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Emergence of technostress among employees working with physical robots

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EMERGENCE OF TECHNOSTRESS AMONG EMPLOYEES WORKING WITH PHYSICAL ROBOTS

Research Paper

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Abstract

Despite the growing body of literature on technostress, there is limited knowledge about the emergence of technostress among people working with physical robots. In this paper, we aim to address this research gap by exploring how technostress emerges among employees working with physical robots. The study was based on qualitative online questionnaire responses from 197 present or previous users of robots at work. Based on our data, we identified several robot-related environmental conditions that contributed to perceived work-related stress. Our findings reveal that the emergence of technostress among employees working with physical robots has distinct characteristics and that the technostressors identified in previous studies are insufficient for explaining stress in this context. Therefore, our study extends the technostress literature and provides insights into employees' experiences in organizations that use physical robots.

Keywords: Technostress, Stress, Physical Robots, Work Context.

1 Introduction

Physical robots have long been ordinary in the manufacturing, automotive, and electronics industries, but they are slowly becoming increasingly common in the service sector and other fields while becoming more adaptable and autonomous (West, 2018). The proliferation of robots and their introduction to the workplace alongside humans (Pollak et al., 2020a) is changing the nature of work and imposing new demands on employees. Despite the benefits of robots, such as increased productivity, research suggests that employees' stress increases when they work closely with physical robots (Arai et al., 2010; Rubagotti et al., 2022), potentially leading to their reduced well-being.

Studies over recent decades have provided important information on technostress—that is, stress arising from the use of information technology (IT)—in both organizational (e.g., Fischer and Riedl, 2017; Galluch et al., 2015; Ragu-Nathan et al., 2008) and personal (e.g., Maier et al., 2015; Salo et al., 2022) settings. Understanding the formation of stress is important, since stress is a major occupational health problem influencing employees' physical and mental well-being (Chen et al., 2023), as well as affecting employee engagement and productivity (Wang et al., 2008; Tarafdar et al., 2007). However, despite the proliferation of robots at work, the emergence and characteristics of technostress in this specific organizational context remain largely uncovered.

As stated by Salo et al. (2019, p. 409) and Ayyagari et al. (2011), the fundamental causes of stress related to a specific technology can only be understood by examining "stress-inducing technological characteristics." Research suggests that humans establish different relationships with robotic agents with virtual actions and a physical embodiment, compared to merely virtual robots, such as software robots, chatbots, or virtual assistants (Broadbent, 2017). As a result of the physical embodiment, a typically movable structure (You and Robert, 2018) and, consequently, perceived non-verbal communication of a robot, interaction with physical robots differs from virtual, disembodied agents (Epley and Waytz, 2010). In social interactions, humans react to physical robots in similar ways as to other humans (Mumm and Mutlu, 2011). Because of this, it is likely that the emergence of technostress in this context differs from stress in traditional IT environments as well as from stress stemming from the use of other types of increasingly agentic IT artifacts (Baird and Maruping, 2021). To understand the stress-inducing characteristics of physical robots and to address this gap in prior research, we aimed to answer the following research question: *How does technostress emerge among employees working with physical robots?*

To answer the research question and capture the nuances of perceived stress, we conducted a qualitative questionnaire with present and previous employees working with physical robots (N = 197). The questionnaire consisted of open-ended questions informed by the guidelines of the critical incident technique (CIT; Gremler, 2004) and qualitative content analysis (Lune and Berg, 2017). Our theoretical contributions complement prior studies on technostress and technostressors by providing new insights into robot-related technostress. We identified multiple robot-related environmental conditions that contribute to technostress and, to the best of our understanding, provide one of the first investigations into this area. Considering practical implications, the findings of our study can help organizations prevent technostress among their employees and support individual robot users in managing the associated stressors that strain well-being. Such implications can benefit individuals, organizations, and the wider society by contributing to existing knowledge about the rapidly expanding field of work-related robotization.

2 Theoretical background

In this section, we introduce the theoretical background of our study. First, we present the concept of technostress and its emergence in work contexts. We then summarize prior research on physical robot-related stress.

2.1 Technostress and technostressors

Technostress research draws mainly on a transactional view of stress (Salo et al., 2022; Tarafdar et al., 2019), understanding it as resulting from stress-stimulating conditions and an individual's response to them (Lazarus and Folkman, 1984). More specifically, stress is defined as a "relationship between the person and the environment that is appraised by the person as taxing or exceeding his or her resources and endangering his or her wellbeing" (Lazarus and Folkman, 1984, p. 19). Consequently, the term *technostress* (Brod, 1982) describes an individual's experienced stress stemming from the use of IT (Tarafdar et al., 2019). In a similar vein, technostress is a subjective processual experience shaped by both environmental conditions (e.g., IT characteristics, social interactions, and assigned workload) and internal conditions (e.g., attitudes, and self-efficacy; Fischer and Riedl, 2017). Negative technostress (i.e., techno-distress) is "one side of the coin" since an individual may appraise an experience as either positive (i.e., techno-eustress) or negative (Califf et al., 2022; Tarafdar et al., 2019). In this paper, however, we focus on negative stress, and henceforth, the term technostress refers to techno-distress.

