BEYOND TECHNOLOGY – THE COGNITIVE AND ORGANISATIONAL IMPACTS OF COBOTS

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Abstract

Work environments are radically changing with the adoption of new technologies. As the trend for automation grows collaborative robots or "*cobots*" are being increasingly adopted by organisations from various industries. As opposed to traditional industrial robots, collaborative robots are complex socio-technical systems that allow close interaction between robots and humans. As a result, these systems can have significant impact on the physical and mental well-being of individuals, and safety can be ensured only by addressing physical, cognitive, and organisational factors. This study aims to provide an understanding of the work practices and behaviours in relation to the cognitive and organisational impact of cobots in Australian industries. By raising awareness of the key challenges and possible solutions to address them, this study provides contributions to academia and industry practice.

1 Introduction

Recent trends in mass customisation and reduced lead times have increased demand for flexible multi-purpose manufacturing systems (Matheson et al., 2019). In this context, collaborative robots or cobots represent an accessible and flexible solution for automation. Compared to traditional industrial robots, cobots are less expensive, more flexible, and do not require heavy fence guarding. In addition, cobots are easy to programme, often including learning by demonstration features which allow non-experts to set the actions required for a specific task. These characteristics often meet the needs of small-medium enterprises for easy and flexible automation (Matheson et al., 2019).

Although cobots currently make up a relatively small proportion of the robotics industry (approximately 3% of robot sales), the cobot market size is expected to increase with sales of 34% by 2025 (Bi et al., 2021). In terms of robot population density, Australia does not find itself among global leaders (Robotics Australia Group, 2022). In the manufacturing sector, the great majority of Australian enterprises are small-sized and the uptake of robotics has been generally limited. This is due to high barriers of entry to traditional robot systems, e.g. complex safety requirements and lack of programming competences. However, the fragility of international supply chains caused by the COVID-19 pandemic have intensified pressure on Australian manufacturers. An increased adoption of robots and cobots could provide greater competitiveness and productivity (Robotics Australia Group, 2022).

With this, safety concerns become more important as cobots are being increasingly used in varying contexts, including industrial cobots, service cobots and medical cobots (Djuric et al., 2016). To ensure safety, human factors must be considered in the design of collaborative applications (Faccio et al., 2022). Human factors (or ergonomics) are defined as the scientific discipline concerned with the understanding of interactions among humans and other elements of a system, and the profession that applies theory, principles, data and methods to design in order to optimise human well-being and overall system performance (ISO 26800:2011). Thus, human factors focus on the psychophysical and social wellbeing of operators (Gualtieri et al., 2021). Accordingly, a safe design should maintain a human-centered focus, considering physical, cognitive and organisational aspects (International Ergonomics Association, 2022). Standards exist for both industrial robots and cobots (ISO/TS 15066; ISO 10218-1; ISO 10218-2), and they provide a variety of protective measures as a prerequisite for the implementation of safe human-robot collaboration. However, these standards maintain a strong focus on physical factors associated with the use of robots and cobots. In the Australian regulatory landscape, a new code of practice has recently been publishes that requires businesses to eliminate or minimise psychological risks in any workplace (Safe Work Australia, 2022). At the same time, research has been increasingly highlighting risks impacting not only physical but also mental well-being.

This study aims to understand the levels of awareness in relation to the cognitive and organisational impact of cobots within Australian industries. To generate a positive effect on humans, physical and mental well-being need to have equal importance. By reviewing existing literature and using a contextual enquiry methodology with participants from various Australian industries, this study aims to provide an overview of the current practice for protecting individuals' well-being in the context of cobot applications, maintaining a focus on mental well-being.

2 Background

Ensuring safety in a workspace where humans and cobots closely interact is complex (Gualtieri et al., 2021). In fact, cobots are complex socio-technical systems, i.e. require the interaction between humans, machines, and other environmental aspects of the organisational system (Baxter & Sommerville, 2011; Davies et al., 2017). For such systems, safety depends on all these elements and their interaction. To analyse the effects on the mental well-being and the current industry practice, this study uses the framework supporting the definition of human factors (or ergonomics), which integrates the areas of physical, cognitive and organisational ergonomics (International Ergonomics Association, 2022) (see Figure 1). On one hand, cognitive ergonomics is concerned with mental processes such as perception (International Ergonomics Association, 2022). While cobots promise to replace physically demanding tasks, the close interaction may cause mental stress and discomfort. On the other hand, organisational ergonomics is concerned with the broader optimisation of socio-technical systems (International Ergonomics Association, 2022). A negative effect on individuals' mental well-being may also be caused by organisational factors, as the introduction of cobots to the workplace affects structures, policies, and processes (Gualtieri et al., 2021).

