European Agency for Safety and Health at Work

Advanced robotics and automation: Implications for occupational safety and health

Summary

European Agency for Safety and Health at Work

Safety and health at work is everyone's concern. It's good for you. It's good for business.

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1 Introduction and objectives

This work is part of the EU-OSHA's research: 'Overview of Policies, Research and Practices in Relation to Advanced Robotics and AI-based Systems for Automation of Tasks and OSH'. The aim of this report is, following the taxonomy developed in EU-OSHA's report "Advanced robotics, artificial intelligence and the automation of tasks: definitions, uses, policies and strategies and occupational safety and health" (EU-OSHA, 2022a), to present challenges and opportunities related to occupational safety and health (OSH) regarding the automation of physical tasks through robotic systems. To support or substitute physical tasks, modern robotic technologies, like mobile robots, assembly robots and exoskeletal robots, are mainly deployed and the scope of physical tasks and functions they can support broadens steadily. This report additionally describes a variety of economic sectors and jobs in which physical tasks are fully or semi-automated. Finally, the impact of their automation through robotic systems on work-related physical, psychosocial and organisational OSH aspects are described and, therewith, the challenges as well as the opportunities for OSH to date and in the future.

2 Methodology

The applied methodology and the major data sources used for this report include systematic reviews and meta-analyses as well as a review of grey literature and forward citation search to identify additional scientific work. The main areas covered in the reviews were artificial intelligence (AI), human-robot interaction (HRI) and automation of tasks, and a specified population-exposure-outcome string. A combined number of 4,070 results were screened, of which 111 contained relevant information for this project. To complement the findings, additional literature research on a variety of sectors was performed. In addition to that, semi-structured interviews of a selected group of experts in the field of advanced robotics were conducted to gain additional qualitative insight into the automation of physical tasks. A total of nine interviews were carried out.

3 Advanced robotics and types of tasks

The results of the research were then categorised into person-related, information-related and object-related tasks, and whether the task in question is fully automated or semi-automated. On an additional level, the automated tasks were divided into routine or non-routine tasks, if they were identifiable as such. The results show that in the reviewed literature not every possible combination of these categories is represented. Currently, available systems mainly support routine tasks. However, as future technological capabilities develop, the automation of more non-routine tasks will become more likely.

3.1 Advanced robotics-based full automation (substitution) of tasks

3.1.1 Person-related

Within a person-related task there is some form of interaction between a person and the technology. This interaction is not limited to the user and the technology specifically, but can also extend beyond these participants. Robotic systems that assist nurses in lifting patients are a prime example of the automation of a person-related task.

Routine task

To be classified as a routine task, the automated process has to have a repetitive element to its steps, which do not change between implementation. The definition of routine from a technological perspective is a lot narrower than from a human perspective. Examples of physical routine person-related tasks can primarily be found in the **healthcare** sector. Robotic **nursing assistants** help nurses by performing non-critical tasks for them, influencing both mental and physical workload. One of them is needle insertion, either to **draw blood** or inject medicine. Specialised nursing robots are capable of **lifting patients** from a bed into a wheelchair or helping them stand up, without the help of a nurse (Kyrarini et al., 2021). **Walking patients and fetching objects** can also be fully automated. **Drinking and eating** assistance forms another usually very time- and labour-intensive task in healthcare (Kyrarini et al., 2021). Specialised **surgical robots** assist and support medical professionals in a variety of tasks. The setting of sutures during surgery is routinely performed by surgeons and a vital factor in the overall success of the intervention (Manolesou et al., 2021).

3.1.2 Object-related

Physical object-related tasks are likely the most well-known form of application for robotic systems. Industrial robots that perform pick and place tasks were one of the first fully automated systems introduced into the workplace.

Routine task

Tasks such as **welding, assembly, paint spraying, packaging and arranging, cutting, moving and sanding** as industrial tasks can be fully automated by robotic systems (Iqbal et al., 2016). This is in alignment with tasks reported by the interviewed experts, who additionally named **heavy lifting**, precise physical activities such as **pick and place tasks**, and the production of small-volume assembly items in a high mix of products/precision works. **Logistics and transportation tasks** are common applications in warehouses, hospitals and supermarkets. Applications of robotics in **mining** are broad and include operating heavy machinery and **lifting** tasks, robotic **dozing, excavation and haulage**, as well as robotic **drilling** and possibly **explosives handling** (Plotnikov et al., 2020).

