U.PORTO
FEUP FACULDADE DE ENGENHARIA
UNIVERSIDADE DO PORTO

DOCTORAL CONGRESS
IN ENGINEERING

Proceedings Book

Symposium on

Occupational Safety and Health

28 - 29 JUNE 2021
FEUP
PORTO - PORTUGAL

TECHNICAL RECORD

Title

4th Symposium on Occupational Safety and Health Proceedings Book

Editors

Olívia Pinho, J. Santos Baptista, Denisse Bustos, Felicidade Niquice, Jacqueline Castelo Branco, Joana Duarte, Maria Fernandes, Raquel Martins, Soraya Vasconcelos, Tatiana Teixeira

Date

June 2021

ISBN

978-972-752-279-8

ORGANIZING COMMITTEE

Chairman

Olívia Pinho - University of Porto, Faculty of Nutrition and Food Science, Portugal

J. Santos Baptista - University of Porto, Faculty of Engineering, Portugal

Members

Denisse Bustos - University of Porto, Faculty of Engineering, Portugal

Felicidade Niquice - University of Porto, Faculty of Engineering, Portugal

Jacqueline Castelo Branco - University of Porto, Faculty of Engineering, Portugal

Joana Duarte - University of Porto, Faculty of Engineering, Portugal

Maria Fernandes - University of Porto, Faculty of Engineering, Portugal

Raquel Martins - University of Porto, Faculty of Engineering, Portugal

Soraya Vasconcelos - University of Porto, Faculty of Engineering, Portugal

Tatiana Teixeira - University of Porto, Faculty of Engineering, Portugal

International Scientific Committee

Ana Raposo - University of Porto, Faculty of Engineering, Portugal

Andrea Pereira - University of Porto, Faculty of Engineering, Portugal

André Lucena - Federal Rural University of the Semi-Arid Region, Brazil

António Sousa - University of Algarve, Portugal

Denisse Bustos - University of Porto, Faculty of Engineering, Portugal

Fernando Gonçalves - Federal Institute of Santa Catarina, Brazil

Hélio Cavalcanti - Federal University of Piauí, Brazil

Jacqueline Castelo Branco - University of Porto, Faculty of Engineering, Portugal

Joana Duarte - University of Porto, Faculty of Engineering, Portugal

Joana Guedes - University of Porto, Faculty of Engineering, Portugal

Joana Madureira - University of Porto, Institute of Public Health, Portugal

Joana Santos - Polytechnic Institute of Porto, School of Health, Portugal

João Rufo - University of Porto, Institute of Public Health, Portugal

João Santos Baptista - University of Porto, Faculty of Engineering, Portugal

Liliana Silva - University of Porto, Faculty of Engineering, Portugal

Maria Luísa Matos - University of Porto, Faculty of Engineering, Portugal

Marko Cvetkovic - University of Porto, Faculty of Engineering, Portugal

Maurilia Bastos - Federal Institute of Santa Catarina, Brazil

Olívia Pinho - University of Porto, Faculty of Engineering, Portugal

Raquel Martins - University of Porto, Faculty of Engineering, Portugal

Susana Sousa - Institute of Science and Innovation in Mechanical and Industrial Engineering, Portugal

Susel Rosário - University of Porto, Faculty of Engineering, Portugal

Teerayut Sa-Ngiamsak - Burapha University, Faculty of Public Health, Thailand

Tomi Zlatar - Federal University of Pernambuco, Brazil

Vanessa Silva - University of Porto, Faculty of Engineering, Portugal

INDEX OF AUTHORS

SUBMITTED PAPERS – by submission order

Oral communications:

Posters:

Foreword

The 4th Occupational Safety and Health Proceedings Book is a collection of the most recent works in the field of occupational safety and health. The included works are focused on the specific topics: occupational health, ergonomics, occupational safety and hygiene, occupational psychosociology

The short papers included in this publication are a selection of contributions to the 4th Doctoral Congress in Engineering (DCE21). All the included works were revised by at least 2 of the 25 members of the international scientific committee.

The Editors would like to thank all authors for their submissions to the DCE21 - Symposium on Occupational Safety and Health. A special thanks to the members of the Scientific Committee who, on behalf of their institutions, contributed to the quality of this book: University of Porto (UP), Institute of Public Health of the University of Porto (ISPUP), Institute of Science and Innovation in Mechanical and Industrial Engineering (INEGI), School of Health of the Polytechnic Institute of Porto (ESS.IPP), University of Algarve (UALG), University of Pernambuco (UPE), Federal Institute of Santa Catarina (IFSC), Federal University of Piauí (UFPI), Federal Rural University of the Semi-Arid Region (UFERSA), Faculty of Public Health of Burapha University, Thailand.

Porto, June 2021

Symposium Organizing Committee

28 - 29 JUNE 2021
FEUP
PORTO - PORTUGAL

SUBMITTED PAPERS

Use of drone (UAV) as a tool for work safety inspection for roofing activities in civil construction: a systematic review

G. C. G. Macêdo[1], T. Zlatar[2], B. Barkokébas Jr[3]

[1]Laboratory on Occupational Safety and Hygiene (LSHT), Polytechnic School (POLI) of the University of Pernambuco (UPE), Recife, BR, (gercica.macedo@gmail.com) ORCID 0000-0001-6620-9091, [2]Laboratory on Occupational Safety and Hygiene (LSHT), Polytechnic School (POLI) of the University of Pernambuco (UPE), Recife, BR, (tomi.zlatar@gmail.com) ORCID 0000-0002-8915-908X, [3]Laboratory on Occupational Safety and Hygiene (LSHT), Polytechnic School (POLI) of the University of Pernambuco (UPE), Recife, BR, (beda.jr@upe.br) ORCID 0000-0003-3130-3277.
https://doi.org/10.24840/978-972-752-279-8_0001-0008

Abstract

Introduction: Falls from heights represent one of the most frequent accidents in civil constructions, mainly caused by different roofing activities. The risks should be first evaluated by conducting safety inspections, and then implementing adequate control measures to eliminate or reduce the risks of accidents. New technologies facilitate those inspections and make the processes much more efficient. The objective of this study was to make a systematic review to analyse works which used a drone as a visual tool for such safety inspection activities, systematize main information needed to consider in developing future drone research in civil construction. Methodology: The research was carried out on the Brazilian platform for scientific journals and conferences called *"CAPES Portal"* through the Preferred Report for Systematic Reviews and Meta-analyzes (PRISMA) methodology. Several keywords were used for searching, including: *"Construction", "Construction Safety", "Safety Inspection", "Safety Management", "Drone", "Unmanned Aerial Vehicles"*. Results and Discussion: In total, 102 articles were identified through the searching. After applying all the inclusion and exclusion criteria (published in the last 10 years, published in English or Portuguese language), In addition, the articles were included only if related to the use of drones in civil construction and if had some relationship with work safety inspection. A total number of 15 articles fulfilled the selection criteria's and were included in this review. The information about the analysed studies included information such as author/reference, the objective of the study, the country where the study was conducted, the activities which were analysed, conclusions, limitations and the type of the drone which was used in the research. In total, 8 of the 15 studies were developed in the United States, representing 53% of the total, while other studies are from Germany (4), Brazil (2), Australia (1) and Spain (1). Most studies analysed the inspection of bridges and roofs. Conclusions: Studies have shown that there is evidence of the advantages of using drones to assist in safety inspections in civil construction, especially in bridges and roofs.

Keywords: Civil construction, Drone, UAV, Safety inspection, Work safety.

INTRODUCTION

According to the Brazilian Ministry of Social Security (2014), the civil construction sector has a high economic importance, whose relevance is also manifested in the large number of workers who work in this sector, which is traditionally labour-intensive. However, the unplanned growth of this activity has caused a lot of damage to those involved (ZLATAR & BARKOKEBAS JR, 2018).

Roofing activities are one of the most dangerous tasks in construction. Workers who perform activities on the roof are three times more likely to suffer fatal occupational injuries when compared to other construction workers (DONG et al., 2013). Falls are the main cause of fatalities in roofing activities, representing 76% of fatalities between 2003 and 2009 (BLS, 2012).

For roofing activities before any work is started, a risk assessment must be carried out. They should be collective protection measures against fall risks based on the results of risk assessments, before selecting individual protection measures. In addition, it is necessary to ensure safe access, places and workplaces, since tiles may not constitute a safe base (BARBOSA FILHO, 2018).

Safety inspections are very effective in preventing accidents. Abudayyeh et al. (2006) affirm that the incidence rates of accidents and illnesses are significantly lower in the companies that carried out safety inspections.

Therefore, new technologies are essential to facilitate inspection activities and make processes more efficient (SAURIN et al., 2005). According to Irizarry & Kim (2015), the use of the Unmanned Aerial Vehicle (UAV), or drone, can contribute to the process of monitoring safety, detecting and correcting errors, corroborating the reduction of accidents. The use of UAVs to perform safety inspection is promising, since it eliminates the need for lifting equipment and specialized operators, in addition to ensuring increased safety during the inspection process and carrying out the activity more efficiently and economically (ESCHMANN et al., 2012; MORGENTHAL; HALLERMANN, 2014).

The objective of this study was to identify and analyse the works that used drones as a visual tool for safety inspection activities, in addition to systematizing the main information needed to be considered in the development of future research with drones in civil construction.

MATERIALS AND METHODS

The methodology used for the research followed the guidelines of the items of the Preferred Report for Systematic Reviews and Meta-analyzes (PRISMA) (Liberati et al., 2009). The research was carried out on the Brazilian database of scientific articles “Journals Portal of the Coordination for the Improvement of Higher Education Personnel – CAPES” (Coordination for the Improvement of Higher Education Personnel, 2017).

Several keywords in the English language were chosen for searching purposes: "Construction", "Construction Safety", "Safety Inspection", "Safety Management", "Drone", "Unmanned Aerial Vehicles", using the "OR" combination present at the CAPES website. The articles were searched through sections "in the title" and "in the subject". Works older than ten years and published in a language other than English and Portuguese were excluded. Articles were included if related to the use of drones in civil construction and if they had some relationship with work safety inspection.

RESULTS AND DISCUSSION

In total, the search resulted in founding 102 articles. After applying defined filters, excluding repeated articles, articles published in a language other than English and Portuguese, including only articles published in the period from 2009 to 2019, and through the selection of articles by the title that were related to the topic of interest, the number of possible articles was reduced to 42 articles for further consideration.