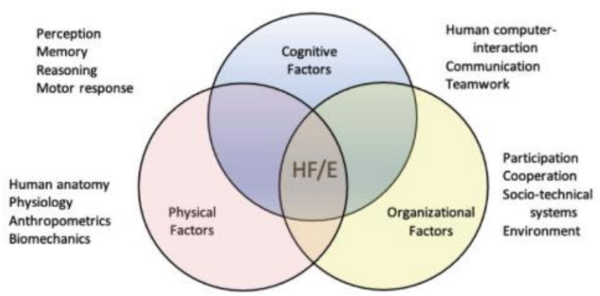

Figure 1 - Human factor and ergonomics key domains (International Ergonomics Association, 2022)

Existing literature mainly focuses on physical factors related to safety. Cognitive factors and organisational ones often receive less interest. At present, in the area of safety for cobots, one third of academic studies relates to cognitive ergonomics, while the remaining focuses on physical concerns (Gualtieri et al., 2021). This smaller portion of research tends to highlight the factors contributing to mental health risks such as discomfort, stress, mental strain, mental workload and lack of trust (Faber et al., 2015; Faccio et al., 2022; Gualtieri et al., 2021; Maurtua et al., 2017; Murashov et al., 2016; Rojas et al., 2019; Sauppé & Mutlu, 2015; Tan et al., 2009; Vasconez et al., 2019; Vicentini, 2021; Villani et al., 2018). Some of the contributing factors include characteristics of the task application such as cobot trajectory and speed (Arai et al., 2010), characteristics of the cobot system such as unclear user interface (Michalos et al., 2014) and robot morphology (Sauppé & Mutlu, 2015), as well as broader organisational factors, such as the potential effect on jobs and related fear for displacement (Maurtua et al., 2017). Within this research area, contributions have used experiments, case studies or small sample interviews to understand safety aspects in the use of cobots. This study is based on interviews with a wide-array of participants from various industries and it investigates the current practice and levels of awareness in relation to the cognitive and organisational impact of cobots, focusing on the effects on individuals' mental well-being in particular. While section 4 and 5 provide an overview of the key challenges identified in the literature and the industry, section 6 lists some of the possible solutions.

3 Methodology

To obtain a clear understanding of the work practices and behaviours in regards to safe cobot use within Australian industries, a contextual enquiry methodology has been used. A systematic literature has been conducted on Scopus, which provides high quality scholarly literature. The search string combines terms referring to collaborative robotics (Vicentini, 2020), namely cobot, collaborative robot, human robot collaboration, cooperation or coexistence, with words referring to safety aspects and hazards, including safety standard, guideline or requirements, risks, hazards, and safe design. The relevant contributions (n=23) were selected based on a manual review of the most influential documents (n=114), defined as contributions that have scored an average number of citations equal to 5 or above.

Semi-structured interviews with a sample of selected stakeholders based in Australia were designed based on early insights provided by a literature review focused on identifying the key risks of cobots. The recruitment utilised a combination of purposive sampling and snowball recruitment strategies to capture a wide array of interview participants. The key inclusion criteria were current experience with cobots or robots with knowledge about potential risks and safety implications, as well as organisations that are considering purchasing cobots. A representation of a diverse cross-section of participants and use-cases across industries resulted in 22 participants. The sample includes manufacturers, distributors, suppliers, integrators, cobot users, potential cobot users and industry partners including academic researchers. Participants come from various industries, including robotics/automation, manufacturing, food, physical rehabilitation, work health and safety, and higher education. The table with a detailed summary of the participants can be found in the appendix.

Interviews were conducted between October 2021 and March 2022, prior to the recent release of the Code of Practice for managing psychological risks at work (Safe Work Australia, 2022).

