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Potential Scenarios and Hazards in the Work of the Future: A Systematic Review of the Peer-Reviewed and Gray Literatures

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Abstract

It would be useful for researchers, practitioners, and decision-makers to anticipate the hazards that workers will face in the future. The focus of this study is a systematic review of published information to identify and characterize scenarios and hazards in the future of work. Eleven bibliographic databases were systematically searched for papers and reports published from 1999 to 2019 that described future of work scenarios or identified future work-related hazards. To compile a comprehensive collection of views of the future, supplemental and ad hoc searches were also performed. After screening all search records against a set of predetermined criteria, the review yielded 36 references (17 peer-reviewed, 4 gray, and 15 supplemental) containing scenarios. In these, the future of work was described along multiple conceptual axes (e.g. labor market changes, societal values, and manual versus cognitive work). Technology was identified as the primary driver of the future of work in most scenarios, and there were divergent views in the literature as to whether technology will create more or fewer jobs than it displaces. Workforce demographics, globalization, climate change, economic conditions, and urbanization were also mentioned as influential factors. Other important themes included human enhancement, social isolation, loneliness, worker monitoring, advanced manufacturing, hazardous exposures, sustainability, biotechnology, and synthetic biology. Pandemics have not been widely considered in the future of work literature, but the recent COVID-19 pandemic illustrates that

was short-sighted. Pandemics may accelerate future of work trends and merit critical consideration in scenario development. Many scenarios described 'new' or 'exacerbated' psychosocial hazards of work, whereas comparatively fewer discussed physical, chemical, or biological hazards. Various preventive recommendations were identified. In particular, reducing stress associated with precarious work and its requirements of continual skill preparation and training was acknowledged as critical for protecting and promoting the health and well-being of the future workforce. In conclusion, the future of work will be comprised of diverse complex scenarios and a mosaic of old and new hazards. These findings may serve as the basis for considering how to shape the future of work.

Keywords: digitalization; future of work; industry 4.0; psychosocial hazards; robots; technological unemployment

Introduction

The nature of work, the workplace, and the workforce are changing rapidly, differently, and to a greater extent than in years past, affecting greater numbers of individuals in profoundly powerful ways (Daheim and Wintermann, 2016; Johansson *et al*., 2017; Jain *et al*., 2018; International Labour Organization (ILO) 2018; World Bank Group, 2019). Waiting until the effects are fully revealed to address them could be highly problematic and inadequate. Instead, anticipatory thinking regarding new and persistent factors affecting work and workers is required.

Rantanen (1999) was one of the earliest investigators to detail future of work scenarios relevant to occupational safety and health (OSH). He foresaw a focal shift from traditional health outcomes, such as mortality and hospitalization, to multifactor determinants of health (e.g. behavioral, environmental, social) and indicators of functional capacity (e.g. work ability, work motivation, and quality of work life). Rantanen (1999) suggested that future scenarios would involve not only current and ongoing hazards but also new ones, yet to be observed.

The current review provides a comprehensive characterization of the future of work in terms of the scenarios that may occur, the hazards that may result from them, and recommendations to address them. It also offers solutions from the literature to address the hazards associated with the future of work.

Methods

A three-pronged approach was used to conduct a comprehensive search for literature describing future of work scenarios and the hazards associated with them.

Prong 1: searching for future of work scenarios in the peer-reviewed literature

Using the principles of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA; Moher *et al*., 2009), the authors conducted a search for peer-reviewed literature containing future of work scenarios. Searches were conducted between April and December 2019 using ABI-Inform, Business Source Complete, EconLit, Embase, Ovid, Public Health Database, PubMed, PsychINFO, SCOPUS, Social Sciences Database, and Sociological Abstracts databases. Initial inclusion criteria required a reference be published in English between 1999 and 2019 and contain in either its title or abstract at least one keyword from the lists generated by the authors (see Supplementary Appendix I). After removing duplicates, the search yielded 1202 records for screening. The authors' process for screening and reviewing these records is detailed in Supplementary Appendix II. The most critical screening criteria included ensuring an article satisfied the current study's operational definition of work scenario: a product (i.e. piece of writing) that either 'describes some possible future state or tells the story of how such a state might come about' (Bishop *et al*., 2007, p. 8). Screening also included an automated search for key terms, a manual review of abstracts for mention of at least one future of work scenario, a refinement of the included publication years (2009 to present), and the level at which work was described (job or task). The authors then worked in pairs to manually complete a critical review and assessment of each article that passed the screening process. Figure 1 provides an overview of the selection process, which resulted in the retention of 17 peer-reviewed articles.

Prong 2: searching for future of work scenarios in the gray literature

The search for future of work scenarios in the gray literature entailed government websites, nongovernment websites (business, industry and academic), Google Scholar, and Google. Initial inclusion criteria required a reference be published in English between 1999 and 2019 and contain in either its title or abstract/text at least one keyword from the lists generated by the authors (see Supplementary Appendix I). If needed, Google searches were further refined using search options for file or site

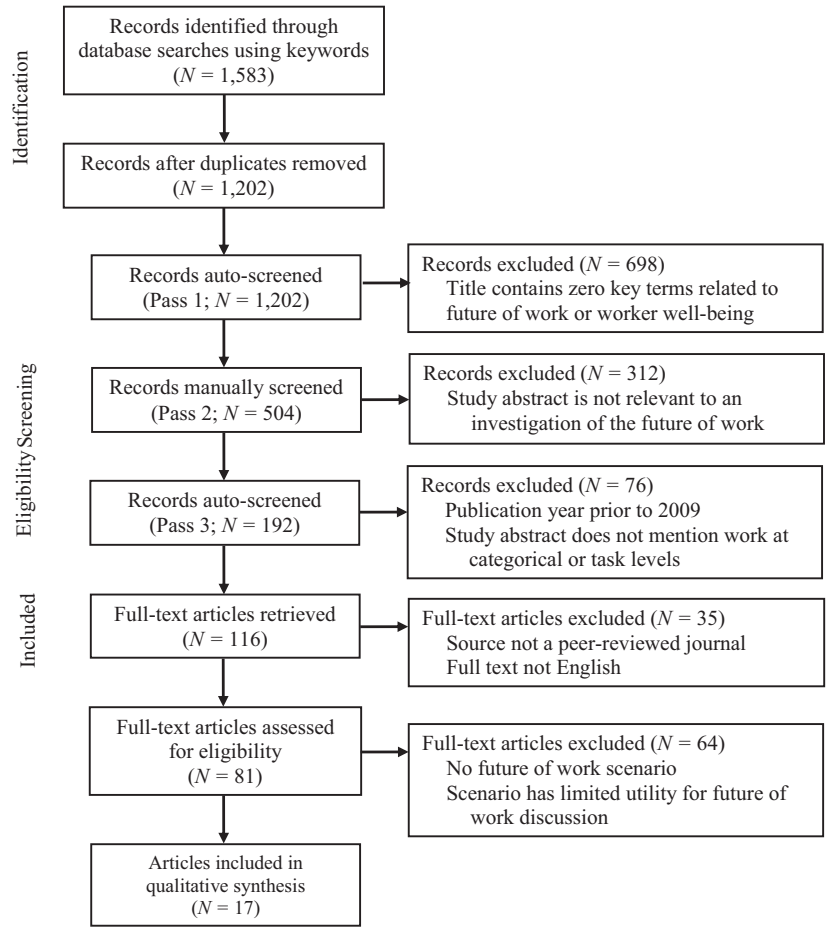


Figure 1. Flow chart for inclusion of peer-reviewed future of work scenarios.

type. All gray literature cited in a recent future of work review issued by the ILO (Balliester and Elsheikhi, 2018) was also added to the initial web search results. In total, 269 records were retrieved. These records were manually screened and reduced to a set that (i) was published in 2009 or later (to mirror the revised peer-reviewed inclusion criteria); (ii) made projections or predictions about the future of work; and (iii) contained at least one term from the following list: *scenario*, *model*, *hazard*, *risk*, and *expos** (e.g. *exposure*, *expose*, *exposed*, etc.). Four documents contained scenarios that clearly predicted or speculated risks or hazards and were retained for analysis.

Prongs l and 2 yielded a surprisingly small number of articles and reports, suggesting the need for additional sources to fully explore future of work scenarios. To accomplish this, an additional search method (Prong 3) was designed to broaden the search for scenarios and hazards.

Prong 3: Supplemental Searching for Scenarios, Hazards, and Themes in the Published Literature

The authors conducted supplemental literature searches of the peer-reviewed, gray, and general literatures to further expand information gathered in the systematic searches. The searches were completed using backward and forward snowball approaches (Wohlin, 2014) as well as ad hoc searches of relevant literature to December 2019. Seven recent future of work literature reviews, found in the initial scan of literature, served as the 'start set' for this search: Ballister and Elsheikhi (2018), McKinsey Global Institute (2017), Acemoglu and Restrepo (2018), Peruffo *et al*., (2017), British Safety Council (2018), ILO (2019), and Schulte and Howard (2019). Papers were included if they pertained to future of work, included at least one keyword from the search list in Supplementary Appendix I, and were consistent with the identification of a future scenario

(rather than commentary) as described by Spaniol and Rowland (2019).

The remainder of this article synthesizes future of work scenarios; summarizes anticipated hazards associated with the future of work from peer-reviewed, gray, and supplemental literatures; discusses major themes considered relevant to the future of work by the authors (see Supplementary Appendix III); and provides recommendations for anticipating and responding to challenges associated with the future of work.