3.2 Advanced robotics-based semi-automation (assistance) of tasks

While some robotic systems already possess the technological sophistication to perform tasks fully autonomously, there are a number of tasks that benefit from partial automation, in which the human is still actively involved in the process, but not in a supervisory role.

3.2.1 Person-related

Routine task

The medical work environment contains a number of small physical tasks that are routinely performed for patients. Other nursing-related tasks for which robots have been used to assist with are **getting dressed and personal hygiene tasks** (Kyrarini et al., 2021). While the process itself can vary from patient to patient, manual patient handling in the form of moving and **lifting** is both a labour-intensive and frequently reoccurring task. When using the robotic system, nursing staff can simply assist the patient in case of risk of falling or injury (Hu et al., 2011). While these tasks can be fully automated, semi-automated systems are currently more prevalent in the field.

3.2.2 Object-related

Routine task

Especially in the manufacturing setting, some tasks are intentionally moved from no automation towards a semi-automated state, through the introduction of robotic systems. Advanced robotics in industrial and manufacturing settings carry out numerous tasks ranging from **picking, packing** and **palletising, welding, assembling items** and **handling materials** to **product inspection** (Matheson et al., 2019). Currently, these kinds of tasks are performed with varying degree of human involvement or supervision, spanning from collaborative involvement to supervision. Some of these tasks relate closely to the area of construction work. Examples of such tasks are automated robotic **bricklaying, moving heavy items** with a robotic arm and gripper operated by a construction worker, and concrete pumps equipped with specialised sensors that allow measurement of critical operational variables like orientation, angles, depths and distances.

3.2.3 Information-related

Routine task

As mentioned for the case of fully automated tasks, in the reviewed literature, there are no researched cases of information-related physical tasks performed by advanced robotic systems. However, investigation of actual implementations of robotic systems, have identified robotic systems that use sensors to collect information from the environment while having processing capabilities as well that could enable them to suggest actions, take actions or just ring an alarm. While there are use cases for this type of information-related use of advanced robotic systems, there is a lack of research on their impact on OSH, both on a cognitive and physical level.

3.3 Impact on jobs

Viewed over the span of a decade, job growth has occurred for highly educated occupational groups with a more analytical focus and which possess the skills to quickly learn and adapt to new technological advancements. Retraining and reskilling of workers are seen as both a consequence and necessary step to continue growth in the industry (de Vries et al., 2020). This is then tied into the reoccurring narrative that the current changes due to robotic systems will lead to rethinking employees' educational goals, fostering the idea of continuous learning, and developing the right, adaptive and new skills (Kim & Park, 2020).

People working in **healthcare**-related jobs will feel the impact of physical task automation. Hospital jobs, which do not require at least a bachelor's degree, were found to be disappearing, indicating a shift towards more knowledge and cognitive-based work (Terminino & Rimbau Gilabert, 2018). The main impact physical task automation through robotic systems is expected to have on nurses is that their overall physical strain reduces (Denault et al., 2019). Sen et al.'s (2020) research regarding work-related musculoskeletal disorders in the **mining** sector revealed that mining jobs specifically would benefit from automation to reduce musculoskeletal disorders and overall risk at the workplace. **Warehouses** can also be dangerous environments. Common safety hazards for employees are slipping, tripping and falling from heights. By using robots to reduce the need for employees to work at heights or to operate high-risk equipment such as forklifts, operators could achieve a significant safety benefit. For **construction** workers, one of the main advantages of using robotics lies in their potential to assist during repetitive or dangerous construction tasks. This shift, however, also means that all groups of workers will have to acquire new skills on how to both handle and supervise the machines.

3.4 Impact on sectors

The analysis of automated physical tasks among sectors reveals a high number of automated or supported tasks in the sector **human health and social work activities**. Here, the majority of tasks can be found in hospital activities. The plethora of possible applications for robotic systems indicates that in the near future the installation of robots in this working environment will gain momentum. On a sectoral level, healthcare and social work is likely to continue to grow in its importance and also as a major field of application for robotic systems.