4 Cognitive and organisational areas impacted by the introduction of cobots

The impact of cobots on human mental well-being is connected to mental health hazards in the workplace. Safety is not limited to addressing physical hazards, but also includes safeguarding psychological state of individuals. In the context of cobots, some of the key areas affected by their adoption can be grouped into three main categories (see Table 1).

Table 1 – Cognitive and organisational areas impacted by the introduction of cobots into the workplace

Category	Description	Hazards
Social environment	As opposed to regular settings in which humans interact socially during work, collaborative robots can negatively affect the harmony of the social environment.	Poor workplace relationships and interactions
Social structure	Introducing cobots may change the role of some workers and their agency and induce a general fear of job loss.	Low job control, poor support from managers
Social acceptance	Communities in which cobots are introduced have varying forms of predisposition for such a technology, which influences the level of acceptance.	Poor organizational change management

4.1 Social environment

Introducing cobots in the workplace affects the social environment of the workplace itself. In the literature, studies describe various effects on the social dynamics following the introduction of cobots into the workplace. While some successful cases highlight cobots being perceived as teammates, others point at the potential disruption to the relationships among workers. Results from the interviews conducted for this study describe a neutral attitude, for which workers simply perceive cobots as a tool.

As collaborative robots play a "co-worker" role, operators may relate to them as social entities and their introduction into the workplace affects workers' perception. Operators perceive their relationship with cobots as human-like, and in some instances, they refer to the robot as *"work partner"* or *"friend"*, and they sometimes attribute personality traits or intent to the cobot. Cobots may intrigue people to engage with them by appearing to have personalities show how they mimic human movement or tasks (Sauppé & Mutlu, 2015).

In other less successful cases, some workers may fear that with the introduction of cobots into the workplace they might lose contact with their colleagues (Bröhl et al., 2016; Gervasi et al., 2020).

Despite of the findings from existing literature, the interviews conducted for this study revealed that most participants perceived cobots more as a tool than a co-worker and when cobots were introduced to a new site, several integrators and suppliers commented that most workers were cautious to engage.

4.2 Social structure

Introducing cobots into the workplace affects its social structure, often leading to a change in the roles and levels of agency of some workers. While most interview participants appeared excited about the future of upskilling workers to operate cobots, there seemed little consideration to the loss of artisanal knowledge and skills that might occur. Several integrators and suppliers commented that most workers were cautious to engage with cobots when they are introduced to a new site due to reasons such as the fear for displacement or the loss of agency in their work.

In general, in terms of potential change in roles, the introduction of cobots often induces fear for job losses among workers (Maurtua et al., 2017; Sauppé & Mutlu, 2015). This was supported by the interviews, which highlighted that the primary contributor for stress and lack of trust was the perceived risk of job loss for workers. Participants from a sales background of e.g. cobot manufacturers and suppliers typically underplayed the severity of this risk, stressing that cobots would only replace unwanted "dirty, dangerous, and repetitive" jobs. However, in interviews with cobot user companies it was unclear whether this claim was entirely accurate. One operator explained that although cobots had made their work less dangerous, they also claimed that the process of programming a cobot for different tasks was repetitive and tedious as well as ultimately working with a cobot. Furthermore, a supplier explained *"…in the industry we used to try to tell people that we don't take jobs, but we do take people's jobs… we may take some people's job but we actually save the company"*. This indicates that the fears of job displacement are justified but have not been as strongly considered as other facets of worker health and safety.

In addition to the change of the roles of workers, the interviews revealed the potential impact upon an operator's agency in feeling a sense of ownership and responsibility over their work. This may contribute to a devaluing of their knowledge and skills. We identified two varied examples of this risk in medical and manufacturing settings. The agency of surgeon's knowledge and skills may be challenged by a cobot that is tasked with observing the surgery and preventing the surgeon from conducting incorrect actions. In interviews with a cobot supplier, they highlighted that in manufacturing settings, programming task applications for cobots was typically conducted by more senior personnel. Operators were reported to simply turn cobots on and off at the beginning and end of their shifts. It was reported in the interviews that operators enjoyed the ability to easily tailor cobot programming to fit to their working style and knowledge of specialist task applications. This indicates that a lack of operator engagement in programming cobots may contribute to a lack of worker agency and overall acceptance of cobots in the workplace.

