Safety Management and Human Factors, Vol. 64, 2022, 221–228
https://doi.org/10.54941/ahfe1002649

Human-Machine Interaction Safety in Manufacturing: A Scoping Review

Ilaria Lombardi[1], Sonia Capece[1], Maria Grazia Lourdes Monaco[2], and Mario Buono[1]

[1]Department of Industrial Engineering, University of Campania Luigi Vanvitelli, 81031 Aversa, Italy
[2]Occupational Medicine Unit, University Hospital of Verona, 37134 Verona, Italy

ABSTRACT

As a consequence of robotics integration in industrial production processes, physical and mental stress levels due to human-machine interaction increased, potentially increasing production errors and worker injuries. A systematic scoping review of the literature published in the last 20 years was carried out via PubMed, Scopus, Web of Science, and Embase to answer this question: 'What is known from the current literature about the effects of human-machine interaction in the workplace?'. The analysis highlighted that the main problems were due to the lack of ergonomy in the work organisation, especially regarding cognitive aspects, and the reduced attention threshold associated with the monotony and repetitiveness of the work tasks. Training and information were the essential aspects in managing the reduction of accidents, also using new technologies such as cross-reality.

Keywords: Human-Machine interaction, Health and safety, Occupational risks, Manufacturing, Injures, Human factors

INTRODUCTION

Industrialisation has led to the widespread use of tools and machines in daily life and the workplace. Still, we have moved to user-centred design in the last few decades and introduced ergonomics or Human Factors (Buono and Capece, 2016). Occupational health and safety have been improved by adapting machines and tools to human capabilities, limitations and anatomy. Today, work systems are increasingly built on a foundation of a system consisting of workers, tools, tasks, and work contexts (Flaspoler et al. 2009). Rapid advances in automation and digitisation mean that current working conditions are subject to dynamic change, especially in industrial environments (Körner et al., 2018), which are objectively exposed to risk given the high rates of occupational injuries and deaths that are regularly encountered (Song and Awolusi, 2020).

Throughout EU-OSHA's European Agency for Safety and Health at Work reports, including the third European Survey of Enterprises on New and Emerging Risks (ESENER-3), workplace health and safety risks are analysed, focusing on psychosocial risks related to work and new technologies

linked to Industry 4.0 (Irastorza, 2019). In spring/summer 2019, a total of 45,420 establishments - across all business sectors and employing at least five people - were surveyed in the 33 countries covered. Although on the one hand, psychosocial and ergonomic factors also related to human-machine interaction resulted in critical issues, on the other hand mechanisation and digitisation play an important role in mitigating these risks. In particular, the introduction and use of digital technologies such as wearable devices and artificial intelligence is an opportunity to support manufacturing processes and workplace safety. Focusing on the possible impacts of automation systems within production lines, the need for ongoing training to keep skills up-to-date is apparent from 79% of the factories surveyed in the EU28. Technology touched on other important points such as workstation set-up and working hours (66%), as well as making it easier for the operator to sit for long periods (65%) and perform repetitive movements (60%) (Irastorza, 2019).

The paper aimed to summarise available research to answer the following question: 'What is known from the current literature about the effects of human-machine interaction in the workplace?'.

METHODS

References were screened by setting the database parameters to English, manufacturing, and study type (original articles published in the peer-reviewed journal). Studies published between January 1990 and March 2020 were searched for in PubMed, Scopus, Web of Science, and Embase. The paper is based on a literature review focused on workplace safety in the manufacturing sector. The following keywords (MESH and non-MESH terms) were used: 'Human-machine' OR 'Human-robot' OR 'Human-computer' AND 'Interaction*' OR 'Interface*' OR 'Cooperation' AND 'Occupational' OR 'Work*'. Two reviewers independently screened the citations (title and abstract) identified from all sources. Subsequently, full-text articles were reviewed to determine the final set of eligible studies. Disagreements were resolved by discussion with the remaining authors. A data extraction form was developed to determine which variables to extract. The following items were included: article identifiers (authors, year of publication); study identifiers (sample size, design, country); the aim of the study; main results. A qualitative description of the included studies can be found below. Tables and diagrams are used to synthesise the main findings. The selection process was carried out using some freeware (Zotero, Rayyan). PRISMA-ScR guidelines on conducting systematic scoping reviews were followed (Tricco et al. 2018).