The next step was a selection by summary, excluding works that did not deal exclusively with drones in civil construction, which reduced the number to 32 articles. The articles were read and analysed, and finally including only 15 of them which dealt with using drones as a tool for safety inspection in civil construction. Figure 1 shows the selection process of articles used in the present systematic review.

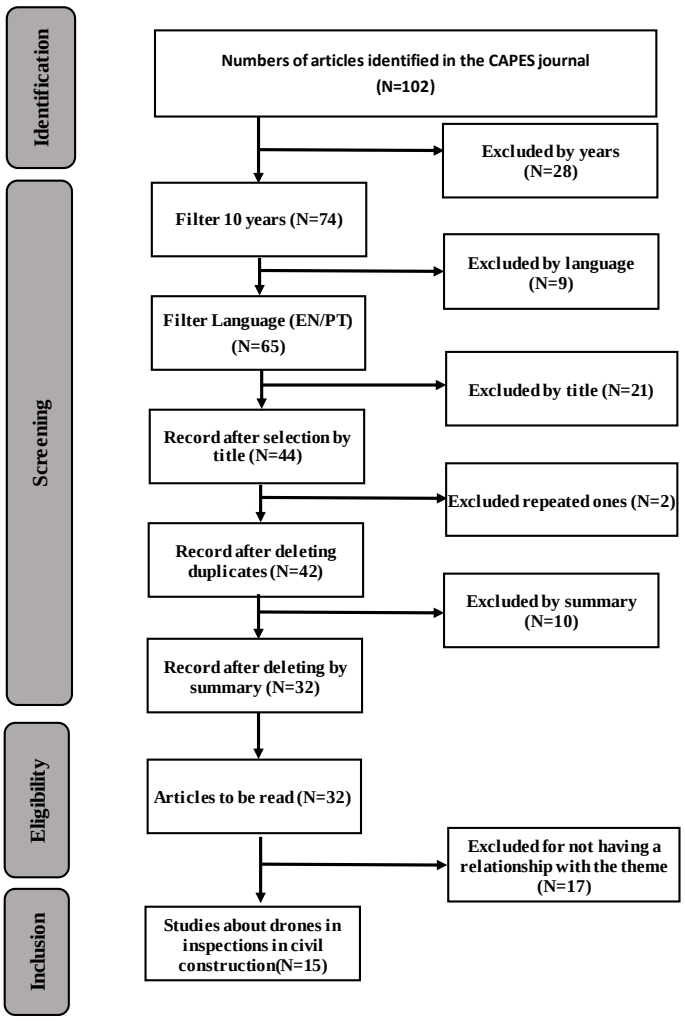

Figure 1. Flowchart of the carried out research

Table 1 illustrates the included articles and some resumed data such as the objective, country of study, analysed activities, conclusions, limitations and the type of drone used in the research.

The analysed studies show that there is a broad range of applications and perspectives of using a drone as a visual tool for safety inspection activities in civil construction. Regarding the countries of origin of the studies, 8 of the 15 studies were developed in the United States, representing 53% of the total, while other studies are from Germany (4), Brazil (2), Australia (1) and Spain (1). Most studies analysed the inspection of bridges and roofs. The studies highlighted the importance of having more in-depth studies on the subject, the high risk of workers involved in traditional inspections due to difficulties to the access on bridges and roofs.

The most analysed criteria for choosing the ideal drone are: flight time, type of camera, camera resolution, payload capacity, cost, ability to transmit video in real-time, autonomous navigation, remote control distance, light in the drone. Most of the included studies used a drone in the line of DJI Phantom 2, 3 or 4. This is due to accessible cost in relation to the competitors and the efficiency of the inspection in civil construction. Noted limitations for conducting studies were: not enough regulation, low light conditions, limited camera rotation, need for training, flight stabilization, flight time, battery life, weather conditions, sensor, the privacy of workers, obstacles.

Table 1. Information about the analysed studies

Nº	Author/References	Objective	Country	Activities analyzed	Conclusions	Limitations	Used drone
1	(Duque et al., 2018)	summarize conclusions about current drone techniques to inspect and analyse different infrastructures	USA		Drone versatility to detect damage to different structures and materials	regulations, low light conditions, GPS, camera rotation, traffic safety	senseFly albris; DJI Phantom 4
2	(Blinn & Issa,2016)	compare the use of a drone to the current state and use of aerial images	USA	power line inspection; construction and maintenance	95% confidence that the use of a drone is less expensive and more financially viable	regulations, formal training	DJI Phantom 2
3	(Eschmann et al.,2012)	scan buildings for inspection and monitoring with a high-resolution digital camera	Germany	facade inspection	represents an adequate technique to create a database	flight stabilization platform, anti-collision	Octocopter MAV inspection platform
4	(Gheisari & Esmaeilli,2016)	identify security practices that can be improved using drone and distinguish users' needs and techniques	USA	proximity to vehicles; cranes, near an unprotected ledge; opening; blind spot of heavy equipment	Use of the important drone in the vicinity of vehicles / cranes / near an unprotected edge / unprotected opening / in the blind spot of heavy equipment	flight time	
5	(Gillins; Gillins; Parrish,2016)	investigate whether the images obtained are comparable to the images that would be acquired with a camera during a conventional inspection	Germany	bridge inspection	lack of zoom on the camera		
6	(Herrmann,2016)	examine current and proposed regulations governing the use of drones and their applicability to the construction industry	USA			uncertainty about whether time and money invested in getting approved for drone use under current rules will be beneficial	DJI Phantom 3
7	(Irizarry; Costa; Kim, 2015a)	identify potentials visual asset applications obtained from the drone for management tasks construction	USA and Brazil	all	monitoring the progress of the the project, assessment of the workplace, logistics, monitoring of safety conditions and quality work inspections carried out	flight time, photo memory capacity, viewing angles	DJI Phantom 2
8	(Irizarry & Gheisari,2016)	security inspection and how a drone can play the role of a security inspection assistant	USA	high parts of walls and roofs	explore potential benefits for security managers and check the current security situation of workers, materials and equipment	improve battery life; weather conditions, endangering the safety of workers in the workplace	AR.Drone Quadricopter

9	(Roca et al.,2013)	area inspection unreachable (high walls and roofs) for data acquisition	Spain		more competitive for the acquisition of data from hard-to-reach places, such as roofs and high facades of buildings	sensor, material and lighting conditions	Okto XL/ Mikrokopter Okto XL
10	(Kim; Irizarry; Costa ,2016)	identify needs, operational challenges, potential factors that influence the drone performance, and potential performance measures	USA	roof, assembly and disassembly, cleaning services, facade processes	"Ease of user interface for drone operation" and "Quality of visual assets" were identified as the most important factors influencing performance	limitation of battery life, weather conditions, worker privacy, obstacles	
11	(Rodrigues et al.,2017)	evaluate the applicability of the drone for a safety inspection at worksites construction, with a focus on identifying unconformities	Brazil		development and validation of a process for a security inspection with UAV	physical barriers; weather conditions; regulations; formation; poor view of internal areas; need to improve real-time feedback; poorly structured safety management system at the construction site	DJI Phantom 3
12	(Seo; Duque; Wacker, 2018)	evaluate the capabilities of robot technology as an inspection tool; support inspections of conventional bridges	USA	bridge inspection	The use of photogrammetry software allowed a more comprehensive and detailed view of the damage; the drone was able to identify cracking, chipping, corrosion, moisture on the bridge	unfavorable weather conditions	DJI Phantom 4
13	Freimuth & Konig (2018)	plan inspections in a 3D environment; the combination of BIM and open source autopilot technology is the basis for a systematic approach	Germany	analysis of facades, roofs	visual and factual information about flight conditions in the planning phase; capture rich information, generating various points of view for each point of interest, accompanied with virtual previews in the planning application		octo copter
14	Chan et al. (2015)	provide a context for using drones for visual bridge inspections, and identify obstacles	Australia	bridge inspection	technology has the potential to significantly reduce the costs of general inspection and inconvenience to passengers	training, certification; proximity to structures and the public; stability	Eight-armed UAV (developed at the University)
15	Hallermann & Morgenthal (2014)	new visual inspection method based on aerial photos and video taken by a drone	Germany	bridge inspection	generates much lower costs compared to the units of conventional control systems, reduced risk of operation during inspections	instability due to the wind; small batteries; climate changes	Flight system BUW Falcon Photo

Despite some limitations, the included studies identified numerous benefit, based on the criteria considered in the studies included. Some of them are: drone versatility to detect damage in different structures and materials; financially viable; monitoring the progress of the project, assessing the logistics workplace, monitoring safety conditions and carrying out quality work inspections; checks the current safety situation of workers, materials and equipment, by having direct interaction with workers; more competitive for the acquisition of data from hard to reach places, such as roofs and high parts of building facades; significantly reduce the costs of general inspection; generates much lower costs; reducing the risk of the activity.

According to Rodrigues et al. (2017), some benefits are listed with respect to the applicability of drones in labour safety inspections in civil construction: reduction of variability; increasing the transparency of unsafe conditions; detailed information about unsafe and safe conditions; registration of security non-conformity requirements and good practices, allowing the analysis of different perspectives; use of indicators and information for decision making; use of visual assets and inspection results for training in occupational safety; cost-effectiveness of viability; potential improvement in safety-related worker behaviour.

Gheisari & Esmaeilli (2016) also mention that drones can provide several advantages for occupational safety managers: drones can move faster than humans; it can reach inaccessible areas of workplaces; it can be equipped with video cameras, wireless sensors, radar or communication hardware for real-time data transfer.

The authors Irizarry, Coast, Kim (2015a) emphasize that drone can provide a low-cost solution for exploring aerial photography-based construction inspection techniques, such as in roofing and building facade activities, and for other applications that would otherwise be impractical or insecure.

Regarding the results obtained in the included studies, according to Irizarry, Coast, Kim (2015a), with the application of the drone, it was possible to improve management in civil construction. According to Rodrigues et al. (2017) it is possible to improve safety inspection in workplaces through better visualization of working conditions. In the results obtained by Seo, Duke, Wacker (2018), the drone is a great potential to complement inspection methods. In the study by Freimuth & Konig (2018) it is mentioned that UAV makes inspection automated and that it captures significant data with only little necessary inputs and is operational. According to Chan et al. (2015) the quality of the drone-based inspection may be better than the human-operated method.

