made between primary and secondary tasks (i.e. high-priority vs. low-priority tasks). The Compensatory Control Model by Hockey (1997) postulates that, under environmental stress, humans can maintain performance on primary tasks, however at the cost of lower performance on secondary tasks. It is unknown whether social stress will have the same effect as environmental stress on primary and secondary task performance. A recent theoretical article however assessed secondary tasks as sensitive to the effects of social stress on performance and called for more experimental studies using it (Sauer et al., 2022). Peifer et al. (2020) found that social stress in a complex multiple task environment left subsequent performance unaffected on both primary and secondary tasks. Overall, experimental research on social stress is still scarce. More studies are needed to complement the existing literature and establish cause-effect relationships (Sauer et al., 2019, 2022).

1.2.2. Effects on subjective state

Beyond performance, social stress may affect operators at the personal level (Sauer et al., 2019, 2022). As indicated above, the SOS model expects social stress to influence personal and social self-esteem (Semmer et al., 2019). In the Compensatory Control Model, performance protection is expected to build up fatigue (Hockey, 1997), which might have effects that are not detectable in performance tasks but rather in subjective indicators. In the meta-analysis by Gerhardt et al. (2021), social stress was negatively related to several subjective variables such as mental well-being, and job satisfaction, and positively related to negative emotions. It is therefore important to assess subjective state variables in addition to performance measures.

Focusing on the social stressors used in the present study, effects on subjective state have been found. Negative performance feedback can impair personal self-esteem (Brown, 2010; Krings et al., 2015; Moore and Klein, 2008) and reduce perceived interpersonal justice (Alder, 2007; Thuillard et al., 2022), or induce negative affective states (Nummenmaa and Niemi, 2004), and anger or tension (Baron, 1988; Cianci et al., 2010). Ostracism has negative effects on the four fundamental needs of belonging, control, meaningful existence and personal self-esteem (Buelow and Wirth, 2017; Jamieson et al., 2010; Robinson et al., 2013; Smith and Williams, 2004; Williams, 2007; Zadro et al., 2004). Additionally, ostracized individuals are more likely to feel burdensome (Buelow and Wirth, 2017), to experience lower positive mood and relatedness (Lustenberger and Jagacinski, 2010) and to act more aggressively (Warburton et al., 2006).

1.3. Machine-induced social stress

The "Computers Are Social Actors"-paradigm (CASA) explains how humans easily tend to apply social scripts and rules mindlessly to computers (Nass et al., 1994; Nass and Moon, 2000; Sundar and Nass, 2000). As soon as a computer exhibits a sufficient level of social cues and is considered an autonomous source of communication, humans will interact with it socially (Nass and Moon, 2000; Sundar and Nass, 2000). This means, for example, applying social rules of politeness or reciprocity to a computer. Originally focusing on computers, CASA has been extended to more moderns types of agents such as chatbots, mobile phones or robots (Gambino et al., 2020). The social interaction between humans and machines is crucial when considering machine-induced social stress. Indeed, the increasing use of autonomous technologies at work leads to a growing risk of machines inducing social stress. In the industry, human-machine interaction is at the heart of what is considered the fourth industrial revolution, or "Industry 4.0" (Galin and Meshcheryakov, 2019). This implies collaborating robots, or "cobots", working jointly on the same task with humans as colleagues rather than as simple tools of the human operator, which includes social aspects (Gualtieri et al., 2022; Paliga, 2022).

Algorithmic management even goes beyond human-machine collaboration. Defined as "the delegation of managerial functions to algorithms" (Jarrahi et al., 2021, p.1), it typically involves tasks such as monitoring operator performance and giving feedback on it, planning and assigning tasks and shifts, giving rewards and fines, assigning employees to teams, and even making operators redundant (Gal et al., 2020; Jarrahi et al., 2021; Kellogg et al., 2018; Lee et al., 2015; Meijerink et al., 2021; Uhde et al., 2020). Algorithmic management is mostly prevalent in the gig economy related to online platforms work, such as for example personal transportation, warehouse work or food and groceries delivery (Galière, 2020; Huang, 2022; Rosenblat and Stark, 2016). However, its presence is increasing in more common work settings and organizations (Jarrahi et al., 2021; von Krogh, 2018; Wesche and Sonderegger, 2019). It appears likely that machine-induced social stress will increase as algorithmic management spreads.

Machine-induced negative feedback and ostracism have been addressed in some studies, with a similar inconclusive result pattern regarding consequences on performance as observed for human induced social stress. For example, following computer negative feedback performance improved (Alder, 2007; Earley, 1988; Fyfe and Rittle-Johnson, 2016; Nebeker and Tatum, 1993; Van Dijk and Kluger, 2011), decreased (Alder, 2007; Resnik and Lammers, 1985; Van Dijk and Kluger, 2011) or stayed unchanged (Kluger and Adler, 1993; Sauer et al., 2021; Thuillard et al., 2022). With regard to the effect on subjective state, previous research has shown that machine-induced negative feedback is perceived as less fair than human feedback (Thuillard et al., 2022). No study investigating the effect of machine-induced ostracism on performance was found. However, it has already been shown about 20 years ago that human can feel ostracized by computers, impairing their four fundamental needs in the process (Zadro et al., 2004). In this study, humans also tended to be angrier when they were ostracized by computers than by humans. Computer-induced ostracism has been replicated many times since experimental studies often used the software

"Cyberball" (Williams and Jarvis, 2006) to induce ostracism (see e.g. Buelow and Wirth, 2017; Jamieson et al., 2010; Robinson et al., 2013; Williams, 2007). In this software, participants can be ostracized by computers or humans alike.

