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European Agency for Safety and Health at Work

Smart digital monitoring systems for occupational safety and health: uses and challenges

Report

European Agency for Safety and Health at Work

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1 Introduction

This study aims to identify the types, purposes and uses of smart digital occupational safety and health (OSH) monitoring systems. It also identifies and assesses **related opportunities, risks and challenges**,[1] and provides recommendations for policy, research and practice for the purpose of improving workers' OSH.

Digital systems and technologies have advanced more rapidly than any innovation in our history,[2] and they are changing and impacting people's lives globally. Of particular note is the emergence of technologies such as: artificial intelligence (AI) and machine learning (ML); wearables, smart personal protective equipment (PPE) and exoskeletons; virtual and augmented reality (VR and AR); widespread connectivity, the Internet of things (IoT) and big data applications, among others.

These smart digital systems and technologies are redefining safety and health at the workplace. This is particularly true for high-risk sectors, such as industrial facilities (e.g. warehousing, manufacturing), construction and engineering, mining and quarrying, agriculture, shipping and others. In these, but also in lesser-risk sectors, new OSH monitoring systems can track a wide cast of workplace risks and help workers and OSH professionals to manage them. Broadly, these systems can help prevent risks, or react to them. For example, **in terms of preventing risks**, new technologies in stand-alone equipment (e.g. exoskeletons), in PPE, in industrial facilities (e.g. workers) and so on are able to nudge and even provide personalised feedback to workers on how to manage their workplace's risks. In addition, they are able to provide aggregate data to OSH managers, which can help them identify where risks occur and act on them. **In terms of reacting to risks**, new OSH monitoring systems can help track, for example, a lone worker who is at risk, through man-down functions, and possibly reduce the time of rescue operations.

Research conducted so far revealed **limitations in definitions and research on new OSH monitoring systems**. First, there is lack of a clear and agreed upon definition among academics, legislators and practitioners of new OSH monitoring systems. Second, there seems to be a disparity between the number of studies and research conducted on technologies (their components, their purposes of use, etc.) and that of their practical application. There also seems to be a lack of consistency and coherence in the published studies (despite their abundance), especially in depicting the purpose of use across sectors and types of job tasks, as linked to occupational hazards and risks. Furthermore, there are few studies that analyse their practical application and provide robust evidence of their effectiveness on OSH, over the short and longer terms. Besides, quantitative and qualitative data seldom distinguish between OSH monitoring, automation and monitoring performance in the context of workplace and worker surveillance.

To meet the objectives of this study and overcome some of the limitations of research to date, **this research focuses on secondary and primary data collection and analysis**. Secondary data include an extensive review of the literature: 182 documents, reports and articles.[3] Quantitative secondary data are mainly based on the *Third European Survey of Enterprises on New and Emerging Risks 2019 (ESENER-3)*,[4] which includes responses from a total of 45,000 workplaces with more than five employees in 33 European countries and where the respondent is 'the person who knows best about safety and health in the workplace.' Primary data consist of a total of 29 online interviews carried out between November 2021 and February 2022 with key stakeholders.[5]

In line with the analytical framework of the study, this report is structured across seven sections: the introduction, five main sections, and a concluding section. **Section 2** focuses on the drivers and barriers to adoption, namely 'Technological push', 'Legislation, standardisation and research', and 'Organisational factors', which include demand and supply-side factors that may increase, limit or bar

[1] Risks are challenges that cannot be overcome and that have to be dealt with. Challenges should be overcome to minimise the involved risks. Overall, the literature tends to use the two concepts interchangeably, and so does this research to a large extent.
[2] See: https://www.un.org/en/un75/impact-digital-technologies
[3] For a detailed list of stakeholders please see Annex 1.
[4] See: https://osha.europa.eu/en/facts-and-figures/esener
[5] For a detailed list of stakeholders please see Annex 2.

uptake. The section also gives indications on the uptake of digital technologies among EU establishments, although data does not clarify the specific purpose of use (i.e. OSH monitoring, or other purposes like monitoring worker performance, work automation).

Section 3 offers a novel and pragmatic definition of new OSH monitoring systems. It also presents the definitions available in the literature with regard to the different technologies that new OSH systems may use. The section then presents a taxonomy of (non-exclusive) types of OSH monitoring systems that are divided into two approaches. The first is **proactive systems** to safety and health, which take place before an accident has occurred. These mainly aim at primary prevention, early identification of presence and exposure to occupational hazards and risks at the workplace, and training and on-the job mentoring (tips, advice, instructions). The second is **reactive systems** that help minimise the consequences of harm, once an emergency / accident has occurred, and to collect accident data, thus favouring accident reporting and investigation. While the above distinction is useful for analytical purposes, it is not as explicit in practice and often OSH monitoring systems present both proactive and reactive functions. Crucially, both types of systems need to be considered as part of a whole, in the context of the OSH continuous cycle of improvement: both proactive and reactive systems may thus lead to improved OSH through (preventive and corrective) measures based on the data collected and analysed.

Section 4 systematically analyses the **opportunities and use of new OSH proactive and reactive monitoring systems**, based on different occupational risks and hazards (physical, safety, ergonomic, psychosocial, organisational, chemical, biological, radiation), across the so-called 4Ps (premises, plant, people and procedures), as linked to object-, person- and information-related job tasks.[6] The section also presents our findings regarding the opportunities and use for specific workers' needs (ageing workforce, lone and inexperienced workers, workers undergoing rehabilitation, diverse workforce including gender, ethnicity / race and neurodiversity). The COVID-19 pandemic is also analysed because of the heightened biological and psychosocial risks it poses and the change in location of work it has entailed for some workers in the context of teleworkable jobs: both COVID-19 (and long COVID) and telework call for specific OSH responses, which digital technology may support.

Section 5 analyses the risks and challenges posed by the new OSH monitoring systems. These include the collection of data that can be potentially inaccurate, limited or even biased, which can in turn pose risks to workers' safety and health. Furthermore, these systems may include renewing psychosocial and organisational risks, as well as blurring and shifting OSH responsibilities from the employers to the systems.

Section 6 specifies whether such risks and challenges pertain to the maturity of technologies, some of which are in their infancy, and/or to the integration (design, implementation) in OSH management. The section also looks at ways to mitigate or overcome risks and challenges, which often require a participatory approach that empowers workers and that is attentive to the specific context of each workplace rather than relying on standardised approaches.

Finally, **section 7** presents our conclusions with regard to what works, for whom and how. We present our recommendations and highlight what the expected trends and challenges are – based on our analysis of primary and secondary data.

[6] EU-OSHA – European Agency for Safety and Health at Work, Advanced robotics, artificial intelligence and the automation of tasks: definitions, uses, policies and strategies and Occupational Safety and Health, 2022. Available at: https://osha.europa.eu/sites/default/files/2022-04/Advanced%20robotics_AI_based%20systems.pdf

2 Drivers, barriers and uptake

2.1 Overview of drivers and barriers to adoption

The OSH acquis, which is composed of 24 EU directives, and in particular Directive 89/391/EEC, intends to promote effective management of OSH, with the objective to introduce measures to encourage improvements in the safety and health of workers at work. The directive also defines employers' obligations in relation to OSH, including keeping a list of accidents or drawing up reports on occupational accidents, conducting risk assessments, and implementing preventive and protective measures.[7] Digital technologies provide solutions that can facilitate the goal of improving OSH management and help employers fulfil their obligations.

There are several drivers and barriers to the adoption of new OSH monitoring systems. These drivers and barriers can be organised across three main themes: **1. Technological push**, which includes supply-side factors, and can be a barrier and a driver; **2. Legislation, standardisation and research**, which relate to the scarcity of pertinent action across these dimensions that may bar or limit adoption; and **3. Organisational factors**, which are demand-side drivers and barriers.

Technological push

From a technological push perspective, the rapid progress and improvement of digital systems and technologies has **accelerated the development of new OSH monitoring systems** in working environments over the past decade. Digital technologies are becoming cheaper, smaller, more accurate, more reliable, customisable, responsive and more comfortable (e.g. exoskeletons, smart PPE), as well as interconnected, fast-paced, and more secure in terms of data collection and analysis.[8]

Despite this, **reliability, customisation, size and costs** remain the main barriers because technological advancement is an ongoing process. Khakurel et al. (2018)[9] underline that while the development of digital technologies specifically as regards OSH is still in its early stages, it is important that safety is considered early on, to avoid or minimise serious concerns in the workforce. What is more, the 'technological push', as opposed to a 'need pull', does not usually involve needs assessments or market research: it might therefore not (exactly) match the needs and preferences of end users and other stakeholders.

The relatively **lengthy time frame for the development** of new technologies in a **niche market** may constitute a **disincentive for smaller companies**, as they may lack the long-term stability and financial resources needed to start up investments in product development, including acquiring the necessary research and development (R&D) expertise.

Equally, **testing** and **certifying** (e.g. by notified bodies) **systems as a whole** (rather than components of a system) **is a complex and costly process.**[10] Evidence gathered from stakeholders consulted for this research, for example, those involved in the development of sensors for OSH monitoring systems in the gas sector, indicates that the testing phase is lengthy. This is due to the complexity of measuring environmental controls such as temperature, humidity, air pressure, CO_2 concentration, volatile organic compounds and aerosol dust concentration.[11]

[7] COUNCIL DIRECTIVE of 12 June 1989 on the introduction of measures to encourage improvements in the safety and health of workers at work (89/391/EEC). Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:01989L0391-20081211&qid=1622711259875&from=en

[8] Ngubo, S. A., Kruger, C. P., Hancke, G. P., & Silva, B. J. (2016). An occupational health and safety monitoring system. In *2016 IEEE 14th International Conference on Industrial Informatics (INDIN)* (pp. 966-971). IEEE. European Parliament. (2015). *The Internet of things. Opportunities and challenges*. European Parliamentary Research Service.

[9] Khakurel, J., Melkas, H., & Porras, J. (2018). Tapping into the wearable device revolution in the work environment: A systematic review. *Information Technology & People, 31*(3), 791-818.

[10] EU-OSHA – European Agency for Safety and Health at Work, *Smart personal protective equipment: intelligent protection for the future*, 2020. Available at: https://osha.europa.eu/en/publications/smart-personal-protective-equipment-intelligent-protection-future/view

[11] Ecorys interviews with representatives of organisations involved in the development of new occupational safety and health (OSH) monitoring technologies and/or systems, conducted between October and December 2021.

Legislation, standardisation and research

With regard to **legislation**, while the EU has a substantial OSH acquis, current EU legislation does not address the implications of technical change in OSH monitoring, which renders it a grey area not only in terms of policy but also practice. This gap in OSH legislation is highlighted in a 2019 briefing requested by the EMPL committee of the European Parliament, which notes that OSH Framework Directive 89/391/EEC does not '*explicitly address the new challenges posed by digital technologies*'.[12] However, the issues of privacy and data protection are addressed by the General Data Protection Regulation (GDPR).[13]

The absence of certification standards can also pose barriers to the adoption of new OSH monitoring systems. For example, smart PPE have no certification standards (as complete products), despite ongoing developments from the European Committee for Standardisation (CEN-CENELEC).[14] Nevertheless, it is worth noting that certification standards are underway for health software products such as apps that can monitor OSH.[15] However, according to interview data, introducing very complex certification standards to new OSH monitoring systems (e.g. to operate under all circumstances) would lead to a significant price increase.

Safety standards are important for purchasers to overcome asymmetry of information[16] vis-à-vis suppliers and manufacturers, regarding product quality (performance, capability) and safety.[17] Standards are also key to creating markets, for example, if technologies from different manufacturers use different standards (or none at all), interoperability will be difficult and consumers may be locked in a given system,[18] which may discourage market penetration, choice, competition and innovation.[19] Furthermore, the lack of consistent standards may hamper large-scale investments, for example, in IoT network infrastructure.[20] Finally, standards are crucial because of the potential risks and challenges associated with new OSH monitoring systems, as they may not only help prevent accidents and ill health but may cause harm. They can also have a social impact in terms of the 'human in control' principle[21] and the respect of human dignity and privacy[22] – which may discourage the adoption of digital solutions.

In turn, **standardisation is complex**. This research has gathered evidence on the complexity of standardisation for smart PPE. First, the design of smart PPE must, for instance, conform with traditional PPE regulation and with certified electronic parts, to ensure that the end product does not create new hazards or higher risks, such as: electrical, battery, electromagnetic field safety and electromagnetic compatibility. Furthermore, standardisation bodies recognise smart PPE as a new type of product altogether, which needs testing and specific standards. For example, 'the presence of conductive fibres to incorporate a personal stereo into a smart raincoat might increase the risk of the wearer suffering a lightning-strike in a thunderstorm - despite the fact that neither rainwear nor personal stereos, when

[12] Cabrelli, D., & Gravelling, R. (2019). *Health and safety in the workplace of the future*. Briefing requested by the EMPL committee of the European Parliament, Policy Department for Economic, Scientific and Quality of Life Policies Directorate-General for Internal Policies. Available at: https://www.europarl.europa.eu/RegData/etudes/BRIE/2019/638434/IPOL_BRI(2019)638434_EN.pdf

[13] Eurofound. (2020). *Employee monitoring and surveillance: The challenges of digitalisation*. Publications Office of the European Union, p. 7. Available at: https://www.eurofound.europa.eu/sites/default/files/ef_publication/field_ef_document/ef20008en.pdf

[14] CEN/TR 16298:2011, 'Smart textiles — definitions, categorisation, applications and standardization needs'.

[15] For more information, see: https://www.iso.org/news/isofocus_141-6.html

[16] Akerlof, G. A. (1978). The market for "lemons": Quality uncertainty and the market mechanism. In P. Diamond, & M. Rothschild (Eds), *Uncertainty in economics* (pp. 235-251). Academic Press. Spence, A. M. (1973). Job market signaling. *Quarterly Journal of Economics, 87*(3), 355–374.

[17] EU-OSHA – European Agency for Safety and Health at Work, *Smart personal protective equipment: intelligent protection for the future*, 2020. Available at: https://osha.europa.eu/en/publications/smart-personal-protective-equipment-intelligent-protection-future/view

[18] European Parliament. (2015). *The Internet of things. Opportunities and challenges*. European Parliamentary Research Service.

[19] European Parliament. (2019). *Standards and the digitalisation of EU industry: Economic implications and policy developments*. Briefing, European Parliamentary Research Service.

[20] World Bank Group. (2017). *Internet of Things: The new government to business platform - A review of opportunities, practices, and challenges*.

[21] Humans, not computers and their algorithms, should be responsible for any relevant decision.

[22] European Trade Union Confederation (ETUC). (2016). *ETUC resolution on digitalisation: 'Towards a fair digital work'*. Available at: https://www.etuc.org/sites/default/files/document/files/en-resol.digitalisation_adopted.pdf

separate, need to be assessed against this risk.'[23] In many cases, a product – even if not using digital technology – may need to comply with more than one standard, but when digital components are involved, then it is this digital and non-digital combination that generates potential risks. Second, complexity may refer to the risks the standards seek to address. As one EU-level stakeholder interviewed for this study argued, defining standards for psychosocial risks (for instance, linked to information and communications technology (ICT), AI and IoT) is very complex. Besides, questions on psychosocial risks could be polarising and there are also cultural differences among countries in the way psychosocial risks are understood.[24]

Standardisation also comes with other problems. For example, in the absence of the public sector's intervention, standardisation may be left to private parties influenced by industry or interest groups. This can raise questions about the quality of the standardisation process, and, at the extreme, compromise it to the disadvantage of OSH.[25]

Besides, according to interview data collected, **smaller companies face substantial obstacles in participating in policy debates** because of the required investment of resources. This challenge is compounded by the fact that standardisation is increasingly taking place at a global level in certain cases, and this is considered by social partners to considerably hamper the participation of EU trade unions in these global forums. As a result, social partners have argued that the EU should invest more in establishing standards for the EU digital single market.[26] Relatedly, Ranavolo et al. (2018)[27] noted, albeit limited to wearables, that standards sometimes deviate from evidence-based practical guidelines, and that governments need to be more proactive in their engagement with the definition of standards.

The **paucity of easily available research on the effectiveness** of these digital systems may further disincentivise their adoption. According to the stakeholders interviewed,[28] there is lack of research and concrete examples regarding the effectiveness of these digital systems. However, examples of these are more prevalent at specific events and conferences, but data are sometimes poorly disseminated. Overall, it is challenging for companies to acquire adequate information in order to weigh costs and expected impacts and benefits inherent to the adoption of new OSH monitoring systems, but this is even more challenging for SMEs.

Organisational factors

There are some demand-driven organisational factors that act as drivers and barriers to the adoption of OSH monitoring systems. First, drivers may draw on the **need and motivation on the part of companies and workers**; in this case, new OSH monitoring systems may be used to fulfil obligations, to improve OSH, and/or to adjust to market or workers' pressures to innovate. Evidently, the perception and awareness of needs may vary vastly across companies and between employers and workers (including inexperienced, migrant, temporary, immunocompromised, elder, pregnant, etc.) who may be less represented by trade unions.

The **COVID-19 pandemic is also a driver**, as companies had to address exposure to biological agents, by ensuring safe processes and behaviours. Changes in the location of work in the context of the COVID-19 pandemic and the **increase in telework** has precipitated a diverse range of OSH hazards linked to home workstations, repetitive strain injuries (RSIs) and right to disconnect, together with the difficulty of ensuring adequate controls.[29] Smart digital monitoring systems can help address these new

[23] EU-OSHA – European Agency for Safety and Health at Work, *Smart personal protective equipment: intelligent protection for the future*, 2020. Available at: https://osha.europa.eu/en/publications/smart-personal-protective-equipment-intelligent-protection-future/view

[24] European Committee for Electrotechnical Standardization (CEN-CENELEC). Available at: https://www.cencenelec.eu/

[25] Eurofound. (2021). *Digitisation in the workplace*. Publications Office of the European Union.

[26] ETUC. (2016). *ETUC resolution on digitalisation: 'Towards a fair digital work'*. Available at: https://www.etuc.org/sites/default/files/document/files/en-resol.digitalisation_adopted.pdf

[27] Ranavolo, A., Draicchio, F., Varrecchia, T., Silvetti, A., & Iavicoli, S. (2018). Wearable monitoring devices for biomechanical risk assessment at work: Current status and future challenges—A systematic review. *International Journal of Environmental Research and Public Health, 15*(9), Article 2001.

[28] Ecorys interviews conducted for this study, between November-February 2021.

[29] EU-OSHA – European Agency for Safety and Health at Work, *Teleworking during the COVID-19 pandemic: risks and prevention strategies*, 2021. Available at: https://osha.europa.eu/en/publications/teleworking-during-covid-19-pandemic-risks-and-prevention-strategies

needs by monitoring OSH remotely and measuring physical (including ergonomic) and mental health and wellbeing data.

There are also barriers and not only drivers at the organisational level. One example is hesitance and lack of buy-in on the part of workers and worker representatives (trade unions, works councils) towards the adoption of digital technologies and monitoring systems. **There are various reasons for worker hesitance and lack of buy-in.** First is the limited **evidence and awareness** among employers and workers about the impact on OSH as a consequence of the use of monitoring systems.[30] Second is the **potentially hidden purpose of employee surveillance**, rather than OSH monitoring. There are trade union concerns that the use of new monitoring technologies and systems would expose the workforce to **productivity pressures**. This carries risks for workers' health and wellbeing according to the literature[31], and as also noted by trade union representatives interviewed for this research.[32] Third, concerns regarding **ethics, data protection, security and privacy** are also voiced by workers and their representatives. Such concerns may apply differently across Member States depending on legislative aspects and trade union power. For instance, in Italy, the privacy of workers is protected in national legislation.[33] In northern Europe, unions often have a formal right to veto any measures that they consider not to be in the interest of their members.[34]

As for employers, another barrier is **complexity of integration** (e.g. cost, length, tailoring solutions to the workplace) in OSH management and in the business. However, the important aspect is not technology *per se* but rather how this technology is integrated in a system that is designed and implemented to respond to OSH needs in a specific context. Besides, the assessment should include the expected impact of the use of OSH monitoring tools on a range of OSH risk factors that might hinder productivity or even support it.

2.2 Trends in uptake

Interviews indicate that the use of digital monitoring technologies and systems used for OSH purposes is becoming more widespread, but that uptake continues to be relatively slow and limited. Interviewees also seem to suggest that **industries where workers are exposed to higher OSH risks** and **big companies** are at the forefront when it comes to the adoption of new OSH monitoring systems.[35]

There is very limited quantitative data that can provide a direct indication of the uptake of new OSH monitoring systems in European workplaces. Proxy indicators related to the **use of digital technologies in the workplace** can provide some indication. According to ESENER-3 data, 4.8% of the surveyed establishments used 'wearable devices' and 3.7% used collaborative robots (cobots) (see Figure 1). These figures can be considered relatively low when compared with technologies such as 'PCs at fixed workplaces' (86.6%), 'laptops, tablets, smartphones or other mobile devices' (76.7%) – indicating a comparatively limited uptake of wearables and robots. However, 11.8% of establishments used systems to determine the content and pace of work and 8.2% used systems to monitor worker performance (rather than monitoring OSH).[36]

[30] EU-OSHA – European Agency for Safety and Health at Work, *Occupational exoskeletons: wearable robotic devices to prevent work-related musculoskeletal disorders in the workplace of the future*, 2020. Available at: https://osha.europa.eu/en/publications/occupational-exoskeletons-wearable-robotic-devices-and-preventing-work-related

[31] Moore, P. V. (2017). *The quantified self in precarity: Work, technology and what counts*. Routledge.

[32] Ecorys interviews with stakeholders from trade unions, employer representatives and research organisations, conducted between November 2021 and February 2022.

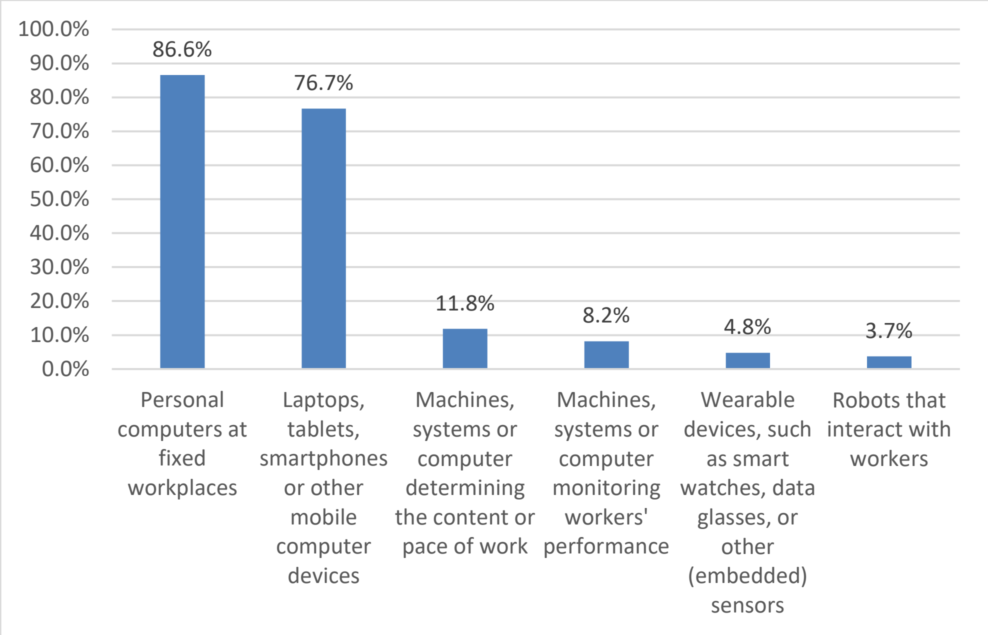
[33] Tebano, L. (2017). Employees' privacy and employers' control between the Italian legal system and European sources. Labour & Law Issues, 3(2), C. 1-C. 20.

[34] Ecorys interviews with stakeholders from trade unions, employer representatives and research organisations, conducted between November 2021 and February 2022.

[35] Ibid.

