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# On future occupational safety and health challenges in industrialized countries — a systematic literature review

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**Abstract**

Occupational safety and health (OSH) have constantly changed and evolved throughout the industrial revolutions and in recent years. The aim of this systematic literature review was to give an overview of future OSH challenges in industrialized countries. A search within the Scopus database returned 31 peer-reviewed journal articles published since 2014 on new and emerging OSH risks and challenges in the future. A review of articles identified future overall OSH challenges, OSH challenges caused by climate change, and OSH challenges related to sustainable development and responsibility. In addition, branch-specific challenges in industries and health care were determined. Individual employees can experience a wide range of OSH challenges from heat stress to poison absorption, musculoskeletal disorders, increased psychosocial load, ergonomic issues, and unexpected accidents and injuries. OSH management is discussed and future studies proposed.

## 1. INTRODUCTION

Changes in working life, society, and the environment challenge current occupational safety and health (OSH) practices, processes, and structures. New and emerging OSH risks stand alongside existing ones. The globalization of economies, changes in demographic structures and working organizations, and downsizing and restructuring of many enterprises have brought new kinds of challenges to working life (Gagliardi et al., 2012). For instance, Siemieniuch et al. (2015) and Thatcher and Yeow (2016) described significant effects on manufacturing from global challenges and drivers such as food security, energy security, renewable energy, resource depletion, emissions, global climate, community security and safety, transportation, land transformation, and the globalization of economic and social activities. Furthermore, Fostervold, Koren, and Nilsen (2018) and Zink and Fischer (2018) emphasized how global supply chains and the digitization of work affect work systems worldwide, posing challenges to working conditions. In this context, the concept of decent work should be acknowledged. The International Labour Organization (ILO) defined decent work in relation to sustainability

and corporate social responsibility, workplace principles and rights at work, international labor standards, employment creation, income opportunities, social protection and tripartite dialogues among governments, employer groups, and workers' organizations (ILO, 2016). As concluded by the ILO (2019a), all employees have a fundamental right to safe, healthy work both now and in the future.

A review of the history of the four industrial revolutions shows how workplaces and OSH have changed and evolved over the years (Henshaw et al., 2007). OSH challenges, though, are known to persist (Hofmann et al., 2017). Authors such as Hofmann et al. (2017) and Henshaw et al. (2007) have described the evolution of OSH during the industrial revolutions. In the United Kingdom, legislation on worker health and safety originated from the first Industrial Revolution and addressed working conditions for children (1833) and women (1844) (Hofmann et al., 2017). In the United States, Massachusetts became the first state to pass a factory safety and health law in 1877 (Henshaw et al., 2007). During the late 1800s, European researchers demonstrated that reduced working hours increased productivity, and their work advanced the understanding of the relationship between fatigue and the occurrence of accidents. In the early to mid-1900s, studies addressed the contributions of monotonous work, accident-prone individuals, and poor working conditions to the occurrence of accidents, injuries, illnesses, and deaths. The foundations for industrial hygiene, occupational medicine, and toxicology were created in the United States. By 1947, all US states had comparable worker compensation protections for workplace injuries (Henshaw et al., 2007; Hofmann et al., 2017). At that time, the ergonomics and human factors discipline began to emerge (Brewer and Hsiang, 2002). It led to enhancements in general equipment design, personal protective equipment design, accident prevention, accident and injury analyses, system ergonomics, system reliability, safety training, and behavior analysis (Hofmann et al., 2017). In addition to the continued emphasis on physical ergonomics, the 1990s saw the maturation of cognitive ergonomics (Thatcher et al., 2018). In the late 1900s, the team surrounding individual workers, leaders, and the broader organization received more attention, resulting in more multilevel, systems views of safety (Hofmann et al., 2017). In Finland, a national strategy for sustainable development was adopted in 2006. The focus has shifted from treating the sick to proactively improving wellbeing and work conditions through joint efforts by management and personnel (Niskanen, 2015).

OSH thus have developed considerably over the past 100 years. However, today, more than 2.78 million employees still die every year because of occupational accidents and work-related diseases (ILO, 2019a). OSH will continue to be affected by the ongoing fourth industrial revolution, which is bringing about the convergence of a set of disruptive technologies, including autonomous robots, additive manufacturing, and the industrial Internet of Things (Badri, Boudreau-Trudel and Souissi, 2018; Chia et al., 2019).

The purpose of this study was to advance the discussion on OSH development and to identify future OSH challenges, especially new and emerging OSH risks. Emerging risks are defined as any occupational risks that are new and increasing. New risks were previously unknown and are caused by new processes, technologies, and workplace types as well as social and organizational changes. Known issues can also be considered to be new risks due to new scientific knowledge and changes in social and public perceptions. Risks are increasing if the number of hazards leading to the risks is growing, the probability of exposure to the hazards is increasing, or the effects of the hazards on workers' health are getting worse (Milczarek et al., 2009; Moraru et al., 2014).

The aim of this study is to identify and analyze new and emerging OSH challenges in industrialized countries presented in the scientific literature. The analysis is based on thematic categorization supplemented with a holistic work system framework analysis and concludes with proposals for future studies. The study aim is met by answering the following research questions:

1. What new and emerging OSH challenges in the future are identified in the research literature?

2. How do these challenges influence employees at the individual level?

## 2. METHODOLOGY

This study was based on a systematic literature review (Grant and Booth, 2009). Figure 1 illustrates the phases of the systematic review. To achieve the study's aims, after analyzing the articles included in the review, future OSH challenges were considered from the perspective of a work system framework.

In the first phase, the keywords were decided by a work group representing academia (three researchers) and the accident insurance industry (two specialists). The search was carried out in the cross-disciplinary international research literature database Scopus (Elsevier, 2019) and took place on January 3, 2019. Table 1 presents the search strategy with the search results. The text fields sought in each search included the titles, abstracts, and keywords of journal articles published since 2014. After the removal of duplicates, 1,108 articles remained.