CONCLUSIONS

Studies have shown that there is evidence of the advantages of using drones to assist in safety inspections in civil construction, especially in bridges and roofs. It generates data and images in a very efficient way and can assist in different phases of the construction process: before, during and after the execution of bridge/roof works. Drones provide the safety inspection to be conducted with higher safety, speed and lower costs, requiring fewer resources compared to the traditional method.

Several benefits and limitations were presented, which should serve as a support in the development of future researches using drones in civil construction. The characteristics of drones should be chosen based on the objective and particularities of the research and environmental conditions in which the drone will be used.

Therefore, some of this information that must be considered are: the most relevant activities to be analyzed; criteria that must be considered when choosing the ideal drone related to the particularities of each situation; difficulties, limitations and benefits with the use of the drone for labour safety inspections in civil construction, among other possibilities.

References

ABUDAYYEH, O., FREDERICKS, T.K., BUTT, S.E., SHAAR, A. 2006. "An investigation of management's commitment to construction safety". *International Journal of Project Management*, v. 24, n.2, p. 167-174.

BARBOSA FILHO, A. N. 2018. "Occupational safety and environmental management". São Paulo: Atlas. ISBN: 9788597018318. 5 ed. 2018.

BLINN, N., ISSA, R.R.A. 2016. "Feasibility Assessment of Unmanned Aircraft Systems for Construction Management Applications". In: *Construction Research Congress*, San Juan, p. 2593-2603. Proceedings.

CHAN, B. et al. 2015. "Towards UAV-based bridge inspection systems : a review and an application perspective". *Structural Monitoring and Maintenance*. Vol. 2, No. 3. 283-300 2015. DOI: http://dx.doi.org/10.12989/smm.2015.2.3.283.

DONG, XIUWEN SUE, SANG D. CHOI, ET AL. 2013. "Fatal Falls from Roofs among U.S Construction Workers". *Journal of Safety Research*, vol. 44, no. 1, National Safety Council and Elsevier Ltd, pp. 17 24, doi:10.1016/j.jsr.2012.08.024.

DUQUE, L. et al. 2018. "Synthesis of Unmanned Aerial Vehicle Applications for Infrastructures". v. 32, n. 4, p. 1–10, J. *Perform. Constr. Facil*., 32(4): 04018046.

ESCHMANN, C. et al. 2012. "Unmanned Aircraft Systems for Remote Building Inspection and Monitoring". p. 1–8, 6th *European Workshop on Structural Health Monitoring* - Th.2.B.1.

FREIMUTH, H., KÖNIG, M. 2018. "Automation in Construction Planning and executing construction inspections with unmanned aerial vehicles". *Automation in Construction*, v. 96, n. March 2017, p. 540–553.

GHEISARI, M., ESMAEILI, B. 2016. "Unmanned Aerial Systems (UAS) for construction safety applications". In: *Construction Research Congress*, San Juan, p. 2642-2650. Proceedings.

GILLINS, M. N., GILLINS, D. T., PARRISH, C. 2016. "Cost-effective bridge safety inspections using Unmanned Aircraft Systems (UAS)". In: *Geotechnical and Structural Engineering Congress*, Phoenix, p. 131-140. Proceedings.

HALLERMANN, N., MORGENTHAL, G. 2014. "Visual inspection strategies for large bridges using Unmanned Aerial Vehicles (UAV)". n. *Conference Paper*. July.

HERRMANN, M. 2016. "Unmanned aerial vehicles in construction: an overview of current and proposed rules". In: *Construction Research Congress*, San Juan, p. 588-596. Proceedings.

IRIZARRY, J., COSTA, D.B., KIM, S. 2015. "Potential applications of Unmanned Aerial systems for construction management tasks". In: *International Conference on Innovative Production and Construction (IPC)*, July, Perth. Proceedings.

IRIZARRY, J., COSTA, D.B., KIM, S. 2015a. "Potential applications of Unmanned Aerial systems for construction management tasks". In: *International Conference on Innovative Production and Construction (IPC)*, July, Perth. Proceedings...

IRIZARRY, J. et al. 2016. "Exploratory Study of Potential Applications of Unmanned Aerial Systems for Construction Management Tasks". v. 2, n. 2015, p. 1–10.

KIM, S., IRIZARY, J., COSTA, D. B. 2016. "Potential Factors Influencing the Performance of Unmanned Aerial System (UAS) Integrated Safety Control for Construction Worksites". *Construction Research Congress*. American Society of Civil Engineers.

LIBERATI, A., ALTMAN, D.G., TETZLAFF, J. 2009. "The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate healthcare interventions: explanation and elaboration". *BMJ*; 339: b2700.

MINISTÉRIO DA PREVIDÊNCIA SOCIAL. 2014. “Informe de Previdência Social”. Disponível em: <http://www.previdencia.gov.br/wpcontent/uploads/2014/10/Ret_Offset_Informe_julho_2014.pdf>. Acesso em: 27 maio 2018.

MORGENTHAL, G., HALLERMANN, N. 2014. “Quality assessment of Unmanned Aerial Vehicle (UAV) based visual inspection of structures”. *Advances in Structural Engineering*, v. 17, n. 3.

ROCA, D., LAGÜELA, S., Díaz-Vilariño, L., ARIAS, J.A. 2013. “Low-cost aerial unit for outdoor inspection of building façades”. *Automation in Construction*, v. 36, p. 128-135.

RODRIGUES, R. et al. 2017. “Applicability of unmanned aerial system (UAS) for safety inspection on construction sites”. *Safety Science*, v. 98, p. 174–185.

SAURIN, T. A. FORMOSO,C.T., CAMBRAIA, F.B., HOWELL, G. 2005. “A cognitive systems engineering perspective of construction safety”. In: *Annual Conference of the International Group for Lean Construction*, 13, 2005, Sydney. Proceedings... Sydney: IGLC.

SEO, J., DUQUE, L., WACKER, J. 2018. "Automation in Construction Drone-enabled bridge inspection methodology and application". *Automation in Construction*, v. 94, n. October 2017, p. 112–126.

U.S. Bureau of Labor Statistics (BLS). 2012. ”Occupational injuries/illnesses and fatalinjury profiles 2003–2009”. *Fatal occupational injuries by selected worker characteristics and selected industry*, all U.S., all ownerships, 2003–2009.

ZLATAR, T; BARKOKÉBAS JR., B. 2018. “Building Information Modelling as a Safety Management Tool for Preventing Falls from Height”. 1. ed. *Lambert Academic Publishing*. 69p. ISBN: 978-613-9-85592-6.

Noise promotes disengagement in dementia patients during non-invasive neurorehabilitation treatment

Aisha Animashaun[1], Gilberto Bernardes[2]

[1]Faculty of Engineering, University of Porto, PT (up201909481@up.pt) ORCID: 0000-0002-7204-7452, [2]INESC TEC, PT (gba@fe.up.pt) ORCID 0000-0003-3884-2687.
https://doi.org/10.24840/978-972-752-279-8_0009-0014

Abstract

Introduction: The lack of engagement and the shortage of motivation and drive, also referred to as apathy, negatively impacts the effectiveness and adherence to treatment and the general well-being of people with neurocognitive disorders (NCDs), such as dementia. Methodology: The hypothesis raised states that the engagement of people with dementia during their non-invasive treatments for NCDs is affected by the noisy source levels and negative auditory stimuli present within environmental treatment settings. An online survey was conducted with the study objectives to assess 1) the engagement levels of dementia patients while interacting with others at home versus in therapy facilities, 2) the emotions perceived when interacting with people at home compared to therapy sessions, 3) the perceived loudness of the environment at home versus in therapy facilities, and 4) which source sounds negatively impact the patients at home and during therapy sessions. A purposive sampling (n=62) targeting relatives, friends, and caregivers of dementia patients was conducted via online community forums in the DACH region. Moreover, a recording session was conducted in a psychotherapist's office to verify the answer to the questionnaire on the noise sources perceived in therapy facilities. Results and Discussion: The raised hypothesis that disruptive auditory stimuli and noise levels influence the engagement levels of demented individuals during treatment is confirmed as the engagement is affected by the perceived noise disruptions when comparing perceived noise levels and engagement at home to those in treatment facilities. Significant statistical results were found between the lower engagement of demented individuals when interacting with people during therapy sessions compared to higher engagement in-home interactions. Furthermore, negatively perceived sound sources can be found in both therapy facilities and home settings. The noise sound sources identified, such as human voices, household appliances and household noises, while recording in the psychotherapist's office align with the questionnaire responses received on this topic. The findings indicate that the perceived heightened noise levels in therapy facilities stand in correlation with the lowered engagement rate perceived during the therapy session compared to the lower noise level and higher engagement encountered when demented individuals interact at home. Conclusion: If the identified noise elements are masked or replaced by other auditory stimuli that promote a soothing soundscape, the original disturbances encountered during therapy and the lack of engagement can possibly be minimized. Further studies need to be conducted in the prototyping of a noise intervention tool to analyze the impact on lack of engagement through noise disturbances.

Keywords. Noise, Engagement, Dementia, Therapy, Apathy.

INTRODUCTION

Neurocognitive disorders (NCDs) are a steadily rising global public health concern. In 2020, around 50 million people worldwide lived with major NCDs, specifically dementia, with nearly 10 million new cases per year[1] NCDs can be found in many diseases, including Alzheimer, Parkinson, Huntington, and Creutzfeldt-Jakob (Reith, 2018). The causes of NCDs are typically associated with advanced age. Still, it can occur from incidents such as traumatic brain injuries, infections, thyroid problems, damage to the blood vessels, and other causes (Kane et al., 2017), increasingly affecting a wide range of people and age groups. Successful treatment methods are limited and can be split into two main categories, invasive and non-invasive methods.

[1] World Health Organization, *Dementia* [website] https://www.who.int/news-room/fact-sheets/detail/dementia (accessed 12 April 2021)

Invasive treatment methods are surgical procedures, such as Deep Brain Stimulation (DBS), a neurosurgical procedure in which a neurotransmitter is placed in the brain to send electrical impulses to specific regions to counteract movement disorders with Parkinson's disease (Kringelbach et al., 2007). Groiss et al. (2009) found that DBS is a highly effective intervention for advanced Parkinson. However, invasive treatments are not suitable for most NCD patients. Only about 10% of Parkinson's patients are eligible for DBS surgery (Lange et al., 2017). Further, patients with pre-existing dementia are at an increased risk of fatal complications, and early death is subject to surgery compared to non-demented patients (Kassahun, 2018). This data visualizes the hindered accessibility of invasive treatment methods for patients with NCDs.