Results

Future of work scenarios and hazards in the peer-reviewed literature

This review identified 17 peer-reviewed papers describing future of work scenarios, summarized in Table 1A. Generally, these are conceptual macro-level scenarios describing broad characteristics of the politico-economic context or attendant labor market. For the purposes of review, these papers are combined into four non-mutually exclusive scenario categories describing a convergence of concepts: (i) changing patterns of employment and work organization, (ii) management of technological change and human–robot interaction, (iii) OSH challenges, and (iv) ethical issues. Figure 2 quantitatively summarizes four major hazard categories based on scenarios found in peer-reviewed sources. The most common scenarios involved the exacerbation or creation of psychosocial hazards, followed by physical hazards. Chemical and biological hazards were rarely represented in the scenarios.

Changing patterns of employment and work organization

Based on the five papers in this category, technology, globalization, demographics, and urbanization were identified as contributing to changing patterns of employment and work organization (Johansson *et al*., 2017; Bellace, 2018; Caruso, 2018; Ghislieri *et al*., 2018; Traulsen and Druedahl, 2018). Overall, the scenarios entail workplaces where smart machines, materials, warehouses, and other factory systems will continuously exchange information with human workers, resulting in a reduced need for human workers. These automated facilities are projected to cause a qualitative knowledge transformation—from bodily and tacit into more theoretical and abstract knowledge and skills and from craftsman-like qualifications to more technical qualifications (Johansson *et al*., 2017; Caruso, 2018). Caruso (2018) offered an evidence-based critique on the promises of knowledge work and the positive effects of digitalization, noting that work organization has become more precarious rather than more horizontally integrated, and workers have yet to experience increased decision-making power or autonomy. Additionally, work has become more creative for only a fraction of highly skilled workers, and the distinction between work-time and life-time has weakened. Bellace (2018) further noted that the needs of workers are becoming delinked from employment, and a new paradigm for labor law is needed. This new paradigm should emphasize the changing nature of work. Moreover, Bellace concluded that in the 21st century, the notion of employment that undergirds labor law has been breaking down. As we move into the information age, labor unions have been weakened by a decline of class consciousness and technological changes.

In this category, future work will be an evolution of the current era. This is depicted as an industrial revolution (Industry 4.0) and is seen to differ from previous ones because it involves exponentially paced technological changes with the potential to cause systemic disruption in most, if not all, industries (Ghislieri *et al*., 2018). The revolution has been described in publications from various countries as an inchoate transformation of production of goods and services resulting from applications of a new wave of innovations (Caruso, 2018). Such digital innovations and the emergence of Industry 4.0 may constitute epochal social changes. One such change may involve labor relationships and the individualization of the relationship between workers and machines, which will affect unions' bargaining power and workers' collective actions (Caruso, 2018). The context of work in the future may be further influenced by the eroding of the 20th-century notion that employers have obligations to employees. The advent and growth of platform work illustrates this change, with companies such as Uber and Lyft declaring they do not 'employ' their workers (Bellace, 2018).

Hazards to workers depicted in these scenarios are related to technological developments and include changing employment patterns, precarious work, unemployment, underemployment, competency obsolescence, psychosocial stress, and work intensification. The increased incorporation of technology (e.g. robots, machines, digitalization) maintains the potential to increase the complexity of production systems across industries, which may increase workload and stress levels and decrease worker motivation (Johansson *et al*., 2017; Latos *et al*., 2018). The risk of addiction to new work-related technologies and pressure to constantly be online and available 24/7, in an 'always on' working world, may also adversely impact the well-being of workers and their families (Ghislieri *et al*., 2018). Additionally,

Table 1. Summary of peer-reviewed, gray, and supplemental literature

Study category[a]	Scenario basis[b]	Study	Time horizon[c]	Scenario	Anticipated hazards, categorized[c,d,e]	Recommendations
A. Summary of peer-reviewed literature						
1	3	Bellace (2018)	0–3 years	The nature of work has changed substantially, requiring a new labor law paradigm.	**Psychosocial**—Disappearance of long-term employment; globalization; income insecurity; job loss; lack of unions; loss of group identity; premature deindustrialization.	Reconsider the purpose of labor law. Recognize the dignity of working persons. Link income security to work.
	3	Caruso (2018)	Unclear	Industry 4.0—technological innovations (e.g. robots, machine learning, artificial intelligence, 3D printing) lead to transformations in the way goods and services are produced.	**Psychosocial**—Alienation; blurred work–home boundaries; decentralized production networks; insecurity; instability; new forms of employment (e.g. employee sharing, job sharing, interim management, mobile work, voucher-based work, portfolio work, crowdworking); polarization; precariousness; skills gaps; social tensions; unemployment; unpredictable working conditions and work organization.	Empower workers to make decisions and regulate workload. Engage in collective decision making. Improve communication. Launch initiatives for competency development and work organization.
	3	Ghislieri *et al.* (2018)	0–3 years	There will be an expanded integration of robots and other automated machines in the workplace. This will be accompanied by a transformation of needed job skills.	**Psychosocial**—24/7 availability; complacency; counterproductive workplace behaviors; decreased informal learning; decreased motivation; decreased situational awareness; decreased vigilance; distrust of automation; inequality; lack of autonomy; misuse, abuse, and disuse of technology; reduced human relationships; reduced organizational commitment; stress; uncertainty.	Capitalize on synergies between educational and training systems. Conduct research (especially longitudinal studies) to examine the effects of technology. Foster collaboration between HR practitioners and work organization researchers. Implement leadership interventions. Improve communication.

Table 1. Continued

Study category[a]	Scenario basis[b]	Study	Time horizon[c]	Scenario	Anticipated hazards, categorized[c,d,e]	Recommendations
	3	Johansson *et al.* (2017)	Unclear	Industry 4.0 will be a technological revolution that includes the automation and digitalization of industry.	**Physical**—Collaborative robots; repetitive work that cannot be automated. **Psychosocial**—24/7 availability; blurred work-home boundaries; cognitive skills gaps; collaborative robots; increased information flow; masculinization and feminization of technology; over-reliance on technology; re-engineering of organizations and work processes; robotization; stress; unclear employment conditions, competence, skills, roles, responsibilities, and labor sourcing strategies; upskilling, deskilling, and reskilling; Wireless Body Area Networks.	Conduct research on crowdsourcing. Conduct organizational and discourse analyses focused on the relationships between technology, skills, identity, and gender. Develop theories to understand changes to workers' relationships, workplace norms, and the organization of work.
	3	Traulsen and Druedahl (2018)	Unclear	The future of pharmacy work will include precarious work arrangements.	**Psychosocial**—Dissatisfaction; globalization; job insecurity; lack of job control; precarious work; training gaps; underemployment.	Build alliances with other healthcare professionals. Create fluid work environments. Operate using standard contracts. Promote interprofessional education.
2	3	Djebrouni and Wolbring (2019)	0–3 years	The role of robotics in human enhancement and rehabilitation is unknown.	**Physical**—Robots. **Psychosocial**—Multitasking; stress; stressful interaction with robots.	Account for potential negative effects of robots for workers with disabilities.
	3	Islam (2018)	0–3 years	Digital technologies will shape the world of work in India.	**Psychosocial**—Displacement; long work hours; multiple jobs; precariousness; stress; uncertainty.	Adequately invest in digital infrastructure. Systematically evaluate wages and working conditions for nonstandard employment. Evaluate how new technologies impact poor and vulnerable populations.
	3	Koppenborg *et al.* (2017)	0–3 years	Future work will include an increased volume and complexity of human–robot collaborations.	**Physical**—Collaborative robots. **Psychosocial**—Anxiety; collaborative robots; fatigue; greater perceived risk; inaccurate mental models; increased workload; lack of concentration; operator error; reduced quality control; stress.	Consider human factors in risk assessments. Design robots that communicate movement plans to human workers. Reduce collisions between robots and operators.

Table 1. Continued

Study category[a]	Scenario basis[b]	Study	Time horizon[c]	Scenario	Anticipated hazards, categorized[c,d,e]	Recommendations
	3	Murashov *et al.* (2016)	0–3 years	Occupational robotics will play an increasing role in the workplace.	**Physical**—Industrial robots; collaborative robots; managerial robots; professional and personal service robots; unpredictability of robot movements. **Psychosocial**—Collaborative robots; job demands; managerial robots; unpredictability of robot movements; job insecurity.	Design robots to assess human emotions and respond accordingly. Establish international consensus standards. Establish robotic safety standards. Implement NIOSH recommendations for work with robots: barriers, adequate clearance distances, remote diagnostics, adequate illumination, and clear markings around robot movement zone. Implement proactive approaches for robotic hazard assessment and risk management. Offer safety training; Reduce robot weight, size, operating speed, and force.
	1	Pham et al. (2018)	0–3 years	Robotics and automation in the workplace may lead to increased rates of unemployment.	**Psychosocial**—Dehumanized work; fewer working hours; increased work pace; job destruction; job loss; salary reduction; shifting economic and power structures.	Increase worker education, both initially and continuing. Implement universal basic income. Tax corporations that deploy robots and cause job loss.
	3	Pyke (2018)	0–3 years	To achieve inclusive growth, technological disruption will need to be managed at the policy level.	**Physical**—Health decrements. **Psychosocial**—Insecurity; job destruction; job loss; long-term unemployment; new enterprise-enterprise and customer-enterprise relationships; skills gaps; social disconnection.	Address community bottlenecks (e.g. healthcare, childcare, transportation, education). Adjust welfare benefits. Create policies to reduce inequality (e.g. minimum wage). Form economic and social councils. Ensure fair distribution of gains through taxation and other policies. Establish national and international standards. Establish social protection systems. Improve employability through job fairs, employment centers, databases, and interview preparation. Offer decent working conditions.