RESULTS

A total of 8,122 papers were identified and, after removing duplicates, 1,834 available articles were selected. According to the inclusion and exclusion criteria, 11 articles were included in the final analysis (see Figure n.1).

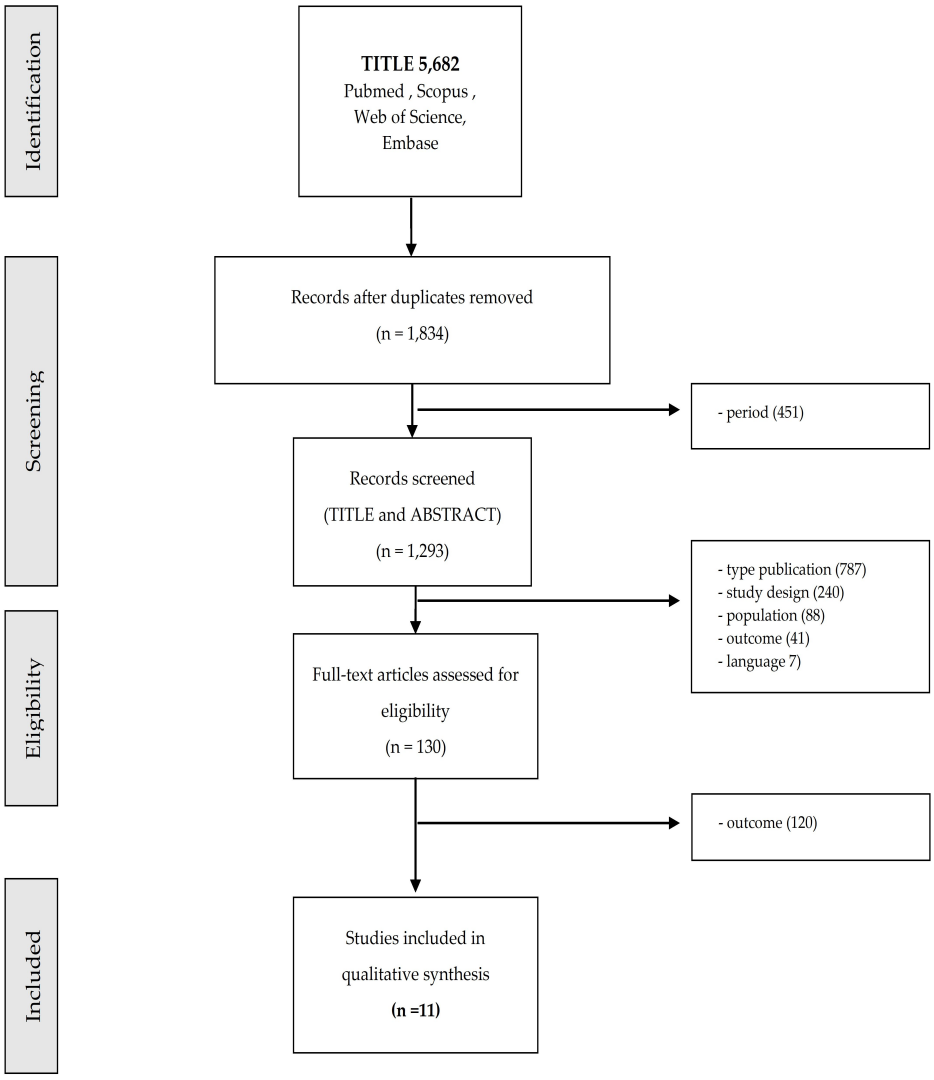

Figure 1: Flow chart diagram depicting the different phases of studies selection process.

DISCUSSION AND CONCLUSION

The current research on safety in the workplace concerning human-machine interaction shows how this is influenced by the characteristics and modalities of the interaction itself. The evaluation of the quality of the interaction with the machine and the safety levels in the workplace can proceed according to two different approaches: the empirical approach that involves samples of users who interact with the machine performing various activities; the analytical approach that does not involve users as test subjects, because one or

Table 1. Summary of articles selected.