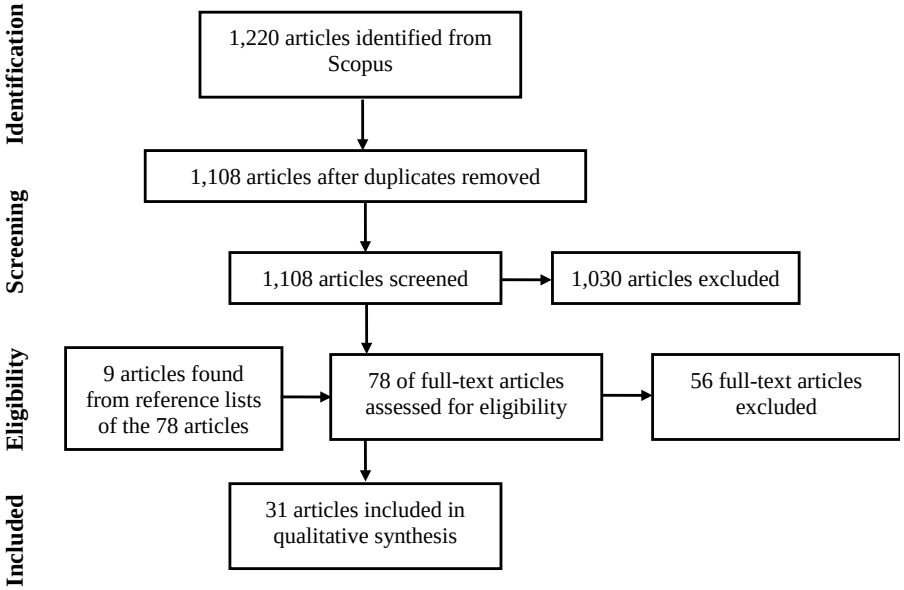


**Figure 1.** Phases of the systematic review

For the remaining 1,108 articles, one review author screened the titles, abstracts, and keywords. In this screening phase, the focus was on determining whether or not the article considered future OSH risks and challenges. After screening, 78 articles were left for closer inspection. Through assessing and determining the eligibility of the full texts of these 78 articles and nine articles found from their references, the following inclusion criteria were set:

1. Types of studies: Qualitative, quantitative, mixed methods studies and literature reviews and overviews. Articles published in peer-reviewed journals after 2014.
2. Types of participants: Any occupational group in industrialized countries with no restrictions on the field, technology, or employee position.
3. Types of intervention: Articles describing OSH risks or more general OSH challenges in the future.
4. Types of outcome measures: Identified OSH risks and challenges in the future.

A total of 56 articles did not meet the inclusion criteria, as described—articles such as those mentioning the need for future studies on OSH in the discussion or conclusion but not focusing on OSH itself and those discussing new technologies but not their OSH

effects were eliminated. A total of 31 scientific journal articles met the inclusion criteria and were included in the systematic review. One review author extracted the data from these. The extracted data included main findings, results, and conclusions, i.e. identified OSH risks and challenges in the future, and these were discussed within the work group. No additional information was asked for nor obtained from the authors of the articles.

**Table 1.** Searches and search results

| # | Searches | Search results |
|---|---|---|
| 1 | “new risks” OR ”emerging risks” AND ”occupational safety” OR ”work* safety” OR future AND challenges | 26 |
| 2 | (“occupational safety” OR “work* safety”) OR (safety AND work) AND (“future challenges” OR “future studies”) | 128 |
| 3 | “changing work* environment” OR “new technology” AND “work* risk*” OR “occupational risk*” | 7 |
| 4 | future AND (“work* life” OR “occupational safety and health” OR OSH OR “work* environment”) AND risk* | 283 |
| 5 | “occupational health” OR ”occupational disease*” AND risk* AND trend* OR future | 745 |
| 6 | “risk management” AND ”work* risk*” OR ”occupational safety risk*” | 31 |
| | Total | 1,220 |

The initial reading of the 31 articles revealed the following three kinds of general challenges: overall OSH challenges, OSH challenges caused by climate change, and OSH challenges related to sustainable development and responsibility. In addition, branch-specific challenges in industries and health care were identified. The articles were divided by these themes, as shown in Table A1 (Appendix 1), which also includes the research methods and the journals’ foci. Grant and Booth’s (2009) categorization of review types was used to define articles that did not mention their review type.

After the initial reading, word cloud analysis (DePaolo and Wilkinson, 2014) was applied to the abstracts of the 31 selected articles using NVivo 11’s analysis tool. In the word cloud, the 100 most frequent words as stemmed were included. The analysis excluded the most common words (“occupational”, “health”, “safety”, and “risk”) that naturally dominated the word cloud as the articles’ foci was OSH and OSH risks. The word cloud analysis results were used to support narrative analyses of the whole texts.

After analyzing the included articles, the results were interpreted utilizing the work system framework to facilitate an individual-centric analysis focusing on challenges from the individual perspective. Work systems, as originally described by, for instance, Smith and Carayon-Sainfort (1989), are human-centric entities that acknowledge tools, technologies, work environments, work tasks, and organizational conditions as elements contributing to work at the individual level. Work systems can also be discussed from the organization perspective (Carayon and Smith, 2000; ISO 6385, 2016), but this study focused on that of the individual.

## 3. RESULTS

### 3.1 OSH challenges in the future

Figure 2 presents the distribution of terms in the word cloud based on their frequency of use in the article abstracts. Among the most frequent words were rather large and complex concepts, such as change, climate, exposure, industry, heat, technologies, global, processes, biology, management, manufacturing, and diseases—which are not all concrete OSH challenges as such but more like factors influencing and contributing to OSH.

In the following sections, the themes shown in Table A1 and supported by the word cloud in Figure 2 are described individually. The themes, presented in the same order as in Table A1, are overall OSH challenges, OSH challenges caused by climate change, OSH challenges related to sustainable development and responsibility, OSH challenges in

industries, and OSH challenges in health care. The first three themes can be considered as general challenges thorough a variety of branches, whereas the latter two themes contain more branch-specific challenges.