In extreme cases, the fear and stress caused by elements such as changes in the job roles or levels of agency can also result in workers sabotaging cobots. A cobot integrator stated that it was relatively common to hear of operators sabotaging cobot systems as they saw it as a threat to their livelihood. The integrator also explained that sabotaging cobot systems could be a relatively easy task which would not require any programming or technical knowledge.

"You can just go to the teach pendant and just delete a few lines here and there, you wouldn't really need to know what those lines even meant". – Integrator.

The integrator shared various examples of how operators in the past had changed programming to foster collision.

"…They've purposely gone in and sort of tried to change the robot code so it crashes into something on purpose, jammed up a conveyor or destroy sensors installed..." – Integrator.

The integrator further emphasised how easy this is by stating: *"you can just delete a line that checks this specific input, and obviously it will no longer check that input, skip over it and crash into something else".*

4.3 Social acceptance

The likelihood of a community to accept the introduction of cobots is related to the predisposition to accept technology. In general, technology acceptance can vary within communities and it can be positively affected by the creation of workforce awareness (Gervasi et al., 2020). In an interview with an integrator, they claimed that brand-new factories would be the only setting in which they would not anticipate workers sabotaging cobots, as there was simply no workplace structural history for cobots to change in the first place. Distributors noted small to medium-sized enterprises were more likely to accept such changes like introducing cobots as management often includes and consults workers in the adoption of new technologies. Acceptance is also related to the levels of trust workers have in respect to cobots. In fact, trust has become an important factor to consider (Djuric et al., 2016; Maurtua et al., 2017). More generally, human perception is an important aspect for the acceptance of cobots, as individuals will not accept an untrustworthy robot (Zacharaki et al., 2020). Maurtua et al. (2017) proposed a study in which they conducted experiments to assess the opinion of workers in regard to the interaction mechanisms and safety. The experiments involved different tasks and the workers' feedback has been collected through questionnaires. Results revealed positive levels of trust, along with the widespread opinion that cobots will help reduce the number of demanding tasks and ultimately increase productivity (see Figure 2).

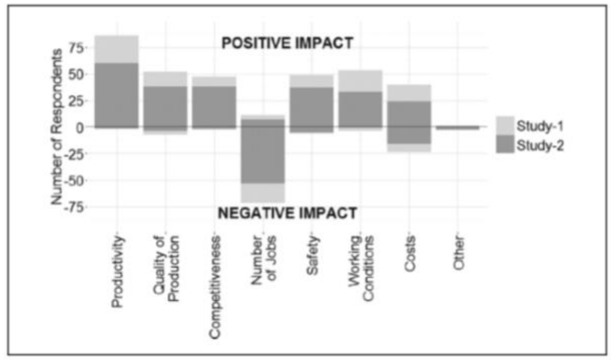

Figure 2 – Workers' opinion survey (Maurtua et al. 2017)

5 Current state in industry practice

5.1 Cobot or robot – that is the question

A prominent issue identified in the interviews was that cobot user companies installed and used cobots for inappropriate applications. This issue was caused by unclear definitional distinctions and use-cases between cobots and industrial robots. Interview participants often used the terms 'robot' and 'cobot' interchangeably to describe human-robot collaboration. If left unclear, companies may use their industrial robot for intended collaborative use or mis-use cobots for non-collaborative applications. Cobots are a special type of industrial robots particularly designed for direct and safe interaction with humans (Romero et al., 2016). While industrial robots applications require to separate the working area with clear physical or sensor-based barriers, such boundaries are not necessary for cobots as they host safety mechanisms that prevent harm to humans (Villani et al., 2018). The following section explores emerging patterns and implications upon cobot safety for use cases outside of the clear conceptualisation of a cobot, either using industrial robots for collaborative applications or using cobots for non-collaborative applications. These patterns not only may contribute to the generation of physical risks, but also create mental stress and discomfort within individuals, thus lowering the levels of social acceptance.

5.1.1 Industrial robots for collaborative applications

While the standards clearly differentiate between industrial robots and cobots, the industry has progressively blurred this line by introducing products that convert existing industrial robots for collaborative use.