Non-invasive treatment methods focus on tools that do not require incision and damage to the tissue (Cousins et al., 2019). They can be pharmacological or non-pharmacological. The effectiveness of pharmacological treatments for NCDs are reportedly low (Mathys, 2018), and its efficacy can be compromised due to the alteration of the blood-brain barrier (Carvey et al., 2009) and the breakdown of the medication in the blood before it can reach the nervous system (Pardridge, 2012; Tonda-Turo et al., 2019). Non-pharmacological methods have been advocated for the heightened success of the treatment plans. Engagement, i.e., active involvement triggered by meaningful activities promoting more energetic and positive moods (Perugia et al., 2017), has been identified as a critical factor in the effectiveness of treatment methods. Lanctôt et al. (2016) show that apathy, i.e., lack of engagement, has a significant impact on people with NCDs. This leads not only to a decrease in participation, increased disability and frustration but further to a low quality of life for patients and caregivers (Brodaty and Burns, 2017; Onyike et al., 2007).

In this context, the hypothesis is raised that the engagement of non-invasive treatments for NCDs is affected by the noise levels and negative auditory stimuli present within environmental treatment settings. To this end, a survey was conducted that aims to assess the above correlation and additionally capture live audio in a therapy facility to identify further the source and attributes of potential negative impacting sounds.

METHODOLOGY

An anonymous, online, computer-based and structured questionnaire was conducted. It was created using Google Forms and consisted of ten sections which were individually displayed on the screen and navigable by pressing forward or back to access the previous or next section. The questionnaire consisted of seventeen questions and took approximately 3-4 minutes to complete. It had the study objectives to understand 1) the engagement levels of dementia patients while interacting with others at home versus in therapy facilities, 2) the emotions perceived when interacting with people at home in comparison to therapy sessions, 3) the perceived loudness of the environment at home versus therapy facilities, 4) which source sounds perceived that negatively impact the patient. The questionnaire was disseminated in six online support groups for family members, friends, and professional caregivers of dementia patients in the German-speaking DACH region. Dementia patients have been chosen as the primary focus group due to their fast-spreading worldwide condition within NCDs and neuropsychiatric symptoms. The questionnaire included binary (yes or no), multiple-choice, and Likert scale questions. The therapies considered include the most common neurorehabilitation therapies (Aldridge, 2008; Greenwood et al., 2003), namely: exercise and mobility programs, speech therapy, cognitive training, psychotherapy, social skill training, music therapy, and art therapy. Following Cowen and Keltner (2017), the 27 varieties of emotional experiences and the wheel of emotions by Plutchik (1980) to identify emotional states were adopted. Sound sources

classification adopts the ontology proposed by Ellis et al. (2017), which distinguishes between seven main sound sources: human sounds, animals, music, the sound of things, environment and background, natural sounds channel, and source-ambiguous sounds. These are then further divided into multiple subcategories, which include but are not limited to human voices, home sounds, musical instruments, vehicles, and acoustic environment.

The analysis of the collected data was conducted in SPSS software to calculate means, test correlations, frequencies and run a statistical significance using a t-test ($p > .05$ is adopted to test the null hypothesis). To complement the identification of potential negative impacting sound sources and their spectral attributes, additionally, the auditory environment in a psychotherapist's office in the city center of Vienna, Austria was recorded. The building was located on a busy street; however, the room faced the inner courtyard and was therefore distinguishably quieter than other rooms in the area. A Zoom H5n with a X/Y microphone capsule was used for the recording, which consists of two matched unidirectional condenser microphones set at a 90-degree angle, mounted on a tripod. The soundscape was recorded three times for 15 minutes during an hour with the microphone in the middle of the room and the door shut. The connecting room was a kitchen followed by a bathroom and a second therapy room where a session was going on, but the door was closed. Therefore, any sounds recorded would have come from the neighbors, courtyard, or the people present in the session in the other closed-off room.

RESULTS AND DISCUSSION

The participants (n=62) of the questionnaire were family and friends of the person with dementia (77.4%), professional caretakers (21%) — as proxies of dementia patients —, and one person with dementia (1.6%). The participants from the DACH region were geographically distributed as follows: Germany (50%), Austria (32.2%), and Switzerland (14.5%). Two participants did not release the location. The stages of dementia ranged from suspected dementia to stage 7, with the most common selected being stage 6 (22.6%) and stage 5 (19.4%). Slightly more than half of the participants stated the person was not currently in therapy (53.2%). The therapies indicated, of which participants were able to select multiple choices, were mobility and exercise programs (54.5%), cognitive training (72.2%), psychotherapy (40.9%), art therapy (18.2%), social behavior training (9.1%), music therapy (22.7%), speech therapy (9.1%).

Significant statistical results were found between the different engagements during interactions in therapy facilities compared to home environments as perceived by relatives, friends, and caregivers. The engagement during treatment was perceived as much lower with a mean of 1.78 compared to 3.13 in home environments on a 5-point scale, 1 being no engagement; 5 being very high engagement in interactions with others.

The perceived emotions in dementia patients while at home (n=62) versus during therapy in therapy facilities (n=20) showed differences in emotional experience. The perceived emotions at home, of which multiple were selectable at once, were awkwardness (59.7%) followed by joyfulness (53.2%), confusion (53.2%) and apathy (30.6%). In therapy facilities, the most dominant perceived emotion was apathy (60%) followed by awkwardness (40%) confusion (35.5%), and joyfulness (35%), in percentages of selection. There was further significance regarding noise levels at home compared to therapy settings. As visualized in Figure 1, the normal curve is visible as a black line referring to the entered data in regard to frequency and noise level, the data suggests higher levels of experienced noise during therapy in facilities

(mean=3.87) compared to at home environments (mean= 2.51) across a 5-point Likert space where one corresponds to very quiet and five to very loud.

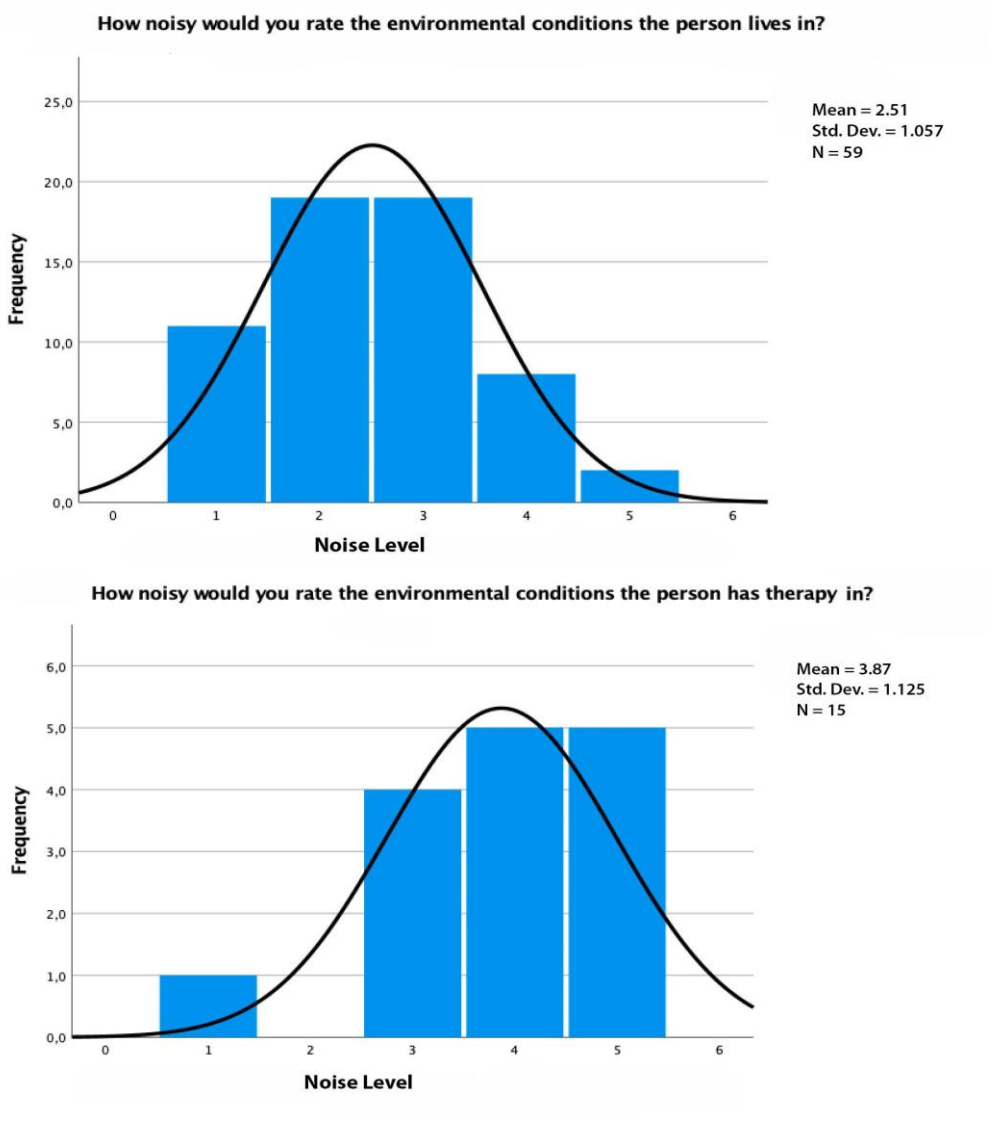

Figure 1. Perceived noise levels at home (upper image) compared to in therapy facilities (bottom image). Solid black lines denote the normal distribution.

However, the smaller number of responses for therapy (n=15) compared to home (n=59) indicates the potential heightened noise levels, and further responses should be collected to draw a cohesive conclusion on noise differences. In both conditions, the most common noisy sound sources identified were: human voices, household noises and devices, instrumental music played by neighbors, and traffic noises. This set of sounds are in line with the recordings taken in the psychotherapist's office, shown in Figure 2.

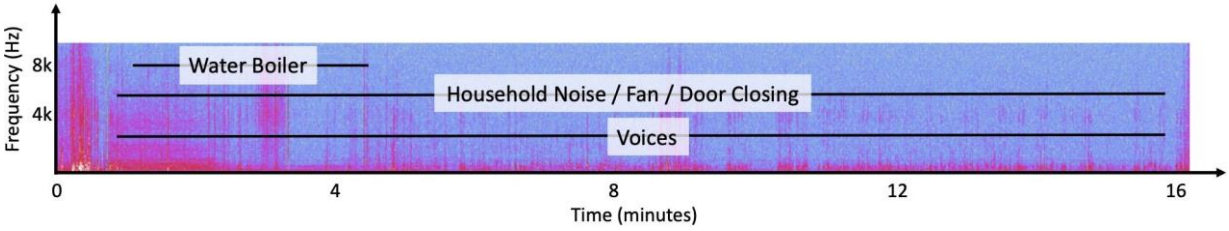

Figure 2. Spectrogram of the collected sound environment in the psychotherapist's office.