Table 1. Continued

Study category[a]	Scenario basis[b]	Study	Time horizon[c]	Scenario	Anticipated hazards, categorized[c,d,e]	Recommendations
	3	Qureshi and Syed (2014)	0–3 years	The use of robots will impact employment and motivation in the health care sector.	**Psychosocial**—Increased educational requirements; polarization; unemployment.	Establish Human Relations initiatives. Offer training and development.
3	3	Chia *et al.* (2019)	Unclear	Industry 4.0 will require a new workplace safety and health strategy, named WSH 4.0.	**Biological**—Synthetic biology. **Psychosocial**—Autonomous robots; blurred work-home boundaries; burnout; collaborative robots; discontinuity of work; displacement; gig economy; precariousness; social disruption; stress; underemployment; unemployment.	Advocate for responsible innovation. Conduct robust surveillance. Construct anticipatory governance frameworks. Design regulatory standards for human–machine interface. Engage in multi-stakeholder dialogue. Facilitate platform cooperativism. Implement adaptive workplace safety and health solutions. Offer professional development. Utilize adaptive risk management.
	1	Hauke *et al.* (2018)	4–10 years	Occupational sectors will have specific OSH concerns in the next 5 years.	**Physical**—Ergonomic stresses; noise; human-machine interface; mobility/traffic density; physical inactivity; unhealthy diet. **Chemical**—Diesel emissions; epoxy resins; mold spores; synthetic medicine resistance; mineral fibers; nanotechnology; UV radiation. **Biological**—Medicine resistance; nanotechnology. **Psychosocial**—Blurred work–life boundaries; demographic changes; extended responsibilities; job insecurity; mobile work; network availability and control; physical violence; psychological violence; pressure to succeed in schools/training programs; skills gaps; work intensification.	Build prevention culture. Conduct cost–benefit analyses for musculoskeletal train and work intensity. Conduct risk assessments for ICTs. Design dynamic office workplaces. Design feedback systems for ergonomics. Develop indicators to measure health as factor of organizational success. Develop noise exposure atlases. Establish guidelines for how to handle worker availability. Establish participative approaches for employee health and professional development. Implement information communication technology (ICT) security measures and safety trainings. Provide incentive systems for health promotion. Provide multitasking training for older employees. Reinforce digital literacy training. Reinforce health literacy training. Reinforce innovation training for managers. Reinforce sensitivity training for managers and employees. Reinforce work ability training. Use exoskeletons when lifting and carrying.

Table 1. Continued

Study category[a]	Scenario basis[b]	Study	Time horizon[c]	Scenario	Anticipated hazards, categorized[c,d,e]	Recommendations
	2	Leso *et al.* (2018)	0–3 years	Industry 4.0 will provide opportunities and challenges to worker safety and health.	**Physical**—Automation; engineering or programming errors in equipment design and maintenance; human error in equipment use. **Psychosocial**—Abstraction; automation; complex management; engineering or programming errors in equipment design and maintenance; human error in equipment use; job destruction; loss of control; mental overload; occupational uncertainty; overwork; privacy invasion; problem-solving demands; psychological pressure; reduced inter-human contact; skills gap; unemployment; work density.	Adopt suitable management strategies for worker protections. Decrease repetitive or monotonous tasks. Design out hazards and risks at design or implementation phase. Engage in proactive approaches to risk assessment. Enhance coping and supporting strategies. Improve the work-home interface. Monitor employee well-being. Offer lifelong learning for professional upgrading and active aging. Use smart personal protective equipment
	3	Niu *et al.* (2019)	0–3 years	AI will impact OSH management strategies in the construction sector.	**Physical**—Crowded worksites. **Chemical**—Toxic vapors. **Psychosocial**—Crowded worksites; distractions; fatigue.	Engage in real-time condition logging by smart construction objects (SCOs). Use tech-based systems to detect hazards and issue alerts. Facilitate SCO information-sharing. Generate and execute autonomous SCO solutions.
4	1	Iavicoli *et al.* (2018)	Unclear	OSH ethics must be developed in response to the changing world of work.	**Chemical**—Nanomaterials. **Psychosocial**—Blurred work–home boundaries; control and monitoring by employer; disconnect between organizational performance economically (turnover, costs, profits) and socially (ethical responsibilities); discrimination; globalization, market intensification; robotics in the workplace; social isolation.	Consider privacy, ethical, social, and other implications when formulating policy. Foster collaboration between OSH and other professionals. Integrate personal, professional, and institutional ethics. Introduce ethics courses to medical curricula. Mine existing data sources. Review the competence of OSH professionals.

Table 1. Continued

Study	Scenario basis[b]	Time horizon[c]	Scenario	Anticipated hazards, categorized[c,d,e]	Recommendations
B. Gray literature describing future of work scenarios and hazards					
Brown *et al.* (2018)	3	11+ years	The continua of collectivism/individualism and integration/fragmentation result in four 'worlds' of work: yellow, red, green, and blue.	**Psychosocial**—Devalued human effort; highly specialized skills set; lack of privacy; nonstandard work arrangements; polarization, turnover; work pace.	Deliberately incorporate technology. Facilitate training. Incentivize adaptability, leadership, creativity, and innovation. Innovate ways to address unemployment due to technology. Pay attention to megatrends.
Eurofound (2018)	1	Unclear	Automation, process digitization, and coordination by platforms impact working conditions.	**Psychosocial**—Ambiguity, artificial intelligence; anxiety; changes to working hours; displacement; financial concerns; instability; lack; of autonomy; limited social and contractual protections; precariousness, polarization, union breakdown.	Advocate for transparency in taxation and employment status. Develop policies that protect and regulate nonstandard work. Examine gender distribution of crowd workers. Reframe union strategies and adapt traditional practices to include digital platforms.
UK Commission for Employment and Skills (2014)	3	11+ years	Four scenarios for the future of employment in the UK: forced flexibility, the great divide, skills activism, and innovation adaptation.	**Psychosocial**—Disappearance of mid-skilled jobs; turnover, unemployment.	Adapt training programs to reflect interdisciplinary approaches. Adapt organizational values to create meaning and value to work. Manage skills and talent across global etworks. Develop blend of technical and collaborative skills. Develop policy- and regulation-based strategies that contribute to job growth. Develop sustainable career and learning paths for young workers. Prepare for increasing workforce diversity. Update skills.
World Economic Forum (2018a)	1	Unclear	The rate of technological change (steady/accelerated), evolution of learning (slow/fast), and magnitude of talent mobility (low/high) lead to eight permutations for the future of work.	**Psychosocial**—Disconnection; dislocation; displacement; financial strain; polarization, restricted migration; skills gaps; unemployment.	Advocate for education reform. Create agile, portable, and sustainable safety nets. Enhance digital access. Govern online platform work. Incentivize job protection. Incentivize labor force participation. Incentivize smart job creation. Manage mobility. Provide opportunities for reskilling, upskilling, and retraining. Support entrepreneurs.
C. Supplemental literature describing future of work scenarios and hazards					
Daheim and Wintermann (2016)	3	11+ years	Three visions of the future result from rapid technological change that will radically transform the way people work.	**Physical**—Climate change (drought and famine). **Psychosocial**—Accelerated social, economic, and technological change; alienation; dissolution of social norms and regulations; extreme political polarization; organized crime; self-employment; social division; unemployment.	Establish new social contracts. Facilitate domestic and international cooperation to improve our understanding and control over technological change. Modify institutions and processes to be more proactive in anticipating and shaping the future. Partner with experts in the cultural sector to create positive representations of work. Teach skills and promote meta-skills that prepare future workers for multi-track employment.

Table 1. Continued

Study	Scenario basis[b]	Time horizon[c]	Scenario	Anticipated hazards, categorized[c,d,e]	Recommendations
DeBruyne and Gerritse (2018)	3	4–10 years	By 2025, fast-developing digitalization will impact work processes and environments for office-based work in The Netherlands.	**Psychosocial**—24/7 availability; automation; blurred work–home boundaries; decreased visibility; digitalization; digital insecurity; disconnection; dynamic labor market; fragmentation; globalization; job loss; shortened labor contracts; skills gap; speed of IT changes.	Build organizations around self-managing teams that can quickly respond to demands. Design a digital infrastructure that supports cooperation and collaboration. Encourage social cohesion in physical and digital environments. Improve flexibility of office spaces. Provide a balance between office, home office, and 'third workplace'.
Dellot *et al.* (2019)	3	11+ years	Technological advances will impact the UK labor market by 2035 in many ways, producing four alternative futures: the big tech economy, the precision economy, the exodus economy, and the empathy economy.	**Psychosocial**—AI; automation; contingent work; cybercrime; digitalization; economic insecurity; emotional labor; globalization; inequality; job fracturing; job loss; on-demand work; platform-based work; polarization; rapid technological change; robots; surveillance; unemployment.	Engage in higher quality debates about what technology is capable of and what that means for workers. Give workers a greater say over technology deployment. Keep regulations on pace with changing labor and technology markets. Renew tax and welfare institutions to widely share the benefits of technological change. Steward the creation of new technologies to address problems during development. Upskill the workforce on an ongoing basis.
Hajkowicz *et al.* (2016)	1	11+ years	Four scenarios identified by assessing megatrends in cells along two axes related to tasks uncertainty and institutional change.	**Psychosocial**—Job displacement and disruption.	Develop skills and aptitudes for tomorrow's jobs. Develop better measures of workforce statistics with forces on productivity well-being and labor markets. Engage in lifelong learning.
Healy *et al.* (2017)	3	Unclear	Technology will impact jobs and skills in Australia, resulting in optimistic, essimistic, and mixed scenarios for the future.	**Psychosocial**—AI; automation; blurred work–home boundaries; casual employment; gig work; globalization; job destruction; job displacement; migration; polarization; rapid technological change; robotics; skills gaps.	Balance efforts to promote of innovation with efforts to minimize the adverse effects of technology. Weigh the negative and positive consequences of change and innovation on work and skills.
HLEG (2019)	1	Unclear	The future of both work and society in general will be immersed in AI.	**Physical**—Injury from AI misuse or insufficient security; Lethal Autonomous Weapon Systems (LAWS). **Psychosocial**—Deception; discrimination; inequality; manipulation; marginalization; prejudice; unjustified surveillance; vulnerability.	Acknowledge both the benefits and risks AI poses for individuals and society. Clearly communicate AI system capabilities and limitations to stakeholders. Create human-centric AI systems. Develop, deploy, and use trustworthy AI systems in a way that adheres to ethical principles. Foster research and innovation to assess AI systems, and widely disseminate results. Measure AI implementation using technical and non-technical methods. Support historically vulnerable groups.