[36] EU-OSHA – European Agency for Safety and Health at Work, *ESENER 2019 Overview Report*, 2022. Available at: https://visualisation.osha.europa.eu/esener/en/survey/overview/2019

Figure 1: Use of different digital technologies in business and organisation (% of workplaces)



Base: All establishments in the EU-27 2020 reporting digital technologies at work (ESENER-3)

At company level (see Figure 2), ESENER-3 data show a strong correlation between the size of the establishment and the uptake of digital technologies. A European OSH expert explains that bigger establishments tend to have more financial resources to invest in long-term R&D and digitalisation than smaller companies. It is also more common that bigger establishments have the necessary technical capacity for integrating monitoring technology across their operations, which provides them with scaling-up advantages. Furthermore, big companies often have the required human resources to analyse their own needs, and to install and deploy the technology, which may also involve carrying out staff trainings and creating manuals.[37]

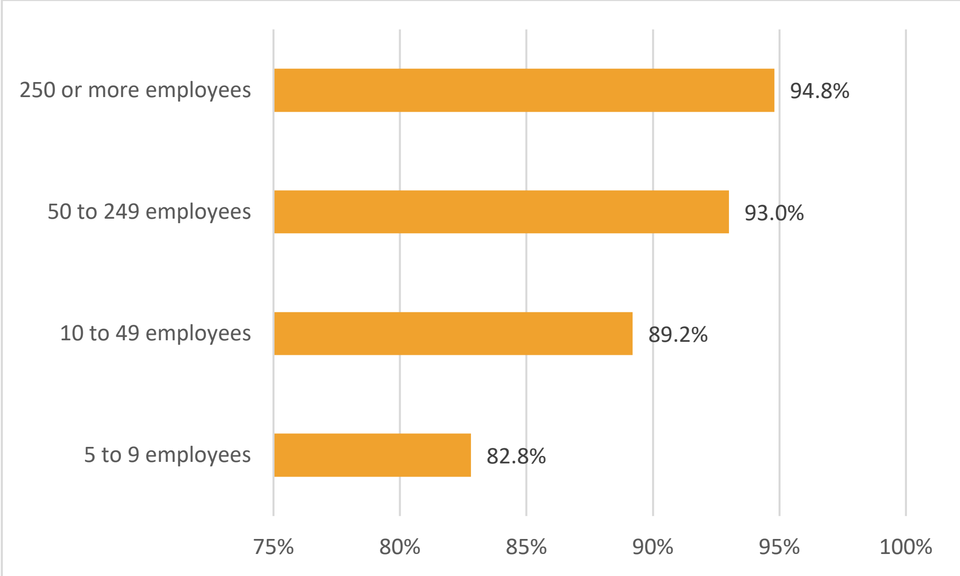
A World Economic Forum survey, in a 2018 report, found that 58% of multinational companies surveyed were likely to adopt virtual reality (VR) and augmented reality (AR) technologies between 2018 and 2022.[38] Eurofound shows that sectors with a higher uptake of VR/AR technologies were the ICT (72%), automotive, aerospace, supply chain and transport (71%) and aviation, travel and tourism (68%).[39] However, there is no clear indication that the purpose of use falls within OSH monitoring.

[37] Ecorys interviews with stakeholders from trade unions, employer representatives and research organisations, conducted between November 2021 and February 2022.

[38] World Economic Forum. *Future of jobs report 2018*. Available at: https://www.weforum.org/reports/the-future-of-jobs-report-2018.

[39] Eurofound. (2021). *Digitisation in the workplace*. Publications Office of the European Union.

Figure 2: Use of digital technologies in companies of different size (% of workplaces)[40]



Source: ESENER-3

Data suggest that new OSH monitoring systems are still in their infancy in some cases, but that **the trend is towards an increased adoption** because of the heightened awareness of old and new OSH needs compared to the recent past, and due to the improved opportunities offered by technological sophistication. Therefore, while adoption is still limited, this could change in the not-so-distant future.

[40] EU-OSHA – European Agency for Safety and Health at Work, *Third European Survey of Enterprises on New and Emerging Risks (ESENER 2019): Overview Report How European workplaces manage safety and health*, 2022. Available at: https://osha.europa.eu/en/publications/esener-2019-overview-report-how-european-workplaces-manage-safety-and-health#:~:text=The%20third%20European%20Survey%20of,the%20previous%20survey%20from%202014.

3 Taxonomy of new OSH monitoring systems across the OSH cycle

3.1 Definition

There is no common and general definition of new OSH monitoring systems at the EU level. The key **definition** available in the literature focuses on their functionality and technological core, and it is offered by van den Broek,[41] who states that 'monitoring technology *systematically observes, keeps an eye on, or oversees and checks the progress or quality of something or someone over a period of time, based on a sensor or a set of sensors*'.

Interviews with multiple stakeholders conducted for this study[42] confirm the lack of a clear, distinct and widely used definition. Research participants noted the complexity of formulating an all-encompassing definition of new OSH monitoring systems due to their diverse nature and the blurred lines between OSH monitoring and performance monitoring.

Indeed, another general definition of monitoring systems focuses more on performance and surveillance than it does on OSH monitoring. In the recent report published by the Joint Research Centre of the European Commission (2021), **monitoring and surveillance systems** are defined as 'any collection and processing of information, whether personally identified or not, for the purposes of influencing and managing those whose data have been garnered.'[43] Evidently, this definition falls outside the scope of the current research, and it points – as mentioned in the introduction – to the blurred boundaries between OSH monitoring and monitoring performance.

However, the distinct importance of OSH monitoring for both employers and workers requires a specific definition of new OSH monitoring systems. Such a definition needs to be short, clear and precise – thus, balancing comprehensiveness and specificity. What is more, a strict requirement of such a definition is that it should (attempt to) not become obsolete very soon. This is particularly important given that digital technologies and OSH monitoring systems are developing rapidly.

Therefore, we propose the following **definition of new OSH monitoring systems**, which draws on existing definitions of OSH and other monitoring systems, and the evidence gathered on their types and purposes:

New OSH monitoring systems use digital technology to collect and analyse data in order to identify and assess risks, prevent and / or minimise harm, and promote occupational safety and health.

3.2 Digital technologies

Digital systems and technologies that support new OSH monitoring systems include, among others: information & communications technology (ICT devices and services; cameras; Artificial Intelligence AI; augmented and / or virtual reality (AR/VR; IoT / widespread connectivity / big data; wearable devices; smart clothes and personal protective equipment (PPE (exoskeletons); drones (unmanned aerial vehicles (UAVs)); and Radio- Frequency dentification Systems (RFID).

- **ICT** includes technologies such as mobile devices, PCs, and teleconferencing software or devices.

[41] EU-OSHA – European Agency for Safety and Health at Work, *Monitoring technology: The 21st century's pursuit of well-being?*, 2017. Available at: https://osha.europa.eu/sites/default/files/Workers_monitoring_and_well-being.pdf

[42] Ecorys interviews with stakeholders from trade unions, employer representatives and research organisations, conducted between November 2021 and February 2022.

[43] Ball, K. (2021). *Electronic monitoring and surveillance in the workplace. Literature review and policy recommendations*. Publications Office of the European Union. Available at: https://publications.jrc.ec.europa.eu/repository/bitstream/JRC125716/jrc125716_electronic_monitoring_and_surveillance_in_the_workplace_final.pdf

- **Cameras to monitor activities.** There are two types: basic systems that only record signals, which can be stored and/or actively monitored; and intelligent systems that use algorithms to interpret data, related to the environment and/or to behaviours, for instance.[44,45,46,47]
- **Wearables**,[48] including **smart PPE**,[49] are small electronic devices with sensors and computational capabilities. Such small devices can be placed in clothing and equipment and provide data.[50] Examples include small electronic devices in exoskeletons[51,52] or smart clothing. More recently, such devices can also be placed on the workers' bodies. For example, a rather new wearable category is that of disposable patches and electronic tattoos that are worn for a certain number of days and (like other OSH monitoring systems) can measure vital signs such as heart's rhythm and electrical activity, blood pressure, body temperature, hydration level and so on.[53]
- **Big data** refers to a combination of three trends: 1. increased levels of connectivity and networking, 2. improved data storage, and 3. advanced data analyses (of which ML is an example). Big data refers to 'large amounts of data produced very quickly by a high number of diverse sources. Data can either be created by people or generated by machines.'[54] Datasets are so big that they may evade human capacity to analyse them, which may be left to algorithms.[55]
- **IoT.** IoT is a cyber-physical system in which the information collected is fed, via the internet, to computers to gather data about production and work processes and to analyse these data with unprecedented granularity.[56] This entails that humans are creating a '"ubiquitous world" in which all devices … will be fully networked.'[57] According to the US National Security and Telecommunications Advisory Committee, IoT reshapes our interaction with the physical world through devices interconnected on a platform (e.g. cloud) and performing functions adaptively based on inputs and programming.[58]
- **AI** refers to the 'multidisciplinary theories, techniques, concepts and technologies implemented in order to develop machines capable of simulating intelligence'.[59.] AI systems 'display intelligent

[44] Cocca, P., Marciano, F., & Alberti, M. (2016). Video surveillance systems to enhance occupational safety: A case study. *Safety Science, 84*, 140-148.
[45] Gavrila, D. M. (1999). The visual analysis of human movement: A survey. *Computer Vision and Image Understanding, 73*(1), 82-98.
[46] Boult, T. E., Micheals, R. J., Gao, X., & Eckmann, M. (2001). Into the woods: Visual surveillance of noncooperative and camouflaged targets in complex outdoor settings. *Proceedings of the IEEE, 89*(10), 1382-1402.
[47] Diehl, C. P. (2000). *Toward efficient collaborative classification for distributed video surveillance* (Doctoral dissertation, Carnegie Mellon University).
[48] Khakurel, J., Melkas, H., & Porras, J. (2018). Tapping into the wearable device revolution in the work environment: A systematic review. *Information Technology & People, 31*(3), 791-818.
[49] EU-OSHA – European Agency for Safety and Health at Work, *Smart personal protective equipment: intelligent protection for the future*, 2020. Available at: https://osha.europa.eu/en/publications/smart-personal-protective-equipment-intelligent-protection-future/view
[50] Kim, S., Nussbaum, M. A., & Gabbard, J. L. (2016). Augmented reality "smart glasses" in the workplace: Industry perspectives and challenges for worker safety and health. *IIE Transactions on Occupational Ergonomics and Human Factors, 4*(4), 253-258.
[51] EU-OSHA – European Agency for Safety and Health at Work, *Occupational exoskeletons: wearable robotic devices to prevent work-related musculoskeletal disorders in the workplace of the future*, 2020. Available at: https://osha.europa.eu/en/publications/occupational-exoskeletons-wearable-robotic-devices-and-preventing-work-related
[52] Exoskeletons are a *personal assistance system that affects the body in a mechanical way*. For more information on their impact to OSH, refer to Liedtke and Glitsch, 2018 in: EU-OSHA – European Agency for Safety and Health at Work, *The impact of using exoskeletons on occupational safety and health*, 2019, pp. 1-10. Available at: https://osha.europa.eu/en/publications/impact-using-exoskeletons-occupational-safety-and-health
[53] Ecorys interviews with stakeholders from trade unions, employer representatives and research organisations, conducted between November 2021 and February 2022.
[54] European Commission. (2020). *Big data*. Available at: https://ec.europa.eu/digital-single-market/en/big-data
[55] Badri, A., Boudreau-Trudel, B., & Souissi, A. S. (2018). Occupational health and safety in the industry 4.0 era: A cause for major concern? *Safety Science, 109*, 403-411.
[56] Eurofound. (2018). *Game changing technologies: Exploring the impact on production processes and work*. Publications Office of the European Union. Available at: https://www.eurofound.europa.eu/publications/report/2018/game-changing-technologies-in-european-manufacturing
[57] EU-OSHA – European Agency for Safety and Health at Work, *The future of work: robotics*, 2015. Available at: https://osha.europa.eu/en/publications/future-work-robotics
[58] World Bank Group. (2017). *Internet of Things : The new government to business platform - A review of opportunities, practices, and challenges*.
[59] Badri, A., Boudreau-Trudel, B., & Souissi, A. S. (2018). Occupational health and safety in the industry 4.0 era: A cause for major concern? *Safety Science, 109*, 403-411.

behaviour by analysing their environment and taking actions – with some degree of autonomy – to achieve specific goals.'[60]

- **ML.** ML is a branch of AI dealing with how computers can learn, grow and improve on their own from data without human intervention.[61]
- **VR** and **AR**: 'VR is a computer-generated scenario that simulates a real-world experience. AR combines real-world experiences with computer-generated content.'[62] AR can be defined as an 'immersive' technology, blurring the lines between reality and the virtual world, enhancing the interaction of the user with the environment.[63] Practically, AR users point their devices (smartphones, wearables, etc.) towards a specific image, which is acquired and processed to create projections (2D or 3D), which the user can interact with.[64]
- Unmanned aerial systems (**UAS**) are 'composed of the vehicle airframe and power supply, vehicle sensors, remote operator, an onboard computer, and vehicle actuators. Sensors gather information about the vehicle's environment and actuators cause movement of the vehicle. The operator can receive information by looking directly at the vehicle (flying by "line-of-sight") or by looking at a video transmitted from the vehicle (flying by "first-person view".)'.[65]
- **RFID** is 'a wireless sensor technology which is based on the detection of electromagnetic signals [that] includes three components: an antenna or coil, a transceiver (with decoder) and a transponder (RF tag) electronically programmed with unique information. There is emission of radio signals by the antenna in order for the tag to be activated and data to be read and written to it.'[66]

3.3 Taxonomy

For policy, research and practical purposes, it is becoming increasingly important to understand the key types of new OSH monitoring systems that are available. This can help clarify the different concepts and dimensions of interest in relation to expected OSH impacts, and the OSH opportunities and risks and challenges of these new OSH monitoring systems.

A taxonomy of new OSH monitoring systems needs to be based on few characteristics but also be comprehensive. It should be relevant to the different levels of prevention and applicable across different sectors, which display specific and/or similar hazards, for various needs of workers, including those linked to COVID-19.

There are **two key overarching approaches of new OSH monitoring systems** – a proactive approach that seeks to prevent harm and, more broadly, promote health; and a reactive one that focuses on the response to accidents and emergencies. In particular:

- **Proactive** types facilitate the process of assessing risks preventively by making it quicker, easier, cheaper and at times continuous (i.e. 24/7); they allow safer and tailored interventions as well as 'on-the-job' feedback or support; they seek to prevent harm by detecting workplace (environmental, behavioural) risks early or even predicting them (when AI and ML are used);

[60] European Commission. (2018). COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE EUROPEAN COUNCIL, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS, Artificial Intelligence for Europe. COM(2018)237. Available at: https://ec.europa.eu/transparency/documents-register/detail?ref=COM(2018)237&lang=en

[61] Sharma, N., Sharma, R., & Jindal, N. (2021). Machine learning and deep learning applications-A vision. *Global Transitions Proceedings, 2*(1), 24-28. https://doi.org/10.1016/j.gltp.2021.01.004

[62] Eurofound. (2021). *Digitisation in the workplace*. Publications Office of the European Union. Available at: https://www.eurofound.europa.eu/publications/report/2021/digitisation-in-the-workplace

[63] Pierdicca, R., Prist, M., Monteriù, A., Frontoni, E., Ciarapica, F., Bevilacqua, M., & MazzutoM G. (2020). Augmented reality smart glasses in the workplace: Safety and security in the Fourth Industrial Revolution era. In L. De Paolis, & P. Bourdot (Eds), *Augmented reality, virtual reality, and computer graphics. AVR 2020. Lecture Notes in Computer Science, Vol. 12243* (pp. 231-247). Springer. https://doi.org/10.1007/978-3-030-58468-9_18

[64] Kim, S., Nussbaum, M. A., & Gabbard, J. L. (2016). Augmented reality "smart glasses" in the workplace: Industry perspectives and challenges for worker safety and health. *IIE Transactions on Occupational Ergonomics and Human Factors, 4*(4), 253-258.

[65] Howard, J., Murashov, V., & Branche, C. M. (2017). Unmanned aerial vehicles in construction and worker safety. *American Journal of Industrial Medicine, 61*(1), 3-10. https://doi.org/10.1002/ajim.22782

[66] Domdouzis, K., Kumar, B., & Anumba, C. (2007). Radio-frequency identification (RFID) applications: A brief introduction. *Advanced Engineering Informatics, 21*(4), 350-355.

they measure exposure or exposure responses[67] to different types of hazards to support evidence-based prevention/intervention (e.g. routine checks and maintenance, provision of data for adaptations and adjustments to improve OSH); and they may also support a more positive approach to health and safety promotion in terms of healthy lifestyles and safer / healthier work processes and workplaces.

- **Reactive** types seek to minimise consequences of accidents and emergencies that have already occurred; improve accident reporting by making it quicker, automatic, cheaper, easier and involving less stigma; and improve accident investigation, by making it safer, more efficient and targeted; and they may also support a more positive approach to health and safety promotion in the workplace in terms of corrective measures to prevent or minimise harm and promote safety in the future.

The two types are strongly linked to the definition of OSH monitoring systems in section 3.1. They are derived from an inductive and deductive approach[68] based on the large number of articles reviewed and the rich interview data collected and analysed. The focus is on the *purpose* of OSH monitoring systems, across stages of prevention (i.e. primary, secondary, tertiary). In view of this, the types are in fact non-exclusive,[69] as a new OSH monitoring system could only fit in one type, in some cases, or aim at more than one purpose (e.g. accident investigation *and* training). On the one hand, this is indicative of the increased complexity of new OSH monitoring systems, which often combine more than one digital technology. On the other hand, this reflects the fact that OSH is characterised by a continuous cycle of improvement, rather than by fully compartmentalised segments of intervention.

Indeed, companies need to regularly define and review their OSH policies, processes, plans and practices. This is to say that, first, the goals and commitments to prevent injuries, fatalities and ill health need to be highlighted. Second, hazards and risks need to be identified and assessed. Third, resources must be put in place to address them. Fourth, roles and responsibilities need to be distributed within the company for pertinent, effective, efficient, equitable and ethical actions to be implemented. This is a **continuous cycle of improvement** that requires analysing data and taking corrective actions when needed, to renew and improve the OSH management life cycle, according to OHSAS 18001 and the new ISO 45001.[70,71]

Table 1: Types of new OSH monitoring systems

Key dimensions	Proactive	Reactive
Purpose / Use	Identifying and preventing health and safety risks Ensuring routine checks and maintenance Training / On-the-job mentoring / support Providing data for adaptations and adjustments to improve OSH	Identifying and minimising consequences of accidents / emergencies Accident reporting Accident investigation Providing data for corrective measures to improve OSH

67 Here, it is worth noting that, sometimes, it is hard to measure exposure, which is one of the reasons why in some cases OSH monitoring systems measure short-term effects. For example, measuring stress by heart-rate-variability.

68 An inductive approach starts from data collected to *develop* a theory, whereas a deductive approach *tests* theory by using data collected.

69 Thus, deviating from an academic type of taxonomy.

70 Lo, C. K. Y., Pagell, M., Fan, D., Wiengarten, F., & Yeung, A. C. L. (2014). OHSAS 18001 certification and operating performance: The role of complexity and coupling. *Journal of Operations Management, 32*(5), 268-280.

71 Fernández-Muñiz, B., Montes-Peón, J. M., & Vázquez-Ordás, C. J. (2012). Occupational risk management under the OHSAS 18001 standard: Analysis of perceptions and attitudes of certified firms. *Journal of Cleaner Production, 24*, 36-47.

	OSH improvement measures	
Technologies	ICT (e.g. communications, laptops, smartphones); cameras (e.g. thermal, infrared, etc.); wearables, smart PPE, monitoring exoskeletons, sensors; wireless sensor networks; RFIDs; IoT; VR, AR; cobots; drones; microphones or other noise measurement devices	
	AI-based / Not AI-based	
Risks	Physical, safety, ergonomic, psychosocial, organisational, biological, chemical, radiation	
Category of risks	Equipment-related Person-related Information-related Sector-related	Sectoral (workplace and the working environment in specific sectors) Plant (machinery and vehicles) People (working methods, relations and behaviour) Procedures (division of tasks, demand – control balance and structure of working hours)
Types of data collection	Personal (individual & aggregated), environmental, equipment-specific	
	Real-time / not real-time	
	Static / dynamic	
	Images, audio, video, environmental, health, behavioural, body posture data	
	Sensitive (e.g. personal) vs non-sensitive (e.g. data related to equipment)	
Types of needs addressed	Workers with specific needs (e.g. ageing workforce, workforce diversity and inclusion, lone worker, inexperienced worker)	
	COVID-19 and long COVID	
	Teleworking	

Types of risks monitored

Prior to presenting the proactive / reactive properties of new OSH monitoring systems, it is important to provide an overview of the types of risks that these systems monitor, the data they collect and the needs they address.

New OSH monitoring systems relate to the **types of OSH risks**[72] that are being monitored and managed. Notably, hazards may refer to the so-called 4Ps: **Plant** (machinery and vehicles); **Premises** (workplace and the working environment); **People** (working methods, relations and behaviour); and **Procedures** (division of tasks, demand – control balance and structure of working hours). Another way to consider hazards is whether they are: physical, safety, ergonomic, psychosocial, organisational, biological, chemical, radiation.

The types of OSH hazards are inherently related to the tasks performed and the work premises, as well as the sectors and industries in which individuals work – with workers in oil and gas, manufacturing, transport, mining, agriculture and forestry, health and social care, and pharmaceutical companies (among others) presenting a combination of similar and different hazards in terms of toxic substances or types of workplace accidents or ensuing musculoskeletal disorders (MSDs) they may be exposed to during the course of their careers, as exposure accumulates.[73]

[72] Risk and hazards are used somewhat interchangeably. However, a 'hazard is something that can cause harm, e.g. electricity, chemicals, working up a ladder, noise, a keyboard, a bully at work, stress, etc. A risk is the chance, high or low, that any hazard will actually cause somebody harm.' https://osha.europa.eu/en/tools-and-resources/eu-osha-thesaurus/term/70194i

[73] See: https://oiraproject.eu/en/oira-tools

Further, different hazards may be present within a given sector across its subsectors: for instance, indoor construction, outdoor construction, and construction - earth work.[74] Therefore, the focus on OSH hazards is an efficient way of subsuming different sectors and industries in the analysis of these smart digital monitoring systems and technologies. It is also a useful way of establishing a link with the type of tasks performed by workers. The latter could for instance relate to objects, people or information; for example, MSDs due to lifting heavy loads and/or objects in construction, or people in health and social care or in agriculture. Information-related tasks are predominantly associated with clerical and managerial job tasks that do not include manual labour, including, for example, human resources employees in a mining company.

Types of data collection

These digital technologies may at times monitor the work environment and equipment (cameras, drones, RFID, for instance) or the individual (notably through wearable technology), or monitor both in a hybrid way (e.g. wearables, smart PPE, sensor networks, GPS and RFID). They may also collect and make sense of data at aggregate / collective workplace level rather than the individual level only.

Some of these digital tools allow for real-time (as opposed to non-real-time) and dynamic (as opposed to static) monitoring and tend to be used across the two types of OSH monitoring systems identified.

The data collected include images, audio, video (e.g. video footage), environmental data (e.g. temperature), health data (e.g. heartrate, body temperature, etc.), behavioural data (e.g. risky behaviour) and body posture data.[75]

Moreover, some of the data collected could be sensitive personal data and should be GDPR compliant (for instance, ethnicity, race, health data, etc.). Collecting workers' data under pressure can have implications on privacy and on OSH as well. Other types of data are not covered by GDPR, for example, environmental levels of health and safety hazards, or data related to the equipment.

Types of needs addressed

New OSH monitoring systems can help to address the specific needs of workers (lone workers, inexperienced ones, ageing workforce, diverse workforce, workers with low language skills, hearing impaired workers, etc.) and of vulnerable contexts, such as the situation resulting from the COVID-19 pandemic. These new systems may support inclusion and diversity, help workers find and remain in employment, and facilitate being healthy and safe from harm and injury on the job. Specific needs have also arisen from COVID-19 and teleworking.