Author, year	Country	Setting	Sample size	Study aims	Main findings
Ayaz H. et al., 2012	USA	Laboratory	24 volunteers (age ranged between 24 to 55 years)	To describe an accurate measure of mental workload in human operators as a critical element of monitoring and adaptive aiding systems designed to improve the efficiency and safety of human-machine systems during critical tasks.	Results indicate that Functional Near Infrared (fNIR) measures are sensitive to mental task load and practice level and provide evidence of the fNIR deployment in the field for its ability to monitor hemodynamic changes associated with relative cognitive workload changes of operators.
Biondi FN et al., 2021	Canada	Laboratory	22 volunteers (12 men, 10 women)	To investigate the effect of cognitive overload on assembly task performance and muscle activity	Working under a high cognitive load not only results in greater muscle activity (greater integrated sEMG) but also affects assembly task completion times, which may directly affect manufacturing cycle times.
Das L. et al., 2017	India	Laboratory	Not specified	To describe a new framework for operator learning and illustrate it using experimental studies	The available input (from eye-tracking) and output (operator actions) data when suitably analysed with respect to the process state can aid in inferring the operator's mental model at any given time. Based on the model, the operator's current knowledge can be deduced and gaps identified.
Fern et al., 2013	Germany	Laboratory	Not applicable	To describe a cognitive model to infer the more likely user's states in data-intensive contexts.	EEG and ECG input variables are represented in a probabilistic model in which links are defined based on the literature. The outcome of the model is a probability of being inept to perform in a suitable way. In case of inaptitude, assistance should be delivered to the user to normalise the current user's state.
Herpers R. et al., 2013	UK	On the field	Not specified	To develop a safety evaluation strategy that applies VR and mixed reality technologies to investigate the usability of working machines.	An evaluation of the study demonstrated that even experienced metal workers accepted the simulation and reacted as if the given task was real. Behavioural data of considered subjects showed comparable profiles and most subjects rated the VR-based approach as a reasonable means for investigating work safety problems.
Körner U. et al., 2018	Germany	Laboratory	36 workers 5 different companies	To identify potential stressors associated with the introduction and use of modern technologies in the manufacturing industry.	The results show that stressors linked to human-machine interaction are technical problems, poor usability, low situation awareness, and increased requirements on employees qualification.

Continued.

Table 1. Continued.

Author, year	Country	Setting	Sample size	Study aims	Main findings
Lu CW. et al., 2012	China	On the field	281 workers (70 male, 211 female)	To investigate the risk of musculoskeletal disorders because of the long work hours and the repetitive activities in an unfitted workstation.	The result shows that the participants reported high musculoskeletal disorder symptoms in the shoulder (59.8%), neck (49.5%), wrist (39.5%), and upper back (30.6%). And, to reduce the ergonomic risk factors, revising the height of the workbenches, chairs and redesigning the truck to decrease the chance of unsuitable positions were recommended and to reduce other ergonomics hazards and set a good human-machine interface and appropriate job design.
Medvedyk Y. et al., 2019	Ukraine	Laboratory	10 volunteers (age ranged between 16 to 25 years)	To create a simple and optimal system for monitoring the quality of cognitive tasks under the influence of external stressors (noise, interference, vibration, etc.) for application in field conditions, verify if the reliable measurement is possible and to determine the recommendations to the measuring system sufficiently simple and sufficiently precise to carry out such measurements.	This preliminary study focuses on the problem of the stress factors influence on the ability of a person to perform mental work. Within the framework of the study, the analysis of changes in human physiological parameters in stress conditions was monitored and experimental studies of the influence of stress factors on solving cognitive tasks using pupillometry were conducted.
Sauer J. et al., 2019	Switzerland	Laboratory	Not applicable	To investigate the issue of social stress in human-machine interaction.	The review shows that a closer link is needed between the separate literature on social stress and automation. Finally, three mechanisms are proposed that may predict how social stress may affect performance: 'blank-out'-mechanism, 'rumination'-mechanism, and 'increased-motivation'-mechanism.
Shahab MA. et al., 2021	India	Laboratory	10 workers 486 tasks	To propose an eye-tracking-based approach that uses the operator's attention allocation during different pre-specified training scenarios along with process data, alarm information, and operator actions.	The salience metric (quantifies the extent of proactive monitoring using time-based information obtained from the trend of process variables. The authors demonstrate the applicability of these metrics to assessing operators' expertise using various case studies. The quantification offered by the metrics precludes subjective factors in the benchmarking of operators, with the concomitant benefits of objectivity and repeatability.
Shuggi IM et al., 2017	USA	Laboratory	36 healthy volunteers (18 men and 18 women, age ranged between 19 to 25 years)	To examine mental workload by employing the NASA TLX as well as the changes in motor performance resulting from the practice of a novel reaching task.	Both group- and cluster-level analyses revealed that: all participants improved their performance throughout motor practice, and an increase in mental workload was associated with a reduction of the quality of motor performance along with a slower rate of motor improvement.