Table 1. Continued

Study	Scenario basis[b]	Time horizon[c]	Scenario	Anticipated hazards, categorized[c,d,e]	Recommendations
Howard (2019)	3	0–3 years	Work will continue to incorporate the use of AI and machine learning.	**Physical**—Fatalities; injuries. **Psychosocial**—Automation; depersonalization; displacement; job destruction; stress; surveillance.	Disclose all data uses. Ensure secure data storage. Ensure voluntary worker participation in monitoring programs. Establish methods to increase human control over cobots, such as human hand guiding, speed and separation monitoring, and power and force limitations. Implement safety-related monitored stopping controls for AI and robots. Use only validated sensor technologies.
International SOS Foundation (2018)	2	11+ years	There will be an increase in complexity of OSH requirements by 2030.	**Psychosocial**—AI; automation; blurred work/home boundaries; globalization.	Consider mental health as equal in importance to physical health. Focus on building resilient cultures rather than individual case management. Move away from 'managing stress' and focus instead on well-being. Seek and obtain leadership commitment to OSH.
Korge (2018)	1	Unclear	Four scenarios of office production work by assessing two axes; one based on goal of digitalization; the other based on complexity of tasks and qualifications.	**Psychosocial**—Automation; decentralization; difficulty with the unknown; digitalization; increased complexity; qualified workers at risk of being deskilling.	Shape the future of work, which is not certain, using strategies that assure long-term market competitiveness. Utilize participatory leadership approaches.
Moore (2019)	3	Unclear	The implementation of technology will significantly change working conditions	**Physical**—Collaborative robots; injuries; musculoskeletal disorders; sensor degradation; unstructured environments; violence. **Psychosocial**—Anxiety; bullying; communication issues; deskilling; discrimination; harassment; gig work; insecurity; job destruction; liability; nonstandard work hours; overwork; precariousness; racism; restructuring; stress; surveillance; training gaps; work intensification; work-life imbalance; violence.	Balance the use of automated processing with human intervention for decision making. Consider ethical implications before deploying new AI. Design standards and regulations for worker surveillance. Establish horizontal and sectoral rules to protect workers and ensure AI integration will yield benefits. Offer workers additional training in the area of problem solving (skills and principles). Train workers to understand the role and function of workplace robots.

Table 1. Continued

Study	Scenario basis[b]	Time horizon[c]	Scenario	Anticipated hazards, categorized[c,d,e]	Recommendations
Ponce del Castillo and Meinert (2016)	1	11+ years	Based on how the next generation of Europe reacts to OSH challenges with respect to social/liberal orientation and rigidity/participation for work organization, four scenarios are offered for the state of work in 2040: well-being, self-reliance, productivity, and protection.	**Physical**—Ergonomic challenges associated with sedentary work and heavy-duty work. **Biological**—Nanomedicine; cell engineering. **Psychosocial**—Burnout, interpersonal conflicts; lack of unions, nonstandard work arrangements; performance pressures; presenteeism; reduced OSH budgets; role overload; social isolation; surveillance of work performance; work intensification.	Apply prevention through design concepts during the development of new technologies and products. Ensure workers have access to healthy working conditions. Train workers to embrace change.
Schultz (2007)	3	4–10 years	Four scenarios for the future of work in the UK result as the cross-product of market competition and resilience to change: a virtue of necessity, the digital rose garden, tough choices, and boom and blame.	**Chemical**—Nanomaterials. **Physical**—Terahertz technology. **Biological**—Biotechnology; new diseases; new flora and fauna; technologies that augment the human body (e.g. bionics, body and brain implants, genomics); stress-depressed immune systems. **Psychosocial**—Blurred work/home boundaries; cybersecurity; deregulation, economic decentralization; globalization; invasive monitoring; lack of unions; nonstandard work arrangements; polarization, social exclusion; stress.	Adapt standards for fitness for work to accommodate changing workforce demographics (e.g. age, lifestyle). Debate the trade-offs between OSH and environmental action. Develop close partnerships between OSH, public health entities, and social services. Distinguish between the roles of enforcers and advisors of OSH. Enforce OSH policies. Inform and prepare the next generation about emerging risks, risk management, and risk communications. Introduce local-based regulations and support local networks. Measure OSH success in terms of well-being rather than accident rates. Regulate and oversee work practices. Review regulatory frameworks and assess them for their adequacy in controlling changing risks in a changing workplace. Use fiscal incentives rather than sanctions to encourage behavior change, especially for small-and-medium enterprises.

Table 1. Continued

Study	Scenario basis[b]	Time horizon[c]	Scenario	Anticipated hazards, categorized[c,d,e]	Recommendations
Stacey *et al.* (2018)	3	4–10 years	ICTs and digitalization will create new OSH challenges and opportunities, resulting in four possible scenarios based on the cross-product of attitudes (government and public) and economic growth/technology applications: evolution, transformation, exploitation, and fragmentation.	**Physical**—Collaborative robots; decreased situational awareness; ergonomic challenges of working anytime and anywhere; exposure to electromagnetic fields (EMFs); loss of bone or muscle density from exoskeleton use; malfunctioning exoskeletons; misinterpreted or lost control commands; repetition; sedentary work; sleep loss from low-intensity light emitted by ICTs. **Psychosocial**—24/7 availability; AI; automation; blurred work/home boundaries; cognitive load; cyberbullying; cybersecurity; deskilling; inadequate regulatory frameworks; job changes; job destruction; lack of unions; longer working life; loss of social skills; monitoring technologies; multiple concurrent employers; nonstandard work arrangements; performance pressure; polarization; privacy invasion; remote management practices; self-employment; sabotage, skills gaps; stress; task deprivation; work-life fit; work pace.	Ensure a level playing field across diverse employment relationships. Ensure the large quantity of surveillance data generated is handled ethically. Implement smart personal protective equipment (PPE). Provide training on both new technologies and 'soft skills' relevant to nonstandard work arrangements (e.g. self-reliance, adaptability, resilience, cultural sensitivity). Use technology (e.g. AR, VR, AI algorithms) to accurately assess and develop effective prevention measures.
Stollt and Meinert (2010)	1	11+ years	Workers and unions may behave and react to changing work-related contexts in four different ways by 2030: life goes on, the grid, alone, and lost cake.	**Psychosocial**—Anger; complex systems; economic crises; isolation; loss of trade unions; poverty; precarious work; resource depletion; social exclusion; unemployment.	Develop strategic plans at the organization level. Identify leverage points for achieving organizational goals.

Table 1. Continued

Study	Scenario basis[b]	Time horizon[c]	Scenario	Anticipated hazards, categorized[d,e]	Recommendations
Subramony *et al.* (2018)	3	11+ years	Service work arrangements will evolve toward unclear employment relationships characterized by long-term social contracts, tightly defined work roles, and the physical proximity of workers and organizations	**Psychosocial**—Ambiguous normative cues; decreased self-worth; dehumanization; diminished sense of ownership; disengagement; insecurity; job dissatisfaction; lack of task and relational interdependence; role stressors; social alienation; turnover.	Build networks of mentors and coaches to assist with professional development. Communicate identity, values, and purpose of each work ecosystem to potential and current workers. Create safety nets to reduce unemployment and enable workers to pursue multiple assignments. Enforce guidelines for information confidentiality and privacy. Leverage social network platforms that are occupation-specific to reinforce a sense of belonging. Provide opportunities and feedback to enhance workers' feelings of competence. Use workers to work-related ecosystems.

[a]Scenario study categories: 1 = changing patterns of employment and work organization; 2 = management of technological change and human–robot interaction; 3 = occupational safety and health (OSH); 4 = ethical considerations.

[b]Basis: 1 = conjecture only; 2 = data only; 3 = conjecture and data.

[c]From date of publication.

[d]Hazards labeled psychosocial may also include those related to the organization of work.

[e]Some hazards were depicted as risk factors in the literature, whereas others were depicted as deleterious effects.