Secondly, the **manufacturing** sector is strongly affected. The experts agreed upon the fact that the manufacturing sector is the main one regarding the deployment of advanced robotics at the moment. There are numerous examples of almost fully automated factory settings in areas such as the automotive industry.

The general sector of **transportation and storage** is also addressed quite frequently in scientific literature and also mentioned by the experts. The logistics market in particular is undergoing rapid changes due to the increase of e-commerce, mass customisation and just-in-time philosophy. The process of labour substitution from automation and robotics is increasing in modern **mining** processes. Less frequently observed in scientific literature but emphasised by the experts are the sectors **construction** and **agriculture**, **forestry and fishing**.

4 OSH implications

4.1 Psychosocial effects

Many psychological aspects are also discussed independently from the specific task type and can to some extent be applied to physical tasks likewise. The scoping review on human-machine interaction and health at work presents relevant categories of human-machine interactions for the analyses of consequences in relation to the automation of tasks. The relevant categories are '*function allocation*, *interface and interaction design* as well as *operation and supervision of machines and systems'* (Robelski & Wischniewski, 2018). The aspect of function allocation within the automation of tasks requires that the working task itself determines the allocation of function between humans and machines, in this case advanced robotic systems (Robelski & Wischniewski, 2018). A common phenomenon in relation to the automation of tasks is automation complacency. Studies show that expertise and training do not have mitigating effects on the occurrence of complacency. As summarised by Parasuraman and Manzey (2010), there is consensus within scientific literature that there are three main factors contributing to the occurrence of automation bias. The first one refers to a tendency of humans observed in decision-making processes, to follow the road of least cognitive effort. The second factor describes the tendency of users to overestimate performance and authority of automation systems. The third factor contributing to automation bias is a phenomenon also observable in shared human tasks. This is the diffusion of responsibility leading to 'social loafing', a tendency of humans to reduce their own effort when working with others (Parasuraman & Manzey, 2010).

Trust

A considerable amount of studies have investigated antecedents for trust in robotic systems. There is consensus that antecedents significantly influencing human trust towards robotic systems can be human-, robot- or context-related and therefore have to be considered carefully when using robotic systems for the automation of tasks (Hancock et al., 2011; Hancock et al., 2020). Within the robot-related antecedents, a robot's attributes and its performance have the strongest impact on trust. It is important not to only consider trust-enhancing aspects, but to also have in mind that some aspects might have detrimental effects on task completion or other issues (Hancock et al., 2020). Unsuited anthropomorphism can lead to dangerous situations like unexpected behaviours, not recognising automation failure or too slow responses to automation failure (Papadimitriou et al., 2020).

4.1.1 Task design

Job control

The concept of job control, which includes the dimensions of decision latitude, timing and method control itself, has a long history in occupational psychology. The positive effects job control can have on workers' wellbeing, motivation, satisfaction and mental health, especially helping to outbalance high job demands, are very well described in scientific literature (Bakker & Demerouti, 2007; Karasek, 1979, 1998). In relation to changing task characteristics and changed levels of job control when using advanced robotics for the (semi-)automation of tasks, the interviewed experts also mentioned the risk of lack of self-efficacy arising from new or modified tasks. However, if task and system boundaries are not made clear, one could face the risk of letting job control or decision latitude become too large, which again can result in decreased wellbeing or stress.

Feeling of control

Task characteristics defined by the level of job control can be perceived differently by human workers. Therefore, closely linked to the concept of job control is the subjective sense of control, which is also a well-established concept in psychology (Spector, 1998). Growing autonomy of robotic systems might incentivise workers to allocate tasks towards them, which the system is capable of performing, without losing their sense of control over the situation. The risk of losing control, whether it is a subjective feeling or an objective circumstance, was also explicitly mentioned by the interviewed experts. The experts further stressed that the 'human in control' principle should be regarded as a leading design guideline.

Work intensity and deskilling

In relation to the design of working tasks, a very often discussed and addressed psychosocial working condition is the aspect of work intensity, for example as described in relation to job control in the Job-Demand-Control Model (Karasek, 1979, 1998) or the broader Job-Demand-Resources Model (Demerouti et al., 2001). The reduction of skill variety is also addressed in the potential polarisation of jobs, a hypothesis discussed in relation to the automation of tasks and digitalisation of work systems. In a simplified way, it states for jobs with low-skill level requirements that the automation of complex routine tasks will cause the job to focus on even more simple tasks rather than enabling the human to perform tasks that require a higher skill level.