The transactional view of technostress has been shown to be helpful in explaining how technostress can emerge. Its two main components are stressor and strain. If an individual perceives specific conditions as threatening to their well-being (i.e., perceives them as stressors), they stimulate negatively associated outcomes to the individual (i.e., strain, such as exhaustion) and prompt stress-reducing behaviors and coping strategies (Fischer and Riedl, 2017; Tarafdar et al., 2007). Ayyagari et al. (2011) further elaborated on how IT characteristics may trigger technostressors and, thus, strain. IT characteristics may act as antecedents of stress by increasing the perceived misfit between the individual and the technological environment, contributing to stressors (Ayyagari et al., 2011). The outcomes of strain include, for example, burnout, exhaustion (Ayyagari et al., 2011; Barber and Santuzzi, 2015), concentration and social-relational problems (Salo et al., 2019), discontinued use of IT (Maier et al., 2015; Maier et al., 2022) at the individual level, and job dissatisfaction, disengagement, and decreased productivity (Wang et al., 2008; Tarafdar et al., 2007) at the organizational level.

Accordingly, technology environmental conditions include elements that are perceived as technostressors that present demands that the individual is not able to tackle (Tarafdar et al., 2019). Ragu-Nathan et al. (2008) discussed the most frequently studied technostressors, such as techno-overload, referring to a situation in which IT forces the individual to "work faster and longer" (Ragu-Nathan et al., 2008, p. 427) due to a flood of information (Reinke and Chamorro-Premuzic, 2014), system-feature overload (Zhang et al., 2016), and multitasking (D'Arcy et al., 2014a). Techno-invasion refers to the invasive nature of IT, whereby IT may oblige employees to feel constantly available (Ragu-Nathan et al., 2008). Techno-complexity refers to a situation in which IT seems complicated and imposes new demands for learning and self-education (Alam, 2016; Ragu-Nathan et al., 2008) or creates disruption and interruptions (Galluch et al., 2015). Techno-insecurity refers to individuals' fear of losing their jobs because of IT (Ragu-Nathan et al., 2008) or of not being able to compete with others in its use (Tarafdar et al., 2007). Techno-uncertainty refers to a situation in which technological changes worry individuals (Ragu-Nathan et al., 2008; Sellberg and Susi, 2012) and/or make them feel that they lack control over IT-related tasks (Barber and Santuzzi, 2015). It should be noted that these five established technostressors are a rather simplistic representation of a complex phenomenon, and the relationships among stressors are not yet thoroughly understood (Chiu et al., 2022). Moreover, technostress may result from sudden, intensely stressful experiences or manifest gradually over time (Salo et al., 2022).

Prior research has identified certain individual and organizational characteristics that increase the risk of people considering specific characteristics of IT to be technostressors. Personality traits may play a role in an individual perceiving certain conditions as threatening (e.g., Maier et al., 2019; Srivastava et al., 2015). However, positive core self-evaluations (Reinke and Chamorro-Premuzic, 2014) and self-efficacy (Kim and Lee, 2021; Li and Wang, 2020; Tams et al., 2018; Tarafdar et al., 2015) can alleviate the effects of technostress. Technostress differs between organizational contexts and personal contexts (Salo et al., 2019); thus, certain organizational mechanisms can either increase or decrease technostress (e.g., perceived control over one's work enhances employee well-being; Galluch et al., 2015; Pirkkalainen et al., 2019; Warr, 1990), and the effect of technostressors can be mitigated by the reorganization of work tasks (Fischer and Riedl, 2017), organizational technical support (Kim and Lee, 2021), or supporting digital literacy (Ragu-Nathan et al., 2008).

2.2 Physical robot–related stress

Prior studies on physical robot–related stress have addressed stressors with a focus on job insecurity (i.e., employees' perceived threat of job loss because of robots) and general safety. Employees working with physical robots may experience job insecurity, which again may lead to stress, burnout, and lower attentiveness to coworkers (Yam et al., 2022) and reduce the meaningfulness of work (Turja et al., 2022). In particular, the development of more autonomous and collaborative robots to work alongside human employees (Franklin et al., 2020; Hentout et al., 2019) has increased the need to ensure employees' physical safety by preventing unwanted or potentially dangerous encounters (Capuozzo et al., 2019).