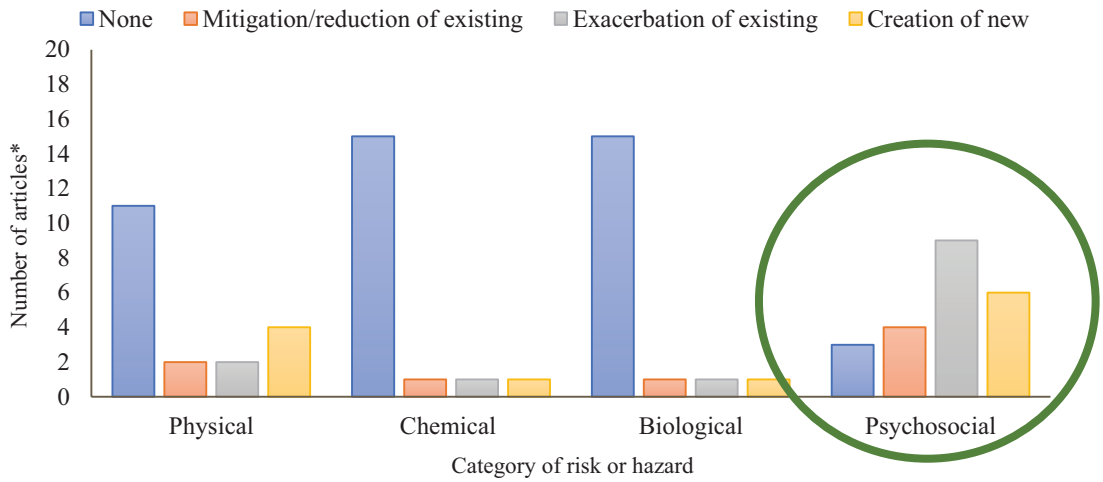
the growth of digitalization may impact gender patterns of workforce participation. The relationship between gender and new technology worker qualifications and identity could also change as technology is introduced into historically male-dominated workplaces and industries (e.g. mining) as physical strength is replaced by technological enhancements that will enable more women workers (Johansson *et al.*, 2017).

Management of technological change and human–robot interaction

According to the seven papers in this category, robots were identified as participating in many of the future work environments (Qureshi and Syed, 2014; Murashov *et al.*, 2016; Koppenborg *et al.*, 2017; Islam, 2018; Pham *et al.*, 2018; Pyke, 2018; Djebrouni and Wolbring, 2019). Key drivers for increased robot use include increasing labor costs and worker shortages (Qureshi and Syed, 2014). Both developed and developing countries are amenable to digitalization and automation, which fuels automation anxiety and causes workers to fear their contributions will become obsolete because of new technologies (Islam, 2018; Pham *et al.*, 2018; Pyke, 2018).

Some of the scenarios in this category (e.g. Pham *et al.*, 2018) speculate many workers will lose their jobs to workplace technologies, such as robots. Certain groups, such as people with disabilities, may benefit from new technologies while also being placed at increased risk of occupational marginalization because of robotics and human enhancements (Djebrouni and Wolbring, 2019). Although some non-scenario studies (e.g. Frey and Osborne, 2013; Baert and Ledent, 2015; Peruffo *et al.*, 2017) have predicted as many as 30–47% of jobs are at risk of automation, automation at the task level rather than occupation level is likely more realistic (Autor *et al.*, 2003).

The interaction of humans and machines—particularly robots—will depend on whether and how humans accept robots. Questions of trust may limit human acceptance rates for robots. Human factors are an important consideration in the design of robots as collaborative human-robot work environments become more common (Koppenborg *et al.*, 2017). For example, Johansson *et al.* (2017) observed a dearth of evidence quantifying the degree to which humans perceive, accept, and treat robots as replacements to human coworkers. Murashov *et al.* (2016) pointed out the labor force's longstanding experience with robots dating to the 1970s, which has influenced the development of various national and international standards for the safe design and use of robots, on which future policymakers can lean. The main hazards related to robots in the future of



* Categories of *mitigation/reduction, exacerbation,* and *creation* are not mutually exclusive. Totals sum to more than 17 in each risk/hazard category.

Figure 2. Frequency of job risks and hazards anticipated for the future of work in the peer-reviewed literature.

work are projected to be mechanical, electrical, thermal, and noise, with traumatic injuries being the greatest physical health effect expected (Murashov *et al*., 2016).

Occupational safety and health challenges

This category—comprised of four papers—provided commentary on OSH challenges associated with anticipated future of work scenarios (Hauke *et al*., 2018; Leso *et al*., 2018; Chia *et al*., 2019; Niu *et al*., 2019). Health and safety recommendations for issues highlighted below can be found in the Recommendations in the Literature section of this article.

Leso *et al*.'s (2018) review of 22 papers describing health and safety issues related to Industry 4.0 emphasized adverse psychological outcomes as the primary health concern for workers. Key issues and concerns in the technology-driven workplace of the future include mental overload, work density, a mismatch of workers' skills and task requirements, privacy invasion, reduced human-to-human contact, and unemployment (Leso *et al*., 2018). New types of accidents may result from a lack of guidance or standards for interfacing with new technologies, and workers may experience increasing tension between the virtual and the real world with increasing technological integration in the workplace (Leso *et al*., 2018).

Chia *et al*. (2019) presented a useful overview of the need for a new workplace safety and health strategy for Industry 4.0. They identified new hazards to well-being, including job displacement and blurring work/home boundaries. Their conclusion suggests current workplace safety and health strategies in developed countries, premised on a quantitative risk management model and traditional full-time employment, will be inadequate considering technological advancements and changing employment relations. They also noted the complexity of the human–machine interface may leave workers unable to cope with the intricacies of technological products and result in failure to use all their available functions. Other noteworthy hazards associated with Industry 4.0 will include psychosocial stressors from 24/7 digital work platforms, physical health risks related to nanoparticles and hazardous volatile organic compounds from additive manufacturing, and biological hazards from virulent and pathologic organisms in synthetic biology. These rapidly developing hazards may increase concern over the adequacy of surveillance systems for adverse effects in the future.

Hauke *et al*. (2018) conducted an online survey of 398 labor inspectors in Germany about future hazards for a variety of industries and occupations. Work intensification topped the list of hazards generated by these subject matter experts. They also expressed a belief that extension of responsibility (due to staff shortages) will go together with increased work intensity in the future.

Finally, Niu *et al*. (2019) focused on the construction sector and called for a smart construction object-enabled OSH management system. This was inspired by smart technologies [e.g. artificial intelligence (AI), robotics],

which provide the opportunity to develop a new wave of OSH management to address 'stagnant management' worldwide.

Ethical issues

Iavicoli *et al.* (2018) focused on ethical concerns in the changing world of work. They identified key drivers and barriers that will influence ethics for future OSH research and practice. Factors such as globalization, demographic changes, and increased technology use and advancements may bring new ethical challenges to the OSH field. In this future of work scenario, it may become increasingly important, yet difficult, to balance the wants, needs, and interests of workers (e.g. healthful and safe work and the right to be informed about risks) with those of organizations (e.g. maximizing production, rights to industrial secrecy) and the common good (e.g. community-level health, safety, and well-being).

Future of work scenarios and hazards in the gray literature

Future scenarios in the gray literature are summarized in Table 1B and were generally described in terms of business models, labor market changes, social values, and category of work (i.e. manual or cognitive). Main topics of these scenarios included technological impact on work, worker control, national economic outlooks, and worker capabilities.

The World Economic Forum (WEF, 2018a) identified eight future of work scenarios based on the rate of technological change and its impact on business models (steady or accelerated), the evolution of learning among the current and the future workforce (slow or fast), and the magnitude of talent mobility across geographies (low or high). The future of work will be defined by combinations of these variables, with different scenarios playing out simultaneously in different areas, industries, age cohorts, and socioeconomic groups (WEF, 2018a). OSH implications of these scenarios will vary based on the level of uncertainty generated and the resultant mental and physical health effects for workers.

The European Foundation for the Improvement of Living and Working Conditions (Eurofound, 2018) identified three broad scenarios for the future of work that combined applications of digital technologies to economic processes. The three categories included the automation of tasks, digitalization of processes, and coordination of platforms, which are considered social vectors of change (Eurofound, 2018). Automation of tasks will eliminate some types of work and create others. Critically, the work must be automated at the task level rather than the job or occupation level. This is particularly true for jobs comprised of non-routine and intellectual tasks, which represent a large portion of work today and would lead to high rates of displacement and unemployment if fully automated (Eurofound, 2018). Digitalization involves change in the work environment and the nature of work processes. Digitalization of economic processes raises some serious concerns for workers' autonomy, privacy, employment stability, income levels, work schedules, and work–life fit. Coordination of platforms is a direct response to changing employment conditions and regulations. A multiplatform system allows for the division of labor into very small tasks that can be tedious and repetitive, which is not an ideal psychosocial work environment and can be associated with feelings of alienation (Eurofound, 2018).

Brown *et al.* (2018) surveyed 10 029 people and identified four mega trends to explicate the future context for work. The trends represented poles on two axes: collectivism ('fairness and equality dominate') versus individualism ('me first rules') and business fragmentation ('small is powerful') versus corporate integration ('big business rules all'). Additionally, to better compete in these scenarios, 70% of respondents indicated that they would use 'treatments' to enhance their brain and body by 2030 if it would improve their employment prospects.

Degryse (2016) evaluated the rapidly evolving scenario of a digital economy and identified various hazards such as lack of job security, disruption of work–family balance, work intensification, stress, burnout, the virtualization of relationships, and the confusion between what is urgent and what is important. The issue of increased training of workers was identified as central to success in the digital economy.