"I do know of some products that can be installed on industrial robots that make them behave like cobots. I think they're called Airskin I think something like that. Where if the capacitive pads make contact with the human, they basically stop instantly, it's almost like an e-stop" – Integrator

Airskin is a modular, add-on safety peripheral that enables human robot collaboration for industrial robots (Wohlkinger & Baldiner, 2021). It is marketed to enable fenceless applications and faster collaborative movement than traditional cobots. It should be noted that distributors and integrators stressed the importance of slower speeds for collaborative robots as critical for minimising serious harm caused by collision. Furthermore, considering that industrial robots are not designed for collaborative use, it is also important to consider whether they have adequate safety sensors and the computational power to adequately run safety detection programs in appropriate time to prevent hazardous collisions.

Although interview participants were aware of the potential of industrial robots for serious harm, they also acknowledged that there was a strong business case for converting industrial robots for human-robot collaboration. Since industrial robots operate at much faster speeds and higher payloads, collaborative applications can significantly increase the potential for serious physical and psychological harm.

"…It [industrial robot] doesn't stop in a safe manner. I've seen robots collide with conveyors and basically bend them. And then it will stop." - Integrator

As the business case for human-robot collaboration continues to grow in Australia, especially for small to medium-sized enterprises, there will be greater interest in enhancing existing industrial robots to operate more collaboratively. This was reflected in the interviews when a cobot researcher shared that they were actively working on converting an industrial robot for collaborative use.

"We're trying to think of cobots as robots that can work closely with people and in fact they don't need to be this so-called cobots that people are selling as cobots. We think some cobots may be much bigger robots, we've got a 200 kg payload robot here that we want it to be a cobots in some situations. Because it's about how it performs, not about some arbitrary label that says 'it can do this' because if it's set up correctly and we can verify it set up in the right way…Then there's no reason why it also can't be a Cobot." – Interviewed researcher

5.1.2 Cobots for non-collaborative applications

"A safety system is safe unless an operator needs an extra tool to sort of defeat it." - Supplier

It became clear in the interview study that users assumed that cobots were inherently safe, meaning that they did not prioritise human safety as their main consideration for using cobots. While cobots have safety features that help minimise harm and comply to standards that make them safer for collaborative use, the danger of marketing them as 'safe alternatives' can lead users to assume that cobots are safe and appropriate for any application that requires collaboration. This expectation was exemplified when speaking to a potential buyer of cobots, who explained "*you don't have to worry about the risks with cobots*". As this interview participant was an executive driving the future of a major manufacturing industry in Australia, there are large-scale ramifications for this type of assumption. This was a consistent response when users were asked about specific risks and harms associated with cobots.

"I can go and sell a collaborative robot but it doesn't mean that the application is collaborative". – Supplier

The main contributor to non-collaborative applications was not the cobot itself but the end-effector and the task assigned to a cobot end-effector. In fact, the most common example of how cobots could be used for non-collaborative applications is the use of unsafe end-effors, such as the installation of a sharp end-effector. A freely moving sharp object could never be safe for collaborative use with humans as it would e.g. circumvent force limitations. Furthermore, an open blade in any workplace remains dangerous even if a cobot is turned off – same applies to other tools like drills etc. This reveals an emerging misunderstanding in what exactly is 'safe' about cobots between cobot users, integrators, and manufacturers.

This misunderstanding of safety stems from misaligned expectations and definitions of what components are considered safe. Suppliers and manufacturers sell cobots as part machines. A part machine cobot comprises of four components; the manipulator (arm), controller/ cabinet (computer & drivers), connecting cable between manipulator and cabinet, and the teach pendant (human interface). As a part machine, suppliers and manufacturers can assure that these components are safe. However, as a part machine cannot perform any task, an end-effector is needed to create a complete machine. Usually, this is the task of the integrator to 'complete' the machine to the local standards, including installing safety certified end-effectors and assessing the task application.

However, cobot users are not required to consult with integrators to purchase a cobot and end-effectors or to change the task and setting of a cobot. 'Plug-and-play' cobots make it easier for end users to change the task application post implementation. In the case of integrated and/or 'plug-and-play' cobots, end users' tend to assume that it is safe for any application. On one hand, interviewed cobot users did not have a clear understanding of the difference between a part and complete machine and how that impacted upon safety. On the other hand, interviewed suppliers noted that they were aware of this misunderstanding and suggested that there needed to be greater awareness surrounding what components they consider safe and where the responsibility of different aspects of cobot safety lay.