Apart from physical safety, safety in the context of acting with physical robots also involves multiple psychological factors (Lasota et al., 2017). A robot's characteristics and behavior, such as its appearance, motion, or interactions, may reduce psychological safety and result in stress (Lasota et al., 2017; Pollak et al., 2020b). A robot's appearance and size affect preferred proximity and speed, as larger robots require greater distance and a slower pace (Arai et al., 2010; Mumm and Mutlu, 2011; Rubagotti et al., 2022). A robot's increased speed or reduced proximity places increased stress on the human operator (Arai et al., 2010; Nonaka et al., 2004; Rubagotti et al., 2022), although a robot's clear acoustic warning signals may mitigate the effect (Fischer et al., 2014).

Close human–robot collaboration requires human employees to develop greater situational awareness and highlights the importance of the robot following a safe trajectory (Lu et al., 2022; Simone et al., 2022). Recent research suggests that a robot user's control over a collaborative robot (e.g., the option of switching to a manual mode) decreases the user's experienced stress, but a perceived lack of control may be compensated for by extensive training and familiarization with robot operation (Pollak et al., 2020a; Robagotti et al., 2022). This is in line with the finding of Vänni et al. (2019) that the main potential causes of stress (or robostress) may be a user's lack of time for and training to use the robot.

Apart from robotic features, social practices and norms established in human–human interaction affect the cooperation between humans and physical robots. Humans seem to be more sensitive to robot behavior and less tolerant of the robot violating their personal space than they would be with other humans (Joosse et al., 2013), although this tendency may decrease as experience with robots increases (Takayama and Pantofaru, 2009). Robots that mirror humanlike interactions or adapt to human behavior may increase their operators' ability to cope with stress (Landi et al., 2018; Lohani et al., 2016; Messeri et al., 2021). In addition, the perceived personality or "likability" of a robot may enhance individuals' appraisals of psychological safety (Lasota et al., 2017; Mumm and Mutlu, 2011; Robert et al., 2020).

3 Methodology

The aim of this study required data that reflected 1) actual real-life users' experiences of physical robots in work contexts and 2) the context-specific characteristics of events humans perceive as stressful when working with physical robots. We decided to collect data using a qualitative online questionnaire since the qualitative research approach is valuable for providing insights into emerging phenomena and unveiling the contexts of actions (Lune and Berg, 2017; Myers, 2020). To capture the richness of stressful experiences, we applied the critical incident technique (CIT; Flanagan, 1954) and qualitative content analysis.

3.1 Data collection

The CIT is a qualitative method based on research participants' own descriptions of their particularly significant experiences or "critical incidents" (Gremler, 2004). Participants are asked to describe the incident in as much detail as possible (Meuter, 2000), and the technique has the following benefits: First, the CIT allows participants to define what is important to them in their own words (i.e., the data are collected from the respondent's perspective; Gremler, 2004). Since stress is a subjective phenomenon (Fischer and Riedl, 2017), the CIT allowed us to collect data on the multiple nuances of stressful events occurring in work contexts. Second, the CIT as a data-driven method is particularly useful for providing new knowledge about emerging phenomena without strictly predefined hypotheses or concepts (Gremler, 2004), which is suitable for our research focus on the changing field of robotics and the largely uncovered interrelation of physical robots and technostress. Finally, the CIT is a useful way of gathering rich data on actual firsthand user experiences (Gremler, 2004), as required in our study. Critical incidents can be either positive or negative, but our study focused on negative stressful experiences. During the data-collection process, we followed the CIT guidelines provided by Gremler (2004), as explained below.

To reach actual robot users, we utilized the online platform Amazon Mechanical Turk (MTurk), which offers a wide target audience from various backgrounds. In MTurk, registered users can participate in various tasks, such as answering questionnaires, for monetary rewards. We followed the recommendations of Jia et al. (2017) and restricted participants to those located in the United States (US), as the US population of MTurk was comparable to other online and offline research populations (Mason and Suri, 2012). To ensure data quality, we restricted participants to those with a human intelligence task (HIT) approval rate of at least 95% and set the minimum number of respondents' previously approved HITs to at least 1,000. Additionally, we filtered the participants into different study paths based on their backgrounds (e.g., participants without actual user experiences of robots could follow a question path about their attitudes and perceptions and thus be paid without being led to misrepresent their identity; Jia et al., 2017). We used participants' MTurk IDs to ensure that each ID could answer the questions only once. Furthermore, the participants were offered reasonable compensation (Jia et al., 2017) above the US federal minimum wage. After data collection, we excluded responses that did not meet our quality criteria (e.g., clearly did not answer the questions asked, copied answers from the Internet, reported not having experienced stress, or failed the attention check question, although the last was not used as the only criterion for exclusion).

