ADVANCED ROBOTICS AND AUTOMATION: WHAT ARE THE RISKS AND OPPORTUNITIES FOR OCCUPATIONAL SAFETY AND HEALTH?

The appearance of new technologies, such as advanced robotic systems that can closely interact with humans, has led to a revival of the debate on the automation potential of jobs and tasks as well as their consequences on occupational safety and health (OSH). Rapid developments and new forms of human-technology interaction create new opportunities and challenges for OSH alongside this technological evolution. Advanced robotics hold the potential for a qualitative shift in opportunities and challenges for OSH or even the creation of entirely new benefits and risks. Gaining insight from both established OSH factors on human-technology interaction, as well as including new scientific findings focused on robotic systems, helps to identify important influences on both risks and opportunities as well as factors specifically relevant to advanced robotics and cobots.

The state of advanced robotics

The combination of artificial intelligence, or smart algorithms, with robotic devices accelerates the level of robotic autonomy and functionalities. The more we find an integration of AI-based software in robotic hardware, the more we observe, for example, an elaborate moving behaviour, especially in unstructured environments or natural language processing. Yet, non-AI-based robotic systems already show a variety of advanced capabilities and are also included in this matter. A number of different advanced robotics capable of interacting with humans are addressed in high quality scientific literature. They can be categorised according to their intended purpose as well as by distinct features like mobility. For the automation of physical tasks, **industrial robots** appear most frequently. According the International Organisation for Standardisation (ISO) standard (ISO 8373:2012), an industrial robot is an 'automatically controlled, reprogrammable multipurpose manipulator programmable in three or more axes', which can be either fixed or mobile. This definition is also adopted by the International Federation of Robotics (IFR). Other types of robotic systems are **teleoperating robotics**, used for example in remote maintenance operations. A second noticeable group that is addressed in scientific literature are **medical robots.** Medical robots for the automation of physical tasks refer to systems like **robotic rollators**[1, 2] in the care of the elderly or impaired as well as **robot-assisted therapy** for balance function rehabilitation after stroke[3]. Still in their early development stage are medical robots designed for carrying and lifting patients, sometimes referred to **as nursing robots**. In the area of **manufacturing**, the increasing integration of AI-based software tools in robotic hardware does lead to new generations of robotic systems. Besides specific purposes, the degree of mobility has also been used to categorise robotic systems. The integration of mobile robots or **autonomous vehicles (AV)** can be observed in a number of work environments. Especially in **logistics and warehousing**, robots are becoming increasingly autonomous.

The form of interaction between humans and robots is described in terms of **collaboration**, **cooperation and co-existence**. Co-existence describes an episodic meeting between humans and robots where the interaction is limited in time and space. The participants share no common goal in their work and their actions are unrelated time-wise. An example of co-existence in the workplace is a transport robot passing by a supervisor in a warehouse. Cooperation and collaboration describe closer interactions between humans and robots in which they share a goal and tasks are dependable time-wise. In a cooperative work setting, both work towards an overarching common goal, but there is a clear division of tasks between human and robot. Each works on different subtasks of the end result, and the allocation of subtasks is determined in advance. Collaboration can be seen as the closest interaction form. Human and robotic actions occur at the same time on the same object. For example, the support of lifting patients creates a collaborative interaction form. The human and robot pursue a common goal and there is immediate coordination required. Subtasks are allocated continuously and, if necessary, adapted to the situation.

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[1] Werner, C., Ullrich, P., Geravand, M., Peer, A., & Hauer, K. (2016). Evaluation studies of robotic rollators by the user perspective: A systematic review. *Gerontology*, *62*(6), 644-653. https://doi.org/10.1159/000444878

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[3] Zheng, Q. X., Ge, L., Wang, C. C., Ma, Q. S., Liao, Y. T., Huang, P. P., & Rask, M. (2019). Robot-assisted therapy for balance function rehabilitation after stroke: A systematic review and meta-analysis. *International Journal of Nursing Studies*, *95*, 7-18. https://doi.org/10.1016/j.ijnurstu.2019.03.015

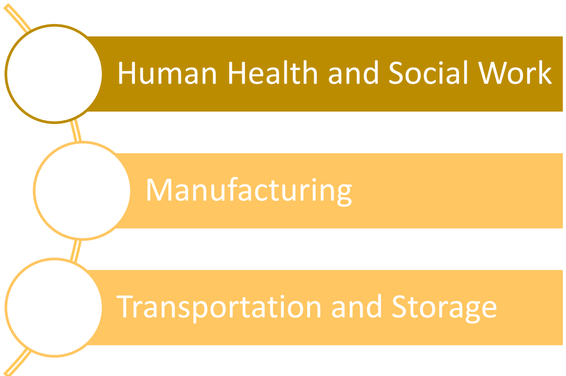
Impact on task, jobs and sectors

Robotic systems can have a positive impact on OSH, especially regarding the so-called 3D jobs (dirty, dull and dangerous).