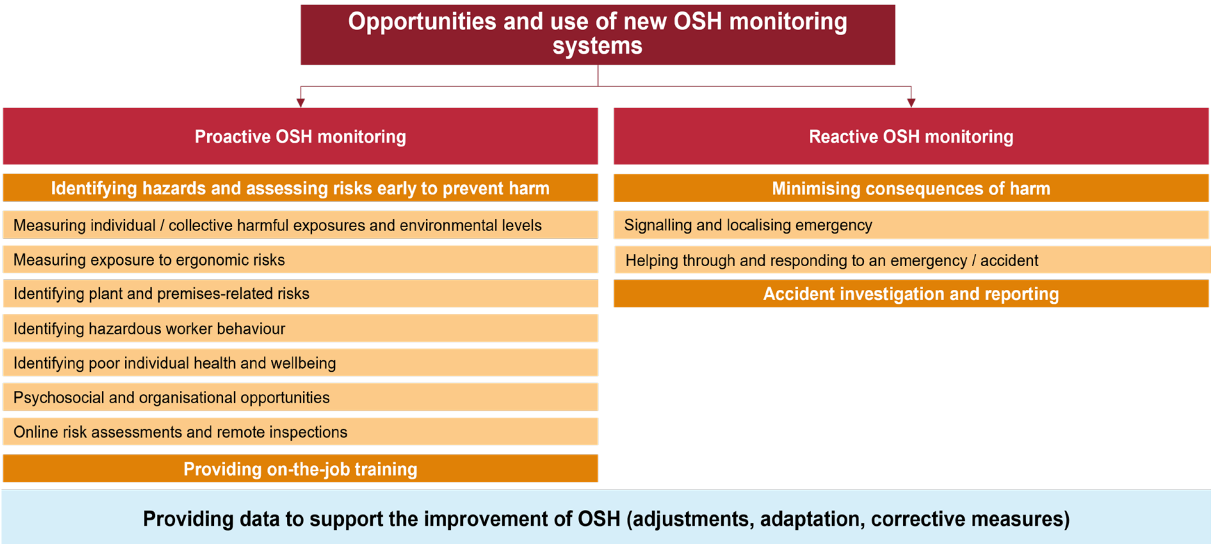
[74] See: https://oiraproject.eu/en/oira-tools?f%5B0%5D=sector%3AConstruction%20%26%20maintenance

[75] EU-OSHA – European Agency for Safety and Health at Work, *Monitoring technology: The 21st century's pursuit of well-being?*, 2017. Available at: https://osha.europa.eu/sites/default/files/Workers_monitoring_and_well-being.pdf

4 Opportunities and use of new OSH monitoring systems

This section presents a summary of the opportunities and use of new OSH proactive and reactive monitoring systems. An overview of how the section is organised is shown in Figure 3. As Figure 3 shows, new OSH monitoring systems focus primarily on four aspects: training,[76] identifying risks, minimising consequences of harm and facilitating accident reporting and investigation.

Figure 3: Overview of section 4 on opportunities / use of new OSH monitoring systems



4.1 Proactive OSH monitoring

Proactive OSH monitoring is the first key approach. It is organised across two key purposes: providing training to workers[77] (section 4.1.2) and identifying hazards and assessing risks early to prevent harm (section 4.1.1). Training is improved to meet the needs of workers and employers. The process of preventing harm is made more effective and efficient by collecting accurate and comprehensive data, including on routine checks and maintenance. In turn, the data collected and analysed can be used to make adaptations and adjustments that strengthen OSH risk prevention. The latter opportunity is not analysed separately, but rather woven into the text. This is because the section systematically focuses on hazards and risks to counter.

4.1.1 Identifying hazards and assessing risks early to prevent harm

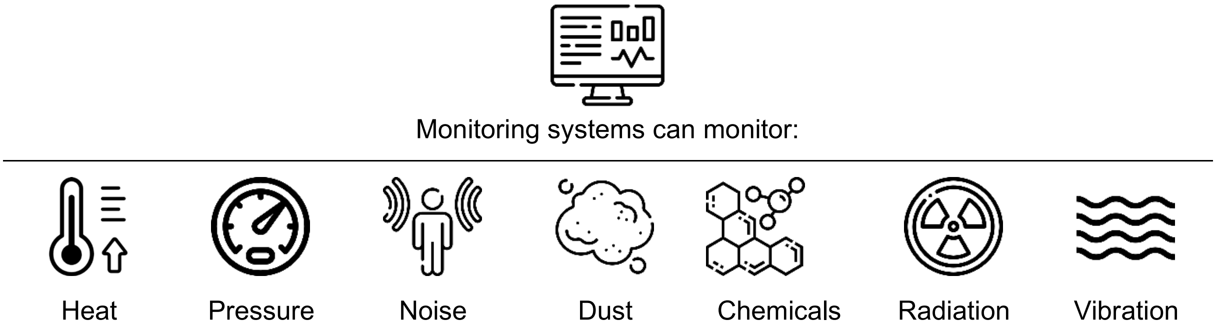
Measuring individual / collective harmful exposures and environmental levels

Harm can be prevented by **measuring in real time routine and non-routine harmful individual / collective workers' exposure**: heat, pressure, noise, dust, chemicals, biological agents, radiation, UV and so on. Furthermore, new OSH monitoring systems also allow to measure the environmental levels of different kinds of risks safely and effectively. Wearables and smart PPE (such as smart glasses, hard hat sets, smart bands, smart shoes, protective gear, with smart electronics parts linked to smartphones and smartwatches) can measure individual exposure as well as environmental levels.[78] Further,

[76] For example, OSH monitoring systems can provide tips/advice on posture while performing manual tasks and/or advice on unsafe working behaviour.
[77] For example, through providing them with feedback (e.g. alerts) about potential risks and with advice that can be tailor-made to the individual worker.
[78] Adjiski, V., Despodov, Z., Mirakovski, D., & Serafimovski, D. (2019). System architecture to bring smart personal protective equipment wearables and sensors to transform safety at work in the underground mining industry. *Rudarsko-geološko-naftni zbornik, 34*(1), 37-44.

environmental levels of different sources of hazardous exposure could also be measured through cameras, wireless sensor networks (WSNs) and drones, according to interview data.

Figure 4: Measuring individual / collective harmful exposures and environmental levels[79]



At the individual level, new OSH systems based on wearables and smart PPE can be used to measure various hazardous exposures across sectors, using **dosimeters and radiometers**. These increasingly allow to measure exposure in real time and record early as well as cumulative exposure, through small, portable and low-cost sensors. Exposure could relate to: nano-objects and agglomerates; dust gas in the oil and gas industry[80]; mercury[81] for petrochemical workers; and UV radiation[82] for outdoor construction workers or agricultural ones. For example, electronic dosimeters of UV exposure automatically record data during working hours (07.30 to 17.30) when worn (e.g. upper arm using a strap). This is important given the depletion of the ozone layer, and the expected increase in incidence of skin cancer.[83,84,85]

They may also **send warning signals to workers** when exposure levels are high and are approaching the daily limits. According to interview data, badges with sensors linked to the IoT may, for example, allow to capture **radiation levels**, alert workers or visitors when they are about to exceed acceptable levels, and advise them to move away from a given area. In the mining sector, for example, 'geofencing' technology is capable of automatically warning workers if they are going into a dangerous zone or detect their movements close to dangerous machines and – in that case – turn them off in an automatic reaction. Moreover, interviewees mentioned such systems can **trace exposure** and find where the contamination occurred – for instance, if there is an in-built **GPS** tracking device in the OSH system.

New OSH monitoring systems make it possible to know whether work is being performed having a **body temperature** within normal parameters in order to avoid heat-related disorders. There are systems using sensors that can take several temperature measurements externally (fingertips, ears, legs, skin) and also internally if swallowed in the form of an ingestible telemetric temperature pill.[86] The place where sensors are located depends on the type of tasks workers may perform and also on how to best protect the sensors and/or make them most reliable. According to interview data, this could be so for road construction workers in summer in the south of Europe, for firefighters, and more generally for all

[79] All icons made by Freepik from Flaticon.com
[80] Binajjaj, A., Sheltami, T., Aliyu, F., & Kaosar, M. (2018). Design and implementation of a wearable gas sensor network for oil and gas industry workers. *Journal of Computers, 13*(3), 300-308.
[81] Mattoli, V., Mazzolai, B., Raffa, V., Mondini, A., & Dario, P. (2007). Design of a new real-time dosimeter to monitor personal exposure to elemental gaseous mercury. *Sensors and Actuators B: Chemical, 123*(1), 158-167.
[82] Banerjee, S., Hoch, E. G., Kaplan, P. D., & Dumont, E. L. (2017). A comparative study of wearable ultraviolet radiometers. In *Proceedings of the IEEE Life Sciences Conference (LSC)* (pp. 9-12), Sydney, Australia, 13-15 December. IEEE.
[83] See: https://www.dguv.de/ifa/fachinfos/strahlung/genesis-uv/index-2.jsp
[84] Strehl, C., Heepenstrick, T., Knuschke, P., & Wittlich, M. (2021). Bringing light into darkness—Comparison of different personal dosimeters for assessment of solar ultraviolet exposure. *International Journal of Environmental Research and Public Health, 18*(17), Article 9071.
[85] Harvard University. (2012, July 26). *Climate change linked to ozone loss: May result in more skin cancer*. Available at: https://www.sciencedaily.com/releases/2012/07/120726142204.htm#:~:text=Summary%3A,increased%20incidence%20of%20skin%20cancer
[86] Bongers, C. C., Hopman, M. T., & Eijsvogels, T. M. (2015). Using an ingestible telemetric temperature pill to assess gastrointestinal temperature during exercise. *Journal of Visualized Experiments*, (104), Article e53258.

workers working under heat and/or moving (parts of) their body, even when it's cold and particularly when wearing heavy gear.

Measurement can also pertain to the broader **environment / workplace**. Wearables can be used both for individual and environmental measurements. Beyond wearables, **heat cameras** can be used to measure heat in professions such as firefighting, mining, agriculture or outdoor construction, waste management, and manufacturing as compounded by rising temperatures[87] (and UV levels). Similarly, wireless sensor networks (**WSNs**)[88] are increasingly used for monitoring the workplace remotely and safely: poisonous dust in poorly ventilated areas, explosive gases that pose a fire hazard, chemicals and biological agents, and humidity could be detected preventively through environmental monitoring. This can apply to different occupations, for instance, in mining and tunnel construction work, among others.[89,90] It applies both to routine levels (e.g. sun exposure for outdoor workers, radiation exposure for healthcare workers) and to situations where there is a leak, for example, a chemical or radiation leak.

UAS[91,92] (drones) can also pick up samples and detect leaks – methane leaks, for example – in industrial settings and also in domains such as precision agriculture where they are less expensive than satellites and manned aircraft.[93]

Finally, **AR** allows to have data on otherwise hidden hazards, including asbestos, for example.[94,95,96]

Measuring exposure to ergonomic risks

New OSH systems may help prevent work-related MSDs (WRMSDs) and RSIs, which may derive from poor postures, including stooped postures, repetitive movements and lifting heavy weights (people, objects). However, WRMSDs may also have a psychosocial component,[97] deriving, for instance, from stress and poor work organisation.

There are many jobs that may be particularly exposed to WRMSDs and RSIs, including computer-related ones in offices or when teleworking, as well as in construction, mining, manufacturing, shipbuilding, agriculture, farming, waste management, hotel and restaurants, transportation and storage, and health and social care, among others.[98,99,100]

New OSH systems, such as **wearables** mounted with **accelerometers**, can measure the number of movements, their speed, type and appropriateness, to detect unsafe or otherwise harmful movements early on and prevent long-term serious health conditions. This is important because WRMSDs are likely

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[87] Dash, S. K., & Kjellstrom, T. (2011). Workplace heat stress in the context of rising temperature in India. *Current Science, 101*(4), 496-503.

[88] Cheung, W. F., Lin, T.-H., & Lin, Y.-C. (2018). A real-time construction safety monitoring system for hazardous gas integrating wireless sensor network and building information modeling technologies. *Sensors, 18*(2), Article 436.

[89] Bakke, B., Stewart, P., Ulvestad, B., & Eduard, W. (2001). Dust and gas exposure in tunnel construction work. *American Industrial Hygiene Association, 62*(4), 457-465.

[90] Muduli, L., Mishra, D. P., & Jana, P. K. (2018). Application of wireless sensor network for environmental monitoring in underground coal mines: A systematic review. *Journal of Network and Computer Applications, 106*, 48-67.

[91] Burgués, J., & Marco, S. (2020). Environmental chemical sensing using small drones: A review. *Science of The Total Environment, 748*, Article 141172.

[92] Hollenbeck, D., Zulevic, D., & Chen, Y. (2021). Advanced leak detection and quantification of methane emissions using sUAS. *Drones, 5*(4), Article 117.

[93] Shafi, U., Mumtaz, R., García-Nieto, J., Hassan, S. A., Zaidi, S. A. R., & Iqbal, N. (2019). Precision agriculture techniques and practices: From considerations to applications. *Sensors, 19*(17), Article 3796.

[94] EU-OSHA – European Agency for Safety and Health at Work, *Foresight on new and emerging occupational safety and health risks associated with digitalisation by 2025*, 2018. Available at: https://osha.europa.eu/en/publications/foresight-new-and-emerging-occupational-safety-and-health-risks-associated

[95] Quezada, G., Devaraj, D., McLaughlin, J., & Hanson, R. (2018). *Asbestos safety futures. Managing risks and embracing opportunities for Australia's asbestos legacy in the digital age*. CSIRO.

[96] See also: https://business.gov.au/-/media/grants-and-programs/brii/regtech/brii-regulatory-technology-factsheet-asbestos-testing-docx.ashx?sc_lang=en&hash=4BC5B1D2B4AB0A60DD185A2BE89993E9

[97] Roquelaure, Y. (2018). *Musculoskeletal disorders and psychosocial factors at work*. Report 142, European Trade Union Institute.

[98] Khakurel, J., Melkas, H., & Porras, J. (2018). Tapping into the wearable device revolution in the work environment: A systematic review. *Information Technology & People, 31*(3), 791-818.

[99] Zhu, Z., Dutta, A., & Dai, F. (2021). Exoskeletons for manual material handling – A review and implication for construction applications. *Automation in Construction, 122*, Article 103493.

[100] Ziaei, M., Choobineh, A., Ghaem, H., & Abdoli-Eramaki, M. (2021). Evaluation of a passive low-back support exoskeleton (Ergo-Vest) for manual waste collection. *Ergonomics, 64*(10), 1255-1270.

to develop over time as physical strain accumulates. **In turn, measurement ensures that workplaces design measures to eliminate or reduce exposure to risk factors or reduce their risks**, although this may not always be possible – for example, in workplaces that may change location often, such as construction and logistics.[101,102] In certain cases, wearables can also warn that the worker needs to stop a certain activity for which a given threshold has been reached: for instance, stop dynamic lifting or reduce sitting time[103] – this is because wearables allow to estimate the biomechanical risk in real time and provide direct feedback to the worker who is constantly monitored.[104]

Further, **ML algorithms** that use kinematic data may be used to increase reliability in distinguishing correct and incorrect postures.[105] With the use of **IoT and mobiles apps**, new OSH systems not only monitor workers' movements and postures, they can also provide real-time biofeedback to the user (e.g. by means of vibration, auditory or visual data on a mobile application), as personalised training for workers to reduce occupational ergonomic hazards. For example, in the market of workplace furniture there are smart seating systems recognising postures and sitting time and giving feedback and advice on a display.

The use of **exoskeletons** (active, passive, hybrid; anthropomorphic, non-anthropomorphic; lower, upper and full body, etc.) can also be key in preventing and reducing WRMSDs. Some exoskeletons can help overcome ergonomic issues by detecting what movement workers want to perform and augmenting their strength, through so-called actuators, or supporting prolonged stressful positions. In particular, active exoskeletons reduce different physical stressors on the body (spinal, muscular, bone, ligament, etc.) and augment the physical capabilities of the workers, while passive exoskeletons allow to keep exhausting positions longer by redistributing forces to protect specific parts of the body.[106] [107] Exoskeletons have many strengths, including 'affordability, durability, compatibility with […] equipment, and versatility when operating diverse kinds of machinery',[108] and they can also perform adequately in difficult working environments with bumpy terrain, narrow staircases and so on.[109]

While increasingly adopted to replace workers when performing hazardous or exhausting tasks, in the context of automation,[110,111.112] **collaborative robots (cobots)** – that use AI algorithms and ML – are another technology that can improve OSH monitoring. For example, data captured by electromyography

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[101] EU-OSHA – European Agency for Safety and Health at Work, *Occupational exoskeletons: wearable robotic devices to prevent work-related musculoskeletal disorders in the workplace of the future*, 2020. Available at: https://osha.europa.eu/en/publications/occupational-exoskeletons-wearable-robotic-devices-and-preventing-work-related

[102] Schick, R. (2018). Einsatz von Exoskeletten in der Arbeitswelt. *Zentralblatt für Arbeitsmedizin, Arbeitsschutz und Ergonomie, 68*(5), 266-269.

[103] Stephenson, A., McDonough, S. M., Murphy, M. H., Nugent, C. D., & Mair, J. L. (2017). Using computer, mobile and wearable technology enhanced interventions to reduce sedentary behaviour: A systematic review and meta-analysis. *International Journal of Behavioral Nutrition and Physical Activity, 14*, Article 105. https://doi.org/10.1186/s12966-017-0561-4

[104] Ranavolo, A., Draicchio, F., Varrecchia, T., Silvetti, A., & Iavicoli, S. (2018). Wearable monitoring devices for biomechanical risk assessment at work: Current status and future challenges—A systematic review. *International Journal of Environmental Research and Public Health, 15*(9), Article 2001.

[105] Conforti, I., Mileti, I., Del Prete, Z., & Palermo, E. (2020). Measuring biomechanical risk in lifting load tasks through wearable system and machine-learning approach. *Sensors, 20*(6), Article 1557.

[106] EU-OSHA – European Agency for Safety and Health at Work, *Occupational exoskeletons: wearable robotic devices to prevent work-related musculoskeletal disorders in the workplace of the future*, 2020. Available at: https://osha.europa.eu/en/publications/occupational-exoskeletons-wearable-robotic-devices-and-preventing-work-related

[107] Svertoka, E., Saafi, S., Rusu-Casandra, A., Burget, R., Marghescu, I., Hosek, J., & Ometov, A. (2021). Wearables for industrial work safety: A survey. *Sensors, 21*(11), Article 3844

[108] Upasani, S., Franco, R., Niewolny, K., & Srinivasan, D. (2019). The potential for exoskeletons to improve health and safety in agriculture—Perspectives from service providers. *IISE Transactions on Occupational Ergonomics and Human Factors, 7*(3-4), 222-229.

[109] Chu, G., Hong, J., Jeong, D. H., Kim, D., Kim, S., Jeong, S., & Choo, J. (2014). The experiments of wearable robot for carrying heavy-weight objects of shipbuilding works. In *2014 IEEE international conference on automation science and engineering (CASE)* (pp. 978-983). IEEE.

[110] Mukai, T., Hirano, S., Nakashima, H., Kato, Y., Sakaida, Y., Guo, S., & Hosoe, S. (2010). Development of a nursing-care assistant robot RIBA that can lift a human in its arms. In *2010 IEEE/RSJ International Conference on Intelligent Robots and Systems* (pp. 5996-6001). IEEE.

[111] Arguenon, V., Bergues-Lagarde, A., Rosenberger, C., Bro, P., & Smari, W. (2006). Multi-agent based prototyping of agriculture robots. In *International Symposium on Collaborative Technologies and Systems (CTS'06)* (pp. 282-288). IEEE.

[112] Bechar, A., & Vigneault, C. (2016). Agricultural robots for field operations: Concepts and components. *Biosystems Engineering, 149*, 94-111.

sensors plugged in smart garments used by workers can be monitored by close-by cobots that can also warn workers of harmful movements and postures in real time.[113]

Identifying plant and premises-related risks

A number of OSH monitoring systems allow to detect and notify workers when **entering a hazardous area**. Hazards may relate to slips, trips and falls – which are particularly risky when working at height (for instance, in outdoor construction work, notably, for work on a roof) – step voltage (i.e. the voltage difference between the feet of a person near an energised, grounded object), forklifts, collisions, and accidents when using and/or interacting with machineries and vehicles, and so on.

Sensors (GPS, WSNs) and software can be used to **identify proximity, measure whether speed is above safety thresholds and activate emergency stop buttons**. For example, **wearables** may detect voltage hazards and places with the most near-miss falls, by analysing historical data.[114] **Radio**-based identification systems in **smart PPE**[115] automatically detect and communicate when an object or a person approaches a forklift's danger zone. Vision systems mounted on smart clothing can be used to avoid human / machine collision[116] and so can **drones and WSNs**, for instance, in precision agriculture.[117]

Besides, according to interview data, certain working tools can be extremely hazardous and risky, for example, chainsaws. **Smart active protective trousers** can be lighter than traditional ones and have a stop function for chainsaws that are getting too close to the worker. Conversely, some **smart PPE** can pose hazards to workers. For instance, PPE that is heavy and difficult to unmount might pose a risk in case a worker has to evacuate the workplace.

Last, UAS and autonomous robots can also identify plant and premises-related hazards. For example, a robotics company has created a robot that is able to follow a hard-coded path and monitor workplace parameters, functionality of equipment and so on.[118]

Identifying hazardous worker behaviour (including link with mental and physical load)

Unsafe behaviour is defined as an action that could cause injury, such as approaching a forklift at high speed or not wearing the (right) equipment.[119] CCTVs, wearables, smart PPE and RFID can be used to detect or even predict (when AI and deep learning are involved) such behaviour.

Video records allow to identify at-risk behaviours (and not only conditions), some of which are extremely difficult to detect.[120] **RFID**[121,122] and **deep learning**[123,124,125] allow to check equipment (e.g. working tools, head, ear and foot protection, etc.) or check whether the (protective) equipment is

[113] EU-OSHA – European Agency for Safety and Health at Work, *Foresight on new and emerging occupational safety and health risks associated with digitalisation by 2025*, 2018. Available at: https://osha.europa.eu/en/publications/foresight-new-and-emerging-occupational-safety-and-health-risks-associated

[114] Baka & Uzunoglu (2016) and Yang & Shen (2015) in: Khakurel, J., Melkas, H., & Porras, J. (2018). Tapping into the wearable device revolution in the work environment: A systematic review. *Information Technology & People, 31*(3), 791-818.

[115] See: https://www.elokon.com/en-EN/references/p-p-schuhvertrieb-relies-on-eloshield

[116] See: https://www.retenua.com/en/products/emitrace/

[117] Popescu, D., Stoican, F., Stamatescu, G., Ichim, L., & Dragana, C. (2020). Advanced UAV–WSN system for intelligent monitoring in precision agriculture. *Sensors, 20*(3), Article 817.

[118] For more information, see: Palmer, A. (2018, October 12). *Spot goes to work: Boston Dynamics reveals its robot dog helping construction workers*. Dailymail.com. https://www.dailymail.co.uk/sciencetech/article-6270857/Boston-Dynamics-reveals-robot-dog-hard-work-helping-construction-workers-carry-heavy-loads.html

[119] Cocca, P., Marciano, F., & Alberti, M. (2016). Video surveillance systems to enhance occupational safety: A case study. *Safety Science, 84*, 140-148.

[120] Ibid.

[121] Mahmad, M. K. N., Rozainy, M. R., & Baharun, N. (2016). Applications of radio frequency identification (RFID) in mining industries. In *IOP Conference Series: Materials science and engineering* (Vol. 133, No. 1) (Article 012050). IOP Publishing.

[122] Mandar, E. M., Dachry, W., & Bensassi, B. (2021). Toward a real-time personal protective equipment compliance control system based on RFID technology. In F. Saeed, T. Al-Hadhrami, F. Mohammed, & E. Mohammed (Eds), *Advances on smart and soft computing* (pp. 553-565). Springer.

[123] Nath, N. D., Behzadan, A. H., & Paal, S. G. (2020). Deep learning for site safety: Real-time detection of personal protective equipment. *Automation in Construction, 112*, Article 103085.

[124] Hung, H. M., Lan, L. T., & Hong, H. S. (2019). A deep learning-based method for real-time personal protective detection. *Le Quy Don Technical University, 199*(13), 23-34.

[125] Fang, Q., Li, H., Luo, X., Ding, L., Luo, H., Rose, T. M., & An, W. (2018). Detecting non-hardhat-use by a deep learning method from far-field surveillance videos. *Automation in Construction, 85*, 1-9.

(correctly) worn. For example, according to interview data, in the **offshore industries** where accidents can be fatal under the wrong conditions, OSH systems can monitor if the worker is not wearing respiratory protection or a tool is missing from a tool belt; the systems can also restrict workers from entering the hazardous area if they are not wearing safety shoes, or disallow work if the equipment has not been checked for longer than required – this is possible by having an ID tracker on the equipment. In offshore industries, new OSH monitoring systems can also be combined or acquire data from the corresponding process safety systems to improve workers' OSH.[126]

These new OSH monitoring systems also offer the opportunity to train workers on the correct use of equipment, and to target and tailor training to workers whose records show they may on average adopt unsafe behaviours more often than their peers; they may also train on the correct disposal of equipment, and they can also spot hazards that were not included in previous risk assessments.

Sometimes unsafe / unhealthy worker behaviour may depend on **worker fatigue and/or stress**. **Wearable-based** systems are used in transport, mining and construction and so on to detect early signs of physical, muscle and mental fatigue, stress, drowsiness, and low alertness and reaction times, or impaired decision-making.[127,128,129,130,131,132,133] Wearables collect data in real time and allow a more accurate assessment of fatigue as compared to surveys and questionnaires alone, and they can prevent accidents by warning workers. They can detect signs of fatigue through cardiac rhythm, changes in eye and head movements, inconsistent steering and braking (for drivers), changes in brain waves and so on. They can also produce personal fatigue scores and predict moments and places or workers at risk through ML and biomathematical modelling and computer algorithms (e.g. part of the weekdays for teachers, specific traffic points for truck drivers).