1.4. Present study

The main goal of this study was to examine experimentally whether social stress affected performance and subjective state, and whether human-induced and machine-induced social stress had different effects. This study should contribute to the ergonomics and human factors literature as it combines the controllable environment of experimental research with the ecological validity of field studies. Indeed, rather than static cognitive tests such as IQ tests for example, the present work makes use of a simulation of a complex multiple-task work environment, called Cabin Air Management System (CAMS; see below section 2.2). CAMS includes primary and secondary tasks and allows measuring performance during social stress induction. In addition to performance measures, we added several subjective variables such as affect, state self-esteem or justice (see section 2.3.3). This was done following the proposition of a 'broadband approach' (Hockey, 1997), which advocates the use of a number of different variables in stress research.

Based on the Compensatory Control Model (Hockey, 1997), we expected primary performance not to be affected by social stress and to stay the same in all three groups (H1a). Secondary performance, however, will be impaired in both experimental groups compared to the control group (H1b). Based on the SOS theory, we expected state self-esteem to be impaired in both experimental groups compared to the control group (2a). Based on previous research (Thuillard et al., 2022; Sauer et al., 2021), we expected affect (2b) and justice (2c) to be lower in both experimental groups compared to the control group. Interpersonal justice in particular will show the lowest level in the machine-induced stress group (2d). Due to the lack of research on machine-induced social stress, we could not know whether differences should be expected compared to human-induced social stress for most variables. Therefore, the present study is partly of an exploratory nature with regard to the differences between the two social stress conditions.

2. Methods

2.1. Participants and experimental design

90 participants (46 females) took part in this study, aged 20–29 years ($M = 23.54$; $SD = 3.11$). Participants were all students, recruited from various faculties of different Swiss Universities. They were recruited by e-mail, flyers and through social media. They were paid 80 CHF for their participation. An excellent understanding of French and good knowledge of English was required. Psychology students or students having participated in similar studies were excluded from this study, since they may be too familiar with experimental scenarios using deception. Informed consent was obtained from all participants, and the study was approved by the internal review board of the Psychology Department of the University of Fribourg.

This study employed a one-way between-subjects design, with social stress being manipulated at three levels. Participants were randomly allocated to either of the three conditions: a human-induced social stress group, a machine-induced social stress group or a control group with no stress induction. A combination of negative performance feedback (informing the participants of their insufficient performance) with ostracism (participants were not allowed to use the chat with the rest of the group) was used to maximize the effect of social stress. We chose to use these stressors due to their prevalence in work settings (Cleveland et al., 1989; Robinson et al., 2013) and due to the fact they can originate from both human and machine (Endsley and Kiris, 1995; Jarrahi et al., 2021; Kellogg et al., 2018; Lee et al., 2015; Zadro et al., 2004). Additionally, using these two stressors together appeared to be ecologically valid since an operator could be ostracized by others following poor work performance.

2.2. Material: simulation environment

This study used a new version of the simulation environment CAMS (see Fig. 1). CAMS simulates a complex work environment in the form of a space station's life-support system (see for details of a previous version; Manzey et al., 2008). Participants act as operators responsible for monitoring and repairing the system in case of malfunctions. CAMS uses dynamic tasks evolving in real time and closely modelling a real work environment. This includes two primary and two secondary tasks, allowing us to measure the allocation of cognitive resources to the different elements of the task environment. Additionally, since social stress induction lasted during the whole experiment, using this tool allowed us to measure performance during social stress exposure. This is unlike previous experiments that usually measured performance subsequently to the stress induction rather than simultaneously. Some new functions such as a chat facility were added to the new CAMS version, allowing for the experimental induction of social stress. Using CAMS in a study requires considerable resources, since participants need extensive training (2 h 15 min in present study) to become familiar with the complexity of the simulation.

2.3. Dependent variables

2.3.1. Manipulation check and control variables

Three items were used as manipulation check for the induction of stress and implementation of ostracism. We also added two items to control the valence and level of stress induced by negative feedback. All five items were developed specifically for this experiment.

Perceived stress. Overall stress was assessed using a single item "Do you feel stressed? How much?", ranging from 1, "*not at all*", to 7, "*extremely*".

Ostracism. We assessed the manipulations' effect on perceived social exclusion ("To what extent did you feel excluded by not being able to use the chat during the experiment?") and believed exclusion ("How much do you think the other participants used the chat?") on a seven-point Likert scale ranging from 1, "*not at all*", to 7, "*a lot*". These two items were presented after an item ("Could you use the chat during the experiment?") that needed a yes/no answer.

Negative feedback. The perceived feedback valence was assessed with a single item: "To what extent did you find the feedback you received …", ranging from 1, "*negative*" to 7, "*positive*". Level of stress induced by the feedback was assessed with a single item; "How stressful did you experience the feedback you received?" ranging from 1, "*not at all*", to 7, "*extremely*".