We conducted a pretest and a pilot study in December 2021 that allowed us to assess the quality of the questionnaire and make minor wording changes. The pilot study responses were included in the final dataset. The rest of the dataset was collected between January and March 2022. The questionnaire consisted mostly of qualitative open-ended questions. In addition, some closed questions were added to collect background information (e.g., regarding age, gender, and education), and critical incident–related questions asked about the duration and timing of the experiences. We targeted employees who were working with physical robots (or had done so in the past), either using them or working alongside them. More specifically, we asked if they had "used physical robots at work (more than tried/trialled)." We defined the term *physical robot* as any robot technology with a physical embodiment excluding, for example, software robots and chatbots. The questionnaire also included questions concerning other studies to be conducted in the future.

Following the CIT examples in the information systems (IS) field provided by Salo et al. (2020) and Salo and Frank (2017), we asked the respondents "to think of a time that stands out in your mind as the most stressful experience when working with a physical robot." Next, we asked the respondents to describe in their own words and in detail what happened during their stressful experiences. Furthermore, we asked about their own perceptions of the root causes of their stressful experiences. To decrease the effect of the limitations of CIT, such as recall bias and respondents' usual unwillingness to take the time to write comprehensive answers (Gremler, 2004), we asked the respondents to recall their experiences and explained that we would take comprehensive answers into account when determining the total duration of completion and compensation for the task.

The final dataset for this study consisted of 197 respondents who had experience working with physical robots. Sixty percent of the respondents were male, thirty-nine percent were female, and one percent chose not to answer. Their ages ranged from 21 to 80 years. The vast majority were employed either full-time or part-time, but a few were students or retired, and one was unemployed. The respondents represented multiple industries and had worked with multiple kinds of robots, including industrial robotic arms, delivery robots, and other kinds of service robots. The manufacturing, information and communication technology, retail, health care, and medical industries were among the most commonly mentioned. Respondents' descriptions of their stressful experiences ranged from 1 to 17 sentences, and all of them answered supporting questions about the robot related to the experience and the perceived root cause of the experience.

3.2 Data analysis

With the CIT, the purpose of analysis is to identify possible emerging themes or patterns from reported incidents (Bitner et al., 1990). Therefore, once we had collected the descriptions of critical incidents, we analyzed them using content analysis (Gremler, 2004). We followed the established procedures of qualitative content analysis presented by Lune and Berg (2017) to explore the emergence of experienced technostress among employees working with physical robots, aiming to identify the conditions that contributed to stressful experiences.

The first author began the analysis by reading through the data and establishing initial data-driven categories related to the research problem. In this phase, initial patterns started to emerge from the data. While the first author was primarily responsible for the coding and analysis, the interpretations were discussed in regular meetings with the second author. After rereading the data, all the authors considered the patterns in light of the relevant literature on technostress (e.g., Tarafdar et al., 2019). Tarafdar et al. (2019, p. 9) described so-called technology environmental conditions as "characteristics of IS that have the potential to create a demand in an individual." Since various robot-related environmental conditions could be identified from the employees' stressful experiences, the first author next coded all the relevant text portions into the theme of "robot-related environmental conditions," which included 14 subcategories, such as technical malfunctions, safety, and the robot's unadaptability. After the initial analysis and discussions among the authors, an independent rater coded a sample of data (n = 50) to validate the coding process and findings. The findings supported the initial analysis, with an intercoder reliability rate of 91%. The final set of codes was agreed upon after careful consideration and discussion of the contradictory interpretations. The subcategories of robot-related environmental conditions were then discussed among the authors and comprised three main categories: 1) technical problem–related conditions, 2) robot characteristics–related conditions, and 3) work-related conditions.

Apart from robot-related conditions, the data provided information about conditions that contributed to stressful experiences but were not directly linked to IT. For example, a respondent facing setup issues due to IT complexity could perceive their lack of experience as an influencing factor. However, these conditions were excluded from this study, as we decided to focus specifically on robot-related conditions—but acknowledging stress as a more complex phenomenon.

Finally, we evaluated the reported stressful experiences and the identified environmental conditions affecting them in light of prior technostress research and the established technostressors of techno-complexity, techno-uncertainty, techno-invasion, techno-overload, and techno-insecurity (e.g., Ragu-Nathan et al., 2008; Tarafdar et al., 2019). In cases where multiple environmental conditions were related to a single incident, we included them in the appropriate respective categories.

4 Findings

In this section, we present the findings of our study. First, we introduce the three identified categories of robot-related environmental conditions contributing to the emergence of technostress: 1) *technical problem–related conditions*, referring to technical problems or challenges that affect the work with a robot but are not necessarily connected to the robot itself—that is, they may be less context specific; 2) *robot characteristics–related conditions*, including typical robotic features that could trigger stress as they are, and 3) *work-related conditions*, referring to the employees' work environment and the task the robot is used in. The categories may not be mutually exclusive and possibly include some overlap among them. However, the categories highlight the different viewpoints of environmental conditions as perceived by the employees. These categories included multiple characteristics of robots, and the specific contexts of working with physical robots that led to stressors.