From the collected audio recording in the psychotherapist's office, which spectral representation is shown in Figure 2, where cold colors refer to low amplitude and warm colors to high amplitude, noisy sound sources were identified which include household applications such as water boilers (1-2 minutes) and fans (3-5 minutes); (unintelligible) human voices from adjacent rooms filling the middle of the spectrum most notably between 3 kHz and 5 kHz (1-15 minutes). The identified sound category sources align with the collected categories in the questionnaire.

CONCLUSIONS AND FUTURE IMPLICATIONS

The raised hypothesis regarding that the engagement during non-invasive treatments for demented individuals can be affected by the noise levels and negative auditory stimuli present within environmental treatment facilities was confirmed. It was found that 1) the engagement levels of dementia patients while interacting with others in therapy facilities was higher than at home, 2) the emotions perceived when interacting with people at home were more positive in comparison to during therapy sessions where increased apathy was found, 3) the perceived loudness of the environment in therapy facilities was significantly higher than at home, 4) the source sounds perceived that negatively impact the patient was similar in both environments, at home and in the therapy facility with the most common being human voices and household noises and appliances. The dementia patients' engagement perceived by relatives and caregivers during therapy is lower than at home, which can be due to the unfamiliar environment regarding the associated emotions of apathy, awkwardness, and confusion. There is a correlation between sound levels and engagement, which are lower during therapy compared to a home setting. The most frequent negative impacting sound sources identified are human voices, household devices, and general household-associated noises. One important future implication of the results is the potential application of a soundscape in both home and health care facilities to positively impact the engagement of people with dementia by minimizing and masking the identified disruptive noise sources found in this study to minimize the impact of negatively associated auditory stimuli ultimately. To this end, imposed sound with different spectral attributes seeks to mask negative impacting sound sources based on a dataset researched by Fan et al. (2017) and Andringa and Lanser (2013). To account for the evolving nature of the soundscape based on short soundscape recordings, the model adopted by Bernardes et al. (2016) and Bernardes (2020) can be used in future developments.

References

Aldridge, D. (2008). *Music Therapy and Neurological Rehabilitation: Performing Health* (Illustrated ed.). Jessica Kingsley.

Andringa, T., & Lanser, J. (2013). How Pleasant Sounds Promote and Annoying Sounds Impede Health: A Cognitive Approach. *International Journal of Environmental Research and Public Health*, 10(4), 1439–1461. https://doi.org/10.3390/ijerph10041439

Bernardes, G., Aly, L., Davies, M. (2016). SEED: Resynthesizing Environmental Sounds from Examples. *Proceedings of the Sound and Music Computing Conference*. 55–62.

Bernardes, G. (2020). Interfacing Sounds: Hierarchical Audio-Content Morphologies for Creative Re-purposing in earGram. *Proceedings of the International Conference on New Interfaces for Musical Expression.*, 537–542.

Brodaty, H., & Burns, K. (2017). Non-pharmacological Management of Apathy in Dementia: A Systematic Review. *The American Journal of Geriatric Psychiatry*, 20(7), 549–564. https://doi.org/10.1097/JGP.0b013e31822be242

Cousins, S., Blencowe, N. S., & Blazeby, J. M. (2019). What is an invasive procedure? A definition to inform study design, evidence synthesis and research tracking. *BMJ Open*, 9(7), 1.https://doi.org/10.1136/bmjopen-2018-028576

Cowen, A. S., & Keltner, D. (2017). Self-report captures 27 distinct categories of emotion bridged by continuous gradients. *Proceedings of the National Academy of Sciences*, 114(38). https://doi.org/10.1073/pnas.1702247114

Carvey, P. M., Hendey, B., & Monahan, A. J. (2009). The blood-brain barrier in neurodegenerative disease: a rhetorical perspective. *Journal of Neurochemistry,* 111(2), 291–314. https://doi.org/10.1111/j.1471-4159.2009.06319.x

Ellis, D., Gemmeke, J., Freedman, D., Jansen, A., Lawrence, W., Moore, R., Plakal, M., & Ritter, M. (2017). Audio Set: An ontology and human-labeled dataset for audio events. *Proc. IEEE ICASSP 2017*, 1–5. https://static.googleusercontent.com/media/research.google.com/de//pubs/archive/45857.pdf

Fan, J., Thorogood, M., & Pasquier, P. (2017). Emo-soundscapes: A dataset for soundscape emotion recognition. 2017 *Seventh International Conference on Affective Computing and Intelligent Interaction (ACII)*. https://doi.org/10.1109/acii.2017.8273600

Greenwood, R. J., McMillan, T. M., Barnes, M. P., & Ward, C. D. (2003). *Handbook of Neurological Rehabilitation* (1st ed.). Psychology Press.

Kane, R. L., Butler, M., Fink, H. A., Brasure, M., Davila, H., Desai, P., Jutkowitz, E., McCreedy, E., Nelson, V. A., McCarten, J. R., Calvert, C., Ratner, E., Hemmy, L. S., & Barclay, T. (2017). Interventions To Prevent Age-Related Cognitive Decline, Mild Cognitive Impairment, and Clinical Alzheimer's-Type Dementia. Agency for Healthcare Research and Quality. Published. https://doi.org/10.23970/ahrqepccer188

Kassahun, W. T. (2018). The effects of pre-existing dementia on surgical outcomes in emergent and nonemergent general surgical procedures: assessing differences in surgical risk with dementia. BMC Geriatrics, 18(1), 1–9. https://doi.org/10.1186/s12877-018-0844-x

Kringelbach, M. L., Jenkinson, N., Owen, S. L. F., & Aziz, T. Z. (2007). Translational principles of deep brain stimulation.

Nature Reviews Neuroscience, 8(8), 623–635. https://doi.org/10.1038/nrn2196

Mathys, M. (2018). Pharmacologic management of behavioral and psychological symptoms of major neurocognitive disorder. *Mental Health Clinician*, 8(6), 284–293. https://doi.org/10.9740/mhc.2018.11.284

Lanctôt, Krista L., Luis Agüera-Ortiz, Henry Brodaty, Paul T. Francis, Yonas E. Geda, Zahinoor Ismail, Gad A. Marshall, et al. "Apathy Associated with Neurocognitive Disorders: Recent Progress and Future Directions." *Alzheimer's & Dementia* 13, no. 1 (2016): 84–100. https://doi.org/10.1016/j.jalz.2016.05.008.

Lange, M., Mauerer, J., Schlaier, J., Janzen, A., Zeman, F., Bogdahn, U., Brawanski, A., & Hochreiter, A. (2017). Underutilization of deep brain stimulation for Parkinson's disease? A survey on possible clinical reasons. Acta Neurochirurgica, 159(5), 771–778. https://doi.org/10.1007/s00701-017-3122-3

Onyike, C. U., Sheppard, J. M. E., Tschanz, J. T., Norton, M. C., Green, R. C., Steinberg, M., Welsh-Bohmer, K. A., Breitner,

J. C., & Lyketsos, C. G. (2007). Epidemiology of Apathy in Older Adults: The Cache County Study. *The American*

Journal of Geriatric Psychiatry, 15(5), 365–375. https://doi.org/10.1097/01.jgp.0000235689.42910.0d

Pardridge, W. M. (2012). Drug Transport across the Blood–Brain Barrier. *Journal of Cerebral Blood Flow & Metabolism*,

32(11), 1959–1972. https://doi.org/10.1038/jcbfm.2012.126

Perugia, G., Rodriguez-Martin, D., Diaz Boladeras, M., Mallofre, A. C., Barakova, E., & Rauterberg, M. (2017).

Electrodermal activity: Explorations in the psychophysiology of engagement with social robots in dementia. 2017 *26th IEEE International Symposium on Robot and Human Interactive Communication (RO-MAN)*, 1248–1254. https://doi.org/10.1109/roman.2017.8172464

Plutchik, R. (1980). A general psychoevolutionary theory of emotion. In R. Plutchik & H. Kellerman (Eds.), Emotion: Theory, research, and experience. *Theories of emotion*, 3-33, 1. New York: Academic.

Reith, W. (2018). Neurodegenerative Erkrankungen. Der Radiologe, 58(3), 241–258. https://doi.org/10.1007/s00117-018-0363-y
Tonda-Turo, C., Origlia, N., Mattu, C., Accorroni, A., & Chiono, V. (2019). Current Limitations in the Treatment of Parkinson's and Alzheimer's Diseases: State-of-the-Art and Future Perspective of Polymeric Carriers. *Current Medicinal Chemistry*, 25(41), 5755–5771. https://doi.org/10.2174/0929867325666180221125759

Short review on occupational noise exposure in the extractive industry and similar works

J. Duarte[1], J. Castelo Branco[2], Fernanda Rodrigues[3], J. Santos Baptista[4]

[1]Associated Laboratory for Energy, Transports and Aeronautics - LAETA (PROA), Faculty of Engineering, University of Porto, PT (jasduarte@fe.up.pt) ORCID 0000-0002-5856-5317, [2]Associated Laboratory for Energy, Transports and Aeronautics - LAETA (PROA), Faculty of Engineering, University of Porto, PT (jcb@fe.up.pt) ORCID 0000-0002-9254-4384, [3]RISCO, ANQIP, University of Aveiro, PT (mfrodrigues@ua.pt) ORCID 0000-0001-9127-7766, [4]Associated Laboratory for Energy, Transports and Aeronautics - LAETA (PROA), Faculty of Engineering, University of Porto, PT (jsbap@fe.up.pt) ORCID 0000-0002-8524-5503.
https://doi.org/10.24840/978-972-752-279-8_00015-0020