2.3.2. Performance measures

The following four measures of performance were recorded throughout the experiment on two primary tasks and two secondary tasks. (a) *Parameters control failure:* percentage of deviation from the safety limits in all five air parameters averaged together. (b) *Malfunctions diagnosis:* number of wrong diagnoses and number of corrected malfunctions. (c) *Reaction time (ms):* mean reaction time on every completed transmission check. (d) *Prospective memory:* percentage of correctly completed logs.

2.3.3. Subjective measures

Affect. The participants' affect was measured by the Self-Assessment Manikin (SAM; Bradley & Lang, 1994) pictographic questionnaire. A nine-point Likert scale was used to measure the dimensions of valence (1, negative vs 9, positive affect) and arousal (low vs high) were measured on a nine-point Likert scale.

State Self- Esteem Scale. The State Self-Esteem Scale by Heatherton and Polivy (1991) measures the temporary variations in self-esteem, on

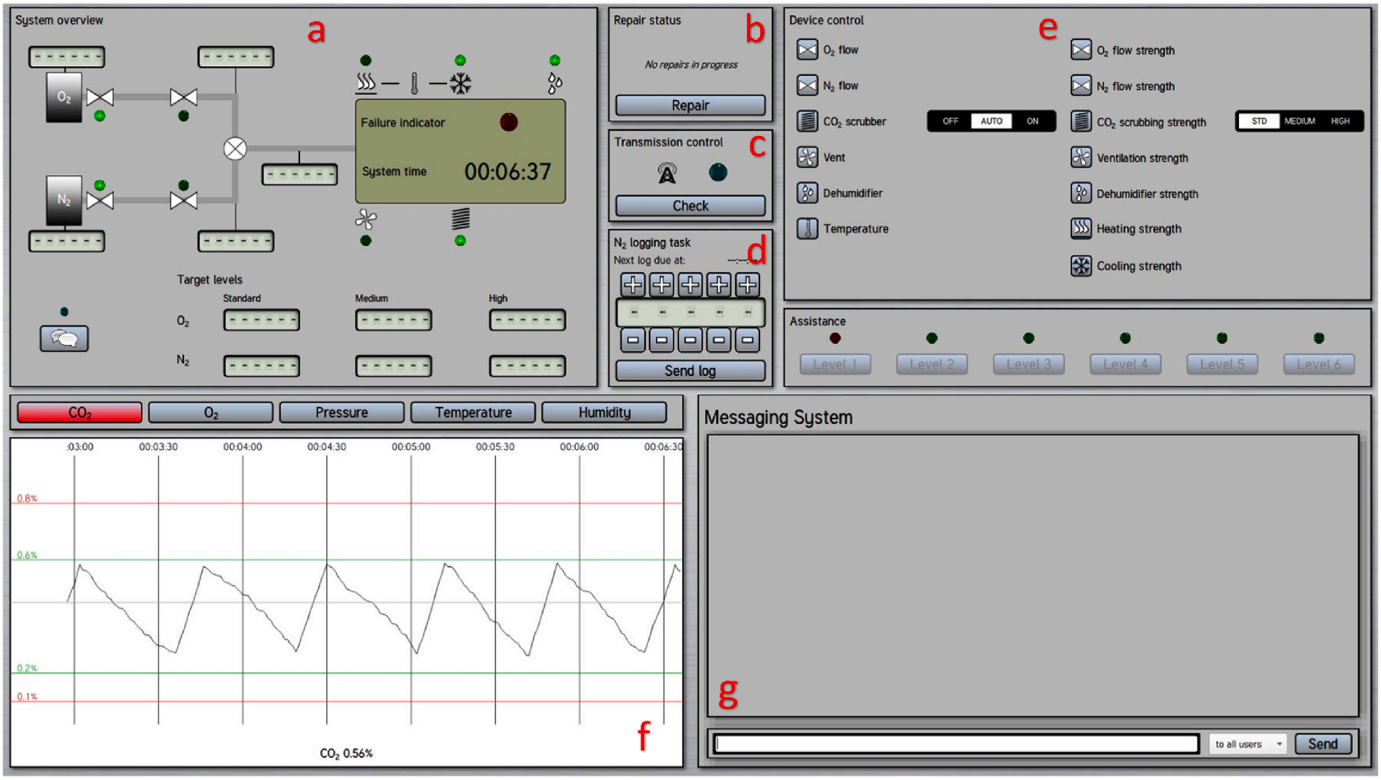

Fig. 1. *Cabin Air Management System (CAMS). The system overview (a), at the upper left side, schematically represents the air management system and the devices involved. At the top center can be found the repair tab (b) and the secondary tasks tabs (c and d). The device and strength controls of all devices and valves are located on the upper right side of the interface (e). The lower left side rectangle displays the five parameters of the cabin's air quality (f) and their change over time. The rectangle at the bottom right shows the chat facility (g).*

three sub-dimensions: performance self-esteem (7 items; McDonald's omega in current study, $\omega = 0.84$, 95% CI [0.79, 0.89]), social self-esteem (6 items; $\omega = 0.82$, 95% CI [0.76, 0.88]) and appearance self-esteem (7 items; $\omega = 0.89$, 95% CI [0.85, 0.92]). The total score uses all 20 items. For each, the higher the score, the higher the self-esteem is. All items were answered on a scale ranging from 1, "*not at all*", to 7 "*extremely*".