**Figure 2.** Distribution of terms based on their frequency of use in article abstracts

### 3.1.1 Overall OSH challenges

Technological, social and organizational changes cause new and emerging risks. As populations age, employees must work for longer. Organizational changes, new roles, the intensification of work, turnover in the labor force, and frequent demands for new learning will increase psychosocial load and work-related stress. Various forms of violence are also an emerging risk (Moraru et al., 2014; Harrison and Dawson, 2016; Héry and Levert, 2017). New technology and robotization pose challenges as recognizing and preventing risks is insufficient. Technological developments can cause musculoskeletal disorders (MSD), such as carpal tunnel syndrome, due to increased computer work (Moraru et al., 2014; Héry and Levert, 2017).

New work-related diseases have emerged alongside known ones, such as illnesses caused by asbestos. Chronic illnesses are one of the biggest challenges. Although biological risks are difficult to predict, future diseases resistant to medicines are a threat. Chemical-related risks are not necessarily new, but the increasing speed of the development of new products is a concern. Furthermore, the dangers of new materials such as nanomaterials are not yet completely known (Harrison and Dawson, 2016). As Moraru et al. (2014) pointed out, nanomaterials raise concerns as nanotubes have a structure identical to asbestos fiber.

### 3.1.2 OSH challenges caused by climate change

Climate change has been identified affecting for example, agriculture, industry, fishing, forestry, small and medium-sized companies, mining, the rescue field, and construction (Marchetti et al., 2016). Climate change has direct effects, such as heatstroke, and indirect effects, such as work environment changes that negatively affect employees. Many researchers have identified problems caused by heat, primarily exhaustion, diminished work performance, heat stress, and heatstroke (Ciardini et al., 2016; Kjellstrom et al., 2016, 2017). Dehydration and heat affect cognitive functions, reaction rate, eyesight, and memory. Fatigue and concentration lapses caused by heat increase the risk of accidents and physical injury. The discomfort caused by heat can make employees use less personal protection equipment, which might, for instance, increase chemical exposure. Workers can also be exposed to burns by accidently touching hot materials. In addition, during hot seasons, employees do not always recover sufficiently between working days. Individual factors such as age, weight, physical condition, alcohol

and drug use, illnesses, and clothing affect heat-caused symptoms (Gatto et al., 2016; Marchetti et al., 2016; Pogačar et al., 2018).

Heat and air humidity are risks especially to those working outside, such as farmers, drivers, pilots, and workers in construction, forestry, and asphalt work. The effects of climate change in different fields can be new, unknown dangers or traditional dangers in new fields, such as slipping, falling, MSD, and chemical exposure. In addition to traditional symptoms, heat can encourage the spread of biological illnesses and the absorption of poisons, and lower tolerance to chemicals. Those working outside have higher risk of exposure to air pollutants and excessive ultraviolet (UV) radiation, which increases the risk for eye injuries, cancer, and sunburn. The harmful effects of UV radiation can be worsened by the combined effects of chemical agents (Ciardini et al., 2016; Grandi et al., 2016; Marchetti et al., 2016; Schulte et al., 2016).

Those working outside also have increased risk of illnesses transmitted by insects and exposure to biological allergens, poisonous plants, mushrooms, and mold (D'Ovidio et al., 2016; Schulte et al., 2016). The spread of insects and poisonous plants and the emergence of possibly new species increase pesticides use, which raises employees' exposure to chemicals. Heat increases the absorption of pesticides by the organs. The combined effects of heat and poisons can also reduce heat tolerance and cause other health hazards (Gatto et al., 2016; Vonesch et al., 2016; Kjellstrom et al., 2017).

Extreme weather conditions are increasing and becoming more serious, affecting, among others, disaster and rescue workers, firefighters, and cleaning and restoration workers. For example, more fires expose firefighters to smoke and reduce their amount of rest. Extreme conditions such as floods and fires can cause post-traumatic stress symptoms in employees (Ciardini et al., 2016; Schulte et al., 2016). Extreme weather conditions also affect, for instance, medical institutions and the nuclear power industry. Medical devices can break down and cause damage to those working close by, and materials used in treatments and waste resulting from treatments can spread into the environment, causing damage even outside hospitals. Extreme conditions can also cause damage to nuclear power plants and their environment, possibly exposing factory workers and first aid workers to radiation, heat, fire, UV radiation, and explosions (Contessa et al., 2016).

#### 3.1.3 OSH challenges related to sustainable development and responsibility

Even though sustainable development is a positive-oriented concept, it still can bring out new risks. For example, the effects of climate engineering are unknown, and when working according to sustainable development, workers encounter new kinds of construction sites and are exposed to different materials, air pollutants, organic compounds, and organisms. The retrofitting of old buildings with renewable energy technologies introduces traditional risks to new situations (Schulte et al., 2016; Valenti et al., 2016; Wandzich and Plaza, 2017). As the human population increases, there is also a need for efficient waste handling. However, those working in recycling and waste handling face many different hazards, such as exposure to gases, metals, chemicals, nanomaterials, dust, and biological materials. Biomethanization in waste handling increases exposure to fungus, which has been connected to asthma, allergies, bronchitis, and infections. The use of and collaboration with robots in waste handling can also present risks (Schulte et al., 2016; Wandzich and Plaza, 2017; Mbareche et al., 2018).

New materials and technologies such as nanotechnology contain unknown risks, and traditional risks are not necessarily recognized. Renewable energy production causes unique dangers in buildings, operations, and maintenance. Some hazards to consider are MSD, microclimates, chemicals, nanomaterials, biological risks, metals, gases, hydrogeological risks, carcinogens, emissions, radiation, electric shocks, and fires. Further new and emerging risks come from self-controlling vehicles in transport, robotics and robots that work closely with people, and human performance-enhancing technologies (Schulte et al., 2016; Valenti et al., 2016; Wandzich and Plaza, 2017).

### 3.1.4 OSH challenges in industries

Untested ways of action and new forms of human–machine interactions, along with new information and communication technology (ICT), nanotechnology, robots, and artificial intelligence (AI), bring new risks and hazards. Advanced manufacturing processes change workplaces and work processes and methods and create new and emerging risks (Brocal and Sebastián, 2015; Kirin et al., 2015; Badri et al., 2018). The complexity of technologies and processes involved in complicated human–machine interactions is an emerging risk to overall production as well as at the individual employee level. Furthermore, the proliferation of ICT has given rise to human–machine interaction issues. ICT and technologies using ICT, such as robotics and AI, will likely have great influence on the nature of work in the coming years (Brocal et al., 2018). The emphasis will be on psychosocial risks due to changes in work contents, management, and organization. Psychosocial pressure and stress are caused by an accelerated work pace, constant learning, needs for broad know-how and constant self-development, possibilities to work where and whenever, and the use of digital tools to observe employees' behavior, performance and productivity (Brocal and Sebastián, 2015; Badri et al., 2018; Leso et al., 2018). Technological developments have also exposed often-connected industry systems to remote attacks that can quickly spread among them (Auffret et al., 2017).