Abstract

Introduction: Occupational noise is still a matter within the industrial practice with nefarious consequences on the worker's health. Pulmonary diseases, cardiovascular problems, disturbances in sleep, fatigue, and, in the worst-case scenarios, hearing loss (this one with a permanent character) are some of the most common adverse effects reported in the literature. This issue covers itself in even more significant concern when analysing the mining industry context. Almost every operation works as a potential noise source, not only for the workers but also for the surrounding populations. Objective: To identify the exposure setting to occupational noise in the extractive industry and similar works (i.e. earthworks), particularly related to tasks and equipment. Methodology: The Preferred reporting items for systematic reviews and meta-analyses (PRISMA) was used as a guideline to help conduct the research and report of this work. The most relevant keywords were selected and later combined in the selected databases and multidisciplinary academic journals in the first phase. After, the articles were filtered with a set of exclusion criteria, to know: 1) Publication year, 2) Document type, 3) Source type, and 4) Language. The subsequent stage was to determine, within the remaining articles, the pertinence of each study and its later inclusion in the study. Each set of data was then classified according to the measurement context, and the results were analysed. Results and discussion: In the records' identification phase, a total of 1148 papers were recovered. By applying the previously mentioned exclusion criteria, 547 were removed related to publication year, 146 due to document type, 12 related to source type and 25 because of language. Additionally, 360 records were excluded because were not in accordance with the proposed objective, 25 were duplicate articles, and 7 had no full-text available. From the last analysis, 11 more papers were excluded, which lead to a final result of 15 included studies. According to the occupational noise measurements set, the records were divided into four categories: activity, equipment, job category, and working area. Different equipment was associated with high noise levels: crusher – between 85.6 and 104 dB, trucks and bulldozes – above 100 dB, and shovel – 103 dB, whereas the only analysed activity was blasting, where studies concluded that increasing distance leads to lower noise measurement values. Conclusions: Considering this research, although it was possible to identify the tasks and equipment usually associated with occupational noise in the extractive industry, a lot of work still needs to be done, especially data analysis. However, this research serves as a starting point for future study.

Keywords: Open pit mine, Earthworks, Equipment, Occupational noise.

INTRODUCTION

Worldwide, occupational noise-induced hearing loss (ONIHL) is still a significant health issue (Zhou, Shi, Zhou, Hu, & Zhang, 2020), mainly because noise is not dissociable from industrial practice, where the consequences are felt in terms of disease burden and financial aspects, both for the worker and society (Chen, Su, & Chen, 2020).

The phenomenon of noise is complex and depends not only on its physical characteristics (such as frequency and sound pressure level) but also on the individual's physiological features. For instance, it is known that the earing canal exponentiates the sound pressure level perceived by the ear and that this occurs more in men than in women (Asady, Fuente, Pourabdian, Forouharmajd, & Shokrolahi, 2021).

General hazardous effects of noise on health include, though are not limited to, sleep disturbance (Ntlhakana, Nelson, & Khoza-Shangase, 2020), pulmonary diseases, type 2 diabetes,

fatigue, distraction (Hon, Tchernikov, Fairclough, & Behar, 2020), cardiovascular problems (Asady et al., 2021; Hon et al., 2020) and hypertension (Li et al., 2019). The noise exposure was also associated in the literature with injury and accident occurrence, as the annoyance effect clouds judgment and endangers action (Hon et al., 2020; Li et al., 2019).

In the extractive industry context, every task and equipment is fairly associated with noise: drilling and blasting, rock and ore transportation, the movement of the machines themselves such as trucks, excavators, bulldozers and many others (Lilic, Cvjetic, Knezevic, Milisavljevic, & Pantelic, 2018; Wichers, Iramina, de Eston, & Ayres da Silva, 2018). Similarly, earthworks, as an example of similar works, uses the same processes and machines, therefore poses the same risks. However, excessive occupational noise is preventable (Hon et al., 2020). Understanding the general processes that contribute to this problem and mitigate its effects, achieved by carefully planning even the simplest operations.

This short review aimed to identify, in the literature, tasks and equipment related to occupational noise in the extractive industry and similar works (involving the same type of equipment and processes).

METHODOLOGY

This short review follows the Preferred reporting items for systematic reviews and meta-analyses (PRISMA) methodology (Moher et al., 2009; Page et al., 2021) and the guidelines proposed by Duarte et al. (2020) in the context of occupational noise exposure in the mining industry and earthworks. The first step was to select the main databases and journals and then, to apply the most appropriate keyword combinations. “Noise” was sequentially combined with “quarry”, “open pit”, “open cast”, “surface mining”, “open cut mining”, “extractive industry”, and “earthworks” in the Title/Abstract/Keywords field on Dimensions, Directory of Open Access Journals, Science Direct, Emerald, IEEE Xplore, INSPEC, SAGE journals, Scopus, Taylor and Francis, Current Contents and Web of Science. As exclusion criteria, the following filters were applied: 1) Publication year (≥ 2010), 2) Document type (everything other than research articles and articles in press were excluded), 3) Source type (only journals and trade publications were considered), and 4) Language (only English-written papers were considered).

Afterwards, every title and abstract were assessed to determine the eligibility of the selected works and only papers in occupational context and providing field data were considered and included in this preliminary study. The preliminary analysis focused on the origin country, activity, type of exploitation, and exploited commodity. Then, data was classified according to the measurement setting to organise information and create comparable standards. From that classification, a narrative appraisal was carried out. This research was carried out in February 2021.

RESULTS AND DISCUSSION

The primary research provided 1148 results. By applying the prior filters, 547 papers were removed due to 1) Publication year, 146 were excluded in relation to 2) Document type, 12 were removed regarding 3) Source type, 25 records were excluded due to 4) Language. After reading the title and abstract of each work, 360 more papers were excluded because they were not within the proposed objective. From the remaining 58 records, 25 were duplicates; therefore, they were also excluded from the research. Additional 7 records had to be removed after not reaching the main author for a full-text retrieve. This led to a total of 26 to full appraisal and discussion, after which more 11 papers were removed attributable to one (or more) of the

following reasons: the article only had theoretical data, the field data did not occur in occupational context, the article did not provide actual field data despite occupational protocol. At the end of this analysis, 15 papers were included in this short review.

Except for one study that takes place in the construction field (Lee, Kim, & Hong, 2019), every other paper set is related to the mining industry, where the exploited commodities varied between marble (Melo Neto, Kohlman Rabbani, Barkokébas Junior, Lago, & Jonathas, 2012) to aggregates (Onder, Onder, & Mutlu, 2012) and andesite (Kosała & Stępień, 2016), limestone (Çınar & Şensöğüt, 2019), coal (Simion, Kovacs, Toth, Ilie, & Gireadă, 2017) and lignite (Srivastava, Gupta, Srivastava, & Kaur, 2010), chromite (Kerketta, Gartia, & Bagh, 2012), copper (Lilic et al., 2018) and iron (Lokhande et al., 2017).

Given that this study's aim is related to occupational exposure to noise, the experimental data was classified according to the measurement setting, which is provided in Table 1, divided into activity, equipment, job category, and working area.

Table 1. Occupational noise measurement setting

Author, year	Activity	Equipment	Job category	Working area
(Srivastava et al., 2010)	x			
(Gupta, Roy, & A. Rajan B, 2012)		x		
(Kerketta et al., 2012)				x
(Melo Neto et al., 2012)			x	
(Onder et al., 2012)			x	
(Cinar & Sensogut, 2013)		x		
(Gyamfi, Amankwaa, Owusu Sekyere, & Boateng, 2016)		x		
(Kosała & Stępień, 2016)	x	x		
(Lokhande et al., 2017)				x
(Simion et al., 2017)		x		
(Lilic et al., 2018)		x		
(Wichers et al., 2018)		x		
(Çınar & Şensöğüt, 2019)				
(Lee et al., 2019)		x		
(Mihut, 2019)		x		

Regarding activity, both studies (Kosała & Stępień, 2016; Srivastava et al., 2010) focused on the blasting operation, where increasing distance leads to lower noise measurement values. The peak pressure level measured at 200 metres from the blast was 132 dB (Srivastava et al., 2010), whereas the equivalent continuous sound pressure level (Leq) for an 8-hour period was 53.3 dB at 86 metres, 37.2 dB at 155 metres, and 31.0 dB at 186 metres.

The selected equipment for each study is detailed in Table 2.

Table 2. Studied equipment

Author, year	Equipment
(Gupta et al., 2012)	Jack hammer drill
(Cinar & Sensogut, 2013)	Bulldozer, cone crusher, excavator, grader, hydraulic hammer, jaw crusher, mill, sieve, truck
(Gyamfi et al., 2016)	Drilling machine, tyre wrench, lathe machine, block making machine, generator set, crusher machine, primary processing machine, secondary processing machine, excavator machine, air compressor
(Kosała & Stępień, 2016)	Crusher, siever, vibrating feeder, wheel conveyor, conveyor, dispenser aggregate for the loading silo
(Simion et al., 2017)	Bucket-wheel excavator
(Lilic et al., 2018)	Truck, shovel, bulldozer, drilling rig, grader, crusher, belt conveyor
(Wichers et al., 2018)	Asphalt mixer, drilling rig, crushing plant
(Lee et al., 2019)	Air compressor, breaker, bulldozer, compactor, crusher, drill, excavator, grader, jack hammer, loader, roller
(Mihut, 2019)	Truck, tractor, motor hacksaw, charger, bulldozer, excavator

Overall results showed that heavy machinery such as trucks and bulldozers had noise levels above 100 dB(A) (Lilic et al., 2018), crusher (despite type – cone or jaw) produced noise levels between 85.6 and 104 dB(A) (Cinar & Sensogut, 2013; Gyamfi et al., 2016; Lee et al., 2019; Lilic et al., 2018), and shovel 103 dB(A) (Lee et al., 2019). Two studies applied the experimental protocol before and after equipment maintenance (Cinar & Sensogut, 2013; Simion et al., 2017) and concluded that the noise level lower after an intervention.

Only two studies recorded noise related to job category (Melo Neto et al., 2012; Onder et al., 2012). Melo Neto et al. (2012) experimental protocol was applied at two marble finishing plants, where polisher workers were exposed to equivalent continuous sound pressure levels between 99 and 105 dB(A) and cutting workers were exposed to noise levels between 100 and 101 dB(A). Office workers were exposed to values below 87 dB(A). In the other study, the job categories of cook, crusher worker, drilling operator, driver, mining machine operator, weighter and work site chief were analysed. The highest exposure was measured for one of the mining machine operators (108 dB(A)) and the drilling operator (95 dB(A)). However, all crusher workers were exposed to noise levels above 90 dB(A).