Consequently, we also discuss the identified technostressors (i.e., the creators of technostress). Table 1 presents a summary of the robot-related environmental conditions contributing to the emergence of technostress, including examples of technostressors.

Technical problem–related conditions	*n*	Example techno-stressor	**Robot characteristics–related conditions**	*n*	Example techno-stressor	**Work-related conditions**	*n*	Example techno-stressor
Technical malfunction	55	Techno-complexity	Unadaptability	28	Physical insecurity	Criticality of the work task	28	Techno-complexity
Programming	45	Techno-complexity	Interaction	25	Techno-complexity	Robot–environment fit	13	Unfitness of IT
Setup	18	Techno-complexity	Reliability	15	Techno-uncertainty	Safety	13	Psychol. insecurity
Maintenance	6	Techno-complexity	Personality	6	Invasion of personal space	Job loss	4	Techno-insecurity
Electricity issues	6	Techno-complexity	Inability to cooperate with other systems	4	Techno-complexity			

Table 1. Robot-related environmental conditions contributing to technostress.

4.1 Technical problem–related conditions

The most frequently mentioned environmental conditions contributing to the emergence of technostress were technical problem–related conditions. Unsurprisingly, **technical malfunctions** were the most common condition leading to employees' perceived stress, including technical errors and glitches that caused robots to shut down completely or fail to perform assigned tasks. Causes of technical malfunctions could be broken parts, such as a defective motor or suction valve, or more obscure mechanical bugs, for which the cause of the malfunction remained unidentified:

> *The robot refused to maintain grip on a 30lb spool. It would just drop the part before getting to the conveyor. A 5 min cycle that repeated for hours despite having every tech and their mother try to troubleshoot the issue.*

One of the employees described an incident that included a technical malfunction as "normal wear and tear on machinery." Similarly, some employees seemed to perceive technical malfunctions as unavoidable or a normal part of working with physical robots. However, perceived stress certainly stemmed from the circumstances: technical malfunctions often led to interruptions or distractions from work, which could contribute to increased time pressure or workload.

Programming contributed to stress on occasions when, for example, faulty programming led to unintended consequences or the reprogramming of a robot proved to be complex or problematic. In some cases, the programming caused stress because of the standards set for the assigned task:

> *The robot had to be programmed to include an additional type of item to be sorted. It was difficult because it took a long time to write the software, and then it had to be tested through trial and error. The robot needed to meet a certain accuracy/success at sorting for it to be considered acceptable.*

Notably, employees often described programming mistakes made by someone else since they, as robot users, were not always personally responsible for programming. However, some employees reported stressful experiences with initial trial-and-error programming, in which stress was often linked to a lack of experience and insufficient skills.

Closely related to, and partly overlapping with, programming were issues related to the **setup** of robots. Besides programming and calibrating, setup may include, for example, preparing an environment suitable for the robot to navigate. One employee described a hardware-related incident in which the electrical wiring of a therapeutic robot was set up incorrectly, so "instead of being therapeutic, it was causing major stress to the patient and making things worse." As with general programming issues, the setup challenges were often related to complex environmental and task-related demands:

> *The arms needs to do some intricate, and precise work on the products we produce. It took a long time to get them to do the job as accurately as is needed, and even when you got it right, it would not take long for it to get back out of adjustment and ruin some of the product.*

Technical problem–related conditions also included mentions of **maintenance** and **electricity**. Poor and insufficient maintenance of robots, such as a lack of timely updates, could lead to problems and stressful experiences, such as unpredictable interruptions. However, maintenance itself could be complicated and technical, leading to stress, especially in cases where the robot equipment was costly or failures in maintenance caused significant losses in production. Electricity issues included blackouts and power outages that inevitably interrupted work but also resulted in losses of data or a need for rebooting:

> *There was a power outage at our premise, and we had no power backup plan. Once it came back, we tried to reboot the autonomous device only to find that it*

> *had become unfunctional. This resulted in long queues and we had no extra manpower to serve the clients. Besides, we also lacked adequate knowledge on how to fix the issue on time, and hence, we had to stop the robot's operations to avoid any further damages.*

The characteristics of technical problem–related conditions contributed especially to the stressor techno-complexity. Many employees perceived robots as difficult to use and questioned their ability to handle challenging situations. One employee described a robot as having multiple possible functions and stated, "I have had a hard time even navigating the system by myself." When, for example, a technical error occurred, it was often cumbersome to identify the cause of the error before the individual could get around to solving the problem. Because of the complexity of many robots, fixing technical malfunctions or programming issues often requires external support. In addition to techno-complexity, technical environmental conditions contributed to the stressor techno-uncertainty. Some employees felt doubtful about adjusting to technological changes and learning to solve programming or setup issues:

> *I had a hard time implementing the technology and adapting to the different tasks that it was suppose to carry out. I had a hard time and was frustrated whenever the robot had to carry out a task that was different from the pre-set ordinary ones.*

A couple of the described incidents contributed to the stressor techno-overload. In these cases, setting up the robot required employees to work harder and longer to meet the demands imposed on them by the robot's implementation.