Despite technological development, human work is still needed. However, the role will shift toward roles in which the human acts as an operator collaborating with and utilizing new technologies. Thus technological development with automation, digitalization, and robotization will make work more safe and fluent (Badri et al., 2018). Employees' roles will include more tasks requiring more decision making, taking more responsibility, carrying out planning tasks, and being involved in complex human–machine interactions. Decreased physical activity and increased static positions, psychosocial load, decision-making challenges, and mistakes in device use cause musculoskeletal and psychosocial problems. Furthermore, new technologies can increase accidents in both maintenance and production, for example, due to inadequate or bad instructions. Mechanical engineering, machines' mobility and flexibility, programming errors, and mistakes by people and intelligent machines can cause unexpected dangers and injuries to those working with or near devices (Brocal and Sebastián, 2015; Badri et al., 2018; Brocal et al., 2018; Leso et al., 2018).

The construction and plastic industries use large amounts of chemicals suspected of disturbing hormonal action. The development of materials and the need for energy-efficient and environmentally friendly buildings have led to the production of new materials. However, the possible interactions of all these materials are not known (Fucic et al., 2018). Insufficient knowledge and the faulty handling of chemical and biological materials create risks in production. For example, new laser technology and application targets create chemical hazards and nanoparticles in materials handling (Brocal and Sebastián, 2015).

Asbestos-caused illnesses still occur despite bans on its use. For example, malignant mesothelioma, which has been connected to asbestos, will still have effects in the future. However, cases of these illnesses will decrease in the future (Girardi et al., 2014; Mensi et al., 2016). The rising field of synthetic biology from laboratory experiments to industrial biofabrication processes will expose a greater number of employees to commercial synthetic biology risks (Howard et al., 2017).

### 3.1.5 OSH challenges in health care

Advances in medicine can cause risks. For example, nano-enabled medical products (NEMP) pose risks in research laboratories, medicine factories and distribution, home care, waste handling, and support services in public health services. Unintentional exposure to NEMP can occur through breathing, skin and mouth contact, and needle usage during medicine preparation, medical treatment, waste handling, and patient

treatment. The combined effect of NEMP touching another material and the risks during the evaporation of NEMP are difficult to assess (Murashov and Howard, 2015).

The potential abuse of increasingly numerous and important medicinal devices intensifies the need for cyber safety. The hacking of devices is dangerous and harmful to individual patients, researchers, and health care institutions. The digitization of bioscience and medicine also presents new risks (Ienca and Vayena, 2018). The increasing use of robotics in health care affects organizations and the division of work and roles. The implementation of robotics can also be challenging and creates risks due to the unexpected nature of health care work (Cresswell, Cunningham-Burley and Sheikh, 2018). In addition, asylum-seekers have been shown having a high risk of tuberculosis, which increases the risk for health care employees (Diel et al., 2016).

### 3.2 Main challenges at the individual level

Humans are affected by a variety of different OSH risks. Part of those can be considered as old and existing ones, however, several new risks and challenges have been brought into the discussion in the literature, as stated above. Figure 3 summarizes these challenges and their expected health effects.

The work system model allows considerations on the categorization of these risks and challenges (Figure 3) based on their origin. These risks and challenges may relate to work environments, technologies and tools utilized, work tasks performed, and/or organizational support received. Related to the work environment, working conditions are affected by heat, radiation, air pollution, extreme weather conditions and the spread of illnesses, allergens, and insects. Due to these factors, individual employees need to adapt to new and different kinds of work environments, such as in sustainable development and renewable energy production. Increased exposure to chemicals and biological factors is a risk, for instance, in industry, health care, and the electrical and energy fields.