As they collect **data at workplace level**, they can generate workforce fatigue scores disaggregated by shifts, rotations, situations or locations that can be used to improve OSH through structural measures.[134]

Identifying poor individual health and wellbeing

Interview data suggest that wearables using mobile / wireless technology can offer the opportunity to monitor physical and mental wellbeing both within and beyond the workplace. For example, mobile health apps can monitor sleep, mental resilience, shift work and so on, and provide feedback to workers that can also help reduce accidents.[135]

Weight, heart rate, blood pressure and hormonal levels are clearly important measurements. Similarly, sleep patterns, sedentary behaviour and unbalanced diet are crucial lifestyle factors that may influence health, and which may in fact be both cause and consequence of lower levels of wellbeing and mental health.

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126 EU-OSHA – European Agency for Safety and Health at Work, *The development of dynamic risk assessment and its implications for occupational safety and health*, 2021. Available at: https://osha.europa.eu/en/publications/development-dynamic-risk-assessment-and-its-implications-occupational-safety-and-health

127 Jung, S.-J., Shin, H.-S., & Chung, W.-Y. (2014). Driver fatigue and drowsiness monitoring system with embedded electrocardiogram sensor on steering wheel. *IET Intelligent Transport Systems, 8*(1), 43-50.

128 Jebelli, H., & Lee, S. (2019). Feasibility of wearable electromyography (EMG) to assess construction workers' muscle fatigue. In I. Mutis, & T. Hartmann (Eds), *Advances in informatics and computing in civil and construction engineering* (pp. 181-187). Springer.

129 de Naurois, C. J., Bourdin, C., Stratulat, A., Diaz, E., & Vercher, J. L. (2019). Detection and prediction of driver drowsiness using artificial neural network models. *Accident Analysis & Prevention, 126*, 95-104.

130 Li, J., Li, H., Umer, W., Wang, H., Xing, X., Zhao, S., & Hou, J. (2020). Identification and classification of construction equipment operators' mental fatigue using wearable eye-tracking technology. *Automation in Construction, 109*, Article 103000.

131 Lee, B. G., Lee, B. L., & Chung, W.Y. (2015). Smartwatch-based driver alertness monitoring with wearable motion and physiological sensor. In *2015 37th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC)* (pp. 6126-6129). IEEE.

132 Aryal, A., Ghahramani, A., & Becerik-Gerber, B. (2017). Monitoring fatigue in construction workers using physiological measurements. *Automation in Construction, 82*, 154-165.

133 Butler, P., & Fee, W. (2015). *Fatigue and the use of wearable technology*. Paper presented at the SPE E&P Health, Safety, Security and Environmental Conference-Americas, Denver, Colorado, 16-18 March.

134 Fatigue Science. (2017). *The science of sleep and workplace fatigue. The risks and costs of human fatigue, and how one technological solution is helping predict and prevent it*.

135 de Korte, E. M., Wiezer, N., Janssen, J. H., Vink, P., & Kraaij, W. (2018). Evaluating an mHealth app for health and well-being at work: Mixed-method qualitative study. *JMIR mHealth and uHealth, 6*(3), Article e72. https://doi.org/10.2196/mhealth.6335

Affordable and widespread wearable technology allow to collect such data and to provide real-time feedback to individuals. Increasingly, wearables also promote health by encouraging individuals to have more active lifestyles, for instance, through gamification and group or personalised activities. Some large tech companies tend to adopt such activities to incentivise their workforce to follow a healthier routine that promotes health. However, there may be less attention in smaller companies or in those sectors where there is a higher level of physical activity, despite the so-called physical activity paradox – according to which occupational physical activity does not give the same health benefits as leisure time activity.[136,137,138]

There is a blurred demarcation between individual health and behaviour outside of work and at work as occupational health. For instance, there is solid literature on the links between sleep and accidents and injuries at the workplace (as well as productivity loss).[139,140] However, it is not necessarily individual behaviour (i.e. outside working hours, during leisure time) that impacts sleep patterns. Work affects sleep too and there is increasing evidence of how (physical and mental) work burnout is associated with sleep complaints and depression[141] and that sleep deprivation may disproportionately affect workers doing shifts.[142]

The opportunity is to collect and analyse data that can look at the person holistically. At the same time, it is important to measure individual exposures and occupational ones separately. This is, for instance, possible due to the use of accelerometers in the context of the SurPASS project, which aims to evaluate an e-system to measure daily (24/7) physical behaviours (physical activity, sedentary behaviours and sleep) at work and during non-work time of working adults.[143] Similar projects have been initiated for other hazards, for instance, for occupational and leisure time UV radiation.[144] The opportunity to collect and analyse these data may be further enhanced through ML / AI algorithms, which would not need the person keeping a personal diary (of leisure time and working time) – that may lead to recording inaccuracies. In all of the above opportunities, pressing issues such as who has access to the data remain.

Psychosocial and organisational opportunities

There are few but substantial psychosocial and organisational opportunities. First, new OSH monitoring systems could help workers to better manage psychosocial workload and stress[145] and make them **safer and feel better and more productive**,[146] especially if data collected leads to structural corrective measures. Second, AI management could lead to **improved task and shift allocation** based on different parameters, to reduce accidents, increase wellbeing, tailor solutions to specific needs and

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136 Holtermann, A., Krause, N., Van Der Beek, A. J., & Straker, L. (2018). The physical activity paradox: Six reasons why occupational physical activity (OPA) does not confer the cardiovascular health benefits that leisure time physical activity does. *British Journal of Sports Medicine, 52*(3), 149-150.

137 Holtermann, A., Schnohr, P., Nordestgaard, B. G., & Marott, J. L. (2021). The physical activity paradox in cardiovascular disease and all-cause mortality: The contemporary Copenhagen General Population Study with 104 046 adults. *European Heart Journal, 42*(15), 1499-1511.

138 Coenen, P., Huysmans, M. A., Holtermann, A., Krause, N., Van Mechelen, W., Straker, L. M., & Van Der Beek, A. J. (2018). Do highly physically active workers die early? A systematic review with meta-analysis of data from 193 696 participants. *British Journal of Sports Medicine, 52*(20), 1320-1326.

139 Uehli, K., Mehta, A. J., Miedinger, D., Hug, K., Schindler, C., Holsboer-Trachsler, E., Leuppi, J. D., & Künzli, N. (2014). Sleep problems and work injuries: A systematic review and meta-analysis. *Sleep Medicine Reviews, 18*(1), 61-73.

140 Rosekind, M. R., Gregory, K. B., Mallis, M. M., Brandt, S. L., Seal, B., & Lerner, D. (2010). The cost of poor sleep: Workplace productivity loss and associated costs. *Journal of Occupational and Environmental Medicine, 52*(1), 91-98.

141 Dahlgren, A., Kecklund, G., & Åkerstedt, T. (2005). Different levels of work-related stress and the effects on sleep, fatigue and cortisol. Scandinavian Journal of Work, Environment & Health, 31(4), 277-285.

142 Kecklund, G., & Axelsson, J. (2016). Health consequences of shift work and insufficient sleep. *BMJ, 2016*(355), Article i5210.

143 See: https://nfa.dk/da/forskning/strategiske-forskningsomraader/om-msb/om_msb_researchers

144 Strehl, C., Heepenstrick, T., Knuschke, P., & Wittlich, M. (2021). Bringing light into darkness—Comparison of different personal dosimeters for assessment of solar ultraviolet exposure. *International Journal of Environmental Research and Public Health, 18*(17), Article 9071.

145 de Vries, H., Kamphuis, W., van der Schans, C., Sanderman, R., & Oldenhuis, H. (2022). Trends in daily heart rate variability fluctuations are associated with longitudinal changes in stress and somatisation in police officers. *Healthcare, 10*(1), Article 144. https://doi.org/10.3390/healthcare10010144

146 Bender, G., & Söderqvist, F. *How to negotiate an algorithm: A case study on voice and automation in Swedish mining.*. Blekinge Institute of Technology (forthcoming).

reduce administrative tasks.[147] Third, drones, sensor networks, AR, cobots and AI can **take up dangerous**[148,149,150] OSH plant and premises monitoring, maintenance and repair **tasks**, which may help decrease occupational stress or the mental health and wellbeing consequences of accidents and injuries. Fourth, remote digital OSH monitoring systems may allow for **better work flexibility and work-life balance**.[151] Fifth, new OSH monitoring systems allow workers to receive, send and process (e.g. virtual diagrams on AR, images instead of text on videos or smart glasses, vibration instead of sound only, etc.) information quickly and easily, thus **improving job meaningfulness and motivation, as well as control over decisions** through training and on-the-job training / mentoring.[152]

Online risk assessments and remote inspections

While many new OSH monitoring systems that combine different digital technologies may help identify hazards and assess risks, there are some that specifically focus on this purpose – for instance, in the contexts of digital risk assessments and inspections – making them better, quicker, easier, safer and more tailored, even remotely.

ICT has allowed in the last decades the creation of interactive questionnaires for workers to pinpoint hazardous environments and unsafe behaviours. New (digital) OSH monitoring systems focus specifically on dynamic risk assessments.[153] Risk assessments constitute the foundation of OSH monitoring. They systematically examine all aspects of work, allow hazards and risks to be identified, and are aimed at putting into place preventive measures, so as to avoid fatalities, injuries and harm. T**he Online interactive Risk Assessment (OiRA**) tool is a user-friendly EU-level tool that forces data collection methods and allows risk forecasting.[154] There are also other similar and comprehensive tools at national level, such as BeSmart.ie, Rie.nl and Prevencion10.es. Besides, there are tools for specific risk factors, such as noise or chemicals.[155]

UAS, sensor networks and AR allow **remote inspections**, for instance, in agriculture and forestry, oil and gas, mining and construction.[156,157,158] They allow to perform virtual walks using VR and plant data, to collect data through the combination of sensors, and UAS also allow to pick samples when needed. For instance, according to Irizarry et al. (2012),[159] ideal drones in the construction sector should have

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[147] Kolbjørnsrud, V., Amico, R., & Thomas, R. J. (2016, November 2). *How artificial intelligence will redefine management*. Harvard Business Review. Available at: https://hbr.org/2016/11/how-artificial-intelligence-will-redefine-management See also: https://www.mark-info.co.uk/insights/articles/shift-scheduling-with-artificial-intelligence-in-promark

[148] EU-OSHA – European Agency for Safety and Health at Work, *Digitalisation and occupational safety and health - An EU-OSHA research programme*, 2019. Available at: https://osha.europa.eu/en/publications/digitalisation-and-occupational-safety-and-health-eu-osha-research-programme

[149] Pishgar, M., Issa, S. F., Sietsema, M., Pratap, P., & Darabi, H. (2021). REDECA: A novel framework to review artificial intelligence and its applications in occupational safety and health. *International Journal of Environmental Research and Public Health, 18*(13), Article 6705.

[150] Howard, J., Murashov, V., & Branche, C. M. (2017). Unmanned aerial vehicles in construction and worker safety. *American Journal of Industrial Medicine, 61*(1), 3-10.

[151] EU-OSHA – European Agency for Safety and Health at Work, *Teleworking during the COVID-19 pandemic: risks and prevention strategies*, 2021. Available at: https://osha.europa.eu/en/publications/teleworking-during-covid-19-pandemic-risks-and-prevention-strategies

[152] Svertoka, E., Saafi, S., Rusu-Casandra, A., Burget, R., Marghescu, I., Hosek, J., & Ometov, A. (2021). Wearables for industrial work safety: A survey. *Sensors, 21*(11), Article 3844.

[153] EU-OSHA – European Agency for Safety and Health at Work, *The development of dynamic risk assessment and its implications for occupational safety and health*, 2021. Available at: https://osha.europa.eu/en/publications/development-dynamic-risk-assessment-and-its-implications-occupational-safety-and-health

[154] See: https://oiraproject.eu/en OSHWiki, *OiRA and other online risk assessment tools in national OSH strategies and legislation*, 2021. Available at: https://oshwiki.eu/wiki/OiRA_and_other_online_risk_assessment_tools_in_national_OSH_strategies_and_legislation

[155] EU-OSHA – European Agency for Safety and Health at Work, *The development of dynamic risk assessment and its implications for occupational safety and health*, 2021. Available at: https://osha.europa.eu/en/publications/development-dynamic-risk-assessment-and-its-implications-occupational-safety-and-health

[156] EU-OSHA – European Agency for Safety and Health at Work, *Digitalisation and occupational safety and health - An EU-OSHA research programme*, 2019. Available at: https://osha.europa.eu/en/publications/digitalisation-and-occupational-safety-and-health-eu-osha-research-programme

[157] Howard, J., Murashov, V., & Branche, C. M. (2017). Unmanned aerial vehicles in construction and worker safety. *American Journal of Industrial Medicine, 61*(1), 3-10.

[158] Pishgar, M., Issa, S. F., Sietsema, M., Pratap, P., & Darabi, H. (2021). REDECA: A novel framework to review artificial intelligence and its applications in occupational safety and health. *International Journal of Environmental Research and Public Health, 18*(13), Article 6705

[159] Irizarry, J., Gheisari, M., & Walker, B. N. (2012). Usability assessment of drone technology as safety inspection tools. *Journal of Information Technology in Construction, 17*(12), 194-212.

'autonomous navigation, vocal interaction, high-resolution cameras, and collaborative user-interface environment.'

New OSH monitoring systems also allow **targeted inspections**, as big data and ML allow to learn from past accidents and provide data on companies at risk. This is, for instance, the function of the Risk Group Prediction Tool, developed by the Norwegian Labour Inspection Authority, which is a risk-based approach to inspections carried out by Labour Inspectorates.[160]

4.1.2 Providing on-the-job training

Many systems can be used for training purposes, making it better, safer and more tailored to workers' (individual) needs. **Cameras and AI** allow an in-depth non-real-time analysis of accidents to facilitate the identification of safe practices. In a video surveillance system experimented with in an Italian heat treatment company, Cocca et al. (2016)[161] noted that cameras were positioned in the areas of highest risk, which were considered the best places to detect workplace hazards and risky working behaviours. The video records were then analysed by a person – but AI could have been used instead. Video footage showing both safe and at-risk practice was archived and used as part of training modules and overall had positive results in a number of OSH areas. Nevertheless, using cameras as well as other new OSH monitoring systems at the workplace can also result in privacy issues. These are addressed in the next sections of this report.

Wearable devices and **smart PPE** have different applications in terms of supporting workers on the job. For example, they allow to deliver content (text, video, audio) when workers are performing their work. This acts as on-the-job real-time mentoring and can assist, for example, when performing maintenance and repairs.[162] Smart glasses with miniaturised video mounted on head, chest or shoulder may show a less experienced worker how a task should be performed, with the video supplemented by a voice-over of a task execution for better guidance.[163] Movement and biomechanical analysis can monitor heart rate variability as a stress indicator as well as provide workers with individual feedback (e.g. actions to correct posture).[164] Such systems have application across many different sectors, including, for instance: manufacturing, metal, construction, mining, chemical and transport.

ICT-based training methodologies focusing on e-learning tutorials have also been effective in improving learning and enhancing a culture of prevention. For example, an e-learning platform for nursing students increased knowledge of safe practices. While the course could be taken remotely, learning and satisfaction were higher when students combined autonomous learning via the e-tool with face-to-face support.[165] Vukićević et al. (2021)[166] note that digital learning – for example, using mobile apps – proactively shows how to recognise hazard and evaluate risks. This is possible through a learning-by-doing approach. Users are tasked with identifying unsafe conditions and behaviours, assessing risk levels and thinking of measures to mitigate them. They can also use their mobiles to take pictures and provide their observations in a report.

Mobile apps can also be combined with **VR and AR**, for instance, through wearables and smart garments, and with IoT. VR and AR can also be combined with computer games technology, so-called serious games, where trainees interact with the environment, which improves users' abilities to spot hazards and assess risks through hands-on training, 'while avoiding potentially hazardous and

[160] EU-OSHA – European Agency for Safety and Health at Work, *The future role of big data and machine learning in health and safety inspection efficiency*, 2019. Available at: https://osha.europa.eu/en/publications/future-role-big-data-and-machine-learning-health-and-safety-inspection-efficiency

[161] Cocca, P., Marciano, F., & Alberti, M. (2016). Video surveillance systems to enhance occupational safety: A case study. *Safety Science, 84*, 140-148.

[162] Khakurel, J., Melkas, H., & Porras, J. (2018). Tapping into the wearable device revolution in the work environment: A systematic review. *Information Technology & People, 31*(3), 791-818.

[163] Lavallière, M., Burstein, A. A., Arezes, P., & Coughlin, J. F. (2016). Tackling the challenges of an aging workforce with the use of wearable technologies and the quantified-self. *Dyna, 83*(197), 38-43.

[164] Svertoka, E., Saafi, S., Rusu-Casandra, A., Burget, R., Marghescu, I., Hosek, J., & Ometov, A. (2021). Wearables for industrial work safety: A survey. *Sensors, 21*(11), Article 3844.

[165] Vaquero-Álvarez, E., Cubero-Atienza, A., Martínez-Jiménez, M. P., Vaquero-Abellán, M., Redel-Macías, M. D., & Aparicio-Martínez, P. (2020). Occupational safety and health training for undergraduates nursing students: A Spanish pilot. *International Journal of Environmental Research and Public Health, 17*(22), Article 8381.

[166] Vukićević, A. M., Mačužić, I., Djapan, M., Milićević, V., & Shamina, L. (2021). Digital training and advanced learning in occupational safety and health based on modern and affordable technologies. *Sustainability, 13*(24), Article 13641.

expensive field training.'[167] These systems can be applied across sectors and industries, including but not limited to construction, mining, aviation, chemical plants, automobile and the broad industrial environment.[168, 169, 170, 171, 172] They immerse workers in an environment where they have to choose between alternative courses of action, in a safe and guided way. Companies in the automotive industry use VR technology together with body motion sensors to reduce accidents and ergonomic issues, and others use it for training and on-the-job mentoring during repair and maintenance.[173] Similarly, AR systems implemented on mobiles, for instance, also guide workers through different actions. The systems can also be tailored to the experience of the worker, thus allowing for a customised training and on-the job mentoring.[174,175]

4.2 Reactive OSH monitoring

Reactive OSH monitoring is the second key approach. It is organised across two key purposes: minimising consequences of accidents / emergencies[176] (section 4.2.1); and reporting and investigating accidents (section 4.2.2). When prevention fails, digital OSH monitoring systems and technologies allow employers to react quickly and effectively to emergency situations. These systems may minimise harm by signalling an emergency and send accurate localisation data, suggesting to workers how they should behave in danger and/or when panicking, thus ensuring that they can overcome a difficult situation and respond to the emergency. They also help in investigating accidents quickly, safely and effectively, and in reporting accidents efficiently and with less stigma. In turn, they provide data that can be used to formulate corrective measures.

4.2.1 Minimising consequences of harm

Signalling and localising emergency

Signalling and localising emergencies allows workers, who would otherwise be at risk of fatality or serious harm, to be located quickly and accurately, and brought to safety. GPS localisation, for example, is key to this regard. It could, for instance, be used for trucks and drivers in distress, for firefighters entering a hazardous rescue area with fire, smoke and high temperatures, for miners and construction workers trapped or who have fallen, and so on.

New OSH monitoring systems allow to **automatically signal the emergency**, for instance, through fall detections using accelerometers, and to send automatic panic alerts even when the worker is unable to make an emergency call. As workers are located, **rescue operations can take less time**.[177,178]

Healthcare professionals may be subject to verbal and physical violence from patients or their relatives, and increasingly so during COVID-19[179] – which has a negative psychosocial and physical impact that compounds the high workload and high risk of biological hazards during the pandemic. CCTVs alone

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[167] Dawood, N., Miller, G., Patacas, J., & Kassem, M. (2014). Construction health and safety training: The utilisation of 4D enabled serious games. *Journal of Information Technology in Construction, 19*, 326-335.
[168] Chittaro, L., Corbett, C. L., McLean, G. A., & Zangrando, N. (2018). Safety knowledge transfer through mobile virtual reality: A study of aviation life preserver donning. *Safety Science, 102*, 159-168.
[169] Nasios, K. (2002). *Improving chemical plant safety training using virtual reality* (Doctoral thesis, University of Nottingham).
[170] Sacks, R., Perlman, A., & Barak, R. (2013). Construction safety training using immersive virtual reality. *Construction Management and Economics, 31*(9), 1005-1017.
[171] Tatic, D., & Tesic, B. (2017). The application of augmented reality technologies for the improvement of occupational safety in an industrial environment. *Computers in Industry, 85*, 1-10.
[172] Pedram, S., Perez, P., Palmisano, S., & Farrelly, M. (2018). A qualitative evaluation of the role of virtual reality as a safety training tool for the mining industry. In A. Naweed, M. Wardaszko, E. Leigh, & S. Meijer (Eds), *Intersections in simulation and gaming* (pp. 188-200). Springer.
[173] Capgemini. (2018). *Augmented and virtual reality in operations – A guide for investment*.
[174] Kim, S., Nussbaum, M. A., & Gabbard, J. L. (2016). Augmented reality "smart glasses" in the workplace: Industry perspectives and challenges for worker safety and health. *IIE Transactions on Occupational Ergonomics and Human Factors, 4*(4), 253-258.
[175] EU-OSHA – European Agency for Safety and Health at Work, *Artificial intelligence for worker management: an overview*, 2022. Available at: https://osha.europa.eu/en/publications/artificial-intelligence-worker-management-overview
[176] The terms accidents and emergencies are used interchangeably.
[177] Lawson, F. (2020, July 31). *How apps with GPS tracking ensure worksite safety*. Industry Today.
[178] Khakurel, J., Melkas, H., & Porras, J. (2018). Tapping into the wearable device revolution in the work environment: A systematic review. *Information Technology & People, 31*(3), 791-818.
[179] Devi, S. (2020). COVID-19 exacerbates violence against health workers. *The Lancet, 396*(10252), 658.

cannot adequately monitor security. However, **AI-based CCTV solutions** allow behaviour recognition through facial expressions and can process large amounts of data rapidly and with a high level of accuracy. Systems can send alerts when violent behaviour is predicted / recognised, thus helping to deescalate critical situations.[180]

It is also possible to use **computer vision** – the field of AI 'that enables computers and systems to derive meaningful information from digital images, videos and other visual inputs – and take actions or make recommendations based on that information'[181] – to detect accidents and alert through apps that also send localisation data.[182]

There are new **wearable** solutions for workers in isolated working environments, which have **man-down features** integrated in digital earpieces to use because of loss of consciousness or disabling injury. This piece of electronic equipment must be accurate and sturdy, and it must also have a low false positive alarm rate.[183] There are also systems consisting of a cloud-based online monitoring with two-way communication in case of emergency and a man-down / tilt / shock function that combines wearables, GPS and RFID.[184]

Connected mines through WSNs also allow to localise workers promptly and assess whether they are moving. The positioning system for rescue operations uses triangulation to localisation tags, which is worn by all workers underground. This real-time surveillance is made possible by Bluetooth, Wi-Fi stations, and underground Wi-Fi or 5G.

Drones also offer vast opportunities in terms of search and rescue operations. They can effectively be used in overground operations, but increasingly also in underground ones. For instance, autonomous drones with GPS and radio frequencies can now identify hazards in underground mining working environments.[185] There are also drones that can be used in the petrochemical industry to identify and locate victims, and also predict new hazardous deflagrations.[186] Further, the opportunity of having thermal cameras on drones that could facilitate rescue operations is being experimented with.[187]

Helping through and responding to an emergency / accident

New OSH monitoring systems may also help through and respond to emergencies and accidents. **Wearables** and **AR** allow to **deliver information** (videos, audio, images, text), for instance, through smart glasses – which the worker can easily and quickly access to make decisions on how to best navigate a difficult situation with the increased knowledge of the situation they are in.