Procedural and Interpersonal Justice. Perceived interpersonal justice was measured using the 'interpersonal justice' subscale from the organizational justice scale (Colquitt et al. (2015). The four items were modified to refer either to the experimenter, or to CAMS. They were filled twice by each participant in order to evaluate interpersonal justice in the interactions with either the experimenter or CAMS. Items asked for example to what extent: "Has the experimenter/the program treated you in a polite manner?". Each item was rated on a 7-point Likert scale, from 1, "*not at all*", to 7, "*extremely*". McDonald's omega in current study was $\omega = 0.61$, 95%CI [0.34-0.8] for human interpersonal justice and $\omega = 0.85$, 95%CI [0.74-0.95] for machine interpersonal justice.

Perceived procedural justice was measured by 4 items from the 'procedural justice' subscale from the organizational justice scale (Colquitt et al., 2015). We selected items that could be modified to refer to the experiment. The selected items asked to what extent: "Were you able to express your views during the experiment?", "Was the experiment applied consistently?", "Was the experiment free of bias?", "Did the experiment uphold ethical and moral standards?". Each item was rated on a seven-point Likert scale, ranging from 1, "*not at all*", to 7, "*extremely*". McDonald's omega was $\omega = 0.45$, 95%CI [0.12-0.67].

2.4. Procedure

2.4.1. Training session

All participants received an extensive training on CAMS (2 h 15 min in total; see Fig. 2). The aim was for participants to really understand how the different sub-systems of CAMS interact with one another, and how their actions would influence the different parameters.

2.4.2. Testing session

Prior to experimental manipulation. The testing session (1 h 30 min; see Fig. 3) took place approximately one week after training and was administered by the same experimenter. Participants returned in different groups ranging from three to four and were randomly assigned to one experimental condition. We tested one condition by group. Participants were separated by screens and had to wear headphones.

Manipulation. In the human stress condition, the experimenter talked to each participant one by one during the warm-up and gave them negative feedback on their performance in the training session. She pointed out that their overall performance score was 60 points out of 300. Using a graph, she showed that they were in the lowest 12%, significantly below average of other participants' performance. She explained that based on this result, she had decided to deactivate their chat facility since they would probably disturb other participants rather than help them. The experimenter was trained to give this feedback in a highly standardized way, and participants were not given the opportunity to discuss the feedback. With regard to ostracism, participants believed that they were the only ones not being allowed to use the chat facility. To increase the strength of this manipulation, CAMS displayed scripted fake messages in the chat facility (always at the same time), with the content hidden, to give the impression that other participants were actively using the chat facility. In the computer stress condition, the same feedback, though adapted to make CAMS appears as the source of social stress, was displayed on the screen at the end of the warm-up. In this case, it was as if CAMS itself took the decision to block a participant from using the chat facility. In the control condition, participants were told that the chat facility was unfortunately faulty and that nobody