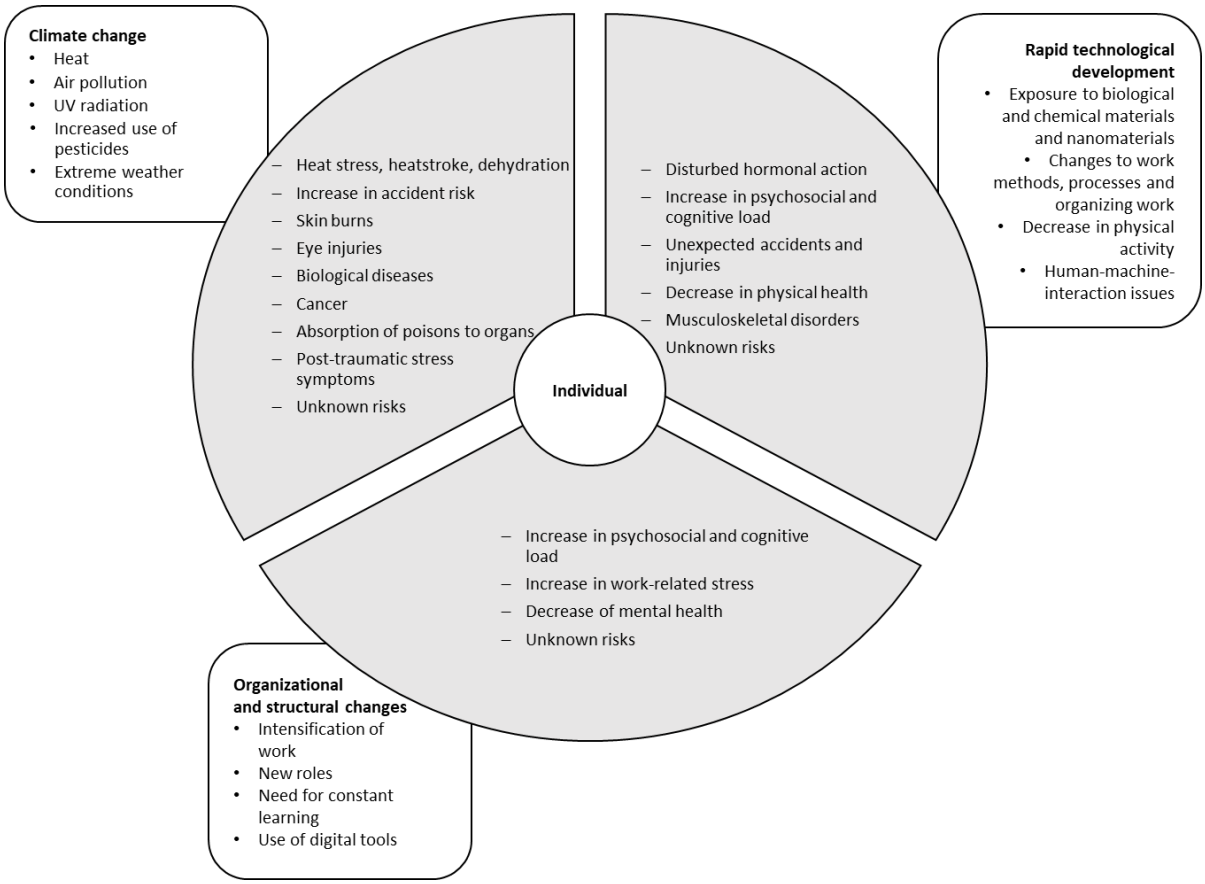


**Figure 3.** Summary of the OSH challenges (white boxes) and their potential effects at an individual level (gray)

As an element crossing both the work environment and the technologies and tools utilized, it has been shown that automated devices and robots can cause mechanical, electrical, and heat hazards and exposure to noise, vibration, radiation, and chemicals. The increased use of ICT has led to human–machine interaction issues. New technology that may not have been properly assessed from the perspective of OSH can cause unexpected exposures and other hazards. For example, three- and four-dimensional and bio- and nano-printing increase exposure to new agents that have unknown effects. New technology and its implementation can cause psychological problems and injuries among those working with or near it.

Climate change, sustainable development, and technological developments create new work tasks, and renewable energy production causes unique dangers. Musculoskeletal and psychosocial problems arise from automated, technology-intensified processes and work environments, diminished physical activity and increased static positions, psychological load, and decision-making challenges. Automation eliminates certain tasks but introduces other repetitive and difficult tasks, which reduce work variability and circulation and can lead to stress and physical injuries.

Examples of organizational features that can create risks include intensified work, long working hours, new roles, continuous learning, and violence. Changes in work contents, management, and organization cause stress, while technological developments affect the organization of work. The 24/7 work culture creates difficulties for individuals in balancing work and leisure time. Digitized management systems can lead to stress, decreased productivity, and increased absences if employees feel that they lack control. Constant monitoring with wearable devices can decrease work wellbeing.

## 4. DISCUSSION

As presented earlier, OSH have developed and improved considerably over the last 100 years. However, as ILO (2019c) points out, at the same time new technology and changes in working life improve OSH in some aspects, they also introduce new risks. Challenges may not be new in themselves, such as automation and robotics, but their development and use in different situations is increasing and intensifying. This study aimed to identify these possible new and emerging future OSH challenges. The present review covered 31 articles, of which a majority were literature reviews and overviews focused on future OSH challenges. Fourteen of the articles discussed OSH challenges caused by climate change and sustainable development, mainly heat and exposure to chemical, biological, and nano materials; nine of the articles considered OSH challenges in certain industries, mostly technological and material developments; and four of the articles presented OSH challenges in health care, such as NEMP. In brief, major changes included weather conditions, increased pesticide use, human–machine interactions, new work roles, the intensification of work, biological, chemical, and nanomaterials exposure and changes in work methods, processes, and organization. Individuals can experience a wide range of OSH challenges, from heat stress to poison absorption, MSD, increased psychosocial load, unexpected accidents and injuries, and ergonomic issues. The expected effects will occur from the present into the next 30 to 100 years (Kjellstrom et al., 2016; Mbareche et al., 2018; Mensi et al., 2016; Wandzich and Plaza, 2017).

Even though new and emerging OSH challenges have been recognized in different studies, the authors of the articles analyzed presented only a few new viewpoints on OSH management. This indicates that it is crucial to continue traditional and preventive OSH measures already used and adapt them to new OSH challenges. The articles were mostly directed at system experts, such as health, safety, and environment specialists; system decision makers, such as management; and system influencers, such as governments, standardization organizations, and regulators (refer to Dul et al., 2012). OSH management now and in the future is dependent on stakeholder interaction at different levels. For instance, system influencers, such as ILO and EU-OSHA, actively publish guidelines for OSH management. This knowledge published by the system influencers should be used at the organization level. As managers always have the main

responsibility of OSH, it is important for them to be aware of OSH challenges now and in the future. In the end, however, individuals as system users have their own obligations to OSH. They must take care of both their own and the other employees' safety and health. Hence they should also be aware of the changes in their own field. The findings presented in this article provide a practical and scientific basis for OSH management actions at different levels. These actions are discussed in more detail in the sections below.

### 4.1 Points to consider in OSH management

As this review shows, the development of technology and materials, with increases in robotics and automation, bring new and emerging OSH risks. Likewise, this rapid technological development has received a great deal of attention, such as in publications by ILO and EU-OSHA. The European Commission (2014), ILO (2014), and Stacey et al. (2018) have pointed out that new technologies bring new products and processes, whose effects on OSH should be studied in depth. New technology and technological changes are often not accompanied by prevention measures, and the incompatibility of the new and old technology can cause unforeseen effects, such as unwanted contacts with the robots, a loss of understanding, control, and knowledge of work processes, overconfidence in robots, and excessive trust in machines. In addition, risks related to cyber-security are highlighted as emerging new risks in this context.