more analysts carry out the evaluation of the machine and the work environment with the help of theoretical models. The description and understanding of the user and the task are key elements of the evaluations; other important elements are mapping task demands and the user's mental and physical workloads during interaction with the machine (Bligard and Osvalder, 2014; Greco et al. 2020).

The 11 selected articles highlighted how competence and training influence the operator in an industrial dimension in which more and more advanced technologies are incorporated. Mechanisation and digitalisation play an essential role in mitigating ergonomic risks, assessed from cognitive (such as mental workload or usability) and physical (such as physical workload or body posture) perspectives. Therefore, the risk of work-related problems is not always entirely avoided by a good ergonomic design of work tools and workspace. Still, factors related to work organisation, user training, and the use of new technologies also come into play. In particular, the introduction and use of digital technologies such as wearable devices and artificial intelligence is an opportunity to support production processes and safety in the workplace (Körner et al. 2018).

The operator is subjected to a high cognitive load due to environmental characteristics, task complexity or repetitiveness, and work organisation. Modern technologies reduce heavy physical labour, speed up work processes, and increase flexibility. On the other hand, data also indicate that technology-related stressors accompany contemporary industrial work. Technical problems were described as frequent stressors; users reported that technical problems lead to interruptions, additional pressure for timelines, and multitasking, in addition to poor usability of the technical systems they work with. Working with highly automated systems creates difficulty in building an adequate mental representation of machine use. Operators are often faced with situations where they are unable to develop or maintain proper levels of awareness, caused by factors such as high system complexity, inadequate visualisation of the current state of the systems, lack of experience in using the systems, and inadequate training and workstation design relative to the operator's anthropometric data, often resulting in musculoskeletal disorders (Lu CW et al. 2012).

In conclusion, the design of work activities and workstations should consider the workers' cognitive load and anthropometry throughout their involvement in the risk assessment to improve safety in the workplace. Moreover, it is essential to enhance the training of 'Operator 4.0, advancing both technique and preparation, improving risks awareness of using the machine, finally ensuring optimal health and safety conditions.

REFERENCES

Ayaz, H., Shewokis, P. A., Bunce, S., Izzetoglu, K., Willems, B., and Onaral, B. (2012) "Optical brain monitoring for operator training and mental workload assessment". NeuroImage, 59(1), 36–47.

Biondi, F. N., Cacanindin, A., Douglas, C., and Cort, J. (2021) "Overloaded and at Work: Investigating the Effect of Cognitive Workload on Assembly Task Performance". Human factors, 63(5), 813–820.

Bligård, L-O., Osvalder, A. (2014) "CCPE: Methodology for a Combined Evaluation of Cognitive and Physical Ergonomics in the Interaction between Human and Machine". Human Factors and Ergonomics in Manufacturing & Service Industries, 24.

Buono, M., Capece, S., (2016) "Design and Ergonomics innovative modelof assessment and validity for passengerseats in the Aerospace industry". Ergonomia: sfide sociali e opportunità professionali dalla creativitÃ alla praticaper aumentare l'impatto dell'ergonomia nella società, XI National Conference SIE 2016, pp. 259.

Das, L., Srinivasan, B., and Srinivasan, R. (2017) "Cognitive behaviour based framework for operator learning: Knowledge and capability assessment through eye tracking".

Fernández, F., Lázaro, I., Gilabert, E., Arnaiz, A., MuÃ±oz, F. M., and Castellanos L., (2013) "A probabilistic model for cognitive-affective user state awareness". 11th IEEE International Conference on Industrial Informatics (INDIN), pp. 762–767.