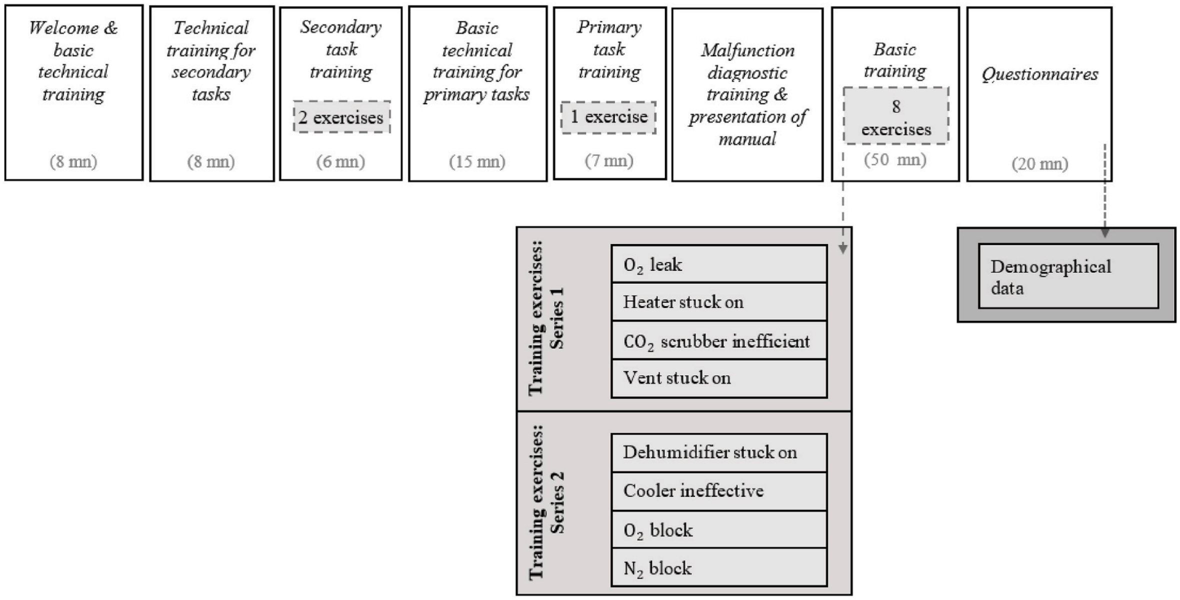

Fig. 2. *Procedure of the training session.*

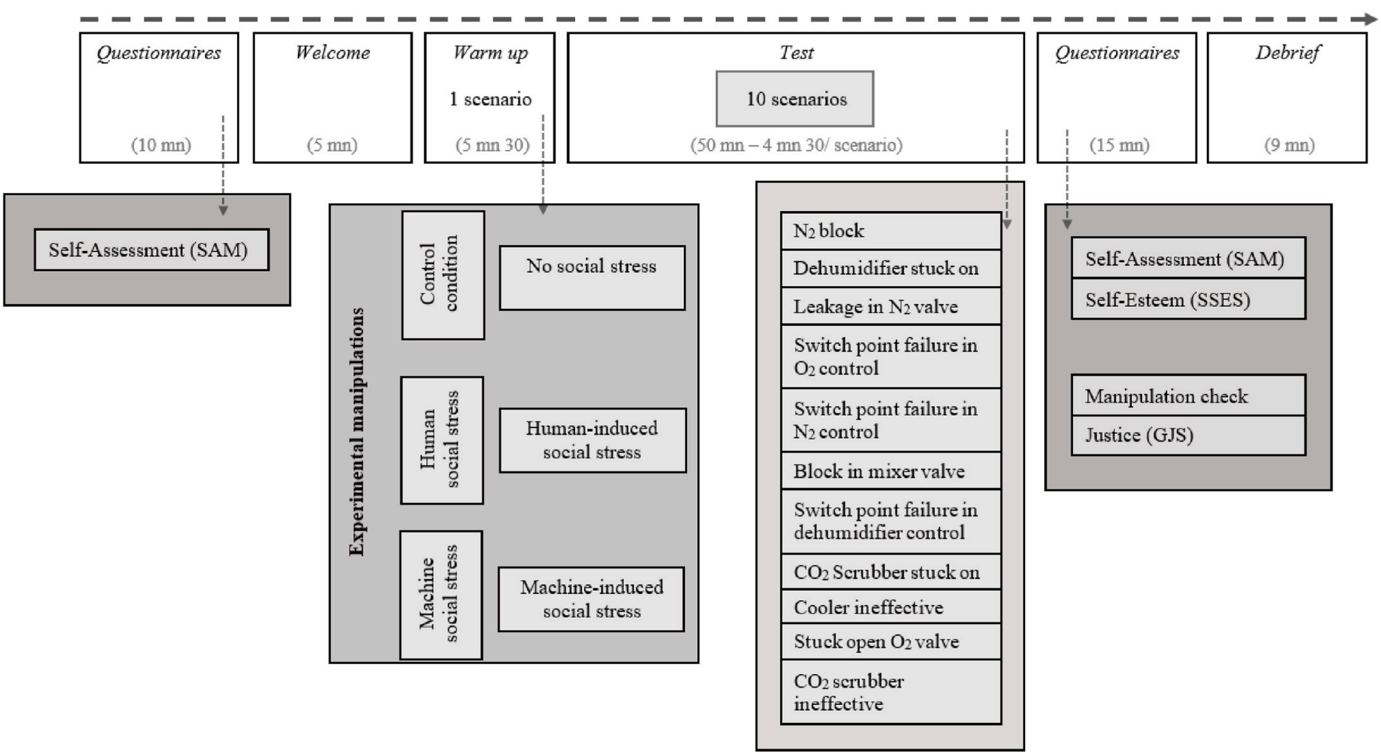

Fig. 3. *Procedure of the testing session.*

could use it, and no fake messages were displayed.

After manipulation. Following the warm-up, participants in both experimental conditions were reminded that the ones that were allowed using the chat could help each other. Participants then completed the testing phase (see Fig. 3), followed by questionnaires.

Debriefing. Participants were fully debriefed. The experimenter apologized for providing inaccurate information, and explained why it was necessary to provide incorrect feedback and to make participants believe that they were ostracized. Participants had the opportunity to ask questions if they had any. The experimenter made sure that participants had understood and accepted the manipulation before leaving.

2.4.3. *Cover story*

Manipulation check questions had to be carefully presented to conceal the purpose of the study (Hauser et al., 2018). A cover story was used to minimize this risk: the ethics committee of the university would like to control whether our experiment respected ethical rules. To this end, participants would have to answer some questions not as part of the experiment, but for the ethics committee. This allowed presenting manipulation check and some subjective state items at the end of the experiment after all other dependent variables.

2.5. Data analysis

Analyses consisted of ANOVAs (with Bonferroni corrected pairwise comparisons), ANCOVAs (for variables measured before and after the experimental manipulation), and t-tests. We controlled for normality of distribution and homogeneity of variance assumptions.

Non-parametric tests, such as a Kruskal-Wallis analysis of variance or a Wilcoxon rank-sum test, were conducted only in cases in which both assumptions were violated. Reliability of the scales used in the present study was assessed with McDonald's omega, based on recommendation by Dunn et al. (2014). Additionally, hypothesis 1a required a different procedure since it predicted a nil effect of social stress on primary performance. Based on Cortina and Folger (1998) and Onnasch (2015), we adapted alpha to a 20% level for the relevant analyses.