Future of work scenarios and hazards in the supplemental literature

A seminal paper by Williams (2008) framed the issue of devising scenarios by identifying a common narrative structure that underpins a multitude of contrasting visions of employment in the future. These narratives adopt a similar storyline, in which all employment is classified into one of two categories (one of which is more favorable than the other) and then ordered into a temporal or normative sequence. In contrast to others' views, Williams argued for a multifaceted understanding of the future that recognizes heterogenous and multiple directions of employment. Commonly, many other scenarios used the 2 × 2 approach (Schultz, 2007; Ponce del Castillo and Meinert, 2016; Hajkowicz *et al.*, 2016; Korge, 2018; Dellot *et al.*, 2019).

Useful supplemental literature was identified and characterized (Table 1C). Using focus groups and a Delphi method, DeBruyne and Gerritse (2018) identified various scenarios of the future of work and their implications for the future physical workplace. Their findings suggest most workers will spend more time outside a traditional office environment by 2025, splitting their production time between the office, home, and elsewhere. This is due, in part, to the notion that future work will be characterized by a reduction in the amount of work that must be accomplished in a company. Instead, work will be comprised of more complex processes and human tasks that must be digitalized, namely knowledge-intensive and service-oriented work. This work will require collaboration with other employees or stakeholders in the supply chain.

Hazards identified by DeBruyne and Gerritse (2018) include the danger of being connected 24/7 and the deterioration of social cohesion within the organization. In addition, labor contracts are expected to shorten, and the number of guaranteed and long-term jobs is expected to diminish. The employment relationship in the future will no longer be connected to a specific function, but rather to where work makes a meaningful contribution to one or more projects, teams, or employers. Increased flexibility will have favorable or unfavorable consequences for work–life balance, and favorable and unfavorable impact on workers' experiences of burnout and their physical and emotional health (Bell and Blanchflower, 2018; DeBruyne and Gerritse 2018).

In a report from the European Agency for Safety and Health at Work (EU-OSHA), Stacey *et al.* (2018) developed four scenarios of the future of work, focusing on digitalization and new emerging risks associated with them. The overall conclusion was that digitalization and related technologies will have a profound effect on the world of work resulting in more complex and diversified work environments (see Table 2). The four scenarios fit into cells of a 2 × 2 matrix where one axis is 'governance and public attitude' (low to high) and the other 'economic growth and technology application' (low/resistive to high/supportive). The four scenarios are labeled: Evolution—half of jobs have changed, with 10% replaced by automation; Transformation—most jobs have changed, with 50% replaced or fundamentally changed by automation; Exploitation—half of jobs are fully automated, with high unemployment; and Fragmentation—20% of mainly lower skilled jobs are fully automated.

More generally, the Reserve Bank of Australia identified four categories of work based on underlying skill context: (i) non-routine cognitive, (ii) non-routine manual, (iii) routine cognitive, and (iv) routine manual to characterize jobs (Acemoglu and Autor, 2010; Healy *et al.*, 2017) see Supplementary Appendix IV. Analyses of Australian data showed a shift away from routine employment towards non-routine employment over the last 30 years, demonstrating that the distribution of work is changing. Considering the empirically supported 'routinization hypothesis', which posits that technology is displacing workers performing routine tasks, Healy *et al.* (2017) compared four reports from Europe (Méda, 2016), the UK (UKCES, 2014), the USA (Shift, 2017), and Australia (CSIRO, 2016) to imagine and contrast multiple future scenarios, simultaneously. Although these reports differ vastly in their purposes, they can be categorized as having optimistic, pessimistic, or mixed (majority) scenarios. Optimistic scenarios described a world of full employment and environmental sustainability, whereas pessimistic scenarios depicted a world with fundamentally weak labor markets, fewer worker protections, and large social inequality. The mixed scenarios revealed a world in which technological change has driven the automation of work, including skilled jobs, to the point of widespread technological unemployment and fragmented tasks, resulting in societal and political pressure to reduce the negative effects (Healy *et al.*, 2017).

In another analysis, Daheim and Wintermann (2016) described the findings of an international Delphi Study by the Millennium Project, in which three highly specific alternative visions of the future were presented. All three scenarios assumed rapid technological change and radical impact on work, where in-demand skills will be unlike those touted today and human–machine cooperation will be more widespread. The three scenarios ranged from depicting accelerated technology, to social and economic change, to political and economic turmoil, to self-actualized economies throughout the world.

Subramony *et al.* (2018) described important hazards in a future scenario for service workers by 2050. The scenario was predicated on a transformation of traditional employee ongoing organizational relationships and work arrangements to a clearly less defined employee relationship, where an employer promotes opened-ended inducements to control the process by which work is performed. In line with this observation, other investigators noted that 'the constant search for the next gig might be a source of anxiety as it involves a sense of job security that engenders emotional examination' (p. 966), (Cappelli and Keller, 2013). This scenario increasingly relies on transient just-in-time work, which raises multiple concerns regarding the nature of

Table 2. Potential hazards in the future of work

Work equipment and tools	How work is organized and managed	Employment status, hierarchies, and relationships	Characteristics of the workforce	Responsibilities for managing OSH	Skills, knowledge and information requirements
Exposure to hazardous substances	Flexibility blurring work/life boundaries	Work casualization/online platforms	Dispersed workforce	Online platform economy	New skills and training needs
Exposure to physical hazards	Digital additions	Autonomous workers	Diverse workforce	Continuity of OSH surveillance and associated records	Lifelong learning
EMF	Digitalized management methods	Lone workers	Multidisciplinary working	Demonstration of compliance	Self-directed online learning
Manual handling	Performance pressure	Loss of social skills and cyber-bulling	Extended working life	Addressing performance enhancing drugs	Knowledge transfer
Sedentary work	Constant oversight	Collaborative employment	New workers	Privacy and confidentiality of sensor data	Deskilling
Workstation ergonomics	Privacy invasion	New collective bargaining methods	Inequality	Respondent to changing climate	Corporate learning
Risk intensification	Cyber security	Worker displacement	Disautomation of aging workers	OSH field not equipped to provide preventative guidance	Self-directed online learning
Control commands lost in transmission	Non-related stress	Unemployment	Discrimination of migrants		
Human–machine interaction and cognitive demands			Discrimination of women workers		
Unforeseen situations					
Lack of transparency of algorithms					
Lack of situational awareness					
Malfunction caused by sabotage					
Traumatic injuries					
Mix of old and new technologies					
Smart PPE					
Over confidence					
Physical discomfort					
Work identified					

Source: Adapted from Stacey *et al.* (2018).

work and the effect on worker well-being, including dehumanization of work and increased stress due to job insecurity and periods of involuntarily unemployment.

The use of AI in Europe may be viewed as a hazard scenario that was analyzed for the ethical issues involved in promoting trustworthy AI (HLEG, 2019). The report of the scenario identifies the principle of preventing harm as critical to consider when deploying AI. Moreover, it concluded that the OSH implications for workers, especially vulnerable groups, must be transparently understood as well as the overall technical robustness and safety and the impact on human autonomy. This report is useful because already there is nascent evidence of hazards of unfair treatment and discrimination (Moore, 2019).

The human–machine interaction scenario for AI-enabled technologies was described by Howard (2019), who noted that 'systems controls which are not fully understandable to humans or fully responsive in practice as they were in design can lead to negative consequences. […] Some accident analyses may be biased to safeguard the integrity of the technical system at the expense of the nearest human operators' (Howard, 2019, p. 921; Elish, 2019). Also, Janssen *et al*., (2019) identified 'mode confusion' as a critical factor that can influence workers' trust in automation and operation of it. Mode confusion occurs when the abstraction of information is insufficient for the user to anticipate a machine's state (Maeda and Ushio, 2017). In the coming years, human interactions with automation are expected to be the subject of mode confusion (Janssen *et al*., 2019).

Just as past industrial revolutions initiated a broad pattern of industrialization that led to sweeping social and political change, so too is AI emergence likely to significantly influence the global economy. 'The integration of AI technologies across human society could also spark a process of cognization analogous to changes wrought by industrialization' (Scharre *et al*., 2018, p. 3). Hazards to workers are not inherent in AI but may arise from how it is implemented (Moore, 2019).

An ad hoc and snowball search of the scientific and gray literature led to the identification of critical themes that will influence the future of work. The themes pertain to the following factors: technological, demographic (young, older, women, migrant, and disabled workers), temporal (time, work, and leisure), global, urban, climate-related, human enhancements (cognitive, physical, worker monitoring), hazardous exposures, advanced manufacturing, biotechnology synthetic biology, sustainability, and political and economic factors. These themes are summarized in Table 3 and described further in Supplementary Appendix III.

Discussion

Inequality as an underlying factor in future scenarios

The concept of unequal distribution of wealth, income, opportunity, gender, race, and access to information underlays many of the scenarios in the gray and supplemental literature (e.g. Daheim and Wintermann, 2016; Shift, 2017; Stacey *et al*., 2018; Brown *et al*., 2018). Clearly, there is a broad awareness and growing discourse on the negative consequences of inequality in the world (Piketty, 2014; Joyce and Xu, 2019). There is a growing consensus that in the future, the changing nature of work may exacerbate these inequalities. Inequality, at the individual or population level, has important consequences for health, which can affect employability, job maintenance, and job opportunities (NASEM, 2017).

OSH implications of the future of work

The various scenarios and projections of the future of work synthesized from the scientific, gray, and supplemental literature identify many hazards with OSH implications as summarized in Tables 1–3. The future of work and its impact on workers will be a mosaic of longstanding hazards that currently exist (e.g. exposures to chemicals, physical, radiological and biological agents); slips, trips, and falls; musculoskeletal hazards; repetitive work and manual material handling; longstanding hazards in new jobs (e.g. psychosocial stress due to technological displacement); and new hazards in new jobs (e.g. collisions with robots, discriminatory monitoring of workers through wearable sensors, and human–machine role ambiguity; Murashov *et al*., 2016; Peckham *et al*., 2017; Badri *et al*., 2018; Leso *et al*., 2018; Pot, 2018; Stacey *et al*., 2018). Figure 3 provides a strategy for assessing these old and new hazards in existing and future jobs.