5.2 Limited consideration for psychological risks and harm

During the interviews, there appeared to be little consideration of the psychological risks that could occur when working with cobots. Interview participants were asked questions regarding various psychological risks stated in literature that could occur. However, despite multiple attempts, participants rarely shared insight into this area. The most prominent cause of distress raised by interview participants was anxiety and stress caused by job precarity.

An interviewed cobot user responsible for managing operators offered their insight into this apparent gap in prioritising psychological risks. They suggested that the traditional cultural context of manufacturing and industrial workshops could make it difficult for operators to feel comfortable in openly and candidly discussing the psychological effects of working with cobots. The fear of being perceived as weak and valueless was touted as another factor that limited participant disclosure of psychological harms. As male-dominated industries, this culture has historically resulted in an under reporting of psychological impact of work upon workers. While outside the scope of this research, investigating the influence of gender upon the reporting of psychological risks would benefit from further research.

5.3 Varied minimum training requirements

The interviews identified a discrepancy in what different actors in the cobot industry understood as essential competencies, skills, and training to safely use cobots. It was highlighted that there is an inconsistent approach to training across the cobot industry. Interview participants' responses indicated varying expectations regarding minimum competencies, skills, and training required to safely use cobots. For some, the entry to engage with cobots was a simple induction program, with these inductions themselves varying in duration from a few hours to a few days. While some interview participants confirmed that they had engaged in some form of formal training, this was not consistent across all interviews. Interview participants reported that usually staff learns by demonstration, on-the-job training, or through experimentation and use. Operators reported that experimenting and testing functions on cobots helped them understand how to use them for specific tasks. However, only one interview participant indicated that they tested programs and function prior to collaborative use. Similarly, cobot users and integrators reported that operators were often not taught how to safely troubleshoot issues with cobots. It is critical that this knowledge gap and dimension is addressed as errors and issues with cobots can increase the risk of physical harm, damage to cobots and other equipment, and psychological strain for operators.

Interview participants had not considered how to ensure compliance with training when faced with a revolving door of new workers interacting with cobots or for staff who are not directly working with cobots. This was a considerable concern for industries with low staff retention rates where training new staff to work with cobots may be time-consuming and expensive. One way that this could be addressed is by integrating cobot training into vocational and trade schools. In interviews with cobot researchers and manufacturers, participants indicated that vocational schools had already begun to incorporate modules to educate students on how to work collaboratively with robots. This sentiment was also echoed by the CEO of a peak body for a manufacturing trade. While this is a promising step forward for the industry, it neglects to acknowledge the tradespeople who already have extensive experience but minimal training in working with cobots and computer interfaces.

6 Implications and conclusions

The key findings from the interviews highlight that discussing cobots with working staff is critical. Open discussions allow to identify potential reservation and mental health risks and it can occur in various ways, including training, demonstrations, and consultation, co-design, and surveys (see Table 2). These approaches allow to address some of the key cognitive and organisational challenges generated by the introduction of cobot into the workplace (i.e. social environment, social structure, social acceptance).

Table 2 - Key solutions to address cognitive and organisational factors

Areas of concern	Action
Training	Training for managers focused on fostering a learning culture while bringing different stakeholder together.
Demonstrations	On-the-job learning together with demonstrations can create a sense of familiarity within workers and improve the acceptance levels among them.
Consultation and co-design	Encouraging staff to optimise their work assignments to their working preferences and to explore how else a cobot can be used allows to increase the sense of workers' agency.
Surveys	Anonymous surveys allow workers to comfortably share feedback and concerns.

Training focused on cobot safety and leadership skills for managers can have a positive influence on the cognitive and organisational impact of cobots. Collaboration with their staff allows to foster a learning culture while bringing different stakeholder together. Ultimately, training provides the opportunity to understand the potential changes that human-robot collaboration introduces, including changes in workers' role. As a result, managers can promote the adoption of collaborative robots as an assistive tool, instead of a possible replacement of the operators, which can reduce the fear of job loss among workers.