4.1.2 Interaction design

Within scientific literature there is a number of robotic interaction design aspects that are discussed in relation to different OSH aspects. Robotic design aspect and interaction design can be associated with different attributes. They can, for example, be related to the outward appearance and embodiment of the robotic system, robotic behaviour and movement or interaction as well as communication styles and channels. Within the area of robotic movement behaviour, aspects like velocity, acceleration and deceleration, trajectories, and approaching or passing strategies fall into the scope of consideration. Communication between humans and advanced robotics can be designed to various degrees. Different interaction design aspects are to varying amounts associated with OSH risks and opportunities. The overall aim is furthermore to increase the feeling of wellbeing, acceptance, trust, positive emotions, and a positive user experience or workflow (for example, see Honig et al., 2018). Likewise, dysfunctional levels of workload, irritation, strain or disruptions shall not be induced by the interaction or even reduced, where possible. However, robotic design aspects are not stand alone considerations and must always contemplate the addressed context and working task.

Anthropomorphic robot design

The aspect of embodiment and more precisely anthropomorphic robotic design is largely addressed within scientific literature. Anthropomorphic robot design can have positive effects on trust towards robots. Design features like eyes or facial expressions can foster natural interaction, acceptance and likeability, especially in social robotics (Fink, 2012). However, there can be negative consequences of anthropomorphic design. These design features will trigger human expectations regarding robotic capabilities and behaviour (Złotowski et al., 2015). If a system has features like eyes, we expect the robot to be able to process visual cues. Anthropomorphic design can also relate to robotic movements or communication strategies. A mismatch can result in irritation or even a significantly perceived lower reliability in industrial settings (Roesler et al., 2020). However, generally speaking, if an anthropomorphic design feature does not serve a functional purpose, it should not be included.

Dialogue principles in HRI

One standard to consult when addressing interaction design is the interaction principles (former dialogue principles) formulated in the EN ISO 9241-110. Interaction principles and general design recommendations can guide the development and evaluation of user interfaces, leading to improved usability. They have been identified to be important and useful for designing system interaction in the context of 'Industry 4.0' (Fischer et al., 2017) and have proven to be an adequate tool for user evaluation of robotic systems (Rosen et al., 2018). In particular, the new degree of autonomy that AI-based systems and advanced robotics bring into a workplace introduces a new quality to the interaction, which could be assessed and improved by applying the dialogue principles early in the development process.

Transparency in HRI

Especially as robotic systems expand in capabilities and autonomy, developers and also legislators need to consider the facet of responsibility and accountability in the interaction. Humans hold robots accountable for their mistakes (Kahn et al., 2012), at least more than other objects. Users place greater blame on the robot and less blame on others when errors occur in the work process. However, one should not simply assume that more information delivered by the system is necessarily better for the user. Too much information might not increase the transparency of a system but lead to an information overload and result in an inability to select and process critical information (Finomore et al., 2011). Hence, creating sufficient transparency is an important yet complicated endeavour.

4.1.3 Operation and supervision

The dimension of operating and supervising a system can be regarded as a direct consequence resulting from the function allocation process and the specific interaction design (Robelski & Wischniewski, 2018).

Attitude and experience towards and with robots

The relative novelty of robotic systems that closely interact with humans in the workplace leads to an inevitably inexperienced and unaccustomed workforce when it comes to the interaction with them. This lack of familiarity can influence their attitude towards them and colour their initial experience. We know, that use and experience can change workers' perceptions of and attitude towards robotic systems. With increased familiarity, the novelty of these systems decreases as preconceived ideas about their capabilities and behaviours evolve towards a more realistic picture (Sanders, 2019.). Both trust and acceptance are likely to increase as attitudes are shaped by exposure to a system (Hancock et al., 2011). Nomura et al. (2011) found that negative attitudes towards robots decreased as experiences of interacting with those increased.

Social support

Social support in the workplace, for example from team members and colleagues, is considered a major factor influencing wellbeing or satisfaction. Research has shown mitigating effects of social support on perceived work-related stressors and a reduction of experienced strain (Viswesvaran et al., 1999). The (semi-)automation of tasks that previously have been performed by humans might eventually lead to new teaming structures. A possible risk could be a decrease in perceived social support as the interaction with human team members might decrease.