4.2 Robot characteristics–related conditions

Some of the employees' stressful experiences were triggered by the robots' characteristics in terms of their typical behavior. Unadaptability reflected a robot's inability to react to changes in the environment or to its inability to adjust its own behavior to the environment and the changing needs of an assigned task. For example, a robot on a production line might not recognize an error and a need to pause the production, instead continuing to repeat its task and causing a jam. Similarly, robots moving goods in a warehouse might not recognize an unexpected obstacle in their way, which, in some cases, could lead to safety hazards.

> *My coworker was working with the robot in the production line for the car production. When robot was combining parts, some parts didn't come together properly and my coworker tried to fix it. But robot didn't see his hand and injured him very bad. I thought robot will kill him and froze. Fortunately robot just injured his hand but it still was a bad injury.*

In addition, employees confronted robots' unadaptability when, for example, a change in work tasks required the reprogramming of the robots. However, the adaptation process could be stressful even if robots were equipped with adaptation capabilities:

> *The robot struggled to understand at first what defects were since they all varied in size and shapes and color. After extensive model building we had a large enough database for the robot to complete the task sufficiently though we still had many false positives.*

The unadaptability of robots contributed especially to the stressor techno-complexity. The need to reprogram or otherwise adapt a robot to the changing needs of the work and the need for employees to be alert to a robot's lack of reactivity highlighted the complexity involved and caused additional confusion. However, the stressful experiences triggered by robots' unadaptability did not always fit into a particular category of established technostressors. Unadaptability is a characteristic of robots that employees cannot influence but must always consider. The possibility of safety hazards, such as getting in the way of a robot, triggered feelings of *physical insecurity* and caused constant stress.

Interaction refers to employees' challenges in communicating with robots. These incidents included robots operated with verbal commands or by means of interfaces via, for example, buttons or touchscreens. Interaction issues occurred when a robot's interface was too complex for an employee to use efficiently or the robot understood only a restricted set of verbal commands given in a certain way. Naturally, these stressful experiences often related to employees' lack of experience and could ease when they learned how to operate the robots. One employee working with a collaborative robot in a warehouse described first having given commands either incorrectly or in too complicated a way:

> *We had just received it from our IT guys and it was supposed to make loading/unloading trucks easier because it would take items from the truck to designated area with a simple voice command, but it kept getting confused.*

Unsurprisingly, the interaction issues contributed to the stressor techno-complexity. The challenges of interaction fostered the impression that robots are complicated to work with and difficult to understand.

Another robot–related condition contributing to stress was the robots' lack of **reliability**. Some employees had difficulty trusting robots to execute the tasks assigned to them, which could stem from repeated technical malfunctions, readjustment needs, or the criticality of tasks. The lack of reliability seemed to contribute especially to the stressor techno-uncertainty—employees felt obligated to rely on robots, whether they wanted to or not.

In a few cases, the environmental condition contributing to stress was the robot's **inability to cooperate with other systems**. In these incidents, the robot lost a connection with another system or failed to read another system's code to guide its next movements, which contributed to techno-complexity and hindered or interrupted employees' work. Finally, some employees had stressful experiences due to the robots' **personalities**. A robot's personality refers to the humanlike features employees attach to the robot they work with. In most cases, robots were designed to imitate humans, such as a concierge robot in a hotel or a social robot, but some employees stated that a robot seemed "aggressive" or to be deliberately "not cooperating." A robot's voice might resemble that of a human but in a "strange" and therefore stressful way, or social robots might not meet employees' expectations and feel "impersonal" despite the simulation of emotions and humanlike behavior. Nevertheless, a production line robot without designed humanlike features appeared to have a personality, as in this example given by one employee:

> *It was on the fritz, and it was going at a pace that was much higher than expected, so even though I know I shouldn't anthropomorphize it, it looked like it was angry. And I for the first time, I needed to power it down, and even though I knew it wouldn't suddenly jump back to life, it still felt like it could, which was creeping me out.*

The established technostressors did not seem to capture the stressful experiences triggered by the robot's personality, and, in a way, the robot's characteristics seemed to *invade an individual's personal space*. As seen in the preceding examples, some employees associated certain types of robot behavior, such as unadaptability, with the behavior of a human employee. The dissimilarities between a physical robot and a human could increase the stressful effects of robot-related environmental conditions.