3. Results

3.1. Manipulation check and control variables

3.1.1. Perceived stress

The post-test state stress measure (see Table 1 for descriptive statistics), with the pre-test measure as a covariate, did not significantly differ between groups; F (2,87) = 1.782, p = .174, partial $\eta^2 = 0.04$.

3.1.2. Perceived ostracism

Significant differences were found in how much participants felt excluded due to not having been able to use the chat, H (2) = 23.1, $p <$ .001. Bonferroni-corrected pairwise comparisons using Wilcoxon rank sum tests showed that the control group was significantly lower than the human group, $p < .001$, and than the machine group, $p < .001$. These two last groups did not differ significantly, $p = .97$.

Similar results were found with regards to how much participants thought others used the chat, H (2) = 30.13, $p < .001$. Bonferroni-corrected pairwise comparisons using Wilcoxon rank sum tests showed that the control group was significantly lower than the human group, $p < .001$, and than the machine group, $p < .001$. These two last groups did not differ significantly, $p = .43$.

3.1.3. Negative feedback

No differences were found between the human and the machine groups for feedback valence; t (58) = −1.56, p = .12, and feedback stressfulness; t (58) = 0.22, p = .82.

3.2. Performance measures

3.2.1. Primary performance

Parameters control failures. The overall deviation from the safety limits in the air parameters did not differ significantly between conditions; F (2, 87) = 0.62, p = .54, partial $\eta^2 = 0.014$ (see Table 2 for descriptive statistics of all performance measures).

Malfunction diagnosis. The analysis of variance revealed no significant effect of social stress on the number of correct diagnoses; F (2, 87) = 0.24, p = .78, partial $\eta^2 = 0.005$ and of wrong diagnoses; F (2, 87) = 1.06, p = .35, partial $\eta^2 = 0.024$. Overall, results appear to provide reasonable support for Hypothesis 1a as both alphas are over the adapted level of 20%.

3.2.2. Secondary performance

Reaction time. Performance on the reaction time task was not affected by social stress. Mean reaction time did not differ significantly between conditions; F (2, 87) = 0.76, p = .47, partial $\eta^2 = 0.017$.

Prospective memory. No significant effect of social stress was found for the percentage of logs completed; F (2, 87) = 0.67, p = .52, partial η^2 = 0.015.

3.3. Subjective state measures

3.3.1. State self-esteem

No significant effects of social stress on state self-esteem were detected, whether it be in the performance subscale; F (2, 87) = 0.98, p = .38, partial $\eta^2 = 0.022$, the social subscale; F (2, 87) = 0.54, p = .58, partial $\eta^2 = 0.012$, the appearance subscale; F (2, 87) = 0.09, p = .91, partial $\eta^2 = 0.002$, or the total score; F (2, 87) = 0.63, p = .53, partial η^2 = 0.014. These results do not support Hypothesis 2a.

3.3.2. Affect

The one-factorial analysis of covariance, with pre-manipulation

Table 2
Means and standard deviations of performance as a function of social stress.

Variable	Control group Mean *(SD)*	Human social stress Mean *(SD)*	Machine social stress Mean *(SD)*
Primary performance			
Parameters control failure (%)	16.41 *(7.19)*	18.93 *(9.6)*	17.63 *(9.07)*
Total number of wrong diagnoses	6.77 *(4.2)*	7.66 *(4.59)*	9 *(8.27)*
Number of correct diagnoses (0–10)	7.2 *(2.73)*	6.9 *(2.01)*	6.77 *(2.47)*
Secondary performance			
Reaction time (ms)	3061 *(602)*	3244 *(539)*	3112 *(602)*
Logs completed (%)	15.41 *(26.64)*	8.79 *(15.92)*	11.38 *(22.54)*

Table 1
Means and standard deviations/median and interquartile range of manipulation check and control variables.

Variable	Control group Mean/Median *(SD/IQR)*	Human social stress Mean/Median *(SD/IQR)*	Machine social stress Mean/Median *(SD/IQR)*
State stress T2 (T1 as covariate; 1-7)	2.67 *(1.49)*	2.24 *(1.3)*	2.39 *(1.58)*
Experienced ostracism (1-7)	1.00 (*.75*)	3.00 *(3.00)* ***	4.00 *(4.00)* ***
Other participants chat use (1-7)	1.00 *(1.00)*	3.00 *(3.00)* ***	5.00 *(3.00)* ***
Feedback valence (1-7)	n.m.	1.97 *(.91)*	2.58 *(1.93)*
Feedback stressfulness (1-7)	n.m.	3.79 *(1.74)*	3.68 *(2.18)*

Notes: * = $p < .05$; ** = $p < .01$; *** = $p < .001$; n.m. = not measured.

(baseline) score as a covariate, showed that valence did not differ between the experimental conditions (see Table 3 for descriptive statistics); F (2, 87) = 2.47, p = .09, partial $\eta^2 = 0.054$. Similar results were found with the ANCOVA for the arousal scale; F (2, 87) = 0.62, p = .54, partial $\eta^2 = 0.014$; as well as the anger item; F (2, 87) = 1.58, p = .21, partial $\eta^2 = 0.035$. These results do not support Hypothesis 2b.