Evidently, automation, digitalization, and the increased use of robotics remove certain repetitive and stressful work tasks. However, employees are still expected to perform difficult and unexpected tasks, such as in maintenance. In addition, the use of robots and AI may induce new threats for MSD, for example, when powered exoskeletons are used to modify employees' habitual physical and ergonomic movements. As Ellwood et al. (2014b) and Stacey et al. (2017, 2018) describe, excessive trust in external support skeletons can lead to a decrease in physical condition or to excessive risk taking because of the additional power given by the support skeleton.

Paralleling our review findings, ILO (2019d) highlights the need to better understand OSH aspects concerning the development and increased use of chemicals. New and emerging risks of chemicals entail exposure to substances with unknown toxicological OSH effects and exposure to substances with known effects in a field with poor access to this information. They (ILO 2019d) point out that there is a need to re-emphasize the risks of long-term conditions, such as occupational cancer. As shown in our review, nanomaterials and nanotechnology should be paid more attention from the OSH perspective. ILO (2018) has stated that nanotechnology is one example of a situation where production is started before the hazards of new products have been adequately assessed. ILO (2019c, 2019d) continued this discussion by describing how certain characteristics of nanomaterials, such as their size, shape, surface areas, and agglomeration, can result in inflammatory processes in human cells and cell death. The increased production and use of nanomaterials expose employees globally to potential adverse OSH effects, such as oxidative stress, inflammation and tissue damage, fibrosis, and tumor generation. In addition, nanomaterials can translocate from the lungs into the blood stream and to organs. One is entitled to ask whether current risk management processes are up-to-date with this emerging field of risk.

The need to update risk management processes is evident. Wandzich and Plaza (2017) recommended risk assessment as one of the keys to designing prevention measures. Integrating prevention into technology, product, and process design is recommended over identifying hazards later. We agree that it is important and recommendable to "design out" or minimize hazards and risks in design and implementation. Risk assessment should run through the lifespan of new technologies, products, and process, from planning, manufacture, transport, installation, and operation to maintenance, demolition, and disposal. As pointed out by Leso et al. (2018) and Valenti et al. (2016), this may require re-defining safety standards and the development of new personnel training processes. In addition, as noted by Cresswell et al. (2018), this technological development process may require new ethical and regulatory frameworks. Thus, it is

evident that all stakeholders, from system influencers to system actors, are needed to secure safe and healthy work in such complex work contexts.

In addition to the abovementioned OSH aspects, more focus should be placed on employee wellbeing. Recent publications by system influencers such as ILO (2019b, 2019c) and Stacey et al. (2018) point out how increased digitalization has decreased privacy through the collection and recording of sensitive personal information at workplaces. Monitoring with wearable devices, productivity apps, and wellness programs diminish employees' privacy and cause stress and feelings of isolation when they lose autonomy in how they carry out their work and interact more with devices and robots than colleagues. Wellbeing can decrease especially when connected to a lack of feelings of control, to uncertainty of work, or to lack of information from data collecting and use. It is evident that more attention should be paid to ethical and legal aspects when monitoring employees with such measures.

As our review shows, psychosocial challenges will increase in the future. Changes in working life have increased non-standard forms of employment, and the balance between home and work is challenged in many occupations. Birtles (2018) and Stacey et al. (2017) highlight that the development of ICT causes psychosocial challenges, such as emotional and cognitive load in the 24/7 economy, the loss of traditional hierarchies and social contacts, and difficulties in keeping the balance between work and leisure time. For instance, while telework can decrease commuting time and the stress and accidents related to it, it can cause psychosocial risks related to lone-working and ergonomics issues of workstations and cognitive load. Again, one is entitled to ask whether current legislation, guidelines, and risk management are up-to-date to face these challenges.

Finally, climate change and sustainability must be discussed in light of OSH. Even though climate change and sustainability as broad and complex phenomena are under constant practical and scientific discussion, it seems that their association to work and working life research is still in its infancy (cf. Bolis et al., 2014). As our review shows, both climate change and sustainable development may be associated to a variety of different OSH risks. ILO (2019c), Kjellstrom et al. (2019), and UNDP (2016) as system influencers have brought into the public discussion the fact that climate change causes increases in global temperatures and extreme weather events and hence is an environmental OSH hazard. Because of climate change, heat stroke, heat stress, and heat exhaustion are becoming more common. Climate change causes poorer chemical tolerance, fatigue, and poorer cognitive function and increases in risk of injury, the burden of respiratory and cardiovascular diseases and vector-borne diseases, and weakens immune function. Challenges also include mental health effects, including suicides because of the loss of one's livelihood, such as a failed harvest. Paralleling our findings, the aforementioned system influencers point out that employees in outdoor sectors—such as agriculture, construction, waste collection, emergency repair work, transport, tourism, and sports as well as industrial workers in indoor settings without proper control of temperature levels—face OSH risks caused by climate change. Employees in emergency, rescue, and clean-up work may have a risk of exposure to chemical and infectious agents, injuries, and hazards related to the recovery of bodies, crowd control, assault, and associated psychological and psychiatric disorders. In addition, office and desk tasks confront challenges at high levels of heat due to exhaustion. A question to be discussed amongst stakeholders is: how prepared are we for the wide range of challenges caused by climate change? To answer the OSH challenges, a re-evaluation of heat stress assessment and heat monitoring, warning and control systems, and strategies are needed to prevent heat stress through the design of workplaces and communities.

### 4.2 Future studies in summary

In addition to abovementioned OSH management challenges, new openings for future studies in this field have been proposed in the articles included in this review. New technologies and materials are widely used in different fields even though their effects on OSH have not been studied (Ellwood et al., 2014). Furthermore, partly due to technological developments, changes are needed in risk management. It can no longer

be only reactive; it must be proactive and pay attention to the environment, society, and technology (Kirin et al., 2015). Badri et al. (2018) suggested more interdisciplinary research to improve the integration of human labor with intelligent equipment. Badri et al. (2018) also pointed out a need for more research on occupational risks at all levels of production, on improving the social responsibility of businesses, on workplace design and configuration, on the effective use of information technologies, and on the consequences for work organization and the associated psychosocial risks. The increased use of robots affects work organization, roles, and methods. Potential challenges, unintended consequences, and cognitive and physical effects should be studied more closely (Brocal et al., 2018; Cresswell et al., 2018; Leso et al., 2018).