In the case of firefighters, for example, **smart PPE** have **active cooling systems**. While hand and forearm immersion in cool water is simple and most effective in reducing heat strain,[188] automatic cooling systems are among the preferred features for the smart PPE of the future, according to firefighters in Australia, Japan, South Korea and the United States. These systems ranked second overall and also when disaggregating by worker age, gender, experience and other characteristics – thus showing the importance of automatic cooling systems across types of workers. They only ranked below 'a location monitoring system', but ranked above other features, including but not limited to: 'a

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[180] See: https://www.scylla.ai/leveraging-ai-video-analytics-for-healthcare-security/
[181] See: https://www.ibm.com/topics/computer-vision
[182] Desai, R., Jadhav, A., Sawant, S., & Thakur, N. (2021). *Accident detection using ML and AI techniques*. ENGPAPER.COM.
[183] Guilbeault-Sauvé, A., De Kelper, B., & Voix, J. (2021). Man down situation detection using an in-ear inertial platform. *Sensors, 21*(5), Article 1730.
[184] See: https://www.ebssmart.com/en/active-view
[185] Hennage, D. H., Nopola, J. R., & Haugen, B. D. (2019). *Fully autonomous drone for underground use*. Paper presented at the 53rd U.S. Rock Mechanics/Geomechanics Symposium, New York City, New York, 23-26 June.
[186] Gamulescu, O. M., Rosca, S. D., Panaite, F., Costandoiu, A., & Riurean, S. (2020). Accident sites management using drones. In *MATEC Web of Conferences* (Vol. 305) (Article 00004). EDP Sciences.
[187] Burke, C., McWhirter, P. R., Veitch-Michaelis, J., McAree, O., Pointon, H. A., Wich, S., & Longmore, S. (2019). Requirements and limitations of thermal drones for effective search and rescue in marine and coastal areas. *Drones, 3*(4), Article 78.
[188] Barr, D., Reilly, T., & Gregson, W. (2011). The impact of different cooling modalities on the physiological responses in firefighters during strenuous work performed in high environmental temperatures. *European Journal of Applied Physiology, 111*(6), 959-967.

wireless communication system' and 'a vision support system'.[189] Active cooling systems may save lives or minimise the consequences of harm when other ways of reducing heat strain are not feasible.

UAS can not only provide localisation of workers in emergency during safe and rescue operations. They can also find defects in the equipment being worn during an emergency – which may help in devising timely approaches to minimising consequences of potential harm, and also **deliver new equipment** that may be needed, such as a breathing apparatus to workers in a mining emergency.[190]

Rescue robots can bring **first aid into the workplace**. Rescue robots are increasingly mobile. For instance, the 'rugbot' is able to navigate environments. It has an active flipper mechanism that makes it possible to move through rubble piles and stairs in construction, it has substantial computation power as it is equipped with a PC and a wide range of sensors on board, and it is energy efficient and sturdy. In particular, the rubgot has a new flipper design with ballscrew and passive link that makes it more reliable, robust and mobile.[191]

4.2.2 Accident investigation and reporting

The first step when there is an accident is to attend to workers, which can be done quickly and effectively through new OSH monitoring systems, as just considered in the section regarding minimising consequences. Following this, new OSH monitoring systems can help in accident investigation and provide information on where the accident occurred, who was present and who the victims were, what actions and/or conditions led to it, and what happened during the accident and the subsequent rescue operations (when needed) – thus establishing a chain of events.[192]

Accurate and unbiased accident data are obtained **quickly and efficiently**, which can be sufficient for investigative purposes or can provide a good basis for further investigation, or to supplement it. Data can refer to exposure to various types of hazards through **dosimeters, radiometers, accelerometers, WSNs, AR** and so on. Data can also be in the format of **geo-localisation, images, sounds and movements**.

In many cases, near-miss data may already have been collected through the preventive use of new OSH monitoring systems. This can be compared or contrasted with accident data. Therefore, there is the potential opportunity of discriminating between what happened in near-miss situations and in actual accidents.

Furthermore, causal factors for workplace accidents are manifold. They may relate to the **individual level**, in terms of lack of knowledge regarding safe practices for which images, recorded movements and RFIDs related to the adoption of protective equipment can all be used to investigate human error, or physiological aspects that may have influenced the accident.

Environmental factors can also be a causal factor of workplace accidents. They can be investigated quickly and efficiently using the new OSH monitoring systems, which in turn help to find out whether and how structural aspects should be corrected, by eliminating hazards or reducing their risks.

What is more, data collected through digital OSH monitoring systems can also provide insights regarding **how rescue operations can be improved** – in terms of response time and actions implemented.

As for **reporting**, new OSH monitoring systems offer the **opportunity of quick and accurate reporting**, which is needed to improve OSH.[193] For example, mobile apps can substitute burdensome paper-based reports, and they are also easier to archive and retrieve. So can audio and visual recordings from the

[189] Lee, J. Y., Park, J., Park, H., Coca, A., Kim, J. H., Taylor, N. A., & Tochihara, Y. (2015). What do firefighters desire from the next generation of personal protective equipment? Outcomes from an international survey. *Industrial Health, 53*(5), 434-444.

[190] Hennage, D. H., Nopola, J. R., & Haugen, B. D. (2019). *Fully autonomous drone for underground use*. Paper presented at the 53rd U.S. Rock Mechanics/Geomechanics Symposium, New York City, New York, 23-26 June.

[191] Chonnaparamutt, W., & Birk, A. (2006). Using rescue robots to increase construction site safety. In *2006 Proceedings of the 23rd ISARC, Tokyo, Japan* (pp. 241-245). International Association for Automation and Robotics in Construction.

[192] Probst, T. M., Bettac, E. L., & Austin, C. T. (2019). Accident under-reporting in the workplace. In R. J. Burke, & A. M. Richardsen (Eds), *Increasing occupational health and safety in workplaces* (pp. 30-47). Edward Elgar Publishing Limited.

[193] See: https://osha.europa.eu/en/blog/world-day-safety-and-health-work

accident scene, which can be sent to the relevant OSH officer automatically.[194] Without digital technologies, this is often a lengthy and burdensome process, which may add to the stress of having experienced or witnessed an accident. Further, incidents are usually recorded after some time has elapsed, which is not inconsequential in terms of reporting accuracy. It is important that reporting is correct and timely, and that it does not aggravate the situation of the worker in terms of physical and mental exhaustion.

Under-reporting is another OSH challenge that can be mitigated by digital technologies through on-the-spot and/or automatic reporting. Under-reporting may be due to lengthy and burdensome processes of reporting, as well as to potential embarrassment and humiliation attached to being involved in an accident, which is influenced by the broader OSH ethos in a given establishment.[195] The concept of an augmented workforce does also apply to the reactive dimension in that smart PPE can obtain data and deliver them, while also taking the pressure off workers and avoiding a culture of blame.[196]

4.3 OSH monitoring and specific needs

New OSH monitoring systems offer various opportunities to meet the specific needs of some workers, including but not limited to: the ageing workforce, lone, inexperienced or migrant workers, workers with low language skills levels and pregnant women as well as workers with ill health, disabled or in rehabilitation.[197,198,199] These digital OSH monitoring systems are also useful to achieve OSH objectives in the context of the COVID-19 pandemic. Besides, for those jobs amenable to teleworking, the COVID-19 pandemic has been a key driver of working outside the employer's premises, which has however resulted in new risks and challenges.[200]

Workers with specific needs

There are various ways in which new OSH monitoring systems can address the need to include an **increasingly diverse workforce**.[201] However, OSH monitoring opportunities are not only offered in the context of an increasingly diverse workforce, but workers may be supported because of the specific location and high risk of their **job tasks**, or due to their **level of experience**.

The **ageing workforce** requires strategies to promote OSH and healthy ageing. This is important because of the accumulation of health advantages and disadvantages in the life course,[202] which may carry over after retirement. Indeed, stressful, physically demanding and hazardous work are correlated with lower levels of healthy ageing: workplace interventions may thus have long-term positive impacts.[203] The use of wearables and the so-called quantified-self allow three types of strategic intervention that can help employers to adapt the workload and improve OSH. These are shown below:

[194] Hussin, M. F. B., Jusoh, M. H., Sulaiman, A. A., Abd Aziz, M. Z., Othman, F., & Ismail, M. H. B. (2014). Accident reporting system using an iOS application. In *2014 IEEE Conference on Systems, Process and Control (ICSPC 2014)* (pp. 13-18). IEEE.

[195] Black, K. J., Munc, A., Sinclair, R. R., & Cheung, J. H. (2019). Stigma at work: The psychological costs and benefits of the pressure to work safely. *Journal of Safety Research, 70*, 181-191.

[196] Lee, J. I., Chang, I., Pradhan, A. S., Kim, J. L., Kim, B. H., & Chung, K. S. (2015). On the use of new generation mobile phone (smart phone) for retrospective accident dosimetry. *Radiation Physics and Chemistry, 116*, 151-154.

[197] Brinzea, V. M. (2019). Encouraging neurodiversity in the evolving workforce: The next frontier to a diverse workplace. *Scientific Bulletin-Economic Sciences, 18*(3), 13-25.

[198] Lloyd-Jones, B., Bass, L., & Jean-Marie, G. (2018). Gender and diversity in the workforce. In M. Y. Byrd, & C. L. Scott (Eds), *Diversity in the workforce* (pp. 81-106). Routledge.

[199] Parry, E., & Tyson, S. (Eds) (2010). *Managing an age-diverse workforce*. Palgrave Macmillan London.

[200] EU-OSHA – European Agency for Safety and Health at Work, *Teleworking during the COVID-19 pandemic: risks and prevention strategies*, 2021. Available at: https://osha.europa.eu/en/publications/teleworking-during-covid-19-pandemic-risks-and-prevention-strategies

[201] Rechel, B., Mladovsky, P., Ingleby, D., Mackenbach, J. P., & McKee, M. (2013). Migration and health in an increasingly diverse Europe. *The Lancet, 381*(9873), 1235-1245.

[202] Ferraro, K. F., Shippee, T. P., & Schafer, M. H. (2009). Cumulative inequality theory for research on aging and the life course. In V. L. Bengston, D. Gans, N. M. Pulney, & M. Silverstein (Eds), *Handbook of theories of aging* (pp. 413-433). Springer Publishing Company.

[203] Nilsen, C., Darin-Mattsson, A., Hyde, M., & Wastesson, J. W. (2021). Life-course trajectories of working conditions and successful ageing. *Scandinavian Journal of Public Health, 50*(5), 593-600.

1. the identification of tasks that are deemed hazardous, for example, for older workers, such as lifting heavy weights;

2. the identification of shifts that may become harder with age (e.g. nightwork, day shifts in presence of high heat); and

3. the collection of real-time health information on physical and mental fatigue and overexertion, as well as loss or decline of physical and cognitive capacity.[204]

Furthermore, heightened risks for specific workers may be quantified depending on **susceptibility to specific hazardous substances**, which can be measured by carrying out DNA sequencing.[205] In addition, there are exoskeletons that monitor stressors and vital signs, support workers (rather than replace them) and reduce the physical load in demanding activities. These opportunities are particularly relevant in view of an ageing workforce, while they can also create better access to work for **disabled people**.[206,207,208,209,210,211,212] Relatedly**,** OSH monitoring systems that send warnings not only by using acoustic alerts but also vibrations or light present opportunities for **workers with hearing impairments**, and they may also be more effective for all workers in workplaces with high noise levels. What is more, new digital technologies and systems can also provide appropriate adaptation for the inclusion of workers with neurodiversity, ensuring that they can excel at work. Example are headphones that incorporate noise cancelling, as neurodiverse workers may be particularly sensitive to acoustic stimuli, and low arousal light and sound settings to warn workers about risks and hazards.[213] Furthermore, **workers with a migrant background and with low language skills** may find it easier to have access to video material and visual clues rather than text – for instance, when reviewing accidents recorded by cameras, in the context of training.[214] Another opportunity is the inclusion of **pregnant women** in traditionally high-risk sectors such as mining, which can be facilitated because technology makes the sector more accessible by creating job tasks (e.g. control rooms) that can be performed in safety – whereas pregnant women are not allowed to work underground.[215] Last, but not least, wearables can

[204] Lavallière, M., Burstein, A. A., Arezes, P., & Coughlin, J. F. (2016). Tackling the challenges of an aging workforce with the use of wearable technologies and the quantified-self. *Dyna, 83*(197), 38-43.

[205] EU-OSHA – European Agency for Safety and Health at Work, *Foresight on new and emerging occupational safety and health risks associated with digitalisation by 2025*, 2018. Available at: https://osha.europa.eu/en/publications/foresight-new-and-emerging-occupational-safety-and-health-risks-associated

[206] EU-OSHA – European Agency for Safety and Health at Work, *Occupational exoskeletons: wearable robotic devices to prevent work-related musculoskeletal disorders in the workplace of the future*, 2020. Available at: https://osha.europa.eu/en/publications/occupational-exoskeletons-wearable-robotic-devices-and-preventing-work-related

[207] EU-OSHA – European Agency for Safety and Health at Work, *Foresight on new and emerging occupational safety and health risks associated with digitalisation by 2025*, 2018. Available at: https://osha.europa.eu/en/publications/foresight-new-and-emerging-occupational-safety-and-health-risks-associated

[208] Upasani, S., Franco, R., Niewolny, K., & Srinivasan, D. (2019). The potential for exoskeletons to improve health and safety in agriculture—Perspectives from service providers. *IISE Transactions on Occupational Ergonomics and Human Factors, 7*(3-4), 222-229.

[209] Zhu, Z., Dutta, A., & Dai, F. (2021). Exoskeletons for manual material handling – A review and implication for construction applications. *Automation in Construction, 122*, Article 103493.

[210] Ziaei, M., Choobineh, A., Ghaem, H., & Abdoli-Eramaki, M. (2021). Evaluation of a passive low-back support exoskeleton (Ergo-Vest) for manual waste collection. *Ergonomics, 64*(10), 1255-1270.

[211] Bogue, R. (2018). Exoskeletons – A review of industrial applications. *Industrial Robot, 45*(5), 585-590.

[212] Chu, G., Hong, J., Jeong, D. H., Kim, D., Kim, S., Jeong, S., & Choo, J. (2014). The experiments of wearable robot for carrying heavy-weight objects of shipbuilding works. In *2014 IEEE international conference on automation science and engineering (CASE)* (pp. 978-983). IEEE.

[213] Mpofu, E., Cagle, R., Chiu, C. Y., Li, Q., & Holloway, L. (2021). Digital tools applications to occupational health and safety for people with autism. In N. Ferreira, I. L. Potgieter, & M. Coetzee (Eds), *Agile coping in the digital workplace* (pp. 147-165). Springer.

[214] Cocca, P., Marciano, F., & Alberti, M. (2016). Video surveillance systems to enhance occupational safety: A case study. *Safety Science, 84*, 140-148.

[215] Bender, G., & Söderqvist, F. *How to negotiate an algorithm: A case study on voice and automation in Swedish mining.*. Blekinge Institute of Technology (forthcoming).

be helpful – **reactively** – for workers **undergoing rehabilitation at home**, as they can be equipped with a function that sends alarm messages to caregivers.[216,217] Rehabilitation also applies to workers experiencing **long COVID**.[218,219]

In terms of task location and risks, **lone workers** or **workers in hazardous locations** can be tracked through GPS software, or they may be equipped with sensors that warn them of impending high-risk hazards to their health and safety. Further, opportunities may also relate to the experience of workers, with **inexperienced workers** able to benefit vastly from the adoption of new OSH monitoring systems, in terms of training and/or being warned about risk factors at work. This is important for companies because of an ageing workforce and the shortages of labour supply across many sectors. It is essential to consider the health and safety of workers early, as this may also favour the retention of healthy individuals.

COVID-19

The COVID-19 pandemic has prompted the need to urgently put in place measures to counter the transmission of infectious biological diseases.[220] New OSH monitoring systems, which rely on wearables, IoT, AI and ML, tracking devices and so on, can help to ensure safer workplaces.[221,222,223]

These systems can measure temperatures and other early warning signs of possible infections. They can ensure that appropriate preventive hygienic measures are adopted by workers (hand hygiene, safe distancing, wearing masks) and that environmental aspects such as air quality and ventilation are measured and addressed.

Measurements of body temperature and oxygen are increasingly important because they can be used as early detection mechanisms of COVID-19-infected workers. Wearables[224] and forehead thermometers[225] have been used. As for **distancing**, the literature refers to smart camera systems based on AI.[226] Interviewees mentioned that a good example is that of wearable devices with a warning buzzer that is activated when sensors attached to two or more workers get too close. **Wearing masks**, another important individual-level preventive measure, can be enforced more easily by ML methods for face mask detection.[227]

Apart from ensuring safe behaviours (distancing, hand hygiene), safe work environments (air ventilation) and the use of protective equipment (face masks), what is important when it comes to infectious, rather

[216] Khakurel, J., Melkas, H., & Porras, J. (2018). Tapping into the wearable device revolution in the work environment: A systematic review. *Information Technology & People, 31*(3), 791-818.

[217] Patel, S., Park, H., Bonato, P., Chan, L., & Rodgers, M. (2012). A review of wearable sensors and systems with application in rehabilitation. *Journal of Neuroengineering and Rehabilitation, 9*, Article 21.

[218] Murray, E., Goodfellow, H., Bindman, J., Blandford, A., Bradbury, K., Chaudhry, T., & Waywell, J. (2022). Development, deployment and evaluation of digitally enabled, remote, supported rehabilitation for people with long COVID-19 (Living With COVID-19 Recovery): Protocol for a mixed-methods study. *BMJ Open, 12*(2), Article e057408.

[219] EU-OSHA – European Agency for Safety and Health at Work, *COVID-19 infection and long covid - guide for workers*, 2021. Available at: https://osha.europa.eu/en/publications/covid-19-infection-and-long-covid-guide-workers

[220] EU-OSHA – European Agency for Safety and Health at Work, *Biological agents and prevention of work-related diseases: A review*, 2020. Available at: https://osha.europa.eu/en/publications/review-specific-work-related-diseases-due-biological-agents

[221] Ting, D. S. W., Carin, L., Dzau, V., & Wong, T. Y. (2020). Digital technology and COVID-19. *Nature Medicine, 26*(4), 459-461.

[222] Awotunde, J. B., Jimoh, R. G., AbdulRaheem, M., Oladipo, I. D., Folorunso, S. O., & Ajamu, G. J. (2022). IoT-based wearable body sensor network for COVID-19 pandemic. In A.-E. Hassanien, S. M. Elghamrawy, & I. Zelinka (Eds), *Advances in data science and intelligent data communication technologies for COVID-19* (pp. 253-275). Springer.

[223] Mondal, M. S., Roy, K., & Sarkar, S. (2020). Design and development of wearable remote temperature monitoring device for smart tracking of COVID-19 fever. In *Proceedings of the 2nd International Conference on IoT, Social, Mobile, Analytics & Cloud in Computational Vision & Bio-Engineering (ISMAC-CVB 2020)* (pp. 665-675). Elsevier.

[224] Krishnamurthi, R., Gopinathan, D., & Kumar, A. (2021). Wearable devices and COVID-19: State of the art, framework, and challenges. In F. Al-Turjman, A. Devi, & A. Nayyar (Eds), *Emerging technologies for battling Covid-19* (pp. 157-180). Springer.

[225] Ebeid, A. G., Selem, E., El-kader, A., & Sherine, M. (2020). Early detection of COVID-19 using a non-contact forehead thermometer. In A. E., Hassanien, A. Slowik, V. Snášel, H. El-Deeb, & F. M. Tolba (Eds), *Proceedings of the International Conference on Advanced Intelligent Systems and Informatics* (pp. 314-323). Springer.

[226] Karaman, O., Alhudhaif, A., & Polat, K. (2021). Development of smart camera systems based on artificial intelligence network for social distance detection to fight against COVID-19. *Applied Soft Computing, 110*, Article 107610.

[227] Loey, M., Manogaran, G., Taha, M. H. N., & Khalifa, N. E. M. (2021). A hybrid deep transfer learning model with machine learning methods for face mask detection in the era of the COVID-19 pandemic. *Measurement, 167*, Article 108288.

than chronic, diseases is **traceability** – and even more so, in the context of COVID-19 because the virus has shown to be highly contagious, with successive variants increasing their ability to spread quickly. According to the European Trade Union Confederation (ETUC), contact tracing apps, albeit rather intrusive, have been one digital technology to ensure traceability and contact. Facial recognition could also help identify those who should have in fact been quarantined.[228]

What is important to emphasise further is that new OSH monitoring systems in the context of COVID-19 may specifically address biological hazards, but at the same time this focus has positive externalities vis-à-vis the psychosocial aspects of our health and wellbeing. This has to do with feeling reassured that OSH monitoring and the adaptation to environmental hazards are duly considered by employers, thus creating a **culture of trust, health and wellbeing, and safety**.

Teleworking

The COVID-19 pandemic has increased teleworking arrangements, as many jobs have proved to be teleworkable. Besides, the specific psychosocial, biological and environmental circumstances linked to the pandemic and the response to it increased both supply and demand-side drivers for teleworking arrangements in a short time. However, teleworking presented many risks: general risks, such as lighting, noise, eye strain, slip, trips and falls; ergonomic ones, such as RSIs resulting from inadequate home workstations; and psychosocial risks linked to isolation from colleagues and line managers, the blurring of boundaries between private and work life, work intensification, and combining work and care responsibilities.[229]

While there is little evidence of new OSH monitoring systems being used in the context of telework, it is important to consider the vast opportunities the digital technology may offer. The reason for this is that employers need to ensure good OSH also for teleworkers and that teleworking arrangements will potentially increase, as compared to pre-COVID levels, which requires strategic directions for the present as well as the future.

Many of the systems seem to potentially provide opportunities with regard to teleworkers' OSH. For example, there is the opportunity to carry out risk assessments remotely, which is important to ensure adequate home workstations. It is also possible to measure the health of teleworkers, to ensure that individuals do not work when ill and rather take some sick leave. Accelerometers could also be used to measure the movements carried out by teleworkers. Different sensors can also measure eye strain, which could be an issue considering that teleworkers may sometimes not have the same large screens at home (or, rather, outside the employer's premises) as they have in the office, or because of glares on the screen. Wearables and other devices may be used to analyse the mental health and wellbeing of teleworkers and encourage them (based on the collected data) to take more regular breaks and engage in physical activity, to help them adopt healthier lifestyles. At a more structural level, data from such devices can signal the need to review work allocation.

[228] European Trade Union Confederation. (2020, September 30). *COVID-19 Watch ETUC briefing on new technologies allowing more surveillance at work*. Briefing note. Available at: https://www.etuc.org/sites/default/files/publication/file/2020-10/20200930_covid-19%20Briefing%20on%20survelliance%20technologies%20%28002%29.pdf

[229] EU-OSHA – European Agency for Safety and Health at Work, *Teleworking during the COVID-19 pandemic: risks and prevention strategies*, 2021. Available at: https://osha.europa.eu/en/publications/teleworking-during-covid-19-pandemic-risks-and-prevention-strategies

5 Risks and challenges of new OSH monitoring systems

New OSH monitoring systems offer a wide range of opportunities, but they also present risks and challenges. This section identifies challenges and risks pertaining to physical health and safety, psychosocial risks, the risk of blurring OSH responsibility and certain limitations regarding training.

5.1 Physical health and safety risks

This section presents the challenges and risks of new OSH monitoring systems to physical health and safety. Figure 5 illustrates the adverse effects of new OSH monitoring systems on health and safety.