4.3 Work-related conditions

A robot's role at work is especially manifested in the **criticality of a work task**. In this case, criticality refers to a condition in which a robot is assigned to execute tasks with so-called high stakes, such as robots in the healthcare sector used to treat patients or robots handling especially rare or expensive materials. In such instances, the robot's role is absolutely critical, and there is little room for failure.

Consequently, the employees' stressful experiences often stemmed from the criticality itself, rather than from errors or obvious reasons not to trust the robot to work flawlessly:

> *Our surgical suite had been waiting for the Da Vinci surgical robot. There had been much hype about it and we had been shown videos. On the day the robot arrived, three of us, as the lead surgical nurses, were asked to attempt to operate the robot based on the videos we had been studying. This was very stressful and my heart skipped a beat. I felt intimidated and was nervous. It was one thing to watch a video of a person operating the robot and quite different actually operating it.*

As seen in the preceding example, the criticality of the task stresses the need for high levels of competence. In a similar vein, one employee described working with a robot that checked vehicles for bombs: "It was stressful taking the course to qualify as an operator of the robot. If I failed, it would put my job in jeopardy."

The criticality of work tasks contributed especially to the stressors techno-complexity and techno-uncertainty, which was emphasized in situations where the robot seemed difficult to use or work with. The importance of employees having sufficient skills to control robots' execution of critical tasks could also lead to uncertainty. Additionally, in some incidents, task criticality required employees to follow extra security requirements and procedures, which contributed to the stressor techno-overload.

In some incidents, the primary environmental condition contributing to stress was the poor **robot–environment fit**, the fit or match of a robot to its work environment. If robots were used in unsuitable environments, employees working with them tended to experience stress, such as when physical obstructions in the environment restricted a robot's work or when the robot was used in an environment or situation that was clearly inappropriate:

> *The robot was a greeter for a conference. I saw the attendees' expressions as they met the robot and many of their first reactions were clearly negative. I had to develop a way of deflecting criticism and try to make the attendees keep an open mind.*

A poor robot–environment fit did not seem to contribute to any specific established technostressor. Some of the incidents hinted at uncertainty or complexity, but the root cause may have been the *unfitness of IT* in a given situation or environment. In other words, the robot did not fulfill the role assigned to it as desired by the employees.

Issues related to **safety** were often closely related to the unadaptability of robots, due to which technology seems to lead to physical insecurity. However, safety issues presumably also affect employees' *psychological insecurity*. Some employees felt stressed simply by the need for caution when working with robots, but in many cases, safety issues arose from unexpected incidents, as in this case described by an employee working with a box-moving robot:

> *Got pinned to a set of metal shelves and when the robot turned to lift the box up to a higher shelf, it lost it's grip on the box. The heavy box headed on the top of my head, spilling all sort of kitchen cleaning chemicals all of me and the floor.*

Finally, some employees experienced a fear of **job loss**. These employees witnessed an increasing automation of work accompanied by the replacement of coworkers with robots. Consequently, they anticipated losing their own jobs. This environmental condition affected their daily work and led to stress. This fear of job loss due to automation contributes to the stressor techno-insecurity, which describes experiences of jobs jeopardized by IT.

5 Discussion

In this study, we examined how technostress emerges among employees working with physical robots by identifying robot-related technology environmental conditions (Tarafdar et al., 2019) that have the potential to lead to stress. In addition, we also examined the identified robot-related environmental conditions in light of the technostressors established in prior technostress research (i.e., techno-complexity, techno-uncertainty, techno-invasion, techno-overload, and techno-insecurity; e.g., Ragu-Nathan et al., 2008; Tarafdar et al., 2019). We identified several robot-related environmental conditions that potentially contribute to technostress, such as technical problem–related conditions (e.g., technical malfunctions), robot characteristics–related conditions (e.g., robots' unadaptability), and environmental conditions related to the work itself, such as task criticality.

Our study contributes to the existing technostress literature in the following ways: First, our study extends the research to the novel context of working with physical robots. Prior research on robots has suggested that humans tend to react differently to robots with a physical embodiment than to merely virtual ones (Broadbent, 2017) or traditional IT environments, resembling relationships with other humans (Mumm and Mutlu, 2011). In similar vein, our findings reveal that the emergence of technostress in the context of physical robots has distinct characteristics, as robots are agentic IT artifacts instead of passive tools (Baird and Maruping, 2021). Second, our study sheds light on the complex entanglements involved in the emergence of technostress (Salo et al., 2022), as our findings show that the technostressors identified in prior literature do not thoroughly explain employees' perceived stress in this context.