Finally, regarding the working area, there were two studies (Kerketta et al., 2012; Lokhande et al., 2017). Industrial area measurements varied between 53.31 and 72.29 dB(A), commercial area ranged between 58.33 and 78.65 dB(A), and work zone, which included heavy machinery, blasting zone and processing plant, varied between 54.79 and 100.56 dB(A) (Kerketta et al., 2012). In the other study, industrial area occupational noise ranged between 64.2 and 73.4 dB(A) during the day, and between 55.2 and 64.4 dB(A) during the night. In the commercial area, the ranges were 62.2-72.7 dB(A) (day) and 52.6-55.6 dB(A) (night); at the mine sites, these values were higher, ranging between 91.1 and 117 dB(A) during the day, and 61.3 and 120.5 dB(A) at night time. Moreover, three haulage roads were assessed, and the measurements were between 61.3 and 71.1 dB(A) (Lokhande et al., 2017).

Despite this general narrative analysis, it is important to state that cultural context should be considered while assessing the results, as specific norms and standards may apply. For instance, in Europe, there are regulative norms that apply to every country. The same does not happen in other parts of the world, were these standards may vary. More focused analysis has to be carried out concerning the comparable data.

CONCLUSIONS

This short review aimed to identify the tasks and equipment associated with noise exposure in the extractive industry and similar works. However, while trying to classify the data and due to the nature of papers, two additional categories were added: job category and working area. Fourteen out of the fifteen papers were in the mining industry and one in the construction industry despite describing similar works. Specifically related to tasks, only the blasting operation was addressed (Kosała & Stępień, 2016; Srivastava et al., 2010), although the list of operations that stand as noise sources (Wichers et al., 2018). On the other hand, regarding equipment, a plethora of examples were provided: bulldozer, jaw and cone crusher, different kinds of sieves, conveyor, excavator, truck, shovel, among many others. Interestingly, most of this equipment presented high noise levels (of 80 dB and above). Only comparable data was used in this work as some of the articles presented their results in graphic form. The job category was created to answer two studies that analysed personal noise level exposure of polisher worker and cutter worker (Melo Neto et al., 2012), and crusher worker, drilling operator, driver, mining machine operator and weighter (Onder et al., 2012). Commercial and industrial zone,

mines, and haulage road were mentioned as the understudy working areas (Kerketta et al., 2012; Lokhande et al., 2017).

From this primary research, it was not possible to identify exposure settings other than the classifications made. However, this primary investigation has set the tone for the subsequent research that has to be carried out: additional records have already been identified and have to be compared to the eligibility standard so to deepen the analysis. Statistical data treatment will needs to be performed to the final set of information. The ultimate objective will be to design the processes and activities having in consideration the nefarious consequences of such exposure not only to workers but also to the surrounding communities.

Acknowledgements

This work was supported by FCT through INEGI, under LAETA project SFRH/BD/143241/2019. The authors would like to acknowledge the Doctoral Program in Occupational Safety and Health for the support in this research.

References

Asady, H., Fuente, A., Pourabdian, S., Forouharmajd, F., & Shokrolahi, I. (2021). Acoustical role of ear canal in exposure to the typical occupational noise levels Hadi. *Medical Journal of the Islamic Republic of Iran*, *5*(May), 35–58. http://doi.org/doi.org/10.47176/mjiri.35.58

Chen, K. H., Su, S. Bin, & Chen, K. T. (2020). An overview of occupational noise-induced hearing loss among workers: epidemiology, pathogenesis, and preventive measures. *Environmental Health and Preventive Medicine*, *25*(1), 1–10. http://doi.org/10.1186/s12199-020-00906-0

Cinar, I., & Sensogut, C. (2013). Evaluation of noise measurements performed in mining sites for environmental aspects. *International Journal of Environmental Research*, *7*(2), 383–386. http://doi.org/10.22059/ijer.2013.616

Çınar, I., & Şensöğüt, C. (2019). Mapping of Noise Propagation in Quarries for Environmental Perspective. *International Journal of Economic and Environmental Geology*, *10*(1), 1–4. article. http://doi.org/10.46660/ojs.v10i1.210

Duarte, J., Castelo Branco, J., & Santos Baptista, J. (2020). Occupational exposure to noise in the extractive industry and earthworks – a systematic review protocol. *International Journal of Occupational and Environmental Safety*, *4*(2), 89–94. http://doi.org/10.24840/2184-0954_004.002_0007

Gupta, P., Roy, S., & A. Rajan B. (2012). Study on Noise Levels Generated due to Jack Hammer Drills in Granite Quarries. *Frontiers in Science*, *2*(3), 47–52. http://doi.org/10.5923/j.fs.20120203.06

Gyamfi, C. K. R., Amankwaa, I., Owusu Sekyere, F., & Boateng, D. (2016). Noise exposure and hearing capabilities of quarry workers in Ghana: A cross-sectional study. *Journal of Environmental and Public Health*, *2016*, 1–7. article. http://doi.org/10.1155/2016/7054276

Hon, C. Y., Tchernikov, I., Fairclough, C., & Behar, A. (2020). Case study in a working environment highlighting the divergence between noise intensity and workers' perception towards noise. *International Journal of Environmental Research and Public Health*, *17*(17), 1–11. http://doi.org/10.3390/ijerph17176122

Kerketta, S., Gartia, R., & Bagh, S. (2012). Hearing threshold, loss, noise levels and worker's profiles of an open cast chromite mines in Odisha, India. *Malaysian Journal of Medical Sciences*, *19*(4), 64–72.

Kosała, K., & Stępień, B. (2016). Analysis of noise pollution in an andesite quarry with the use of simulation studies and evaluation indices. *International Journal of Occupational Safety and Ergonomics*, *22*(1), 92–101. article. http://doi.org/10.1080/10803548.2015.1106702

Lee, S. C., Kim, J. H., & Hong, J. Y. (2019). Characterizing perceived aspects of adverse impact of noise on construction managers on construction sites. *Building and Environment*, *152*(February), 17–27. http://doi.org/10.1016/j.buildenv.2019.02.005

Li, X., Dong, Q., Wang, B., Song, H., Wang, S., & Zhu, B. (2019). The Influence of Occupational Noise Exposure on Cardiovascular and Hearing Conditions among Industrial Workers. *Scientific Reports*, *9*(1), 1–7. http://doi.org/10.1038/s41598-019-47901-2

Lilic, N., Cvjetic, A., Knezevic, D., Milisavljevic, V., & Pantelic, U. (2018). Dust and Noise Environmental Impact Assessment and Control in Serbian Mining Practice. *Minerals*, *8*(2), 34. http://doi.org/10.3390/min8020034

Lokhande, S. K., Dhawale, S. A., Pathak, S. S., Gautam, R., Jain, M. C., & Bodhe, G. L. (2017). Appraisal of noise level dissemination surrounding mining and industrial areas of Keonjhar, Odisha: A comprehensive approach using noise mapping. *Archives of Acoustics*, *42*(3), 423–432. JOUR. http://doi.org/10.1515/aoa-2017-0044

Melo Neto, R. P., Kohlman Rabbani, E. R., Barkokébas Junior, B., Lago, E. M. G., & Jonathas, J. B. (2012). Quantitative noise analysis at two marble finishing plants in Olinda, Pernambuco, Brazil. *Work*, *41*(SUPPL.1), 5850–5852. http://doi.org/10.3233/WOR-2012-0972-5850

Mihut, N.-M. (2019). Noise pollution in the course of the steps of preparing the mining field for the operation of the open cast mine Pinoasa. *Fiability & Durability*, *1*(1), 232–236. article.

Moher, D., Liberati, A., Tetzlaff, J., Altman, D., Altman, D., Antes, G., … Tugwell, P. (2009). Preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement. *PLoS Medicine*, *6*(7). http://doi.org/10.1371/journal.pmed.1000097

Ntlhakana, L., Nelson, G., & Khoza-Shangase, K. (2020). Estimating miners at risk for occupational noise-induced hearing loss: A review of data from a South African platinum mine. *South African Journal of Communication Disorders*, *67*(2), 1–8. http://doi.org/10.4102/sajcd.v67i2.677

Onder, M., Onder, S., & Mutlu, A. (2012). Determination of noise induced hearing loss in mining: an application of hierarchical loglinear modelling. *ENVIRONMENTAL MONITORING AND ASSESSMENT*, *184*(4), 2443–2451. article. http://doi.org/10.1007/s10661-011-2129-0

Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., … Moher, D. (2021). The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. *PLOS Medicine*, *18*(3), e1003583. JOUR. Retrieved from https://doi.org/10.1371/journal.pmed.1003583

Simion, S., Kovacs, M., Toth, L., Ilie, C., & Gireadă, A. (2017). *Workers exposure to noise in surface extractive industry*. *Environmental Engineering and Management Journal* (Vol. 16).

Srivastava, R. K., Gupta, N. C., Srivastava, R., & Kaur, A. (2010). Noise levels in lignite mining area of Kutch (Gujrat) and mitigation measures. *Journal of Industrial Pollution Control*, *26*(1), 79–81.

Wichers, M., Iramina, W. S., de Eston, S. M., & Ayres da Silva, A. L. M. (2018). Using a noise monitoring station in a small quarry located in an urban area. *Environmental Monitoring and Assessment*, *190*(1). article. http://doi.org/10.1007/s10661-017-6404-6

Wohlin, C., & Claes. (2014). Guidelines for snowballing in systematic literature studies and a replication in software engineering. In *Proceedings of the 18th International Conference on Evaluation and Assessment in Software Engineering - EASE '14* (pp. 1–10). inproceedings, New York, New York, USA: ACM Press. http://doi.org/10.1145/2601248.2601268

Zhou, J., Shi, Z., Zhou, L., Hu, Y., & Zhang, M. (2020). Occupational noise-induced hearing loss in China: A systematic review and meta-analysis. *BMJ Open*, *10*(9). http://doi.org/10.1136/bmjopen-2020-039576

Firefighters occupational exposure assessment: a systematic literature review

Tatiana Teixeira[1], Isabel Dias[2], Joana Santos[3], Denisse Bustos[4] J. C. Guedes[5]

[1]Faculty of Engineering, University of Porto, PT (tati.teixeira.30@gmail.com) ORCID 0000-0001-5636-1030 , [2]Department of Sociology, Faculty of Arts, University of Porto, PT and Sociology Institute, University of Porto, PT (mdias@letras.up.pt) ORCID 0000-0001-8688-4385, [3]Environmental Health Department, School of Health, Polytechnic of Porto, PT (jds@ess.ipp.pt) ORCID 0000-0002-2777-3244, [4]Associated Laboratory for Energy, Transports and Aeronautics - LAETA (PROA), Faculty of Engineering, University of Porto, PT (ldbs@fe.up.pt) ORCID 0000-0002-4942-7625, [5]Associated Laboratory for Energy, Transports and Aeronautics - LAETA (PROA), Faculty of Engineering, University of Porto, PT (jccg@fe.up.pt) ORCID 0000-0003-2367-2187.
https://doi.org/10.24840/978-972-752-279-8_0021-0030