As the human population increases, and climate change affects the environment, the focus on sustainable solutions and renewable energy is increasing. It is important to evaluate traditional and new OHS risks to transfer OHS knowledge and identify OHS training needs. A systematic evaluation of new technology, products, and processes throughout their lifespan is also needed (Valenti et al., 2016). Moraru et al. (2014) stated that nanomaterials raise concerns as nanotubes and asbestos fibers have an identical structure; therefore, the effects on OSH need to be studied further. For example, it is critical to conduct a risk assessment of NEMP in health care (Murashov and Howard, 2015).

Many authors have suggested that more research is needed on climate change and its effects, such as regarding work performance, pesticides use, solutions to mitigate heat stress, and the long-term effects of infectious diseases (Gatto et al., 2016; Kjellstrom et al., 2016; Vonesch et al., 2016; Pogačar et al., 2018). Schulte et al. (2016) proposed that follow-up, research, and risk assessment are needed to better understand and classify the connections between OSH and climate change.

In addition to abovementioned research needs, a study by the Partnership for European Research in Occupational Safety and Health (PEROSH) identified as important research topics older workers, disabled and chronically sick workers (work disability prevention and return-to-work research), changing employment patterns and practices, health inequalities, and vulnerable workers. Other topics include migrant workers, enterprises' reorganization processes, electromagnetic fields, women in work and gender aspects, and the OSH consequences of market integration based on reduced barriers to the free movement of goods (Gagliardi et al., 2017). Furthermore, as introduced in section 3.2, the work system model can be applied to categorizing OSH challenges. It should be further studied whether and how the balanced work system model reacts to new and emerging risks and how they influence work performance at the individual and organizational levels.

### 4.3 Limitations

Even though this review followed the PRISMA guidelines, we have identified obvious biases, as follows (PRISMA, 2009; Liberati et al., 2009). The article selection process introduced a potential bias. The search resulted in 1,220 articles, but only a small portion (3%) concerned OSH risks and challenges in the future. The literature review used the cross-disciplinary database Scopus. Since Scopus was the only database used, some articles may have fallen outside the analysis. Furthermore, the researcher's own interpretations may have affected the article selection and analysis. The risk of bias of individual studies is mostly affected by the fact that many of the journal articles included in this study were literature reviews or overviews with little information on their methodological choices and study processes, as can be seen from Table A1. From those which did have empirical data, Valenti et al. (2016) had only 34 respondents in their survey, Héry and Levert (2017) used workshops with 12 to 15 experts, Cresswell et al. (2018) had 21 interviews, Mbareche et al. (2018) took samples from seven sites, Pogacar et al. (2018) had 400 respondents, Auffret et al. (2017) had nearly 100 participants in their survey, and Mensi et al. (2016) analyzed 4,442 cases and Girardi et al. (2014) analyzed 1,600 cases of malignant mesothelioma. The limited amount of empirical material may decrease the reliability of the results. Finally, the review included

eight articles from a theme issue of the journal Annali Dell'Istituto Superiore di Sanita. This publication bias consequently may have affected the results as to which themes occurred the most. In addition, 60% of the authors (N = 146) of the articles dealt with in this review represented only three countries—Italy, the United States, and Canada. The review was conducted in English. It is possible that large language areas, such as Germany, France, Spain, Japan, and the Nordic countries, did not get enough coverage due to their traditions of also publishing in their own language in this field.

Although this review is based on a wide field of high-level literature, we naturally could not realize a very dangerous OSH risk that is very relevant now in the whole world while this article will be published, year 2020. With this we refer to the coronavirus, COVID-19, and the world of work which is now under distress (ILO, 2020). Web sites, such as from ILO and WHO, are very much needed in the OSH situations like this when preventive actions and responses are acutely needed.

## 5. CONCLUSIONS

Rapid technological development, organizational and structural changes, and climate change bring new and emerging risks for occupational safety in industrialized countries. These risks will arise from hazards related to heat, increasing psychosocial load, work stress, and human–machine interactions, new materials such as nanomaterials, increasing exposure to biological factors, radiation, and chemical factors, and increased use of automated devices that cause mechanical, electrical, and heat hazards. In this review, these new and emerging risks are summarized and analyzed to give an overall view of future OSH challenges.

Based on the review findings, more research is still needed to secure safe and fluent work. In order to succeed, OSH effects must be considered when using new technologies, materials, and work methods. Current risk management and OSH management processes and practices must be updated to face these challenges. This requires broad collaboration between different stakeholders from system influencers to system actors.

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**Table A1.** Selected articles divided by themes. The order inside the themes is from most recent to oldest