Flaspoler, E., Hauke, A., Pappachan, P., Reinert, D., Bleyer, T., Henke, N., Kaluza, S., Schieder, A., Windel, A., Karwowski, W., Slaminen, S., Blaise, J., Claudon, L., Ciccotelli, J., Eeckelaert, L., Verjans, M., Muylaert, K. and De Beeck, R., (2009) "The human machine interface as an emerging risk. EU-OSHA – European Agency for Safety and Health at Work".

Greco, A., Caterino, M., Fera, M., and Gerbino, S. (2020) "Digital Twin for Monitoring Ergonomics during Manufacturing Production", Applied Sciences 10, n. 21: 7758.

Herpers, R., Scherfgen, D., Vieth, M., Saitov, T., Felsner, S., Hofhammer, T., Schaefer, M., and Huelke, M. (2013) "Vr-Based Safety Evaluation of Automatically Controlled Machine Tools," 2013 5th International Conference on Games and Virtual Worlds for Serious Applications (VS-GAMES), 2013, pp. 1–4.

Irastorza X. (2019). Third European Survey of Enterprises on New and Emerging Risks (ESENER 3), EU-OSHA – European Agency for Safety and Health at Work.

Körner, U., MÃ¼ller-Thur, K., Lunau, T., Dragano, N., Angerer, P., and Buchner, A., (2018) "Perceived stress in human-machine interaction in modern manufacturing environments-Results of a qualitative interview study".

Lu„ C. W., Yao C. C., and Kuo, C. W. (2012) "The ergonomics approach for thin film transistor-liquid crystal display manufacturing process". Work (Reading, Mass.), 41 Suppl 1, 5627–5630.

Medvedyk, T., Antoniuk, I., and Lebid, S. (2019) "Influence of stress factors on cognitive tasks performance". 2019 IEEE 20th International Conference on Computational Problems of Electrical Engineering, CPEE 2019.

Rayyan, (Last access 28 February 2022). The Rayyan's website: www.rayyan.ai

Sauer, J., Schmutz, S., Sonderegger, A., and Messerli, N. (2019) "Social stress and performance in human-machine interaction: a neglected research field". Ergonomics, 62(11), 1377–1391.

Shahab, M.A., Iqbal, M. U., Srinivasan, B., and Srinivasan, R., (2021) "Metrics for objectively assessing operator training using eye gaze patterns", Process Safety and Environmental Protection, Vol. 156, Pages 508-520, ISSN 0957–5820.

Shuggi, I. M., Oh, H., Shewokis, P. A., and Gentili, R. J., (2017) "Mental workload and motor performance dynamics during practice of reaching movements under various levels of task difficulty". Neuroscience, 360, 166–179.

Song, S., Awolusi, I., (2020) "Industrial Safety Management Using Innovative and Proactive Strategies", in G. Moynihan (ed.), Concepts, Applications and Emerging Opportunities in Industrial Engineering, IntechOpen, London.

Torres, Y., Nadeau, S., and Landau, K., (2021) "Classification and Quantification of Human Error in Manufacturing: A Case Study in Complex Manual Assembly" Applied Sciences 11, no. 2: 749.

Tricco, A.C., Lillie, E., Zarin, W., O'Brien, K.K., Colquhoun, H., Levac, D., Moher, D., Peters, M.D.J., Horsley, T., Weeks, L., Hempel, S., Akl, E.A., Chang, C., McGowan, J., Stewart, L., Hartling, L., Aldcroft, A., Wilson, M.G., Garritty, C., Lewin, S., Godfrey, C.M., Macdonald, M.T., Langlois, E.V., Soares-Weiser, K., Moriarty, J., Clifford, T., TunÃ§alp, Ö., Straus, S.E., (2018) "PRISMA Extension for Scoping Reviews (PRISMA-ScR): Checklist and Explanation". Annals of internal medicie, Volume 169 No.7, pp. 467–473. ISSN 0003-4819.

Tricco, Andrea C, Lillie, Erin, Zarin, Wasifa et al. (2018) "Prisma Extension for Scoping Reviews (PRISMA-ScR): Checklist and Explanation". Annals of Internal Medicine, Volume 169 No.7, pp. 467–473.

Zotero, (Last access 31 January 2022). The Zotero's website: www.zotero.org