The identified technical–problem related conditions were less context-specific, as they were not necessarily connected to the robot itself. Therefore, the identified conditions contribute to the established technostressors, especially to the stressor techno-complexity through difficulties in robot operation. Robot characteristics–related conditions and work–related conditions contribute to the stressors techno-complexity and techno-uncertainty through the constant need for new learning, but the established technostressors do not thoroughly explain these experiences. Identified conditions of a robot's unadaptability and various safety issues can contribute to both physical insecurity and psychological insecurity due to IT. Prior technostress research has identified "security-related stress," but the concept has been used to describe information security, or employees' stress due to an organization's information security requirements (e.g., D'Arcy et al., 2014b). Techno-insecurity refers mainly to employees' fear of losing their jobs because of IT (Ragu-Nathan et al., 2008). We conclude that the physical and psychological insecurity imposed by the characteristics of physical robots offers a new perspective to be considered in technostress research.

Furthermore, the perceived personality of a robot seems to contribute to technostress in a previously unidentified way. Besides the personality of a robot, some employees associated robot behavior, such as unadaptability, with the behavior of a human employee. The dissimilarities between a physical robot and a human may increase the stressful effects of robot-related environmental conditions if the robot invades an employee's personal space or violates cultural norms or conventions. Prior research has suggested that the perceived personality as well as humanlike interactions of a robot and its adaptation to human behavior may increase their operator's ability to cope with stress (Landi et al., 2018; Lasota et al., 2017; Lohani et al., 2016; Messeri et al., 2021; Robert et al., 2020). Our findings suggest that a physical embodiment of a robot combined with its motion and speed distinguishes the examined context from previous technostress research, as physical robots may concretely invade an employee's personal space with adverse consequences for the employee's physical and psychological well-being.

Finally, a poor robot–environment fit contributes to technostress via the unfitness of the IT. Prior technostress research has covered task–technology fit as a mitigator of technostress (Ayyagari, 2012; Vendramin et al., 2021), although poor task–technology fit is recognized as causing distress (Goodhue, 1995). However, in the context of physical robots, poor fit may also involve the physical environment. If robots were used in unsuitable environments, such as in a hotel supposed to offer personalized customer service, employees working with them tended to experience stress.

In addition to technostress research, our study contributes to research on robot-related stress. Prior research in this area has focused on the importance of safety (Capuozzo et al., 2019; Rubagotti et al., 2022). Our findings confirm the significance of both physical and psychological safety but also illustrate the variety and complexity of stress-inducing conditions potentially contributing to robot-related stress.

In addition to the research contributions, our study has some practical implications. Our findings show that employees may be negatively affected by common technical difficulties and IT characteristics specific to working with physical robots. A robot's unadaptability, for example, can highlight the importance of adequate safety requirements in the work environment. Besides physical safety, organizations using or implementing physical robots should consider employees' psychological safety, especially in high-stress environments. Organizations may be able to mitigate the effects of the perceived complexity and uncertainty of working with robots by investing in training employees to strengthen their self-efficacy, which could also compensate for a perceived lack of control (Robagotti et al., 2022). From an individual employee perspective, the findings may help employees recognize the antecedents of perceived stress and adjust their work routines accordingly, if possible.

There are some limitations to our research. First, perceived stress may vary depending on the industry, type of robot, or employee role, which are factors we did not focus on. As such, the robot-related environmental conditions identified in our study are certainly not complete but do reflect the experiences of the participants in this particular study. Second, collecting data with a questionnaire involves some limitations, such as the inability to ask clarifying questions and confirm interpretations. Third, the CIT as a data collection method has some limitations, such as the possibility of recall bias and the selective nature of the collected data (Hughes, 2008), since the technique may not capture everyday or gradually evolving stress. Finally, despite the iterative and collective process, the initial analysis of the data was mainly based on the interpretation of one author.

Since some of the employees described technical malfunctions as everyday events, it is likely that some elements of technostress related to working with physical robots accumulate over time (Salo et al., 2022). Therefore, we encourage future research to investigate technostress in this specific context utilizing, for example, qualitative interview approaches. The insufficiency of the established technostressors and the identified importance of physical and psychological insecurity, as well as the possible unfitness of IT and the invasion of employee's personal space, call for more research and validation. Furthermore, the relationship between the perceived personality of a robot or its anthropomorphic features and technostress remains largely unexplored. Prior research has suggested that these features may mitigate stress (Benlian et al., 2021), but our study implies that the relationship may not be straightforward. The emergence of technostress may vary according to robot type, requiring further research in different and more specific contexts, such as in the context of virtual robots. Finally, future research should examine the effect of identified stress-influencing factors on individuals' coping strategies and the mitigation of technostress among employees working with physical robots.

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