As one might expect, most physical tasks impacted by the automation of advanced robotics are object-related. However, there are also some physical tasks affected by the automation of tasks which are person-related. An example, which occurs in different sectors (medicine, manufacturing and construction) but is automated or supported likewise by different types of robotic systems, is the task of lifting objects or even people. This example demonstrates how the same task is affected among different sectors and associated jobs. Tasks that will be more likely to be automated are **repetitive and routine tasks**. These tasks can be programmed and coded and one can build a system that learns from this data using AI-techniques. Therefore, physical routine and less complex tasks are more likely to be replaced. There might be the potential of **job destruction**, especially among **low-skilled** jobs with high levels of repetitiveness and routine characteristics. In a slightly contrasting view, it has to be noted that **many routine physical tasks** have already been automated through mechanisation, and that there may be fewer tasks left to automate there. The use of collaborative robots even has the **potential to create more jobs**. These systems have the potential to combine the strength of humans with those of machines. Teaming humans with robots can increase productivity and therefore benefit the organisation, which in turn is able to invest more and to create new jobs. However, at the same time, these systems can perform the work task of more than one human worker at a time. Consequently, we will be observing a change towards a situation where one human orchestrates multiple robotic systems.

The analysis of automated physical tasks among sectors reveals a high number of automated or supported tasks in the sector of **human health and social work activities**. The majority of these tasks can be found in **hospital activities**.

Figure 1: The three most common sectors for the automation of physical tasks (according to scientific literature)



Secondly, the **manufacturing** sector is strongly influenced. Within the manufacturing sector, the **automotive industry** is often named as the main one. However, the **human health and social work activities** sector is represented slightly more in scientific literature, which might be due to a publication bias though. The **transportation and storage** sector is also addressed quite frequently in scientific literature and also mentioned by experts. Less frequently observed in scientific literature, but emphasized by the experts, are the sectors of **construction** and **agriculture**, **forestry and fishing**. Robotic applications are especially useful to take over or support workers with tasks that involve handling heavy loads (e.g. automated cranes). The **agriculture, forestry and fishing** sector is quite developed regarding autonomous systems, and innovation of these technologies in the sector is rapidly increasing.

OSH relevant dimensions in human-robot interaction

Based on prior research, four different dimensions for HRI which can be associated with different OSH related risk and opportunities have been identified: **function or task allocation**, **task design**, **interaction design** as well as **operation and supervision**. These dimensions are not strictly discrete and do show dependencies among each other.

Function allocation and task design

Automation itself is a continuum where different functions can be automated to varying degrees[4]. As capabilities of advanced robotics proceed, we can observe a shift from traditional task allocation processes to more dynamic ones. There are a number of psychological aspects to consider, which can be influenced by real-time ad hoc task allocation, like **perceived process control**, **mental effort**, **perceived fairness**, **task identity** and acceptance of the allocation result, flow and self-efficacy or satisfaction[5]. Flexibility in task execution of both human and robot requires a very high degree of technological development. **Function or task allocation** might become more dynamic as robotic systems hold the promise of flexible use. Assuming an appropriate technological readiness

[4] Parasuraman, R., Sheridan, T. B., & Wickens, C. D. (2000). A model for types and levels of human interaction with automation. *IEEE Transactions on Systems, Man, and Cybernetics – Part A: Systems and Humans*, *30*(3), 286-297. https://doi.org/10.1109/3468.844354

[5] Tausch, A., Kluge, A., & Adolph, L. (2020). Psychological effects of the allocation process in human-robot interaction – A model for research on ad hoc task allocation. *Frontiers in Psychology*, *11*, 2267. https://doi.org/10.3389/fpsyg.2020.564672

and suitable use cases for such application, not only the result of a function allocation process but the process itself will pose risks and opportunities for OSH, which are discussed in the respective section below. A direct consequence of the allocation process is the remaining work task (job content) for the human. One major characteristic of the design of work tasks, which itself can impose OSH related risks and opportunities, is related to the amount and quality of decision latitude or **job control** given to the human worker.

Interaction design

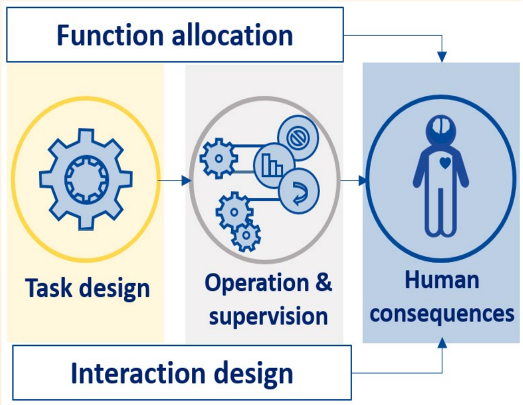
Responsibility and accountability need to be clarified when it comes to human-robot interaction. Workers need to be aware of a robot's capabilities and limitations.