3.3.3. Justice

The Kruskall-Wallis test revealed significant differences in interpersonal human justice; H (2) = 12.42, p = .002. Bonferroni-corrected pairwise comparisons using Wilcoxon rank sum tests showed that participants in the control group evaluated the experimenter as significantly more just than the human group, p = .001. Fairness ratings in the machine group did not differ from the control group, p = .61, or from the human group, p = .11. No such differences were found for computer interpersonal justice; F (2, 87) = 0.25, p = .78, partial $\eta^2 = 0.006$.

Significant differences between conditions were detected for procedural justice; H (2) = 6.62, p = .036. Bonferroni-corrected pairwise comparisons using Wilcoxon rank sum tests showed that the control group was significantly higher than the human group, p = .036. The machine group did not differ from the control group, p = 1, or from the human group, p = .24.

The justice results overall only partially support Hypothesis 2c, in that only the human group showed an impairment of justice. Hypothesis 2d was not supported.

4. Discussion

The present study investigated whether human-induced and machine-induced social stress affect subsequent performance and subjective state by using a simulation of a complex work environment. Results indicated that the feedback was perceived as quite negative and relatively stressful, and that participants did feel excluded from the others by not being able to use the chat. This pointed towards a successful manipulation of social stress. Nevertheless, performance was unaffected by social stress. With regard to subjective state measures, social stress only partly influenced interpersonal and procedural justice, leaving other variables such as affect or state self-esteem unimpaired.

4.1. Performance

Based on Hockey's Compensatory Control Model, we expected that primary performance would be protected from social stress (H1a), but that performance on the secondary tasks would be impaired (H1b). No effect of social stress on any performance variable was detected, supporting H1a but not H1b. This pattern of nil effects could be seen as a case of the 'blank-out' mechanism (Sauer et al., 2019), in that participants managed to protect their performance from social stress. The present results might be seen as positive, indicating an ability from participants to shield their primary *and* secondary performance from both human-induced and machine-induced social stress. A possible 'blank-out' mechanism may have been observed in previous studies (Peifer et al., 2020; Sauer et al., 2021; Thuillard et al., 2022).

CAMS is a complex system requiring high cognitive resources to be operated. This high demand might simply have left no resources for rumination, thus preventing performance impairment despite the induction of social stress. In their meta-analysis, Kluger and DeNisi (1996) partly support this argument by showing that feedback has weaker effects on performance in complex tasks. This could mean that operators working on complex systems would be more protected from social stress due to the nature of their work. Compared to cognitively less demanding tasks, a stronger stress induction would be necessary to impair performance. Performance protection may also have caused physiological strain, as in Peifer et al. (2020). Physiological strain was not measured in the present study. It might however have potentially serious health consequences on the long term. Alternatively, according to Sauer et al. (2022), social stress may impair performance not on the main task but on unscheduled probe tasks for example, which is called performance after-effects. Such a phenomenon might have happened in the present study.

4.2. Subjective variables

We expected social stress to lower state self-esteem (H2a), affect (H2b) and justice (H2c) in the experimental groups compared to the control group. For interpersonal justice in particular, we expected the machine group to show the lowest score (H2d).

No effect of social stress on affect or state self-esteem were detected. Interpersonal and procedural justice were reduced in the human stress group only. Overall, subjective variables showed rather low support for our hypotheses. This relative absence of effect on subjective state is surprising in the sense that according to the Compensatory Control Model, performance protection is associated with some costs. Costs on mood or self-esteem have been identified in the literature before following potential 'blank-out' effects (Sauer et al., 2021; Thuillard et al., 2022). A link could be made with the emotion regulation literature. Different emotion regulation strategies have different effects at the physiological level (Webb et al., 2012). *Suppression* for example (i.e. not showing any feeling) is considered maladaptive and can lead to a higher sympathetic activation (Gross, 1998). This could be seen as a physiological cost of regulating social stress if participants used such a strategy to regulate their reaction. In the same line of argument, we could imagine that the protection mode may have been extended to subjective variables as well, with physiological strain being a sign of this protection.

Participants in the human stress condition felt they were treated less fairly by the experimenter than the control group. When the same questions were asked about CAMS instead of the experimenter, no difference was detected. Procedural justice (i.e. how fair decision-making is), includes in the present study the decision to exclude someone from the chat. Interestingly, only the human stress group perceived the procedures as more unfair than the control group. This is different from

Table 3
Means and standard deviations/median and interquartile range of subjective state as a function of social stress.

Variable	Control group Mean/Median *(SD/IQR)*	Human social stress Mean/Median *(SD/IQR)*	Machine social stress Mean/Median *(SD/IQR)*
Affect: valence (1-9)	6.57 *(1.57)*	5.93 *(1.89)*	5.71 *(1.92)*
Affect: arousal (1-9)	4.7 *(1.98)*	4.55 *(1.64)*	4.84 *(2.03)*
State anger (1-9)	1.57 *(1.1)*	2.07 *(1.39)*	1.71 *(1.19)*
State self-esteem (20-140)	99.73 *(21.43)*	97.31 *(22.35)*	93.97 *(16.47)*
	* * *		
Human interpersonal justice (1-7)	7.00 *(.25)*	6.00 *(1.25)*	7.00 *(1.00)*
Machine interpersonal justice (1-7)	6.10 *(1.4)*	6.00 *(1.09)*	5.88 *(1.45)*
	*		
Procedural justice (1-7)	6.25 *(.75)*	5.75 *(1.25)*	6.25 *(.875)*

Notes: * = $p < .05$; ** = $p < .01$; *** = $p < .001$.