| **Article** | Article's theme | Journal's foci | Methods and material |
|---|---|---|---|
| Héry and Levert (2017) | Overall OSH challenges | Contemporary world's biggest issues and possible futures | Foresight study, six one-day workshops. Participants: Twelve to fifteen experts from a variety of backgrounds and disciplines. |
| Harrison and Dawson (2016) | Overall OSH challenges | Occupational health and safety | Literature review, search strategy not defined. |
| Moraru et al. (2014) | Overall OSH challenges | Management systems | Overview, data collection and analysis method not specified. |
| Pogačar et al. (2018) | OSH challenges caused by climate change | Interactions between living organisms and factors of the natural and artificial atmospheric environment | Heat conditions projections and analysis focusing on the pattern of the summer heat waves of 2016 with measurements of air temperature and a survey with 400 respondents. |
| Kjellstrom, Lemke, and Otto (2017) | OSH challenges caused by climate change | Publications of the World Health Organization's Regional Office for South-East Asia | Overview, data collection and analysis method not specified. |
| Ciardini et al. (2016) | OSH challenges caused by climate change | Biomedicine, health sciences | Overview, data collection and analysis method not specified. |
| Contessa, Grandi, Scognamiglio, Genovese, and Sandri (2016) | OSH challenges caused by climate change | Biomedicine, health sciences | Overview, data collection and analysis method not specified. |
| D'Ovidio, Annesi-Maesano, D'Amato, and Cecchi (2016) | OSH challenges caused by climate change | Biomedicine, health sciences | Overview, data collection and analysis method not specified. |
| Gatto, Cabella, and Gherardi (2016) | OSH challenges caused by climate change | Biomedicine, health sciences | Overview, data collection and analysis method not specified. |
| Grandi, Borra, Militello, and Polichetti (2016) | OSH challenges caused by climate change | Biomedicine, health sciences | Overview, data collection, and analysis method not specified. |
| Kjellstrom et al. (2016) | OSH challenges caused by climate change | Public health | Overview, data collection, and analysis method not specified. Heat conditions projections. |
| Marchetti, Capone, and Freda (2016) | OSH challenges caused by climate change | Biomedicine, health sciences | Literature review, search strategy, and practices not defined. |
| Schulte et al. (2016) | OSH challenges caused by climate change | Occupational and environmental hygiene and safety | Literature review. Databases for English language articles: ABI/Inform; Compendex; Embase; Environment Abstracts; Environ- mental Science Journals; Global Health; Health & Safety Science Journals; NIOSHTIC-2; PubMed; Risk Abstracts; Scopus; Toxicology Abstracts; Toxline; and Web of Science. Seven categories of climate-related occupational hazards identified in the 2009 framework were used as the search terms. |
| Vonesch et al. (2016) | OSH challenges caused by climate change | Biomedicine, health sciences | Literature review. Technical publications and articles retrieved from the databank of PubMed with additional main Internet sources. Key words: "climate changes", "vector-borne disease", "infectious diseases", "human health", "Europe" alone and/or in combination with "employees", "workers", and "occupational". Main Internet sources: World Health Organization (WHO), Centers for Disease Control and Prevention (CDC), European Centre for Disease Prevention and Control (ECDC), Intergovernmental Panel on Climate Change (IPCC). Search strategy and practices not completely defined. |
| Mbareche et al. (2018) | OSH challenges related to sustainable development and responsibility | Air pollution control, waste management | Two biomethanization facilities in Canada: seven sites sampled once in the summer and once in the winter (air sampling, fungal spore concentration using the filtration protocol, DNA extraction, real-time PCR quantification, next-generation sequencing, and sequencing data processing). Nonparametric Mann-Whitney U test and a permutational multivariate analysis of variance were performed. |
| Wandzich and Plaza (2017) | OSH challenges related to sustainable development and responsibility | Ensure that occupational and environmental health nurses are the authority on health, safety, productivity and disability management for worker populations | Based on a European Agency for Safety and Health at Work (EU-OSHA) report, Green Jobs and Occupational Safety, and Health. |
| Valenti, Gagliardi, Fortuna, and Iavicoli (2016) | OSH challenges related to sustainable development and responsibility | Biomedicine, health sciences | Survey with 34 respondents and workshop with the stakeholders involved in survey. |
| Badri et al. (2018) | OSH challenges in industries | Science and technology of human and industrial safety | Literature review. Database used: Scopus. Key words: "health and safety" with terms most widely associated with Industry 4.0 ("industrie 4.0", "industry 4.0", "manufacturing 4.0", "smart production", "smart manufacturing", "smart factory", "smart industry", "factory of the future" and "advanced manufacturing"). 11 peer-reviewed articles. |
| Brocal, González, and | OSH challenges in industries | Science and technology of human | TICHNER (Technique to Identify and Characterize NERs) applied to literature overview. Search strategy |

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| Sebastián (2018) | | and industrial safety | and practices not completely defined. |
| Fucic et al. (2018) | OSH challenges in industries | Environmental health sciences and public health | Overview, data collection, and analysis method not specified. |
| Leso, Fontana, and Iavicoli (2018) | OSH challenges in industries | Occupational diseases, industrial hygiene | Literature review. Databases: PubMed, ISI Web of Science, and Scopus. Articles published from 2011 to 2018. Key words: "Industry 4.0" AND "occupational health" or "occupational safety". Then extended the research to additional threads, including "Industry 4.0", "smart industry", "smart factory", "smart technologies", and "robotic devices" which were individually combined with terms related to occupational scenarios, such as "occupational risks", "work organization", "workplace environments", and "occupational injuries". Total of 22 publications. |
| Auffret et al. (2017) | OSH challenges in industries | Interconnection networks | Structured survey and interviews, workshops, and conferences over a period of three years. Survey participants include near 100 participants from both government and private sectors. Workshops and conferences included speakers from the U.S., Europe, and Asia and had over 400 cybersecurity professional participants. |
| Mensi et al. (2016) | OSH challenges in industries | Occupational and environmental health | Malignant mesothelioma registry (MM) of the Lombardy Region, Italy. All cases of MM (N = 4,442) diagnosed between January 2000 and December 2012. Poisson models and projections were performed. |
| Brocal and Sebastián (2015) | OSH challenges in industries | Core engineering disciplines | Identifying and decomposing new and emerging risks associated with advanced manufacturing processes from a report by the European Agency for Safety and Health at Work (EU-OSHA) |
| Kirin, Božić, Brzaković, and Vučetić (2015) | OSH challenges in industries | Theory of fracture mechanics | Overview, data collection, and analysis method not specified. |
| Girardi, Bressan, and Merler (2014) | OSH challenges in industries | Cancer epidemiology | Malignant mesothelioma cases (N = 1,600) from the Regional Mesothelioma Registry, Italy, from 1987 to 2010. Parametric and non-parametric tests and age-period-cohort analysis were performed. |
| Cresswell, Cunningham-Burley, and Sheikh (2018) | OSH challenges in health care | Health informatics and health services research | Total of 21 qualitative semi-structured, one-to-one interviews. Thematic analysis. |
| Ienca and Vayena (2018) | OSH challenges in health care | Medicine | Overview, data collection, and analysis method not specified. |
| Diel, Loddenkemper, and Nienhaus (2016) | OSH challenges in health care | Occupational and environmental health | Tree age software to develop a dynamic Markov decision tree was used. Univariate and multivariate sensitivity analyses were performed. |
| Murashov and Howard (2015) | OSH challenges in health care | Occupational and environmental hygiene and safety | Overview, data collection, and analysis method not specified. |
| Howard, Murashov, and Schulte (2017) | Other | Occupational and environmental hygiene and safety | Overview, data collection, and analysis method not specified. |