Robotic design aspects and interaction design can 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, approaching or passing strategies fall into the scope of consideration. Communication between human and advanced robotics can be designed to various degrees. Research has been conducted on comparing the effects of different communications channels, for example, the effectiveness of combining several modalities like gesture and speech[6]. Other attempts focus on specific verbal interaction scenarios, for example, when robotic systems request aid from the human-interaction partner[7]. These different interaction design aspects are to varying degrees associated with OSH risks and opportunities. The similarity in interaction-design research is the attempt to identify attributes and characteristics that enable a smooth and natural interaction. The overall aim is to increase the feeling of **well-being**, **acceptance**, **trust**, **positive emotions**, and a **positive user experience or workflow**[8]. Likewise, dysfunctional levels of **workload**, **irritation**, **strain or disruptions** shall not be induced by the interaction, but should be reduced where possible. However, robotic design aspects are not stand-alone considerations, but must always contemplate the addressed context and work task. For example, interaction requirements differ between a healthcare-related robot and an industrial robot.

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[9]. 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 interacting with them. With increased familiarity, the novelty of these systems decreases as preconceived ideas about their capabilities and behaviours evolve towards a more realistic picture[10]. Nomura and colleagues found that the negative attitudes towards robotic systems decrease d as experiences of interacting with robots increased. High levels or **robot autonomy** were also associated with a lowered feeling of **responsibility** regarding the work task[11]. Hence, transparent robotic design and behaviour is crucial to prevent possible risks like reduced feeling of responsibility and accountability with the system. Furthermore, in environments where operators have to perform non-automated tasks while supervising automation, **complacency** can occur[12]. It is therefore important to recognise the level of mental workload the operation and supervision over a robotic system can cause and include it in any consideration of introducing multitasking supervision and operation to a work environment.

Figure 2: Dimensions of HRI



[6] Berg, J., & Lu, S. (2020). Review of interfaces for industrial human-robot interaction. *Current Robotics Reports*, *1*(2), 27-34. https://doi.org/10.1007/s43154-020-00005-6

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Opportunities for OSH

The 'human in control' principle poses an important design guideline in human-robot interaction to prevent decreasing levels of job control.

Introducing advanced robotic systems into a workplace can open up a number of OSH related opportunities for workers**.** Regarding **function or task allocation**, there are a number of psychological aspects to consider, like perceived process control, mental effort, perceived fairness, task identity and acceptance of the allocation result, flow and self-efficacy or satisfaction[13]. However, if the task allocation is performed well, it can increase system performance, **reduce errors**, **optimise workload**, **increase motivation**, **satisfaction and wellbeing.** In addition to that, **trust** and **acceptance** are likely to increase, as attitudes are shaped by exposure to a system[14].

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 compensate for high job demands, are very well described in scientific literature[15, 16, 17]. The possibility for workers to perform certain work tasks with a flexible robotic system might hold the opportunity to **increase levels of job control**, when following certain design recommendations[18]. The 'human in control' principle should be regarded as a leading design guideline. Providing sufficient system transparency or even enabling individualised interaction strategies can ensure a seamless interaction.

Apart from psychological opportunities, advanced robotic can also cause positive impact on the **physical wellbeing and safety** of workers. The use of such systems in hazardous and dangerous working environments 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. In addition to these factors, the reduction of physical strain or unfavourable work, poses another tangible OSH opportunity[19].

OSH risks

Risks associated with function allocation include a number of human consequences like **complacency effects**, **decision biases**, **reduced situation awareness**, **unbalanced mental workload**, **mistrust** and **over-reliance**. In relation **to task design** as a consequence of the function allocation process, especially the risk of **low levels of job control**, also associated with that **low levels of feeling in control**, **low self-efficacy**, **low satisfaction**, **motivation** and **wellbeing** has to be stressed. High levels of **robot autonomy** are also associated with the risk of **lowering the feeling of control** and the feeling of **responsibility** for the work task. A **tight coupling** of the worker to the robot's task further has the risk of increasing **stress**.

Furthermore, the absence of design principles is associated with adverse effects. Especially 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**.

The (semi-) automation of tasks that have previously been performed by humans might also 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. However, this phenomenon is not yet extensively addressed in scientific literature.