Fear of job loss

Some workers will not perceive robotic systems as a beneficial technology but as a potential risk to their employment. Reichert and Tauchmann (2011) investigated levels of psychological distress for workers with job insecurity and found that employees with little job security suffer from poorer psychological health. Furthermore, the effects of job insecurity are exacerbated for workers who have pre-existing mental health problems. Kozak et al. (2020) assessed that job insecurity due to automation through robotic systems is not an irrational fear of the unknown but rather a rational reflection of automatability risks of tasks to which workers are exposed. They stress the need for further implementation of skill development policies for the labour force to combat both actual job loss and the subjective fear of it.

4.2 Physical effects

The physical impact of task automation through robotic systems can be categorised into the following potential and intended benefits, and possible risks. Within the category of positive impact we see one major area being the distancing of human workers from dangerous or strenuous environments (Gharbia et al., 2019; Sen et al., 2014). The other group of positive effects comes from robotic systems physically supporting workers in specific tasks, in which the continuous or repeated physical strain poses a health risk (Kyrarini et al., 2021). Many generic tasks automated through robotic systems, such as lifting a work piece or even transportation of an item around the workplace, can fall under this category. Work-related musculoskeletal pain and injuries are common among nurses. Hence, the automation of especially strenuous tasks can greatly benefit their health. It is advisable that the work cells should allow a reduction of physical workload by changing the work cycle and the robot system's performance according to the operator's physical conditions. This is to benefit the worker's physical wellbeing, in line with the interviewees' interpretation of how a robot can impact a worker.

Next to positive shifts with regard to a worker's physical condition, experts also point out that new technology could lead to new kinds of physical hazards. As many robotic systems currently perform a task that somewhat involves movement, possibly movement with an additional physical load, collision risks have been highlighted repeatedly. While a collision between a worker and robotic system itself already poses a health risk, the potential for injury increases when the robot is handling an object or has a sharp or pointy gripper attached. Unintentional movements can hit the human being or trap the person between the robot and a fixed part, for example, squeezing the hand. Therefore, limits for the force of contact need to be considered. Another risk factor is mechanical failures: if there is no proper maintenance, there might be an error, leading to possibly the same outcomes as a control error.