On-the-job learning combined with demonstrations of cobot use can create a sense of familiarity of workers with a cobot and improve the acceptance levels among them. More generally, a consistent collaboration between operators and managers can positively influences the social acceptance during transitionary periods.

Encouraging working staff to optimise their work assignments to their working preferences and to explore how else a cobot can be used allows to increase the sense of workers' agency.

Although open discussions can be an effective way of addressing workers' concerns, in some contexts staff may not feel comfortable to openly share their opinions. As discussed, during industrial workshops operators may fear of being perceived as weak and unsupportive and therefore may decide not to share their concerns. In these cases, using anonymous surveys can be an effective solution to capture feedback and concerns, and to further enhance discussion. Bröhl et al. (2016) propose an analysis framework to survey social acceptance of robots in industrial settings. This survey analyses multiple factors that range from context-specific items to aspects related to the interaction between humans and robots. The survey items are summarised in Table 3 (Bröhl et al., 2016; Gervasi et al., 2020).

Table 3 – Sample of items and factors from Bröhl et al. (2016) social acceptance model

Factor	Description
Subjective norm	In general, the organization supports the use of the robot
Image	People in my organization who use the robot have more prestige than those who do not
Job relevance	The use of the robot is pertinent to my various job-related tasks
Output quality	The quality of the output I get from the robot is high
Result demonstrability	I have no difficulty telling others about the results of using the robot
Perceived enjoyment	I find using the robot to be enjoyable
Social implication	I fear that I lose the contact to my colleagues because of the robot
Legal implication (occupational safety)	I do not mind if the robot works with me at a shared workstation
Legal implication (data protection)	I do not mind, if the robot records personal information about me
Ethical implications	I fear that I will lose my job because of the robot
Perceived safety	I feel safe while using the robot
Self-efficacy	I can use the robot, if someone shows me how to do it first
Robot anxiety	Robots make me feel uncomfortable
Perceived usefulness	Using the robot improves my performance in my job
Perceived ease of use	My interaction with the robot is easy
Behavioural intention	If I could choose, whether the robot supports me at work, I would appreciate working with the robot
Use behaviour	I prefer the robot to other machines in the industrial environment

Thus, this study contributes to a more holistic understanding of socio-technical success factors of cobot adoption and resulting work health and safety. In addition, this study allows to inform industry practice and regulators about the levels of awareness in respect to social impact within organisations across industrial sectors.

Acknowledgments

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Appendix

Table 4 – Breakdown of research participants

No#	Interview participant category	Industry/sector	Participant position title
1	Cobot User	Tertiary Education	Coordinator/ Technician
2	Potential Cobot User	Food	Operational Manager
3	Distributor, Supplier, Integrator	Robotics/ Automation	Electronic Engineer
4	Distributor, Supplier, Integrator	Robotics / Automation	Founder & Project Manager
5	Industry Partner (*Risk Assessor*)	Independent Product Safety Assessors	Director
6	Industry Partner (Risk Assessor)	Independent Product Safety Assessors	Business Development Manager
7	Cobot User	Film	Director of Photography & Senior Motion Control Operator
8	Manufacturer	Safety Peripheral Equipment	Chief Technology Officer
9	Industry Partner (Risk Assessor)	Work, Health, and Safety	Work Health and Safety Inspector
10	Industry Partner (Researcher)	Robotics	Professor
11	Industry Partner (Researcher)	Robotics	Senior Lecturer
12	Supplier	Robotics/ Automation	Business Development Manager
13	Integrator	Robotics/ Automation	Director
14	Integrator + Cobot User	Higher Education	CEO
15	Supplier + Integrator	Robotics/ Automation	Project Engineer
16	Cobot User	Physical Rehabilitation	CEO & Founder
17	Cobot User	Custom Manufacturing	Operator and Head of Finishing
18	Industry Partner (Researcher)	Advanced Manufacturing	Professor & Centre Director
19	Cobot User	Higher Education	Technical Officer
20	Cobot User	Custom Manufacturing	Operational Manager
21	Supplier	Cobot Manufacturer	Operational Manager
22	Supplier	Cobot Manufacturer	Sales Engineer

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