Figure 5: Overview of physical health and safety risks of new OSH monitoring systems

Adverse and unknown net effects (e.g. exoskeletons, VR, AI)[230]	Sensors' accuracy[231]	Malfunctioning (e.g. batteries, smart PPE, UAS)[232]	Work intensification / de-intensification (e.g. new OSH monitoring systems)[233]

New OSH monitoring systems may have **adverse effects and have a negative net impact sometimes**. For example, **exoskeletons** present a number of potential risks. First, according to the French National Research and Safety Institute for the Prevention of Occupational Accidents and Diseases (INRS),[234] they modify the redistribution of effort and can result in the emergence of new biomechanical constraints and risk factors for **MSDs**. A key challenge is ensuring that exoskeletons reduce pressure in some parts of the body, without increasing pressure in other parts – as the net effect of this redistribution could possibly be negative. Second, exoskeletons could **hinder movement and lead to collisions** because of their bulky structure, and they may cause **discomfort, skin irritation, or increase cardiovascular load and stress**. De Looze et al. (2016)[235] note that, despite the substantial global interest in a digital technology such as exoskeletons, these multiple technical issues need to be addressed. Third, they may **make workers over-confident in their abilities**, as they might give workers an impression of invulnerability that could result in harm and accidents.[236]

Similarly, **VR and AR** may cause disorientation, motion sickness (also called cyber-sickness) and eye strain, owing largely to three factors: hardware, content and human-related.[237]

AI, ML, deep learning and algorithms may also present **adverse effects**. For example, when an accident is about to happen, AI may be tasked with supporting critical decision-making, but it is important

[230] Icon made by surang from Flaticon.com
[231] Icon made by Freepik from Flaticon.com
[232] Icon made by Freepik from Flaticon.com
[233] Icon made by Eucalyp from Flaticon.com
[234] INRS. (2020). *Using exoskeletons at work : The message of prevention*. Available at: https://en.inrs.fr/news/exoskeletons-6-critical-points.html
[235] De Looze, M. P., Bosch, T., Krause, F., Stadler, K. S., & O'Sullivan, L. W. (2016). Exoskeletons for industrial application and their potential effects on physical work load. *Ergonomics*, *59*(5), 671-681.
[236] EU-OSHA – European Agency for Safety and Health at Work, *Digitalisation and occupational safety and health - An EU-OSHA research programme*, 2019. Available at: https://osha.europa.eu/en/publications/digitalisation-and-occupational-safety-and-health-eu-osha-research-programme
[237] Chang, E., Kim, H. T., & Yoo, B. (2020). Virtual reality sickness: A review of causes and measurements. *International Journal of Human–Computer Interaction, 36*(17), 1658-1682. https://doi.org/10.1080/10447318.2020.1778351

that these systems have reliable, accurate and unbiased data, as there may be unintended consequences of the specifications of certain evaluation criteria or of deep-learning processes.[238]

As for **sensor technology**, despite its increasing sophistication, the **challenge of collecting accurate data** to avoid workers being exposed to higher-than-safe levels of toxic substances (and other hazards) remains. Even when technologies are certified, their **accuracy is assessed in laboratory-type environments** that may not accurately replicate the adverse working conditions. According to Khakurel et al. (2018),[239] accuracy varies when data are collected in laboratory or in outdoor settings. Interviewees emphasised that this is particularly the case in **working environments that may limit sensor accuracy** because of, for example, fire, dust, heat and presence of steel. Besides, in real work settings technologies may face unexpected challenges: for example, in drone systems, thermal cameras may not be able to localise a worker if the difference between the person and the surroundings is not pronounced, which may relate to the clothes worn, whether they are wet or dry, and so on.[240] Lastly, human-machine interfaces (face, gestures, voice, eye movement, brain signals) could misinterpret altered or low-strength signals – for instance, due to batteries running low, interferences, language and pronunciation issues.[241]

Smart digital technologies may also malfunction. Batteries may not only be inefficient in dire environmental situations or stop working, they may also overheat, catch fire or explode.[242] A **sensor-based vest** may have water penetrate its electrical parts, which can cause short circuits or electric shocks. **UAS** can present safety risks to proximate workers due to system malfunction or due to cyberattacks. This can be particularly true for semi-autonomous or autonomous UAVs where humans are not operators.[243,244,245]

OSH monitoring systems may also **intensify work** and thus cause harm to workers. In such cases, an existing worker might have to deal with additional workload. At the same time, OSH monitoring systems can also cause harm by **de-intensifying work**: by completely removing workers from tasks such as manual handling, they might reduce their overall physical fitness, leading to loss of muscle / bone density or joint flexibility.[246] Lastly, while OSH monitoring systems could remove workers from performing the most hazardous tasks – for instance, using a drone to perform maintenance checks – this may not always be possible, and OSH monitoring systems could sometimes leave the most hazardous tasks to workers, such as unplanned maintenance, for example.[247]

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[238] EU-OSHA – European Agency for Safety and Health at Work, *Artificial intelligence for worker management: an overview*, 2022. Available at: https://osha.europa.eu/en/publications/artificial-intelligence-worker-management-overview

[239] Khakurel, J., Melkas, H., & Porras, J. (2018). Tapping into the wearable device revolution in the work environment: A systematic review. *Information Technology & People, 31*(3), 791-818.

[240] Burke, C., McWhirter, P. R., Veitch-Michaelis, J., McAree, O., Pointon, H. A., Wich, S., & Longmore, S. (2019). Requirements and limitations of thermal drones for effective search and rescue in marine and coastal areas. *Drones, 3*(4), Article 78.

[241] EU-OSHA – European Agency for Safety and Health at Work, *Foresight on new and emerging occupational safety and health risks associated with digitalisation by 2025*, 2018. Available at: https://osha.europa.eu/en/publications/foresight-new-and-emerging-occupational-safety-and-health-risks-associated

[242] EU-OSHA – European Agency for Safety and Health at Work, *Smart personal protective equipment: intelligent protection for the future*, 2020. Available at: https://osha.europa.eu/en/publications/smart-personal-protective-equipment-intelligent-protection-future/view

[243] EU-OSHA – European Agency for Safety and Health at Work, *Foresight on new and emerging occupational safety and health risks associated with digitalisation by 2025*, 2018. Available at: https://osha.europa.eu/en/publications/foresight-new-and-emerging-occupational-safety-and-health-risks-associated

[244] EU-OSHA – European Agency for Safety and Health at Work, *Cobots, robots and drones: the impact of digital technology on OSH in agriculture and forestry*, 2021. Available at: https://osha.europa.eu/en/publications/cobots-robots-and-drones-impact-digital-technology-osh-agriculture-and-forestry

[245] Howard, J., Murashov, V., & Branche, C. M. (2017). Unmanned aerial vehicles in construction and worker safety. *American Journal of Industrial Medicine, 61*(1), 3-10. https://onlinelibrary.wiley.com/doi/abs/10.1002/ajim.22782

[246] EU-OSHA – European Agency for Safety and Health at Work, *Digitalisation and occupational safety and health - An EU-OSHA research programme*, 2019. Available at: https://osha.europa.eu/en/publications/digitalisation-and-occupational-safety-and-health-eu-osha-research-programme

[247] EU-OSHA – European Agency for Safety and Health at Work, *Foresight on new and emerging occupational safety and health risks associated with digitalisation by 2025*, 2018. Available at: https://osha.europa.eu/en/publications/foresight-new-and-emerging-occupational-safety-and-health-risks-associated

5.2 Psychosocial risks

This section turns to the psychosocial risks of new OSH monitoring systems. EU-OSHA lists a series of potentially adverse psychosocial effects from electronic performance measurement (EPM), which can offer a good proxy – and these points are indeed corroborated by interview data. They are shown in Figure 6.

Figure 6: EPM effects on psychosocial health[248]

Can be an invasion of privacy which is generally experienced to be a stressor

Can lead to work alienation in several ways:

- resulting in loss of control on behalf of workers,
- lowering satisfaction and morale,
- reducing social contact among workers,
- promoting quantity against quality, and
- overwhelming OSH managers with data and feedback expectations.

Source: Authors' recreation based on EU-OSHA – European Agency for Safety and Health at Work, Monitoring technology: The 21st century's pursuit of well-being?, 2017, p. 4. Available at: https://osha.europa.eu/sites/default/files/Workers_monitoring_and_well-being.pdf

New (OSH) monitoring systems can be perceived as an invasion of privacy, which can be stressful, and lead to work alienation in several ways.[249][250] First, there are still big questions with regard to **data privacy, ownership and security**. Digital devices collect vast amounts of data, which can be sensitive personal data, for instance, related to ethnic origin, health, genetic and biometric data, and so on. Therefore, for workers and worker representatives it is important to understand who has the right to see and use the data, how the latter are merged, stored and transferred to third parties such as external service providers and social platforms, and how / when data will be erased. What is more, cybersecurity entails the risk of data breaches and thefts, as linked to illicit uses, for example. In 2020, GDPR data breaches increased by a fifth compared to 2019 – overall, 281,000 data breaches were recorded.[251] It is thus important for workers to understand what types of security measures are in place to protect against unauthorised access.

Second, another aspect to consider is what the data are used for, exemplary in the context of **'digital surveillance'** as linked to work intensification.[252] Workers and their representatives sometimes perceive that their management uses OSH monitoring systems to increase their control over workers'

[248] Icons made by Freepik from Flaticon.com

[249] Carpenter, D., McLeod, A., Hicks, C., & Maasberg, M. (2018). Privacy and biometrics: An empirical examination of employee concerns. *Information Systems Frontiers, 20*(1), 91-110. European Commission, European Political Strategy Centre, & Servoz, M. (2019). *AI, the future of work? : Work of the future! : On how artificial intelligence, robotics and automation are transforming jobs and the economy in Europe*. Publications Office of the European Union. Available at: https://op.europa.eu/en/publication-detail/-/publication/096526d7-17d8-11ea-8c1f-01aa75ed71a1

[250] EU-OSHA – European Agency for Safety and Health at Work, *Monitoring technology: The 21st century's pursuit of well-being?*, 2017. Available at: https://osha.europa.eu/sites/default/files/Workers_monitoring_and_well-being.pdf

[251] See: https://www.research-live.com/article/news/gdpr-breaches-increased-by-a-fifth-in-2020/id/5078982

[252] Ball, K. (2021). *Electronic monitoring and surveillance in the workplace. Literature review and policy recommendations*. Publications Office of the European Union. Available at: https://publications.jrc.ec.europa.eu/repository/bitstream/JRC125716/jrc125716_electronic_monitoring_and_surveillance_in_the_workplace_final.pdf

performance in the context of increasingly challenging targets.[253] OSH monitoring systems for teleworkers may also include risks and challenges related to performance monitoring. Based on the data captured, employers may be able to know where workers are, what they are doing, how (tired) they are feeling, whether they are sleeping and so on. They may also know who takes toilet breaks and for how long.[254] This can generate anxiety and stress due to an **always-on culture**[255] **and *anticipatory surveillance* fear**,[256] for example, digital technology frequently sends alerts, warnings or reminders, which can be stressful as it gives a sense of constant oversight.

Third, there are concerns over **workplace discrimination** based on the data captured by the devices,[257] as information could, for example, be used to decide who to hire, retain or fire.[258] These risks compromise the dignity and self-fulfilment of workers, which are central aspects of their health and wellbeing – intended as having control over their own life.[259]

Fourth, the shift to **algorithmic management** may pose psychosocial risks because of the impact on working relationships, communication and trust. AI management can reduce contact between management and workers, as well as between co-workers. It can thus undermine workplace connection and motivation. The reduced scope for task rotation and variety may lead to **increased job dissatisfaction**, for example, for workers assigned to lone, monotonous and repetitive work that increases their isolation. Besides, algorithmic decision-making that may not be transparent and open may lead to the **perception of injustices and alienation**, and may curb creativity and autonomy.[260,261]

Fifth, algorithms may not be calibrated sufficiently well to perform adequately in the context of a diverse workforce, for instance based on race and ethnicity, gender and so on. There is still a **high error rate of face recognition algorithms** for 18-30 year-old black women,[262] for example, and the same reasoning can apply to data related to blood samples and hormonal levels.[263,264] It is not always the case that these systems are used for OSH monitoring, but there are substantial opportunities to use them for such purpose, despite the need to ensure the collection of unbiased data.

Sixth, psychosocial risks may derive from **frustration and fear over technologies malfunctioning** or not being comfortable and easily customisable.[265]

Seventh, for management, the vast amount of data collected and to interpret may result in a **cognitive overload** given the big data gathered that are hardly sustainable, unless the process is automated.[266]

[253] European Trade Union Confederation. (2018). *Digitalisation and workers participation. What trade unions, company level workers and online platform workers in Europe think*. Available at: https://www.etuc.org/sites/default/files/publication/file/2018-09/Voss%20Report%20EN2.pdf

[254] Bender, G., & Söderqvist, F. *How to negotiate an algorithm: A case study on voice and automation in Swedish mining*. Blekinge Institute of Technology (forthcoming).

[255] Ecorys interviews conducted for this study, between November 2021 and February 2022.

[256] Samek Lodovici, M. et al. (2021). *The impact of teleworking and digital work on workers and society*. Policy Department for Economic, Scientific and Quality of Life Policies. Available at: https://www.europarl.europa.eu/RegData/etudes/STUD/2021/662904/IPOL_STU(2021)662904_EN.pdf

[257] Kortuem, G., Alford, D., Ball, L., Busby, J., Davies, N., Efstratiou, C., Finney, J., White, M. I., & Kinder, K. (2007). Sensor networks or smart artifacts? An exploration of organizational issues of an industrial health and safety monitoring system. In J. Krumm, G. D. Abowd, A. Seneviratne, & T. Strang (Eds), *UbiComp 2007: Ubiquitous Computing. UbiComp 2007. Lecture Notes in Computer Science, Vol. 4717* (pp. 465-482). Springer. Available at: https://eprints.lancs.ac.uk/id/eprint/13020/1/Ubicomp-2007.pdf

[258] Khakurel, J., Melkas, H., & Porras, J. (2018). Tapping into the wearable device revolution in the work environment: A systematic review. *Information Technology & People, 31*(3), 791-818.

[259] Alli, B. O., & International Labour Office. (2001). *Fundamental principles of occupational health and safety*. ILO.

[260] European Trade Union Confederation. (2020). *Resolution on the European strategies on artificial intelligence and data*. Available at: https://www.etuc.org/en/document/resolution-european-strategies-artificial-intelligence-and-data

[261] Zednik, C. (2021). Solving the black box problem: A normative framework for explainable artificial intelligence. *Philosophy & Technology, 34*(2), 265-288.

[262] Furl, N., Phillips, P. J., & O'Toole, A. J. (2002). Face recognition algorithms and the other-race effect: computational mechanisms for a developmental contact hypothesis. *Cognitive Science, 26*(6), 797-815.
See: https://sitn.hms.harvard.edu/flash/2020/racial-discrimination-in-face-recognition-technology/

[263] Mullings, L., & Schulz, A. J. (2006). Intersectionality and health: An Introduction. In A. J. Schulz, & L. Mullings (Eds), *Gender, race, class, & health: Intersectional approaches* (pp. 3-17). Jossey-Bass/Wiley.

[264] Wood, S., Martin, U., Gill, P., Greenfield, S. M., Haque, M. S., Mant, J., Mohammed, M. A., Heer, G., Johal, A., Kaur, R., Schwartz, C., & McManus, R. J. (2012). Blood pressure in different ethnic groups (BP-Eth): A mixed methods study. *BMJ Open, 2*(6), Article e001598.

[265] Ecorys interviews conducted for this study, between November 2021 and February 2022.

[266] See: https://www.ehstoday.com/ppe/article/21919117/how-wearablescould-disrupt-workplace-safety

Besides, this also applies to workers who may receive a high volume of data / content, when using VR/AR.[267]

Finally, adverse psychosocial effects such as stress and anxiety can be **disproportionate for the most disadvantaged workers**. For example, production workers might feel more stressed because they perform tasks where performance is closely monitored. In such cases, simply relying on monitoring, without factoring in a human manager, can have an impact on the mental wellbeing of vulnerable workers who might not know how to respond to the increase in pressure.[268] Similarly, older workers might experience stress related to the introduction of a new technology at the workplace.[269]

Psychosocial risks might also explain the general **reluctance** of workers with regard to the introduction of new OSH monitoring systems, and their respective technologies at the workplace. In some cases, some systems are more acceptable than others.[270] However, all in all, the **lack of trust** of workers towards technologies in some of these systems, such as AI, and their uses by employers remains.[271]

5.3 Responsibility and OSH monitoring systems

OSH management requires that preventive measures be implemented to eliminate hazards and/or reduce risks, according to the so-called hierarchy of controls, which includes: 1. elimination, 2. substitution, 3. engineering controls (e.g. ventilation, scaffolding, safety nets), 4. administrative controls (e.g. task rotation, risk assessments), and 5. PPE. However, new OSH monitoring systems may blur OSH responsibility in practice by making employers increasingly reliant on them at the expense of other OSH measures.

One risk is that employers may not carry out adequate risk assessments and may not adopt corrective measures, based on the data gathered through digital technologies, and that the new OSH monitoring systems might **substitute other OSH obligations**. This may create a sense of false worker safety and of having fulfilled obligations, but in fact these changes are only cosmetic.[272] This situation is particularly dangerous when new OSH monitoring systems are simply transplanted rather than adapted to an establishment, without tailoring the solution to the workplace and workers' needs.

Another risk is that there may be more emphasis on **personal control measures** than on **collective ones (e.g. smart PPE)**. According to the hierarchy of controls, (smart) PPE should only be used as a last resort measure when all others have failed to produce effective results.[273] Collective protective measures protect all workers rather than one only, at a given time. The two types of measures are not mutually exclusive: they should be seen as complementary, given personal control measures can add an extra layer of protection for any *residual risk*.[274]

More broadly, there are **blurred boundaries between individual health and behaviours and occupational health**. The use of wearables tends to blur the distinction between private and work life, with data recording 24/7. But while wearables may warn workers that they are sleep deprived, work-related stress and mental fatigue are very likely to negatively affect sleep patterns. Wearables and their related wellbeing programmes may however point to individual measures (e.g. having a better diet, going to bed early, drinking less coffee, being more physically active, etc.) when occupational (and even public health) ones may be required.

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[267] EU-OSHA – European Agency for Safety and Health at Work, *Digitalisation and occupational safety and health - An EU-OSHA research programme*, 2019. Available at: https://osha.europa.eu/en/publications/digitalisation-and-occupational-safety-and-health-eu-osha-research-programme
[268] Ecorys interviews with stakeholders from trade unions, employer representatives and research organisations, conducted between November 2021 and February 2022.
[269] Holte, K. A., Follo, G., Kjestveit, K., & Stræte, E. P. (2018). Agriculture into the future: New technology, new organisation and new occupational health and safety risks? In S. Bagnara, R. Tartaglia, S. Albolino, T. Alexander, & Y. Fujita (Eds), *Proceedings of the 20th Congress of the International Ergonomics Association (IEA 2018)* (pp. 404-413). Springer.
[270] Aydin, B. (2019). Public acceptance of drones: Knowledge, attitudes, and practice. *Technology in Society, 59*, Article 101180.
[271] EU-OSHA – European Agency for Safety and Health at Work, *Artificial intelligence for worker management: an overview*, 2022. Available at: https://osha.europa.eu/en/publications/artificial-intelligence-worker-management-overview
[272] Ecorys interviews with stakeholders from trade unions, employer representatives and research organisations, conducted between November 2021 and February 2022.
[273] See: https://www.hse.gov.uk/construction/lwit/assets/downloads/hierarchy-risk-controls.pdf
[274] See: https://www.haspod.com/blog/management/residual-risk

Besides, new OSH monitoring systems also pose the **challenge of having to train**[275] **workers** (to use the systems) and management (to use new monitoring systems and to manage with such systems). Thus, it creates further OSH responsibility, while helping to fulfil others. For instance, the use of smart PPE should always be accompanied by training on their possibilities and limitations: if not, they risk causing serious harm.

5.4 Limited training

New OSH monitoring systems may help to train workers in a tailored and safe way, for instance, using ICT, AR/VR and so on. However, these systems may have limitations in terms of the limited technical content they expose workers to. Besides, training methodologies for these tools are likely to be in their infant stage.[276]

Therefore, new OSH monitoring systems cannot substitute actual training: content is limited, methodologies are being developed and they may not provide the same benefits as in-person teaching. Besides, they may also cause dizziness in certain cases, or eye strain, thus reproducing health and safety risks.

[275] European Commission, European Political Strategy Centre, & Servoz, M. (2019). *AI, the future of work? : Work of the future! : On how artificial intelligence, robotics and automation are transforming jobs and the economy in Europe*. Publications Office of the European Union. Available at: https://op.europa.eu/en/publication-detail/-/publication/096526d7-17d8-11ea-8c1f-01aa75ed71a1

[276] IBM. (2020). *AR and VR in the workplace. Extended reality reimagines how work is done*. Available at: https://www.ibm.com/downloads/cas/4REM48XZ

6 Stages of risks and challenges, and measures to mitigate / overcome them

6.1 Technological maturity

There are ample challenges and risks related to the technological advancement or maturity of digital tools. As seen in sections 5.1 to 5.3, certain digital technologies may still be in their early stages of development. Risks and challenges pertain to accuracy, processing capabilities, efficiency, malfunctions or even explosions (e.g. batteries). Further, digital technologies may present challenges related to their sensor accuracy, customisation and usability, as well as limits to their applications (e.g. training material). This could lead to inaccurate and biased data collection, transmission and interpretation of data, and to physical risks and psychosocial ones, for instance, related to the opacity of such systems and to fears of equipment and OSH monitoring systems malfunctioning.

However, there are differences in maturity between technologies and their different applications across sectors and job tasks. For instance, the smart PPE industry is considered rather young, despite having grown substantially over the last decade.[277] Similarly, AI is considered challenging ethically and opaque in terms of evaluation criteria adopted and the reasoning of AI, as well as in terms of psychosocial risks deriving from a human-machine interface.[278] Persuasive technology is deemed promising and relevant to wellbeing at the workplace, but it is also viewed as a branch of science that is in its early stages of development overall. What is more, certain digital technologies may be more advanced in specific sectors. According to Eurofound, IoT has already reached operational maturity in high-tech sectors.[279] Despite this, for Espinoza et al. (2020),[280] there are still challenges linked to infrastructure, privacy and data security.

In terms of mitigation measures, there is ample scope for **technological research** to vastly improve on the current digital tools at disposal. However, the stakeholders interviewed note that it is important to create a fertile environment for research. By contrast, **complex legislation and lack of adequate standardisation** are considered to hinder innovation from the side of developers. Employers also need adequate legal and regulatory frameworks to test new solutions.[281] What is more, while some digital technologies have become almost ubiquitous and there are vast markets, other technologies – or their electronic components – may offer very little incentives to manufacturers in terms of R&D because of the niche and small markets they cater for.

It is also deemed important to **train workers**, as they may need to interact with new digital technology in a different way than they are used to. They should also be made aware of what the limitations of the OSH monitoring systems are, and become familiarised with new processes through clear communication from management.[282] Training should also include how to behave in unexpected situations, as linked, for instance, to the functioning of AI and cobots, and how they may affect OSH

[277] EU-OSHA – European Agency for Safety and Health at Work, *Smart personal protective equipment: intelligent protection for the future*, 2020. Available at: https://osha.europa.eu/en/publications/smart-personal-protective-equipment-intelligent-protection-future/view

[278] EU-OSHA – European Agency for Safety and Health at Work, *Impact of artificial intelligence on occupational safety and health*, 2021. Available at: https://osha.europa.eu/en/publications/impact-artificial-intelligence-occupational-safety-and-health

[279] Eurofound. (2021). *Digitisation in the workplace*. Publications Office of the European Union. Available at: https://www.eurofound.europa.eu/publications/report/2021/digitisation-in-the-workplace

[280] Espinoza, H., Kling, G., McGroarty, F., O'Mahony, M., & Ziouvelou, X. (2020). Estimating the impact of the Internet of things on productivity in Europe. *Heliyon, 6*(5), Article e03935.

[281] Ceemet. (2021). *Digitalisation and the world of occupational safety and health*. Available at: https://www.ceemet.org/site/assets/files/4384/ceemet_digitalisation_and_safety_health_2021.pdf

[282] EU-OSHA – European Agency for Safety and Health at Work, *Foresight on new and emerging occupational safety and health risks associated with digitalisation by 2025*, 2018. Available at: https://osha.europa.eu/en/publications/foresight-new-and-emerging-occupational-safety-and-health-risks-associated

standards.[283] In this context, workplace resources as well as close collaboration between workers and OSH professionals on the ground can be an effective way to train workers.[284]

6.2 Design and implementation

Human-centred design aims to tailor OSH monitoring systems to the needs of users. This approach improves human wellbeing, enhances the effectiveness of OSH monitoring systems, and increases user satisfaction, accessibility and sustainability, while also mitigating possible adverse effects on OSH.[285,286]

New OSH monitoring systems should also be **tailored to each specific workplace**. Employers should identify hazards and assess risks.[287] OSH systems should be fit-for-purpose with regard to specific rules and practices of a given establishment, and their potential impact on working processes should be assessed, to ensure that it matches organisational needs, the working environment, and the expectations of all stakeholders (employers, workers, social partners, etc.).[288] While this is true, adaptability / configurability of these systems still remains a challenge.

Designing and implementing new OSH monitoring systems requires engaging workers as early as possible, by making sure they have a voice and **participate** in its design and goals,[289,290] but also that they give feedback on their satisfaction[291] – ideally, attention could also be devoted to the needs of specific workers and not only consider average satisfaction rates across all workers.[292]

It is important to consider **information ecology**, that is, how and what data are collected, for what purposes, who has access to it, what data privacy and security mechanisms are in place, and who is in charge of them.[293]

Research shows that participatory interventions involving the workforce (e.g. in testing, selecting, optimising the new OSH monitoring system and in training activities) are important to **overcome hesitance and ensure buy-in.**[294,295,296] More broadly, the integration of new OSH monitoring systems

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[283] European Commission, European Political Strategy Centre, & Servoz, M. (2019). *AI, the future of work? : Work of the future! : On how artificial intelligence, robotics and automation are transforming jobs and the economy in Europe*. Publications Office of the European Union. Available at: https://op.europa.eu/en/publication-detail/-/publication/096526d7-17d8-11ea-8c1f-01aa75ed71a1

[284] For more information on how to effectively integrate new OSH monitoring systems at the workplace, refer to EU-OSHA's forthcoming publication on workplace resources: Overview and assessment of workplace level resources.