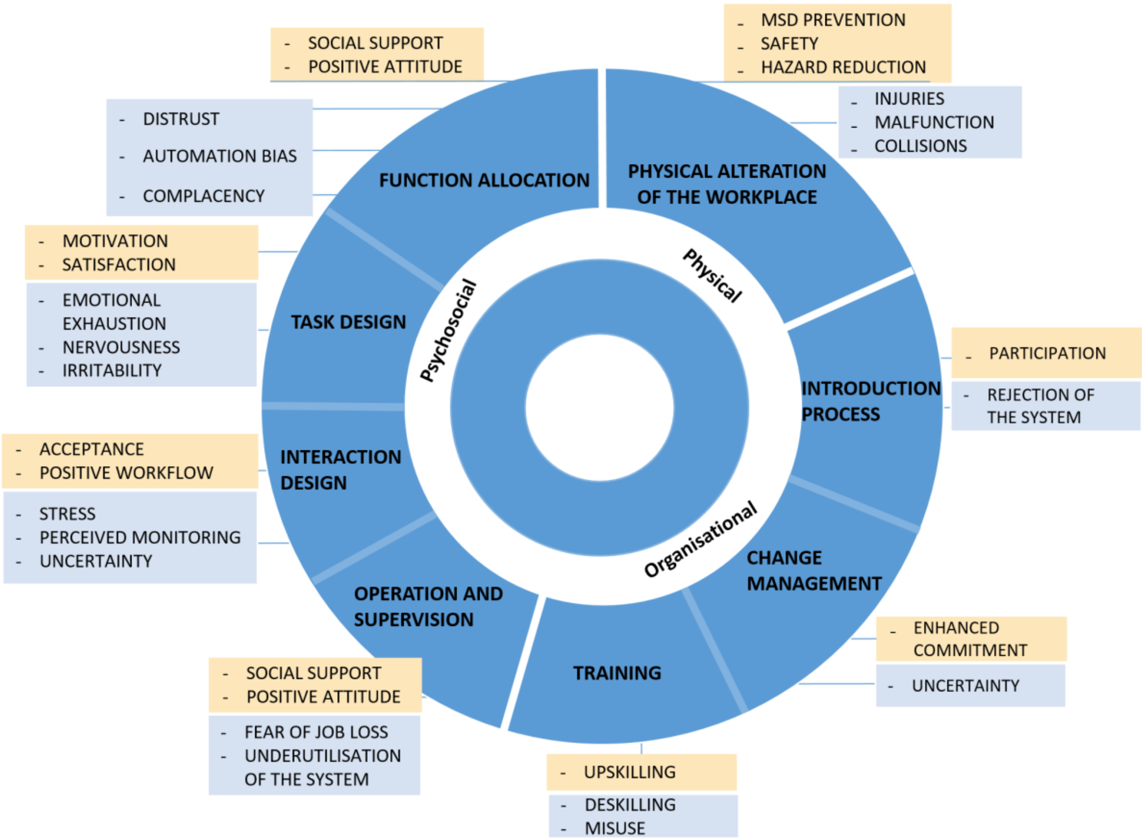
4.3 Organisational effects

Communicating future changes to employees can reduce the feeling of uncertainty towards the rationale behind the change. Furthermore, clear and direct communication has also been found to promote change and supportive behaviour from workers (Bordia et al., 2004). In addition to communication prior to the implementation, the work area in which the robot will be employed needs to be rearranged and the tasks of the workers newly defined. Here especially, the aspect of risk assessments was stressed by the interviewed experts. Furthermore, the experts named training of employees, evaluation and supervision of the worksite, and procedures for good maintenance as potential tools.

One of the biggest organisational changes these work environments will have to face is the demand for re- and upskilling. This entails training the staff in working with the new robotic technology, while simultaneously avoiding deskilling and the loss of other crucial competences. Considering these factors and providing the needed opportunities for employees might also increase their participation in the organisational changes. Employee participation in implementation and decision-making has been found to enable supportive behaviour from employees (Gagne et al., 2000).

Figure 1 presents an overview of the relevant identified dimensions in relation to psychosocial, physical and organisational aspects and possible associated OSH-related risks and benefits.

Figure 1: Overview of OSH-relevant dimensions and effects



4.4 Standards

Apart from Type-A standards (basic safety standards) and Type-B standards (generic safety standards) that also apply if relevant, there are currently three machine safety standards (Type-C standards) for robotic systems. The full list can be found in the report. To summarise the experts' opinions on standards in relation to robotic systems it has to be noted that they do see room for improvement in the existing standards regarding specific aspects. However, there is currently no need for additional standards, as expressed by the experts. This reflects the current number of fully integrated HRI applications we currently observe in Europe, as, for example, indicated by the results of the ESENER-3 data (EU-OSHA, 2022a). Within the research of this project, specific OSH risks of advanced robotics and AI-based system have been identified. While there are risks specifically associated with the use of advanced robotics, risk assessment tools that cover both risk identification and risk analysis for them are currently rare and often not readily available.

4.5 Risk assessment

The specific OSH impact of introducing an advanced robotics or AI-based system into a workplace is often hard to gage and varies upon the specific system, automated task and environment. The same applies for the overall risk of introducing and implementing such systems into the workplace. In recent years, there have been first drafts of cobot-specific risk assessment tools (e.g. Stone et al., 2021; Raza et al., 2021), however there are few tested and published tools publicly available. Risk assessment tools also face an additional challenge, associated with frequent changes of the environment in which many cobots operate. Nevertheless, accurate and in depth risk assessment of a technology in the workplace is vital to ensure OSH, and the lack of assessment tools capable of providing this for advanced robotic systems, cobots and AI based systems for the automation tasks, needs to be considered going forward.

5 Summary and conclusion

When analysing the types of tasks and automation degree for which advanced robotics applications are currently used, we see a strong focus on routine person-related and object-related tasks for semi-automation and full automation, respectively. Within person-related tasks we find many nursing tasks, including lifting or assisting patients with food or drinks. Furthermore, surgical and other medical tasks are partly or fully supported. Within object-related tasks there is a strong focus on tasks common in the manufacturing sector, warehousing and crafts. Furthermore, we find packaging as well as transportation and delivery tasks in different areas like manufacturing, hospitals and warehouses being fully automated. Assembly tasks are object-related tasks, which are found to be partly assisted by advanced robotics.