The unflagging pressure of technology on workers, as manifested by the increasing pace and intensity of work and the expectation for humans to be able to function effectively with robots and in response to algorithms, could have devastating consequences (Marchant *et al*., 2014; Degryse, 2016). Flexible labor markets and the decline of trade unions may put future workers at risk of decreased job protection, whereas automation, lack of skills, and the inability to fill job vacancies may put as many as 400 million workers worldwide at risk of job displacement (MGI, 2017). Furthermore, workers displaced by technology will not necessarily be the same workers hired for new jobs created by technology. All these changes are predicted to lead to the development

Table 3. Critical themes in the future of work literature[a]

Technological inevitability	Technology alone will not shape the future of work; social context dialogue and process are key (Winner, 1998; Perez, 2002; Little, 2008; Lemieux, 2014; Autor, 2015; Curry, 2015; Susskind and Susskind, 2015; ILO, 2017a; Creticos, 2018).
Young workers	Many children that entered school in recent years are projected to work with skills that do not yet exist. The demand for advanced cognitive and behavioral skills will increase and the demand for narrow job-specific skills will continue to decrease. (Krueger and Kuman, 2004; Council for Work and Health, 2014; Ederer *et al*., 2015; Cunningham and Villasenos, 2016; McGuinness *et al*., 2017; World Bank Group, 2019).
Older workers	Workers aged 55 and over (during the next few decades) will become one of the fastest growing segments of the workforce in many countries (ILO, 2018). Countries with higher rates of projected aging generally have larger proportions of older workers at risk of automation (Paton, 2014; Foresight, 2016; Basu *et al*., 2018; Harris *et al*., 2018; Healy and Williams, 2018; McGowen and Corrado, 2019).
Women workers	Women and men may experience technological job displacement differently since women traditionally perform more routine cognitive tasks. Women need to have more access to technology and training (Brussevich *et al*., 2018; World Bank Group, 2019).
Migrant workers	In the future, there is likely to be more than 160 million migrant workers globally. Migrant workers frequently experience increased rates of morbidity, mortality, and injury. (ILO, 2017b; IOM, 2017; Flynn and Wickramage, 2017; ESPAS, 2018).
Workers with disabilities	Future of work literature is linked to research focused on those living and working with disabilities. New technologies may both help and discriminate against persons with disabilities (Department of Work and Pensions, 2017; Kanady, 2018).
Time, work, and leisure	There is a general perception that the 'pace of life' is accelerating and social acceleration has been linked to shorter attention spans (Lorenz-Spreen *et al*., 2019). Time availability is an important determinant of work, leisure, and work–life balance (Karasek, 1979; Cooper *et al*., 2001; Meireles, 2005; Eurofound, 2012; Moore and Tenney, 2012; Rosa, 2013; Vostal, 2014; Eurofound, 2015; Wajcman, 2015; Kubicek *et al*., 2015; Ordonez *et al*., 2015; Whatley, 2018).
Social isolation and loneliness	Decentralized work may lead to social isolation and loneliness. Loneliness may have an impact on mortality equivalent to smoking 15 cigarettes per day (Rook, 1984; Murthy, 2017; Holt-Lunstad *et al*., 2010; Jeffrey *et al*., 2017; Nemecek, 2018; Ozcelik and Barsade, 2018; McMillan, 2019; Patel *et al*., 2019).
Globalization	A new phase of globalization is likely but will still be a determinant of job loss (due to 'off-shoring'), which is associated with adverse health effects (Benach *et al*., 2004; Kawachi, 2008; Dobbs *et al*., 2015).
Urbanization	In addition to worker safety and security indirect factors such as wage polarization, housing costs, and need for social services will be critical issues for how the future of work will be impacted by and impact urbanization (OECD, 2014; DuPuis *et al*., 2016; WEF, 2018a).
Climate-related factors	Outdoor work will be hotter. Working capacity of heat-exposed workers is expected to decrease, while deaths and illness in workers exposed to heat is expected to increase (Dunne *et al*., 2013; Kjellstrom *et al*., 2014; Schulte *et al*., 2016; Clayton *et al*., 2017; Maitre *et al*., 2018; Rigaud *et al*., 2018; Sylla *et al*., 2018; Cho, 2019; Dong *et al*., 2019).
Cognitive enhancement	Increased use of cognitive enhancing drugs is likely. Drugs that enhance cognitive capabilities (and that may also have physical effects) may be inappropriately promoted instead of work organization improvements (Dale and Bloomfield, 2016; MarketWatch, 2018).
Physical enhancement	Growing use of physical enhancements (such as exoskeletons) may increase the incidence of deleterious effects (Academy of Medical Sciences, 2012; Federici *et al*., 2015; Young and Ferris, 2017; Zingman *et al*., 2017; McGowan, 2018; Butler and Gillette, 2019; Hargreaves *et al*., 2019).
Worker monitoring	Wearable sensors or other monitoring technologies may result in violation of privacy and autonomy and lead to discrimination (Bandodkar *et al*., 2016; Moore, 2018; EU-OSHA, 2019; Zuboff, 2019).
Advanced manufacturing	Advances that involve changes in the process of manufacturing may present new hazards and old hazards in new settings (Hassall, 2015; Geraci *et al*., 2018; Pomeroy-Carter *et al*., 2018; Roth *et al*., 2019; Wang *et al*., 2020).

Table 3. Continued

Hazardous exposures and disease	There are a vast number of chemicals in commerce and millions of workers with exposures to them (Calvert *et al*., 2012). Exposures may put them more at risk of occupational cancer may lead to occupational cancers in the future. There maybe a shift of exposures to developing nations. Also, physical, biological, radiological, and musculoskeletal factors also can be hazardous to large number of workers (EU-OSHA, 2007; Watanabe *et al*., 2011; Haagsma *et al*., 2012; Valencia, 2013; UNECE, 2015; Madhav *et al*., 2017; Fritschi, 2019; Wang, 2020; Siemiatycki and Rushton, 2020; Shearer *et al*., 2020).
Biotechnology and synthetic biology	Biological processes may become a major source of economic growth. Creation of new or altered life raises significant concern about potential health effects and ethical issues (Hewett *et al*., 2016; NAS, 2017; Howard *et al*., 2017; Gomez-Tatay and Hernandez-Andreu, 2019).
Sustainability	Many future workers may seek jobs that practice or address sustainability. Focusing on sustainability may be a new approach for advancing worker safety and health (OSHA, 2016). However, green jobs may have hazards (Brundtland, 1987; Bradbrook *et al*., 2013).
Political and economic factors	How societies organize and conduct themselves will favorably or unfavorably influence working conditions and the future of work (Walters and Wadsworth, 2014; Lippel *et al*., 2017; Chandy, 2016; Pyke, 2018; Kinder, 2019).

[a]See Supplementary Appendix III for discussion of each theme.

of an array of psychosocial factors that can, in turn, lead to physical and psychological health effects (Benach *et al*., 2004; Koranyi *et al*., 2019; Rönnblad *et al*., 2019). These hazards will arise from work tasks, the precarity of work, and job insecurities, and are relevant not only for workers sufficiently employed but also for workers classified as either underemployed or unemployed (Janlert, 1997; Dooley, 2003; Dorling, 2009; Bjorklund *et al*., 2015; Benach *et al*., 2016).

Indeed, for the first time in the modern era, economic growth is becoming detached from employment. Brynjolfsson and McAfee (2014) refer to this as the 'great uncoupling'. It is unknown whether the unemployment that will result from technological and economic change will be a transitional or long-term effect, though some populations will become unemployed. The cohort of displaced workers and their dependents may need social protection and mitigating action. Long periods of unemployment may lead to depression, anxiety, poor self-esteem, divorce, substance abuse, increased chronic diseases, suicide, and mortality (Henkel, 2011; Marchant *et al*., 2014). What is more, unemployment may result in a lack of meaning in the lives of workers even if income substitution options can be implemented. The elimination of work itself may also be a source of dehumanization, despite the economic premise that favors leisure over work (Mokyr *et al*., 2015).

Increasingly, investigators are aware of the need to assess the hazards workers face over their life course to account for the dynamic relationship between work, nonwork, and health that evolves over time (Janlert, 1997; Burdorf, 2012; Amick *et al*., 2016; Degryse, 2016; Serra *et al*., 2017; Schulte *et al*., 2017). To that end, the concept of 'worker well-being' is becoming the current and future goal of the OSH field (Anttonen and Rasänen, 2008; Allen, 2014; Schulte *et al*., 2015; Chari *et al*., 2018). Therefore, it is critical to assess the hazards and precariousness due to jobs and between jobs in one's working life, and essential to consider the integration of work and nonwork (Standing, 2011; Schulte *et al*., 2015, 2017; Amick *et al*., 2016; Bell and Blanchflower, 2018). This will be especially important in the future of work, given evidence to date on the impact of changing jobs, being displaced from jobs, and not being able to get a job (Degryse, 2016; Rönnblad *et al*., 2019). Indeed, along with the well-established physical, ergonomic, chemical, radiological, biological, and other hazards, many of the determinants of worker well-being are and will be expected to be psychosocial in nature and related to the quality and availability of work (Degryse, 2016; DeBruyne and Gerritse, 2018; Jain *et al*., 2018; Leso *et al*., 2018; Stacey *et al*., 2018).