[285] EU-OSHA – European Agency for Safety and Health at Work, *Occupational exoskeletons: wearable robotic devices to prevent work-related musculoskeletal disorders in the workplace of the future*, 2020. Available at: https://osha.europa.eu/en/publications/occupational-exoskeletons-wearable-robotic-devices-and-preventing-work-related

[286] Ceemet. (2021). *Digitalisation and the world of occupational safety and health*. Available at: https://www.ceemet.org/site/assets/files/4384/ceemet_digitalisation_and_safety_health_2021.pdf

[287] Cocca, P., Marciano, F., & Alberti, M. (2016). Video surveillance systems to enhance occupational safety: A case study. *Safety Science, 84*, 140-148.

[288] Kortuem, G., Alford, D., Ball, L., Busby, J., Davies, N., Efstratiou, C., Finney, J., White, M. I., & Kinder, K. (2007). Sensor networks or smart artifacts? An exploration of organizational issues of an industrial health and safety monitoring system. In J. Krumm, G. D. Abowd, A. Seneviratne, & T. Strang (Eds), *UbiComp 2007: Ubiquitous Computing. UbiComp 2007. Lecture Notes in Computer Science, Vol. 4717* (pp. 465-482). Springer. Available at: https://eprints.lancs.ac.uk/id/eprint/13020/1/Ubicomp-2007.pdf

[289] EU-OSHA – European Agency for Safety and Health at Work, *The digitalisation of work: psychosocial risk factors and work-related musculoskeletal disorders*, 2021. Available at: https://osha.europa.eu/en/publications/digitalisation-work-psychosocial-risk-factors-and-work-related-musculoskeletal

[290] Cocca, P., Marciano, F., & Alberti, M. (2016). Video surveillance systems to enhance occupational safety: A case study. *Safety Science, 84*, 140-148.

[291] Dawood, N., Miller, G., Patacas, J., & Kassem, M. (2014). Construction health and safety training: The utilisation of 4D enabled serious games. *Journal of Information Technology in Construction, 19*, 326-335.

[292] European Trade Union Confederation. (2018). *Digitalisation and workers participation. What trade unions, company level workers and online platform workers in Europe think*. Available at: https://www.etuc.org/sites/default/files/publication/file/2018-09/Voss%20Report%20EN2.pdf

[293] Khakurel, J., Melkas, H., & Porras, J. (2018). Tapping into the wearable device revolution in the work environment: A systematic review. *Information Technology & People, 31*(3), 791-818.

[294] Cocca, P., Marciano, F., & Alberti, M. (2016). Video surveillance systems to enhance occupational safety: A case study. *Safety Science, 84*, 140-148.

[295] EU-OSHA – European Agency for Safety and Health at Work, *The digitalisation of work: psychosocial risk factors and work-related musculoskeletal disorders*, 2021. Available at: https://osha.europa.eu/en/publications/digitalisation-work-psychosocial-risk-factors-and-work-related-musculoskeletal

[296] Yassaee, M., Mettler, T., & Winter, R. (2019). Principles for the design of digital occupational health systems. *Information and Organization, 29*(2), 77-90.

is often considered to be favoured by a broader approach, within given companies, aimed at creating an **organisational culture of trust**.[297]

Apart from ensuring buy-in, a participatory and empowering approach to OSH monitoring through digital technologies may **limit unlawful practices**. For example, an action to monitor social distancing between workers in the context of the COVID-19 pandemic has seen a workers council in a German company bring a lawsuit against the employer – because the OSH system was not first discussed with workers' representatives.[298, 299] Finally, in terms of design, appropriate security measures must be in place ensuring that systems are not prone to cyberthreats (e.g. **data breaches**).

[297] Kortuem, G., Alford, D., Ball, L., Busby, J., Davies, N., Efstratiou, C., Finney, J., White, M. I., & Kinder, K. (2007). Sensor networks or smart artifacts? An exploration of organizational issues of an industrial health and safety monitoring system. In J. Krumm, G. D. Abowd, A. Seneviratne, & T. Strang (Eds), *UbiComp 2007: Ubiquitous Computing. UbiComp 2007. Lecture Notes in Computer Science, Vol. 4717* (pp. 465-482). Springer. Available at: https://eprints.lancs.ac.uk/id/eprint/13020/1/Ubicomp-2007.pdf

[298] European Trade Union Confederation. (2020, September 30). *COVID-19 Watch ETUC briefing on new technologies allowing more surveillance at work*. Briefing note. Available at: https://www.etuc.org/sites/default/files/publication/file/2020-10/20200930_covid-19%20Briefing%20on%20surveliance%20technologies%20%28002%29.pdf

[299] For more information on how to effectively integrate new OSH monitoring systems at the workplace, refer to EU-OSHA's forthcoming publication on workplace resources: Overview and assessment of workplace level resources.

7 Conclusion

7.1 What works, for whom and how

Research into new OSH monitoring systems is **not clearly conceptualised** and **systematised** as demonstrated by the lack of a widely accepted definition. It also **offers very limited evidence** resulting from robust studies or evaluations in relation to the impact on workers and the workplace. Moreover, there seems to be a general concern on whether such systems monitor OSH, performance – or both.

Despite these limitations, **this research has provided some fruitful insights into what works**, by looking at the opportunity and use of new OSH monitoring systems, suggesting a purpose-based definition, and providing a taxonomy of two (non-exclusive) types: proactive and reactive, which respectively prevent and/or minimise harm.

New OSH monitoring systems use digital technology to collect and analyse data in order to identify and assess risks, prevent and/or minimise harm, and promote occupational safety and health.

New OSH monitoring systems prevent harm (including ill health) or minimise the consequences of an accident / emergency. They identify and assess hazards and risks, across sectors and job tasks; allow to perform checks and maintenance work safely or remotely; send warning signals to workers; activate emergency buttons; trace exposure; help navigate or support with hazardous working situations, including but not limited to rescue operations; have panic buttons, man-down and localisation features; and can improve training, risk assessments, inspections, accident reporting and investigation.

Furthermore, they can have a **positive psychosocial impact** linked to: the improved OSH culture tailored to workers' needs, reduced stress (e.g. increased safety, tailored shifts, less burdensome and stigmatised accident reporting, etc.), and enhanced job meaningfulness.

New OSH monitoring systems **can allow to gain data-driven insights on how to promote OSH through adjustments, adaptions and corrective measures in the workplace**. Data are generally accurate, comprehensive and unbiased. These are often real-time and automatic data, which improves their accuracy (e.g. for assessing mental and physical fatigue, for accident reporting). There is also often a continuous acquisition of data, which could be 24/7 in certain cases or throughout working hours. The continuity of data collection is important because it gives a more accurate picture of risks and hazards than the one offered by a snapshot at a given time (i.e. certain risks may be higher at one point in time and for specific shifts, and lower at a different one). Leading and lagging indicators is also important to note; lagging indicators can alert to a failure in an area of an OSH programme or to the existence of a hazard, while leading indicators can notify if OSH activities are effective at preventing incidents.[300] Besides, the data is also comprehensive as it includes individual, collective / aggregate (workforce), environmental and equipment-related data that can inform evidence-based decision-making in the long run.

Moreover, they can acquire **quantified data at the individual level and promote healthy lifestyles** (e.g. physical activity, sleeping patterns, healthier diets), which are easy to take up because of the gamification approach that is often utilised.

Digital technologies used by OSH monitoring systems offer **various opportunities to improve OSH** (see section 4). **Digital technologies, sensors and software are often used in combination in new OSH monitoring systems.** This is not surprising, because of **IoT** – their interconnectedness and exchange of data over the Internet. Such exchange offers **big data**, which can be used for data-driven insights into the workplace and workers' health and safety, for example, through AI. **AI** is intimately linked to big data, it relies on it to progress and learn, and big data is difficult to master without the support of AI. Besides, AI has the capacity to leapfrog other technologies (e.g., camera systems) and has strong predictive power as well as the **ability to accomplish complex goals** of the most disparate nature.

[300] See: https://www.osha.gov/leading-indicators#:~:text=While%20lagging%20indicators%20can%20alert,are%20effective%20at%20preventing%20incidents

This research has also indicated **'for whom'** these systems work. Solutions must not be one-size-fits-all but **tailored or adapted to different needs**, such as **workers' and companies'** needs: 1. across sectors and job tasks; 2. in the context of increased workforce diversity and an ageing workforce; and 3. needs that derive from the **broader environment**, for instance, as linked to COVID-19 (and long COVID) and increased teleworking arrangements.

In terms of **'how'** these systems work, and the factors that may account for their successful design and implementation, there are two aspects that need to be emphasised.

Consultations with workers and their representatives about the design, use and information ecology of new OSH monitoring systems are clearly important and can promote health and wellbeing by increasing workers' control over decisions, facilitate their buy-in, thus overcoming hesitance, support the regulation and use of the systems in ways that benefit OSH conditions, and protect workers from potentially negative consequences (including data breaches or an ineffective way of applying GDPR, work intensification, surveillance, or the blurring of lines between work and private space).

Furthermore, it is **important to enhance human accountability** in the use and the interpretation of data collected by new OSH monitoring systems, particularly when AI is involved**.** This is a key factor that can prevent slippage into full automation, data surveillance and opaque machine decision-making.

7.2 Remaining challenges and recommendations

Despite the positives, there are still some remaining risks and challenges that need to be considered. A well-known problem is the ability to determine allocation of risk category, related to health, for an employee. This is often determined by the algorithm. However, minor variations in sensing might suddenly have large implications for the given feedback. Careless interpretation might worry users unnecessarily (false positives) or ease their minds while they should worry (false negatives).

In addition, OSH monitoring systems collect and analyse data to improve OSH. But such data may have limitations. When they are not fully accurate, they can **undermine data-driven solutions** and **limit the ability to prevent or minimise the consequences of harm**. Data feeding and data processing may be difficult for humans (e.g. cognitive overload, paralysis by analysis) and tends to remain opaque overall when machines perform it (e.g. AI) – which may **compound physical, safety and psychosocial risks**. Crucially, data collection raises concerns (data privacy, ownership and security, digital surveillance, workplace discrimination, etc.) – particularly when workers and worker representatives are not consulted in the design and implementation stages, that is, when they do not have a voice in their goals and use.

New OSH monitoring systems may also **create new hazards or heighten risks**. For instance, in terms of physical and safety risks and hazards, they may malfunction, be hacked by cyberattacks, or cause explosions, MSDs, collisions, cuts and burns, cybersickness or eye strain. In addition, they may make the so-called augmented workforce over-confident in its abilities, which can result in exposure to greater OSH risks. Greater OSH risks can also occur from an overreliance on new OSH monitoring systems at the expense of other OSH procedures.

Similarly, they **could have an impact on psychosocial risks**, for example, because of frustration over the equipment or systems' malfunctioning, the stress due to the lone, monotonous and repetitive tasks assigned, and the frequent warnings received by digital technologies.

What is more, new OSH monitoring systems may **blur OSH responsibility**. They are not meant to simply substitute all employers' obligations. Their purpose is fundamentally that of promoting OSH through various adjustments and corrections related to how work is performed – based on data-driven insights. Ideally, this should also be a continuous cycle of improvement: with 'first-level solutions' applied in the workplace then being reviewed by workers who may suggest 'second-level solutions' (to be reviewed by the management). Besides, even when corrective measures are adopted, they may focus on personal control measures rather than collective ones, thus not respecting the hierarchy of controls. Further, employers should ensure that adequate training, coaching and feedback support in general are offered on using and managing with these systems.

Lastly, **challenges also pertain to the barriers to adoption** of these new OSH monitoring systems, including, for instance: complex and not-updated legislation, lack of adequate standards, cost implications related to the development of new OSH monitoring technologies and systems, and in particular solutions that are tailored to specific organisational and workers' needs.

Therefore, there are some policy pointers and recommendations for research and practice

Policy:

- To consider the **impact of OSH monitoring systems on workers' rights, working conditions and OSH**. Legal and policy frameworks regulating these areas should **keep pace** with the fast development of digital tools and the implications of their use in the workplace. This can be through the inclusion of OSH monitoring systems in the OSH legislation to ensure their healthy and safe implementation in the context of the hierarchy of controls (e.g. employers' responsibility for a safe environment in relation to smart PPE, or worker participation and dialogue in relation to risk assessment supporting tools, etc.). Another suggestion is to create a framework contextualising OSH monitoring systems within the hierarchy of controls and delineating roles and responsibilities of employers and workers.
- Legislation, regulation and issues around liability should concomitantly focus on **facilitating innovation** rather than stifle technological advancement.
- To ensure **adequate standardisation** that supports product quality and safety, and the creation of markets.
- To **bring together employers, employee representatives and occupational physicians** and reach collective agreements on how OSH monitoring systems are to be used at the workplace.

Research:

- To fill **the research gap with regards to OSH risks** brought about by the use of new OSH monitoring systems.
- To **carry out research at workplace level** to understand what happens in practice across companies in different sectors, so as to assess the extent to which and the ways these digital systems may promote OSH.
- To focus on research that **provides robust data on the effectiveness** of OSH monitoring systems, with attention devoted to specific needs and workers.
- To **better disseminate research** so that it is more easily accessible to employers.

Companies:

- To consider from the **early design stage** what the potential **positive and negative impacts** of the adoption of new OSH monitoring systems may be.
- To be clear regarding **'information ecology'** (how the data is used, who can access it and who owns it) and to ensure robust **data security**.
- To ensure that the design and implementation respects the **'human in control'** principle.
- To ensure **workers and worker representatives' participation** in the design and implementation of the systems.
- To ensure that new systems have a positive impact not only in terms of **physical health and safety** but also with regard to **mental health and wellbeing**.
- To conceive **new OSH monitoring systems as tools to improve and promote OSH** through workplace adaptations, adjustments, corrective measures, worker training, and a reinforced culture of trust and participation – **rather than ends in themselves**. In other words, to conceive new OSH monitoring systems as part of the solution, but not the solution itself.

7.3 Expected trends

In conclusion, while new OSH digital monitoring systems do not appear to be **widespread yet**, their uptake is expected to increase and the break-down of barriers that have thus far limited their market penetration is likely to make their use more frequent across workplaces.

While research participants interviewed in the course of the study and the literature on the subject stated that **the trend is towards an increased adoption of these digital systems in the near future**, it is quite challenging to assess what specific scenarios lie ahead.

In particular, it is possible to imagine a best-case scenario where new OSH monitoring systems organically help to address, improve and promote OSH, by meeting companies' and workers' needs. In this case, the systems would be a **tool to empower rather than overpower workers**, which would also be fruitful for businesses in terms of investments in OSH and OSH awareness and enhanced worker motivation and participation.

At the same time, there are **concerns** – primarily linked to the opacity of AI and the risk of using the digital systems for other aims rather than OSH, for example, monitoring performance, data privacy – where machines and not humans are in control and efficiency and productivity issues are the primary focus, rather than workers' health and safety.

It is thus important to bear in mind the recommendations for policy, research and practice (companies), to **ensure the dignity, rights and OSH of workers, and a positive socioeconomic and occupational impact** of new OSH monitoring systems – overall and for specific workers' needs.

As digital technologies increasingly tend to become ubiquitous in our world – within and beyond the workplace – and offer immense opportunities, it is possible that **portions of privacy may be sacrificed** for the goal of improving OSH as well as (physical and mental) health and wellbeing outside the workplace. If this is the direction we are heading, it will be important to ensure that citizens and workers play the role of **well-informed subjects having control over their life, work and data**, rather than objects overpowered by technological advancement.

8 Annexes

To redact the report, the research team has relied on two main sources of evidence:

- A literature review including 180 sources.
- Key informant interviews, n=29.
- The research team assessed the above sources on their own merit, but also triangulated findings. The protocols for each of the two data collection methods are shown in Annexes 1 and 2.
- The research team has also conducted a quantitative analysis based on ESENER-3 (2019) data to complement insights from the literature review and the interviews. The available ESENER data by company size, sector, workers' occupation/type and country helped the team to explore the factors underpinning the implementation of monitoring systems, their expected OSH impact, or the drivers and barriers to their market penetration.

8.1 Annex 1: Literature review methodology

The first step in the literature review was to determine the scope, and then to design a research protocol including search, inclusion and analysis criteria.

8.1.1 Scope of literature review

The scope of the literature review is shown in Table 2.

Table 2. Scope of literature review, including initial inclusion criteria

Scope	Description
Research scope	Monitoring technologies used for the purpose of monitoring (improving) OSH, with respect to their broad OSH implications.
Content / Relevance	Resources with content specifically mentioning the themes analysed throughout Tasks 1 and 2 (as well as 3 to a minor extent) and with direct relevance to new OSH monitoring systems and technologies.
Year of publication	Documents published starting 1 January 2016 and exceptionally older documents (not older than 10 years) based on their relevance.
Publisher	Key sources include the European Commission, European Parliament, EU-OSHA, Eurofound, academic articles, social partners, companies, consultancies, broader grey literature, and available evaluations of programmes / projects that have funded the development of new monitoring systems for workers' OSH.
Author	Key resource has name of authors / publisher.
Language	English, but also non-English when appropriate.
Geographical scope	Both EU and global.
Study design	All types of study designs, including expert opinions and less theoretically grounded research approaches.

8.1.2 Literature review search criteria

Based on the above table, the search criteria for this report were determined, as shown in Table 3.

Table 3. Literature review search criteria

Task	Key concept	Additional concept 1	Additional concept 2
Task 1	Type of monitoring system	Definition, description	Design, application, use.
	Types of digital technologies used in monitoring systems	Definition, description	ICT, mobile devices (digital technologies), PCs, teleconferencing, AI, advanced robotics, cobots, widespread connectivity, big data, IoT, wearables smart PPE, exoskeletons, smart clothes, AR and/or VR, 3D printing, drones, UAVs.
	Approaches	Uptake of system, drivers and barriers to uptake	Sectors / Industry: construction, healthcare, services, including HORECA, agriculture, manufacturing, processing, R&D, business, education, etc.
		System integration in OSH management	Blue / white-collar jobs: blue and/or white-collar, vulnerable jobs, jobs involving shifts, sedentary vs active jobs.
		Purpose of use – sector, type of job, type of worker, COVID-19	Tasks: person-related, object-related, information-related; routine / non-routine tasks.
		Impact, improved OSH	Worker background and diversity: age, older workforce, digitally native, gender, women, men, disabled workers, returning after sick leave, teleworkers, platform workers (gig, app-based, crowd-based), self-employed.
			Environments: workers in unhealthy, dangerous environments; workers at risk of violence.
	Standards	EU-level standardisation, Member State-level standardisation, current standardisation initiatives	Gaps, needs, drivers, barriers.
Task 2	Opportunities	Monitoring	Risk assessment, inspection, reporting, etc.
			Quicker, easier, more targeted (or targeting), cheaper, less resource-intensive, less stigma.
		Physical health and safety	Accidents, injuries and other OSH risk prevention.
			Ergonomic, RSIs, biological, chemical, toxic, MSDs, eye strain, heavy weights, slips, trips and falls prevention, 4Ps.
			Healthy lifestyle incentivisation.
		Psychosocial factors	Flexibility of working time and work location, improved autonomy, control.
		Organisational factors	Work organisation, work management, right to disconnect, workplace culture.
	Risks / Challenges	Monitoring	Risk assessment, inspection, reporting, investigating.

Task	Key concept	Additional concept 1	Additional concept 2
		Physical health	Accidents, injuries, ergonomic, RSIs, biological, chemical, toxic, MSDs, eye strain, heavy weights, slips, trips and falls, etc.
			Unhealthy lifestyles, sedentary, etc.
		Psychosocial Organisational	Work-life balance, blurring of boundaries, work intensification, human-machine interface, lack of control, isolation, surveillance, harassment, violence, offense behaviour, etc.
		Data privacy, data ownership, ethics, cybersecurity	Overcollection and non-transparent gathering of biometric data, surveillance, gathering worker performance data, trust, sense of justice, sense of privacy.
		Organisational factors	Work organisation, work management, right to disconnect, workplace culture.
	Stage of risk	Design, implementation, maturity of system, maturity of digital technologies	Reliability, data availability, patent information, etc.
	Risk mitigation measures	Training workforce, workforce participation, consultation, voice, working / organisational culture / ethos	Employee (training, participation, voice), management (training, participation, voice), works councils.
Task 3	Workplace resources	Type, level of development	EU, Member State, sectoral, company.
		Health and safety, training, voice, privacy, integration of monitoring system	Level of internal OSH competence, OSH management.
		Gaps, needs, best practice	Systematic OSH management.
		Impact	Regulatory, socio-cultural, context.
		Recommendations	Policy, research, practice.

Based on the search criteria in Table 3, the research team retrieved a large number of articles, which were then screened according to the criteria in Table 4 below.

Table 4. Screening criteria of literature review sources

Source	Search terms applicable	Screening				Extracted for analysis
		Task(s) relevant	Relevance	Depth	Quality	Yes / No
Reference (author, title, year of publication*, publisher website) **Colour cell in red if before 1 January 2016*	[From search terms in review protocol]	1, 2, 3, or any combination thereof	High / Medium / Low	High / Medium / Low	High / Medium / Low	Researcher's comments / Abstract if available

After screening the articles, the research team qualified 182 of them for analysis. The research team then used an Excel grid for data aggregation and analysis.

8.1.3 Literature review list

Below, the literature review list for this report is presented. As mentioned above, the list includes 180 sources.

Documents reviewed in depth

1. Adjiski, V., Despodov, Z., Mirakovski, D., & Serafimovski, D. (2019). System architecture to bring smart personal protective equipment wearables and sensors to transform safety at work in the underground mining industry. *Rudarsko-geološko-naftni zbornik, 34*(1), 37-44.

2. Akerlof, G. A. (1978). The market for “lemons”: Quality uncertainty and the market mechanism. In P. Diamond, & M. Rothschild (Eds), *Uncertainty in economics* (pp. 235-251). Academic Press.Alli, B. O., & International Labour Office. (2001). *Fundamental principles of occupational health and safety*. ILO.

3. Aloisi, A., & Gramano, E. (2019). Artificial intelligence is watching you at work. digital surveillance, employee monitoring, and regulatory issues in the EU context. *Comparative Labor Law & Policy Journal, 41*(1), 95-121. Available at: https://ssrn.com/abstract=3399548

4. Arguenon, V., Bergues-Lagarde, A., Rosenberger, C., Bro, P., & Smari, W. (2006). Multi-agent based prototyping of agriculture robots. In *International Symposium on Collaborative Technologies and Systems (CTS'06)* (pp. 282-288). IEEE.

5. Aryal, A., Ghahramani, A., & Becerik-Gerber, B. (2017). Monitoring fatigue in construction workers using physiological measurements. *Automation in Construction, 82*, 154-165.

6. Asad, M. M., Sherwani, F., Hassan, R. B., Sahito, Z., & Khan, N. (2021). Workforce safety education and training for oil and gas industry: A conceptual framework for virtual reality-based HAZFO expert 2.0. *Journal of Engineering, Design and Technology, 20*(5), 1122-1131. http://dx.doi.org/10.1108/JEDT-08-2020-0330

7. Awotunde, J. B., Jimoh, R. G., AbdulRaheem, M., Oladipo, I. D., Folorunso, S. O., & Ajamu, G. J. (2022). IoT-based wearable body sensor network for COVID-19 pandemic. In A.-E. Hassanien, S. M. Elghamrawy, & I. Zelinka (Eds), *Advances in data science and intelligent data communication technologies for COVID-19* (pp. 253-275). Springer.

8. Aydin, B. (2019). Public acceptance of drones: Knowledge, attitudes, and practice. *Technology in Society, 59*, Article 101180.

9. Badri, A., Boudreau-Trudel, B., & Souissi, A. S. (2018). Occupational health and safety in the industry 4.0 era: A cause for major concern? *Safety Science, 109*, 403-411.

10. Baka, A. D., & Uzunoglu, N. K. (2016). Protecting workers from step voltage hazards. *IEEE Technology and Society Magazine, 35*(1), 69-74. https://ieeexplore.ieee.org/abstract/document/7430027/

11. Bakke, B., Stewart, P., Ulvestad, B., & Eduard, W. (2001). Dust and gas exposure in tunnel construction work. *American Industrial Hygiene Association, 62*(4), 457-465.

12. Ball, K. (2021). *Electronic monitoring and surveillance in the workplace. Literature review and policy recommendations*. Publications Office of the European Union. Available at: https://publications.jrc.ec.europa.eu/repository/bitstream/JRC125716/jrc125716_electronic_monitoring_and_surveillance_in_the_workplace_final.pdf

13. Bances, E., Schneider, U., Siegerta, J., & Bauernhansl, T. (2020). Exoskeletons towards industries 4.0: Benefits and challenges of the IoT communication architecture. *Procedia Manufacturing, 20*, 49-56. https://www.sciencedirect.com/science/article/pii/S2351978920306521

14. Banerjee, S., Hoch, E. G., Kaplan, P. D., & Dumont, E. L. (2017). A comparative study of wearable ultraviolet radiometers. In *Proceedings of the IEEE Life Sciences Conference (LSC)* (pp. 9-12), Sydney, Australia, 13-15 December. IEEE.