One primary finding is that within scientific literature currently OSH risks and opportunities do not or only very rarely consider a task approach. There is a clear lack in studies addressing HRI and associated OSH risks and opportunities in purely physical tasks. Hence, the findings that are presented can be regarded as general findings up to some extent, applicable to all robotic applications.

From scientific literature we were able to identify four different dimensions for HRI that can be associated with different OSH-related risk and opportunities: function or task allocation, task design and interaction design as well as operation and supervision.

Regarding the dimension of function or task allocation, we see that these processes might become more dynamic as robotic systems hold the promise of flexible use. If both are performed well, it can increase system performance, reduce errors, optimise workload, and increase motivation, satisfaction and wellbeing. However, associated risks with function allocation include a number of human consequences like complacency effects, decision biases, reduced situation awareness, unbalanced mental workload, mistrust and over-reliance. Higher degrees of automation might reduce the mental workload of an operator, but it can also result in a loss of situational awareness and worse failure performance (Onnasch et al., 2014).

In relation to task design as a consequence of the function allocation process, especially the risk of low levels of job control and associated with that low levels of feeling in control, low self-efficacy, low satisfaction, motivation and wellbeing have to be stressed. High levels of robot autonomy were also associated with the risk of lowering the feeling of control and, furthermore, the feeling of responsibility for the working task. A tight coupling of the worker to the robot's task additionally has the risk of increasing stress.

The application of well-known design principles will benefit the overall interaction process. Their absence is associated with adverse effects. The importance of some design principles might shift, especially as the demand for a transparent robotic design and behaviour is crucial to prevent possible risks like reduced feeling of responsibility and accountability, over- or under-reliance as well as a feeling of alienation or loss of control.

With the use for advanced robotics especially in hazardous and dangerous working environments there is a clear opportunity to be emphasised. Robotic systems firstly provide the potential to completely remove humans from these unfavourable circumstances. Secondly, especially in assembly and lifting tasks, robotic systems can improve physical health related to musculoskeletal disorders. Physical risks like collision or ones related to mechanical or electrical failures are also mentioned.

In relation to organisational effects we especially see the relevance of the introduction process, or the change process associated with introducing advanced robots to the workplace. If this process is not considered carefully in terms of an adequate task analysis, worker participation, communication strategy, and an ongoing evaluation and monitoring process, companies will face the risk of low acceptance, rejection and disuse of the system. Also important is the aspect of appropriate training for workers to prevent the risk of deskilling and loss of crucial competences.

Trust has been studied to an extraordinary higher degree in HRI. The fact that successful cooperation is influenced by the trust between the cooperating parties is well known (Costa et al., 2001). In relation to trust, robotic traits like mobility, anthropomorphic or zoomorphic design, multimodal interaction possibilities, and multi-purpose usage for proximal and remote applications may suggest that human trust towards robots differs compared to trust towards regular automation technology (Hancock et al., 2011; Hancock et al., 2020). Not enough trust in a robotic system can have negative consequences for the interaction. In contrast to a lack of trust, one could assume that very high trust in the robotic system has positive effects. If there is excessive trust, the duty of care towards the robot, for example, is neglected (Hancock et al., 2011), which can lead to further damage or, if a defect is not noticed, damage to the work piece or injuries to people. If the degree of trust that is placed in the robot matches the capabilities of the robot, efficient and safe collaboration can take place (Hancock et al., 2011).

We were able to identify relevant HRI dimensions from which specific OSH-related risks and opportunities were derived. These more general OSH observations regarding robotic systems help to understand that regardless of application context, some fundamental criteria should be considered. Even if the single effects of the addressed dimensions vary from workplace to workplace, it is advised to always consider them. In that context, enforcement could become really challenging for traditional labour inspectorates. Accurate and in depth risk assessment of a technology in the workplace is vital to ensure OSH. Taking the addressed OSH risks and benefits into careful consideration will result in a human-centred application of advanced robotics for the automation of tasks.

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