The application of robotic systems can hold the risk of **even further decreasing levels of job control**. Workers might feel like they are **only supporting the robot's work**. Low levels of control and dependency on the robotic systems is also known as technological coupling in scientific literature[20]. A tight and non-flexible coupling of human

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tasks to robotic performance could **lower task performance flexibility** and increase a **machine determined work rate**. Both aspects have the potential to be associated with a number of adverse psychosocial effects like **emotional exhaustion**, **nervousness or irritability**, an **overall poorer mental health** and **less intrinsic job satisfaction**[19]. This may lead to a **feeling of only supporting the robot's work** and **decreasing the subjective value** of one's own work. However, if task and system boundaries are not made clear, one could be facing the risk of letting job control or decision latitude becoming too large, which again can result in decreased wellbeing or stress.

Closely linked to technological coupling is the potential risk of **work intensification** through introducing advanced robotics if human resource time for completing the work tasks in the new working system is insufficiently allocated. Furthermore, the potential risk of **deskilling effects** arises. As robotic systems perform part of the work, workers do not complete all the tasks anymore and therefore lose the comprehension of the complete process. The **reduction of skill variety** is also addressed in the potential polarisation of jobs[21]. In essence, it states that for jobs with low-skill level requirements the automation of complex routine tasks will cause the job to focus on even simpler tasks rather than enabling the human to perform tasks which require a higher-skill level.

Inadequate task allocation and design can be mostly associated with psychosocial risks like reduced wellbeing, emotional exhaustion, nervousness or irritability. Mechanical robotic failures may cause physical harm.

A common phenomenon related to the automation of tasks is automation complacency. The effect is reduced when automation reliability does not remain constant over time but varies. However, inconsistent system performance might **negatively impact the trust** in the robotic system. A second well-explored and well-documented automation phenomenon addressed in scientific literature is the **risk of automation bias** and two types of related errors – omission and commission errors. Omission errors occur if the user does not respond to a critical situation regarding an alert function[22]. Commission errors are related to specific recommendations by the automation system and are described as following the advice of the system although it is incorrect. To avoid this kind of risk, workers need to exhibit an adequate level of trust towards the robotic system, neither overreliance nor neglect towards it. Hence, it is crucial that workers are aware of the exact capabilities of the robotic system.

Another risk factor are **errors and mechanical failures**. Unforeseen movements can potentially cause physical harm to the operator. Therefore, limits to the force of contact need to be considered. These kind of control errors can occur at both the design or operation stage and they are often attributed to a malfunction of the software, but might also be caused by human error. To avoid mechanical errors, proper electrical installation and maintenance need to be ensured, as well as adequate training for the operators to avoid and, if necessary, de-escalate the situation.

The risk of **fear of job loss** can be triggered especially if workers have no experience with robotic systems and introduction processes do not consider this fear. To mitigate this risk, it can help to involve workers early in the process of introducing the system to the workplace. Some workers will not perceive these systems as potentially beneficial technology, but as a risk to their employment, which can lead to fears of unemployment and financial insecurity[22]. Reichert and Tauchmann investigate levels of psychological distress for workers with job insecurity and found that they suffer from **poorer psychological health**[23]. Furthermore, the effects of job insecurity are exacerbated for workers who have pre-existing mental health problems. Workers in higher positions fear robots at work less than manual, blue-collar workers and people with lower education[24]. Kozak and colleagues 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. Providing workers with new skillsets could simultaneously facilitate their adaptations to requirements of the new work environment in a digital economy and provide them with a subjective sense of security[25].

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Recommendations

Introducing advanced robotics to a workplace demands ample consideration of both potential risks and opportunities for OSH.

The main dimensions that pose potential risks and opportunities for OSH in HRI are **function allocation** and **task design**, **interaction design** as well as **operation and supervision**. These dimensions have to be considered to variable degrees and are slightly directed to different stakeholders. However, the application of a specific robotic system within a working system requires paying attention to all of the addressed dimensions. Therefore, it is necessary to encourage and enable exchange and learnings from relevant stakeholders like the designer, system integrator, works council and employees.

One factor to enable successful implementation of robotic systems is worker **involvement**. This is important for several reasons. It can decrease the fear of job loss, and further increase acceptance of the system. Furthermore, the implementation of **skill-development** policies for the labour force should be considered to combat both actual job loss and the subjective fear of it.

Focusing on upskilling or reskilling workers in the process of automation will also counteract the feeling that the worker is only supporting the robot's work.

Existing interaction design principles, task design, the allocation of responsibility and accountability should strongly be considered when creating new work systems. A work pace determined by the robotic system or missing interruption possibilities should be avoided. The **'human in control' principle** should be regarded as a leading design guideline on different levels, ranging from the interacting individual to relevant stakeholders. Furthermore, the **'transparency' principle** proves to be of major importance. Actions and decisions as well as system capabilities and limitations of advanced robots need to be transparent and explainable to the human. Again, this can apply to the direct, individual interaction as well as to different levels, like overall organisational transparency in relation to the robotic system.

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