15. Barata, J., & Cunha, P. (2019). Safety is the new black: The increasing role of wearables in occupational health and safety in construction. In W. Abramowicz, & R. Corchuelo (Eds), *Business Information Systems, Volume 353*. Springer. Available at: https://www.springerprofessional.de/en/safety-is-the-new-black-the-increasing-role-of-wearables-in-occu/16820306

16. Barr, D., Reilly, T., & Gregson, W. (2011). The impact of different cooling modalities on the physiological responses in firefighters during strenuous work performed in high environmental temperatures. *European Journal of Applied Physiology, 111*(6), 959-967.

17. Bechar, A., & Vigneault, C. (2016). Agricultural robots for field operations: Concepts and components. *Biosystems Engineering, 149*, 94-111.

18. Bender, G., & Söderqvist, F. *How to negotiate an algorithm: A case study on voice and automation in Swedish mining*. Blekinge Institute of Technology (forthcoming).

19. Bianchini, A., Donini, F., Pellegrini, M., & Saccani, C. (2017). An innovative methodology for measuring the effective implementation of an Occupational Health and Safety Management System in the European Union. *Safety Science, 92*, 26-33. https://www.sciencedirect.com/science/article/abs/pii/S0925753516302375

20. Binajjaj, A., Sheltami, T., Aliyu, F., & Kaosar, M. (2018). Design and implementation of a wearable gas sensor network for oil and gas industry workers. *Journal of Computers, 13*(3), 300-308.

21. Black, K. J., Munc, A., Sinclair, R. R., & Cheung, J. H. (2019). Stigma at work: The psychological costs and benefits of the pressure to work safely. *Journal of Safety Research, 70*, 181-191.

22. Bogue, R. (2018). Exoskeletons – A review of industrial applications. *Industrial Robot, 45*(5), 585-590.

23. Bongers, C. C., Hopman, M. T., & Eijsvogels, T. M. (2015). Using an ingestible telemetric temperature pill to assess gastrointestinal temperature during exercise. *Journal of Visualized Experiments*, (104), Article e53258.

24. Boult, T. E., Micheals, R. J., Gao, X., & Eckmann, M. (2001). Into the woods: Visual surveillance of noncooperative and camouflaged targets in complex outdoor settings. *Proceedings of the IEEE, 89*(10), 1382-1402.

25. Burgués, J., & Marco, S. (2020). Environmental chemical sensing using small drones: A review. *Science of The Total Environment, 748*, Article 141172.

26. Burke, C., McWhirter, P. R., Veitch-Michaelis, J., McAree, O., Pointon, H. A., Wich, S., & Longmore, S. (2019). Requirements and limitations of thermal drones for effective search and rescue in marine and coastal areas. *Drones, 3*(4), Article 78.

27. Butler, P., & Fee, W. (2015). *Fatigue and the use of wearable technology*. Paper presented at the SPE E&P Health, Safety, Security and Environmental Conference-Americas, Denver, Colorado, 16-18 March.

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8.2 Annex 2: Interview methodology

8.2.1 Key informant interviews

To complement the literature review, the research team consulted 29 key informants through individual and group interviews. The selection of informants sought to cover the scope of the report from multiple angles. Initially, the interview team designed two distinct topic guides to cover different elements of the report. However, in practice, the two topic guides were often used together, to make the most out of interviewees able to cover both topics.

8.2.2 Interview guides

Table 5. Interview guide (1)

Objective 1. Review, compile, define and categorise the new systems that can be used by employers to monitor OSH

Context, role and expertise

- Please give an overview of your position, and areas of responsibility.
- What type of involvement have you had in designing / implementing / assessing / researching new monitoring systems for improving workers' occupational safety and health (OSH)?
    - Prompt: different types of monitoring systems, technologies, sectors, occupations, types of workers, types of companies.

Defining new monitoring systems for OSH

- How would you define (new) monitoring systems used by employers to monitor OSH?
- How about other monitoring systems used by other actors that could be used by employers (e.g. new monitoring systems for OSH developed by insurance companies, public institutions or social partners)?
    - Prompt: what are the generic features of these systems (across sectors, occupations, types of workers, types of companies)?
- To your knowledge, what are the different types of (new) monitoring systems used to monitor and/or improve OSH?
    - Prompt: across sectors, occupations, types of workers, types of companies of different sizes.
- What types of technologies are these systems based on?

Objective 1.

Review, compile, define and categorise the new systems that can be used by employers to monitor OSH

- Prompt: relevant smart PPEs, wearables, sensors, web-based systems, monitoring software suits, smartphone apps, smart glasses, ICT-based applications, e-tools) or combinations of these technologies.

- What types of jobs are these new monitoring systems and technologies used to monitor?
  - In which sector(s)?
  - For which task(s)?
  - In what type of companies?
  - For what type of employees (in terms of characteristics such as gender, age, migrant background, medical condition, employment status)?

Objective 2.

Assess current and potential future uses and purposes of implementation in different sectors and jobs / occupations, and in the context of COVID-19

Uptake of (new) monitoring systems for OSH

- How common is the implementation of these systems?
- How are these new systems integrated into existing OSH management processes?
- How do employers implement and monitor the use of new monitoring systems in the workplace? *and processes do they rely on; are there common patterns*

Drivers and barriers

- What is the rationale behind the implementation of such systems?
  - Prompt: What OSH challenges do these systems aim to respond to? What are the health and safety risks these systems aim to counter?
- How are the new OSH monitoring systems integrated with OSH management?
- What are the conditions allowing management and workers to gain ownership of these systems and to fully integrate them into their work practices?
- What are the financial costs associated with the implementation of a monitoring system? Can the implementation of these systems result in additional financial gains?
- How has COVID influenced the use of new monitoring systems? Are there noticeable patterns? systems? Are there noticeable patterns?

OSH impact

- What is the expected impact of the different systems on different OSH dimensions?
- What are the expected OSH benefits of implementing such systems?
  - Prompts: reduced exposure to noise, toxic substances,heat, reduction in the number of work accidents, etc.
- To your knowledge, is there any available evidence on how new OSH monitoring systems result in improved OSH?
  - Prompts: Could you make a distinction between physical OSH improvements and psychosocial OSH improvements?

- To what extent could standardisation be a barrier to the exploitation of new technologies? (*including current standardisation initiatives, gaps and needs)*

Objective 3.

Assess relevant standards developed to date at EU and Member State levels

Challenges in relation to standardisation

- What is the current state of play in relation to the standardisation, for example, of smart PPE or other technologies used in new monitoring systems?
- What are the key challenges? How can they be overcome?
- To what extent could standardisation (or a lack of) become a barrier to the exploitation of new technologies for the purposes of new monitoring systems that seek to improve workers' OSH?

Current / future initiatives to standardisation

- Are there any significant current or future initiatives in relation to standardisation at EU level / national level in the EU or beyond?
- What type of initiatives would you find helpful in addressing standardisation?

Final questions (as relevant)

- What recommendations should be considered in relation to new monitoring systems for workers' OSH?
  - For EU-OSHA / EU institutions and national policymakers?
  - For the practical implementation of these systems?
  - For research?
- Could you suggest any other stakeholder we should interview?
- Are there any documents, workplace resources, studies or other information relevant to the topic that you can share with us?

Thank you for your time!

Table 6. Interview guide (2)

Context, role and expertise

- Please give an overview of your position, and areas of responsibility.
- What type of involvement have you had in designing / implementing / assessing / researching new monitoring systems for improving workers' occupational safety and health (OSH)?

Main OSH opportunities / benefits

- What are key types of OSH opportunities associated with the design, introduction and use / implementation of different categories of new systems for monitoring workers' safety and health? *(Prompt: regarding dimensions such as: system design, implementation, the maturity of systems, risks to physical health concerns, barriers to health enhancing resources*)
- In your view, what are the key opportunities / benefits associated with supporting OSH compliance and effective enforcement? *(Prompt for – why and how that is)*
  - *Acquiring data – on workers' fitness-to-perform; on worker fatigue, etc.*
  - *Making the workplace a less hazardous environment (accidents, exposure to toxic substances, etc.)*

  - *Ergonomic (musculoskeletal disorders, repetitive strain injuries, etc.)*
  - *Psychosocial (flexibility, work-life balance, etc.)*
  - *Risk assessments*
  - *Inspections (efficiency, targeting)*
  - *Reporting (ease, reliability, less stigma)*
  - *Promoting healthy lifestyles*
  - *Others*
- For each of these opportunities / benefits:
  - *(if not already mentioned)* What specific digital technology do you have in mind when considering such opportunities? (ICT, wearables, virtual and augmented reality (VR and AR), big data, drones, etc.).
  - To what extent and in what ways do opportunities vary across sectors, occupations, types of company and company size?
  - To what extent and in what ways do opportunities vary for different worker groups (age, gender, age, skills, disability, employment status, migratory status)?
- In your view, what works (and how and why) in making sure that such opportunities for OSH are seized?
  - Participation of employees, including representatives, in the design phase of how these instruments will be used
  - Discussion / Awareness of potential benefits arising from them
  - Training to make sure digital technologies are used well (training for employees at different levels, including line managers)
  - Legislation, regulation and agreements at supranational, national, inter-sectoral, sectoral and company levels

Main risks / challenges to OSH

- What are key types of OSH challenges / risks associated with the design, introduction and use / implementation of different categories of new systems for monitoring workers' safety and health? *(Prompt: regarding dimensions such as: system design, implementation, the maturity of systems, risks to physical health concerns, barriers to health enhancing resources)*
- In your view, what are the key challenges / risks associated with supporting OSH compliance and effective enforcement? *(Prompt for – why and how that is)*
- What are the key risks and challenges associated with digital OSH monitoring systems? *(Prompt for – why and how that is)*
  - Renewing risks to OSH physical health concerns (accidents, ergonomic issues, eye strain, etc.)
  - Renewing OSH psychosocial health concerns (blurring of work and life boundaries, increased work intensity, fear of job loss, isolation, loss of control, surveillance, etc.)
  - Effects on HR, working processes, organisational hierarchy
  - Lack of clarity regarding who is in charge of OSH (for instance, platform workers)
  - Barriers to health enhancing resources, such as social security and collective bargaining (for instance, platform workers)

- For each of these challenges / risks:
  - *(if not already mentioned)* What specific digital technology do you have in mind when considering such challenges? (ICT, wearables, virtual and augmented reality (VR and AR), big data, drones, etc.).
  - To what extent and in what ways do opportunities vary across sectors, occupations, types of company and company size?
  - To what extent and in what ways do opportunities vary for different worker groups (age, gender, age, skills, disability, employment status, migratory status)?
- What is being done to mitigate / overcome these risks and challenges, in your view? Could anything be improved in terms of mitigating / overcoming them?
- Could labour inspections that review health and safety management systems use new OSH monitoring systems for risk assessments?
- How have challenges changed over time? What has been learnt and addressed throughout the past 5-10 years?

Key implications, gaps and needs in relation to new systems of monitoring workers' OSH

- What are the implications of new systems for monitoring workers' safety and health on different worker groups (e.g. with a view to characteristics such as age, gender, skills, work ability, migrant workers, employment status, or form and place of work)?
- Are there any gaps, limitations and needs that need specific attention in relation to these smart digital systems?
  - What are the gaps of particular concern, in your view?
  - Data privacy and ownership
  - Cybersecurity
  - Discrimination, including algorithm discrimination
  - Long-term effects of certain digital technologies
  - Human-machine and machine-machine interface
  - Instrument reliability / standardisation
  - What are the main limitations of concern, in your view?
  - What are the main needs of concern, in your view?
- To what extent and in what ways do challenges and opportunities vary based on types of monitoring systems, types of sectors and jobs, size of companies and groups of workers?
- Which types of systems, types of jobs and groups of workers should our research focus more on (e.g. through case studies in Work Package 2)?

Opportunities and challenges: potential drivers

- Which factors are currently influencing or will influence the opportunities and challenges of OSH as related to digital technologies in the near future? *Prompt for:*
  - Ageing workforce vs digital natives
  - Reliability of digital systems
  - Rapid development of digital systems
  - Underinvestment in OSH
  - OSH awareness

- Lifestyle issues
- Changes in the location of work (telework, for instance)
- Changes in work organisation and management
- Migration and intra-EU mobility
- Gender and inclusion
- Disability and inclusion
- Atypical employment (including platform work, and bogus self-employment)
- COVID-19
- Austerity measures
- Size and cost of electronics / sensors
- New technologies and processing power
- Other (please specify)

Final questions (as relevant)

- What sort of OSH trends linked to digital systems to do you expect? For example, do you expect OSH to improve or to deteriorate in the coming years? What is / could be the role of new monitoring systems for improving workers' OSH? What do you foresee that the future could bring in terms of systems, but also in terms of policies, regulations or legislation?
- What recommendations should be considered in relation to new monitoring systems for workers' OSH?
  - For EU-OSHA / EU institutions and national policymakers?
  - For the practical implementation of these systems?
  - For research?
- Could you suggest any other stakeholder we should interview?
  - Are there any documents, workplace resources, studies or other information relevant to the topic that you can share with us?

Thank you for your time!

8.2.3 List of key informants

The list of key informants is available below. To preserve the anonymity of the informants, no direct attribution is made in-text.

Table 7. List of key informants

Name	Position	Organisation
Dr Michael BRETSCHNEIDER-HAGEMES	Head of the employee office of the KAN office	Trade Union liaison KAN Health and Safety
Jacqui MCLAUGHLIN	CEO	Reactec
Rafael MOSBERGER	CEO	Retenua - Intelligent Sensor Systems
John BECKETT	Vice President Operations	British Columbia Maritime Employers Association

Name	Position	Organisation
Peter BURMAN	Project Manager	Boliden, mining company
Prof. Andreas HOLTERMANN	Head of Research	National Research Centre for the Working Environment, Denmark
Jan Michiel MEEUWSEN (interviewed twice)	Manager, International Affairs	Partnership for European Research in Occupational Safety and Health (PEROSH)
Carsten MÖHLMANN (interviewed twice)	Leading research expert	German Social Accident Insurance (DGUV) - Section Exposure to Hazardous Substances – Measurement Techniques and Assessment
Claudine STREHL	Head of project	GENESIS-UV
Kris DE MEESTER	Principal Consultant and Chairman of Health and Safety Working Group of Business Europe	Federation of Enterprises in Belgium asbl/vzw (also Health and Safety Working Group of Business Europe)
Andrew PAKES	Director of Communications and Research	Prospect UK
Ignacio DORESTE HERNANDEZ	Advisor for Health and Safety	ETUC
Solveiga EIDUKYNAITE GERARD	Policy Analyst	EMPL-C2, Health and Safety at Work
Fredrik SÖDERQVIST	PhD Candidate	Blekinge Institute of Technology
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Dr Paola COCCA	Assistant Professor	University of Brescia
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Israel CAMPERO	PhD Candidate	University of Eindhoven
Sergio MÁRQUEZ SÁNCHEZ	Industrial Engineer, Project Manager and Researcher	University of Salamanca
Prof. Victoria ARRANDALE	Professor	University of Toronto, Dalla Lana School of Public Health
Dr Tim BOWMER	Chairman	European Chemicals Agency (ECHA)
Henk VANHOUTTE	Secretary General	European Safety Federation
Diego SOLIÑO	COO	Wear Health - Workforce Performance Analytics
Matthew HART	Founder	Soter Analytics
Ralf GIERCKE	President	European Network of Health and Safety Professional Organisations (ENSHPO)
Prof. Gerard ZWETSLOOT	Founder	Gerard Zwetsloot, Research & Consultancy

8.2.4 *Overview of interview guides*

Task 1

Definition and categorisation of the new systems that can be used by employers to monitor OSH.

- What type of involvement have you had in designing / implementing / assessing / researching new monitoring systems for improving workers' occupational safety and health (OSH)?
- How would you define (new) monitoring systems used by employers to monitor or improve OSH?

- To your knowledge, what are the different types of (new) monitoring systems used to monitor and/or improve OSH across sectors, types of jobs, types of tasks, types of workers and types of companies of different sizes?
- What types of technologies are these systems based on?

Current and potential future uses and purposes of implementation in different sectors and jobs, types of tasks and in the context of COVID-19.

- How common is the implementation of monitoring systems for OSH?
- How are these new systems integrated into existing OSH management processes?
- How do employers implement and monitor the use of new monitoring systems in the workplace?
- What are the conditions allowing management and workers to gain ownership of these systems and to fully integrate them into their work practices?
- What are the financial costs associated with the implementation of a monitoring system? Can the implementation of these systems result in additional financial gains?
- How has COVID-19 influenced the use of new monitoring systems? Are there noticeable patterns?
- What are the expected OSH benefits of implementing such systems? Is there an evidence base that they work?

Assessment of relevant standards.

- What is the current state of play in relation to the standardisation, for example, of smart PPE or other technologies used in new monitoring systems? What are the key challenges? How can they be overcome?
- To what extent could standardisation (or a lack of) become a barrier to the exploitation of new technologies for the purposes of new monitoring systems that seek to improve workers' OSH?
- Are there any significant current or future initiatives in relation to standardisation at EU level / national level in the EU or beyond?
- What type of initiatives would you find helpful in addressing standardisation?
- What recommendations should be considered in relation to new monitoring systems for workers' OSH?
    - For EU-OSHA / EU institutions and national policymakers?
    - For the practical implementation of these systems?
    - For research?

Task 2

Assessment of the OSH opportunities and challenges associated with new systems for monitoring workers' safety and health.

- What are key types of OSH opportunities / challenges (risks) associated with the design, introduction and use / implementation of different categories of new systems for monitoring workers' safety and health?
- What specific digital technology do you have in mind when considering such opportunities / challenges (risks)?
- In your view, what works (and how and why) to seize these opportunities and address these challenges (risks)?
- How have challenges changed over time? What has been learnt and addressed throughout the past 5-10 years?
- To what extent and how do opportunities / risks vary based on monitoring systems, and across sectors, types of jobs, types of tasks, types of company, company size and types of workers?
- What are the implications of new systems for monitoring workers' safety and health on different worker groups (e.g. with a view to characteristics such as age, gender, skills, work ability, migrant workers, employment status, or form and place of work)?

- Are there any gaps, limitations and needs that need specific attention in relation to these smart digital systems?
- Which types of systems, types of jobs and groups of workers should our research focus more on (e.g. through case studies in Work Package 2)?
- Which factors are currently influencing or will influence the opportunities and challenges of OSH as related to digital technologies in the near future?

Task 3

Overview and assessment of workplace resources

- What work-level resources are you aware of / have been used within your company to date in relation to new monitoring systems for workers' OSH? (Prompt: initiatives, codes of practices, company-level policies, guidelines, standards, training material, recommendations)
- To what extent do these types of resources enable effective integration of the OSH monitoring systems with OSH management?
- What are the gaps and needs in terms of workplace-level resources? What constitutes best practice?
- What is the impact of the regulatory and socio-cultural context on the implementation of new monitoring systems for OSH?
- What are the recommendations to consider when using OSH monitoring tools in the workplace at a sectoral / professional / workplace level?
- Are there any documents, workplace resources, studies or other information relevant to the topic that you can share with us?

8.3 Annex 3: Table of risks for OSH monitoring systems

Table 8. Risks of OSH monitoring systems

	Data issues			***Causes harm***			***Fails to***		
	Collection	**Analysis**	**Privacy / Ownership / (Cyber)Security**	**Physical Health**	**Safety**	**Mental health & wellbeing**	**Prevent harm**	**Minimise harm**	**Promote OSH**
Sensors / Cameras / GPS *(often mounted on digital technologies such as smart PPE, drones, etc; and sometimes powered by AI)*	1. Accuracy often assessed in laboratory-type environments - working environments may limit accuracy	1. Cognitive overload	All apply, particularly for sensitive personal data	1. May not accurately identify poor individual health	1. Sensors may short circuit, give electric shocks (e.g. sensor-based vest in contact with water)	1. Surveillance 2. Fears of system malfunctioning 3. May not accurately identify poor individual mental health	1. Fails to detect unsafe conditions or behaviours in a timely manner	1. Fails to localise worker in distress due to sensor / camera inefficiency / reliability / accuracy	1. Fails to collect adequate / reliable data to inform corrective measures in the workplace
Batteries	n / a	n / a	n / a	n / a	1. May overheat, short circuit, catch fire, explode or work inefficiently (e.g. in dire working situations)	1. Fears of system malfunctioning	n /a	n /a	n /a
Exoskeletons	1. Accuracy often assessed in laboratory-type environments 2. working environments may limit accuracy	n / a	1. Cybersecurity	1. Bio-mechanical constraints and risk factors for MSDs 2. Skin irritation 3. Increase cardiovascular load and stress	1. May hinder movement and lead to collisions because of their bulky structure 2. May malfunction and / or be hacked 3. Workers over-confident, impression of invulnerability	1. Frustration over not being comfortable and easily customisable 2. Fears of system malfunctioning 3. May be hacked	1. Fails to detect unsafe conditions or behaviours in a timely manner 2. Fails to protect from pressures	1. Fails to automatically signal and localise emergency (e.g. man-down)	1. Fails to collect adequate / reliable data to inform corrective measures in the workplace

	Data issues			***Causes harm***			***Fails to***		
Smart PPE	n / a	n / a	n / a	n / a	4. Workers over-confident, impression of invulnerability	1. Frustration over not being comfortable and easily customisable 2. Fears of system malfunctioning	1. Fails to detect unsafe conditions or behaviours in a timely manner	1. Fails to automatically signal and localise emergency (e.g. man-down)	1. Fails to collect adequate / reliable data to inform corrective measures in the workplace
Wearables	n / a	n / a	All apply, particularly for sensitive personal data - but higher acceptability overall	1. May not accurately identify poor individual health	n / a	1. May not accurately identify poor individual mental health	1. Fails to detect unsafe conditions or behaviours in a timely manner	1. Fails to automatically signal and localise emergency (e.g. man-down)	1. Fails to collect adequate / reliable data to inform corrective measures in the workplace
VR/AR	n / a	n / a	n / a	1. Disorientation 2. Cybersickness 3. Eye strain					
Drones	n / a	n / a	1. Cybersecurity	n / a	Risks to proximate workers, particularly without human operator, due to:1. System malfunction 2. Cyberattacks	1. Fears of system malfunctioning 2. Low acceptability and workers' buy-in		1. Fails to automatically signal and localise emergency (e.g. man-down) 2. Fails to respond to emergency due to access barriers / limited mobility	
Cobots	1. May be fed inaccurate or inaccurately analysed data		1. Cybersecurity	n / a	Collisions	n / a	1. Fails to detect unsafe conditions or behaviours in a timely manner	1. Fails to automatically signal and localise emergency (e.g. man-down) 2. Fails to respond to emergency due to access barriers / limited mobility	
IoT / Big data	1. Cognitive overload - linked to vast amount of data collected and to interpret		All apply, particularly for sensitive personal data	n / a	n / a	n / a	n / a	n / a	n / a

	Data issues			***Causes harm***			***Fails to***		
AI / ML	1. In infant stage in terms of accuracy and reliability 2. Issues with transparency of analysis 3. May be biased - algorithms may not be calibrated sufficiently well to perform adequately in the context of a diverse workforce				1. May make wrong choices based on poor data inputs or inadequate 'intelligence', which may cause accidents	Algorithmic decision-making may: 1. Not be transparent and open 2. Lead to perception of injustices and alienation 3. Curb creativity and autonomy	1. Fails to prevent or even predict harm		
Overall risks		1. Challenge of understanding lifestyle and work-related health risk factors	All apply, particularly for sensitive personal data	1. Intensify work 2. De-intensify work 3. Repetitive tasks	1. Intensify work 2. May leave most hazardous tasks to workers	1. Intensify work 2. De-intensify work 3. Repetitive tasks 4. May leave most hazardous tasks to workers 5. Surveillance and always-on culture 6. Fears of system malfunctioning 7. Workplace discrimination 8. Algorithmic management	Failure to prevent or even predict harm	Failure to respond quickly and effectively to emergencies and accidents	Failure to use data to promote structural adjustments together with workers

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The European Agency for Safety and Health at Work (EU-OSHA) contributes to making Europe a safer, healthier and more productive place to work. The Agency researches, develops, and distributes reliable, balanced, and impartial safety and health information and organises pan-European awareness raising campaigns. Set up by the European Union in 1994 and based in Bilbao, Spain, the Agency brings together representatives from the European Commission, Member State governments, employers' and workers' organisations, as well as leading experts in each of the EU Member States and

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