Ötting and Maier (2018), who found no difference in procedural justice following decisions from a human, a robot or a computer system. Logg et al. (2019) found that people tend to accept algorithmic judgment more than human judgment. Participants might have accepted more easily to be removed from the chat by CAMS than by the experimenter.

Contrary to what was hypothesized, social stress did not influence state self-esteem. This is surprising since social stress acting through threats to self-esteem is at the core of the 'Stress as Offense to Self'-approach (Semmer et al., 2019). Additionally, social stress has been found in the literature to influence self-esteem (e.g. (Eatough et al., 2016; Sauer et al., 2021; Schulte-Braucks et al., 2019)). The SOS approach offers a possible explanation for this lack of effect on self-esteem: they hypothesize strategies to protect or restore self-esteem. In case of negative feedback for example, attributing it to a lack of fairness, or justice, of the supervisor may help protect self-esteem (Semmer et al., 2019). This lack of justice was found for the human stress group. Human-induced social stress would then be more threatening than machine-induced social stress, contrary to our hypothesis. In the present study, lower justice might have been a cost of protecting one's self against human-induced social stress. While a protection mechanism against threats to self-esteem appears to be a positive finding, it might have a negative side as well. According to Colquitt et al. (2013), lower justice may, in the long term, decrease positive work behaviour and increase negative work behaviour. The meta-analysis by Gerhardt et al. (2021) also underlines the importance of justice in the work domain, as they found lack of justice to be the social stressor with the strongest effects on attitudinal outcomes such as commitment or job satisfaction.

4.3. Limitations and future studies

Several limitations of this study should be stated: (a) We acknowledge that there are limitations with regard to the manipulation of ostracism used in the present study. It can be argued that the difference between the experimental groups and the control group regarding ostracism was relatively small, considering that participants in the control group were not able to use the chat either. Although it was necessary to prevent participants in the control group from using the chat, which naturally would have biased their performance, this limitation may explain some nil effects found in this study. Even though social stress was also induced using negative feedback, the manipulation could have been stronger with a different operationalization of ostracism. Future research aiming to use ostracism as a social stressor should design the manipulation with particular care. Ideally, future studies should use confederates who actively exclude participants so that the induction of social stress will be stronger. Using ostracism in combination with other social stressors, or repeatedly inducing social stress, are other options to increase the strength of the manipulation. (b) Several subjective variables could only be measured at the end of the experiment. It is possible that some transient effects, such as subjective stress, remained undetected due to the timing of the measurement. Similarly, we did not investigate performance after-effects. Future studies should measure subjective variables during the CAMS simulation (ideally combined with physiological measures), as well as performance after-effects. (c) The cover story used to present some questionnaires as originating from the ethics committee (section 2.4.3), which might have raised less suspicion towards the true purpose of the experiment, might at the same time have biased answers in favour of the experimenters. This could explain the small difference between conditions for the justice variables, which were presented under this cover story. (d) Social stress was only induced on one occasion. Our results do not provide information about the effects of repeated exposure to social stress in the long term. For example, long working hours can increase mental fatigue and lower performance in complex tasks (Chen et al., 2022), which might in turn make operators more vulnerable to social stress. Future research should compare different levels of intensity, frequency and duration of social stressors. (e) We could not use the same medium for social stress induction in both experimental conditions. It is possible this influenced the results in some way (see e.g. Alder and Ambrose, 2005). Future studies comparing human and machines as sources of social stress should aim to control for medium across experimental conditions. It would also be important that future research attempts to measure the 'blank-out', 'rumination' and 'increased motivation' mechanisms postulated in Sauer et al. (2019).

4.4. Implications

Machine-induced social stress having no negative influence on participants could have serious implications, *if* these results were to be replicated. In the perspective of algorithmic management, these results could be seen as encouraging for the practice of delegating management tasks to automation. Indeed, human-induced stress had undesirable effects when machine-induced stress did not. This could be taken as an argument in favour of automation of management and the workplace in general. However, qualitative data from studies with samples of workers in actual platform-based gig work raised many issues with algorithmic management, such as low autonomy, transparency and control over working hours and tasks (Galière, 2020; Griesbach et al., 2019; Huang, 2022; Kellogg et al., 2018; Lee et al., 2015; Rosenblat and Stark, 2016; Uhde et al., 2020). It could be that machine-induced stress has a different effect depending on the type of work and tasks. As discussed above, operating CAMS is cognitively highly demanding, which might help shielding performance from social stress. It could mean that workers in similarly complex work environments (such as nuclear power plant operators, air traffic controllers or other safety-critical domains) might be less sensitive to machine-induced social stress as workers in platform-based gig work. More research is needed before recommendations on the implementation of automation at work could be made with a sufficient level of confidence.

4.5. Conclusion

The landscape of work has evolved and transformed at staggering speed and depth. Automation under different forms is increasingly prevalent in the workplace, and with it come new, complex forms of human-machine interactions able to induce social stress. Increasingly more people earn a living in platform-based gig work, effectively managed by algorithms. This phenomenon is likely to continue its growth and expand to more work settings, affecting more people. It is therefore crucial for research and the field of ergonomics and human factors in particular to better understand the effects of such complex interactions between humans and machines.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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