Recommendations in the literature

The future of work will be a mosaic of scenarios of old, current, and new jobs and hazards (see Fig. 3). Below, the authors outline select key recommendations found during the course of the review process (see Tables 1 and 2). The looming question is what can be done to shape the future, today. Overall, there will need to be collaborative efforts among stakeholders and other decision-makers on the implementation of measures to ensure a smooth and safe transition to the future (ILO, 2017a; Badri *et al*., 2018; OECD, 2019). Critical in this quest is how to prevent and manage psychosocial

risks, which are already superseding physical health risks and are of growing concern for the future workforce (Degryse, 2016; ILO, 2017a; Stacey *et al*., 2018). Badri *et al*. (2018) also identified 12 recommendations to foster this transition successfully. Among them were efforts to conduct research on psychosocial risks, prevention through design, and research on emergent risks at all levels of production. Another common recommendation found in the literature to help remedy key potential hazards workers will face is to provide them with lifelong and future-ready adult learning, training, reskilling, and upskilling (Bradbrook *et al*., 2013; British Safety Council, 2018; Stockton *et al*., 2018; OECD, 2019; Work Bank Group, 2019). Also, universal basic income has been raised as an intervention for precarious or nonstandard work (Hoynes and Rothstein, 2019).

Various investigators identified preventive measures related to future hazards. Howard (2019) concluded that 'a proactive approach to AI and its implications for the future of work requires OSH professionals develop strategic foresight to anticipate and prepare for the possibilities and challenges of AI-enabled technologies on worker safety, health, and well-being' (p. 922). Similarly, Leso *et al*. (2018) identified the need for risk assessment at the process design phase. They also promoted the need for international standards and adequate-specific training of workers. The EU-OSHA published a model of new and emergent risks to evaluate work settings. To complement and clarify the EU-OSHA (2013) definition, Fernandez and Perez (2015) developed a more refined risk model applicable to advanced manufacturing processes.

An RSA survey of British Members of Parliament revealed concern for the impact of technology, but 43% of respondents indicated lack of knowledge regarding how to influence it (Dellot *et al*., 2019). The RSA report on the future of work explains that we do have choices: 'We can choose to establish a robust regulatory regime for technology and data rights […] to create a tax system that shifts the burden onto those with the broadest shoulders […] to overhaul our education system so that we treat lifelong learning more seriously…[or] to create a competition policy that stands up to the power of large firms when they impinge on the wellbeing of workers' (Dellot *et al*., 2019, p. 3).

Types of Jobs	Future Work Hazards	
	Old	New
Traditional jobs	• Utilize the body of knowledge from safety, industrial hygiene and occupational medicine. • Identify where old hazards are not being addressed adequately. • Determine how to apply what we already know to a re-employed/re-deployed workforce.	• Develop agenda to investigate new hazards in old jobs. • Conduct ongoing assessment of guidance and regulations. • Conduct timely support research, disseminate results and transfer it into practice.
Future jobs	• Determine the extent to which old hazards will be manifest in future jobs. • Determine how to adapt old guidance to new jobs. • Determine how to identify and apply "old" knowledge to these new jobs.	• Be alert for sentinel events. • Identify leading indicators. • Identify new scenarios. • Use forecasting.

(Adapted from National Institute for Occupational Safety and Health [NIOSH] (2013)

Figure 3. Strategy for assessing hazards in the future of work.

Another approach by EU-OSHA (Stacey *et al.*, 2018) identified various strategies that could mitigate the OSH challenges of digitalization and ICI-enabled technologies:

- The development of an ethical framework for digitalization and codes of conduct
- A strong 'prevention through design' approach that integrates a user/worker-centered design approach
- Collaboration between academics, industry, social partners, and governments on research and innovation in developments by information and communication technology-emerging technologies (ICT-ETs)/digital technologies to properly take account of the human aspects
- The involvement of workers in the implementation of any digitalization strategies
- Advanced workplace risk assessments, using the unprecedented opportunities offered by ICT-ETs, while also considering the full range of their possible impacts in terms of OSH challenges, as identified in this foresight project
- A regulatory framework to clarify OSH liabilities and responsibilities in relation to new systems and new ways of working
- An adapted education system and training for workers
- The provision of effective OSH services to digital workers

A critical next step is identifying mechanisms to accurately predict which jobs and tasks will change and disappear, including the timeframes in which these changes will occur (Chang and Huynh, 2016; Peruffo *et al.*, 2017). In 2013, Vasic and Billard (2013) urgently called for a definition of robots, which may replace workers, and for specific safety guidelines to be addressed by the scientific and industrial community. They identified autonomous vehicles and mobile robots as two of the most urgent areas where safety guidelines are needed.

The International SOS Foundation (2018) assessed what significant OSH changes need to be prepared for by 2030. Based on a global survey, key results revealed that 84% of respondents believed there will be an increase in complexity of health and safety requirements. Four major global factors include the (i) UN 2030 Agenda for Sustainable Development and its Sustainable Development Goals; (ii) revised Occupational Health and Safety Global Reporting Initiative (GRI) Standard; (iii) the ISO 45001; and (iv) ILO Guidelines on Occupational Safety and Health Management Systems. More than half of the survey respondents anticipated that health, safety, and environment will be a board level or 'C-suite' role by 2030. New scenarios and hazards and a growing incidence and prevalence of noncommunicable disease will present future challenges to the OSH field. To meet these challenges, the field may require a holistic 'biopsychosocial' approach (one that addresses the interconnection between biology, psychology, and socioeconomic factors) to promote health, well-being, and workability (Harrison and Dawson, 2016).

Peckham *et al.* (2017) suggested that the changing nature of work requires a reconceptualization of occupational health in the future and a more holistic and public health-oriented model addressing worker health. The broader concept of worker well-being also emerged as one that will be considered in the 21st century (Chen and Cooper, 2014; Schulte *et al.*, 2015; Litchfield *et al.*, 2016; Peckham *et al.*, 2017; Hudson *et al.*, 2019).

The ILO (2019) called for a more 'human-centered' agenda for the future of work and safety and health to address not only hazards in a single job but also along the work–life continuum. To this end, in January 2019, the ILO Global Commission on the future of work called for a Universal Labour Guarantee, including fundamental workers' rights, an 'adequate living wage', limits on hours of work, ensuring safe and healthy workplaces, as well as the recognition of safety and health at work as a fundamental principle and right at work.

Limitations

The current study was designed to characterize future of work scenarios and hazards described in the published literature rather than offer a critical review of the extant literature. As such, it was delimited to sources from the peer-reviewed and gray literature that included descriptions of the future, which met Bishop *et al.*'s (2007) definition of 'scenario'. Critical studies and commentaries focused on present OSH conditions or trend extrapolation were not included. However, to ensure the current study's literature review strategy captured a comprehensive set of future of work perspectives, author affiliations were assessed for the 36 peer-reviewed, gray, and supplemental scenario sources. The affiliations included a considerable mix of academic/professional disciplines (e.g. OSH, economics, business management, engineering, and social science) and countries of origin (e.g. USA, Western Europe, Australia, China, Saudi Arabia, and Singapore), offering no evidence of any obvious skew or bias in the alternative futures that were reviewed. There were, however, notable gaps in the future of work scenarios that were identified by the three-pronged search methodology. Generally, the scenarios were described in broader labor

market terms. They frequently provided nonspecific depictions of work in the future, describing tasks in terms dichotomized axes (e.g. 'manual or cognitive'; 'routine or non-routine'). The scenarios also included a lack of attention to topics frequently considered critical in future projections, such as climate change, infectious disease, social isolation, and the burden of chronic disease. Rare, too, was the inclusion of worker voice or input in the visioning and development of the future of work. Recent events illustrate the significant lack of attention to pandemics in the future of work literature. Although the future of work is driven by powerful forces such as technology, demographics, and globalization, the current COVID-19 pandemic could have a modifying effect by accelerating trends already underway (McGowan 2020). These trends include isolation of many workers, exacerbating inequalities among workers, and displacing workers from jobs. Though there is little empirical evidence on the effect of pandemics on work and the economy, there have been many predictions that future pandemics are likely, and the COVID-19 illustrates the way a pandemic can change work. This pandemic is likely to have long-term impacts and will serve as a warning for preparing for future ones.

Consequently, the authors of the current review provide a detailed discussion of these and many other factors that may influence the future of work in Supplementary Appendix III. A summary of that discussion is offered in Table 3.

Conclusion

Critical in the future will be how the workplace and work continue to evolve and how the workforce will subsequently be impacted. A preponderance of scenarios and reports indicate the potential for a large prevalence of psychosocial hazards in work or from lack of work. Despite the historical record that technology has generally produced more jobs than it has displaced, concern remains that technology will lead to a future where available jobs are fewer in number and extreme in quality, either very high or very low, with little available middle ground (ILO, 2017a). This is particularly true in countries with higher rates of projected aging. These countries tend to have a larger proportion of older workers at risk of automation (Basu *et al.*, 2018). Two problematic situations are likely to occur. First, many workers will suffer from anxiety and stress due to job possibilities or the lack thereof. Second, although many workers will likely acquire new jobs after displacement, a cohort of workers will not. These individuals will require supportive services and resources that may not be adequately available. To avoid a bleak future, technology and work must be managed collectively in the interest of generating international solutions (ILO, 2017a). Clearly, increased future of work-related global dialogue, support, investment, and commitment will be required with relevant OSH stakeholders and partners at all levels. This review may provide a useful resource for such deliberations.

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Conflict of interest

The authors declare no conflict of interest relating to the material presented in this article.

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