Abstract

Introduction: Over the years, the evolution of forest fires has occurred as a result of the evolution of the human species. However, forest fires are still a major challenge for society, placing firefighters with greater occupational exposure. The present study has as main objective to carry out a systematic review of the literature on the main techniques and variables for assessing the occupational exposure of firefighters, during the fight against forest fires. Methodology: The systematic review utilised The Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement methodology. This methodology was applied in the Scopus, Web of Science, Pubmed and Academic Search Complete databases with different keywords. The review will include articles written in English only. Results: In the present study, 34 articles were included, in which it was found that exposure to smoking is the most studied variable, and it was in 2019 that a greater evolution of studies in this area of research was observed. Regarding the variables, the studies were organised in groups. Here it is possible to check the different variables selected by the authors and the methods and equipment applied. Discussion: The fact that firefighters carry out their tasks in diverse scenarios and extreme conditions has hindered the application of innovative equipment. It is necessary to combine different variables and equipment for the assessment of occupational exposure. However, it is not always possible to develop this type of equipment in order to be inserted from the user's perspective, from the perspective of the environment, where it will be applied, and from an economic perspective, making it difficult to effectively apply it in the field. Conclusion: As future perspectives, it is recommended that new variables are introduced together, in order to improve the assessment of occupational exposure, namely, through the use of carbon monoxide (CO) and lactate assessment.

Keywords: Occupational Innovation; Occupational Exposure; Extreme conditions; Firefighters.

INTRODUCTION

In 2018, Portugal accounted for 467 fire brigades and 27649 firefighters (PORDATA, 2018). The climate changes that have been taking place in recent years, have made fighting forest fires more difficult and time-consuming, making Portugal one of the countries with the highest forest fire risk ranking. Some large fires are already known that have caused high numbers of deaths in firefighters (Viegas, 2017). The performance of firefighters' activities in front of a fire is physically and mentally demanding, exposing individuals to heat, fatigue, stress, noise and exposure to chemical substances, through inhalation and dermal contact (Broyles et al., 2019; Neitzel et al., 2009; Serra et al., 1996; Swiston et al., 2008).

The toxic agents that are often found in smoke from forest fires and that are known to cause major impacts on the respiratory tract are Carbon Monoxide, Formaldehyde and Respirable Particles (Neitzel et al., 2009). Studies of the impacts on the health of forest fires have used different aspects and research methodologies. One of the variables that have been extensively studied is the acute toxicity of smoking. Exposure to smoke from forest fires is equivalent to exposure to tobacco smoke. It is a smoke with mixtures of polycyclic aromatic hydrocarbons (Adetona et al., 2017; Nathaniel Rothman et al., 1993).

Forest fires are still a major challenge for a society, where the area of investigation of the occupational exposure of firefighters demonstrates a strong need to be further developed and built, in order to

reduce the negative impacts that this area has on the community (Miranda et al., 2010). The aim objective of this study is to carry out a systematic review of the literature on the main techniques and variables for assessing the occupational exposure of firefighters, during the fight against forest fires.

METHODOLOGY

For the systematic literature review, the Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement methodology was adopted. The research strategy was developed based on the extension of the Preferred Reporting Items for Systematic Review and Meta-Analysis Protocols (PRISMA-P). The research focused on the SCOPUS, Web Of Science, Pubmed, and Academic Search Complete databases. There were no date restrictions on the selection of articles, and language selected was English. The selected keywords were: Firefighters, Forest Fire; Occupational Exposure; Occupational Health; Occupational Exposure Limits; Occupational Hygiene; Work Injuries; Professional Diseases; Cognitive Function; Occupational Safety; Subjectivity of Perceived Effort; Fatigue; Physiological Response; Physiological Monitoring; Stress and Occupational Innovation. All articles with samples of firefighters were included, without age or sex restrictions. Articles with field and laboratory methodologies applied exclusively to forest fires and with samples of firefighters were accepted. After selection in the databases, the articles were analysed and selected by the abstract. Finally, the methodology of each article was analysed, identifying the variables used and the main results.

RESULTS

A total of 369 articles were obtained, which, after applying the filters in each database, resulted in 329 articles. Of these, only 34 articles were included in the methodology and for eligibility criteria. In Table 1, it is possible to verify the articles selected in different steps, including the filters applied.

Table 1. Articles selected

Data Base	Results	Document Type	Article Type	Language	Selected by title	Abstract selected	Methodology Analysis
Scopus	99	83	83	83	29		
Pubmed	171	169	169	161	33		
Web Of Science	74	65	65	65	11	45	34
Academic Search Ultimate	25	24	24	20	0		
Total	369	341	341	329	73		

In 2019, there was a peak in this area of investigation, and the keyword corresponding to this peak is “Occupational Exposure”. In Figure 1, it is possible to check the selection of articles using the prism diagram.

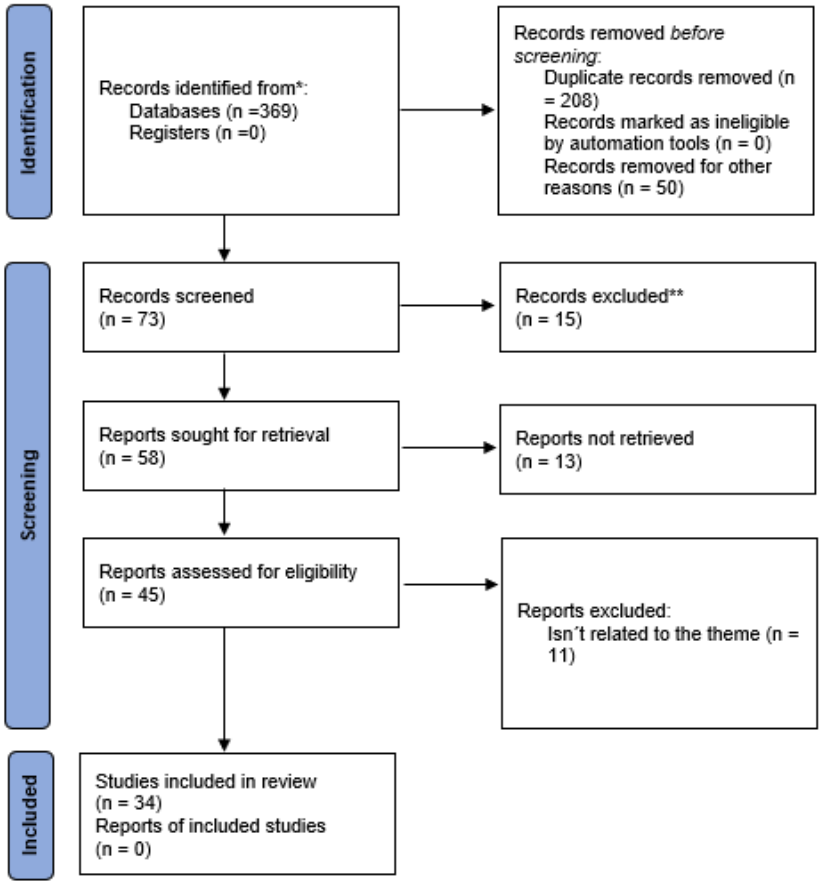

Figure 1. PRISMA flow diagram (Page et al., 2021)

With regard to variables, the studies were organised into groups, namely stress, exposure to smoke (here included articles referring to exposure to carbon monoxide (CO), respirable particles (PM), formaldehydes, radionuclides and hydrocarbons), exposure noise, lung function (including articles referring to respiratory symptoms), exposure biomarkers, thermal stress, cancer, nutrition and hydration, workload and cognitive function. In Table 2 it is possible to verify the variables used by the different authors and the techniques applied.

Table 2. Variables and apllied techniques

Reference	Variables	Tools/Equipments
(N. Rothman et al., 1993)	Sociodemographic data	Questionnaires
	Deoxyribonucleic acid	Enzyme-linked immunosorbent assay (ELISA)
(Nathaniel Rothman et al., 1993)	Sociodemographic data	Questionnaires
	Deoxyribonucleic acid	Blood sample
(Serra et al., 1996)	Respiratory function	Jaegher Masterlab
(Betchley et al., 1997)	Dados sociodemográficos	Questionnaires
	Sociodemographic data	Questionnaires
(Reinhardt & Ottmar, 2004)	Carbon Monoxid	ID-209 Method (OSHA)
	carbon dioxide	ID-209 Method(OSHA)
	Benzene	Gas chromatography / flame ionization detection (NIOSH)
	Formaldehyde	High performance liquid chromatography according to EPA TO-11 method
	Acrolein	
	PM3,5	Teflon R
(Almeida et al., 2007)	Spirometry	Vmax® computer software version 4.04, SensorMedics, Thermo Electron
	Sociodemographic data	Firefighter Coping Self-Efficacy Scale Quiz
(Swiston et al., 2008)	Carbon Monoxid	Pac III portable monitor; Drager
	Blood sample	Peripheral venupuncture
	Spirometry	EasyOne Spirometer
(Neitzel et al., 2009)	Urinary methoxyphenols	Urine
	Carbon Monoxid	Draeger PAC III single gas meters
	PM2,5	Filtros Teflo Gelman 37 mm
(Miranda et al., 2010)	Carbon monoxid	GasAlertMicroClip e CO GasAlertextreme
	PM2,5	SidePackAM510 Personal Aerosol Monitor
	Volatile Organic Compounds	Detetor GasAlertMicro 5 PID
	Nitrogen Dioxide	Detetor GasAlertMicro 5 PID
(Adetona et al., 2011)	Particle Matter	Air Check Model 224-PCXR sampler, using a 37 mm Teflo Gelman filter and with Pac III single gas monitors
(J. A. Rodríguez-Marroyo et al., 2011).	Core temperature	JonahTM intestinal temperature capsule
	Heart rate	Polar Team, Polar Electro Oy, Kempele, Finland
(Reisen et al., 2011)	Carbon monoxid	Dräger Pac III E
	Formaldehyde	UMEx 100
	Breathable particles	SidePak AM510 Personal Aerosol Monitor

(Apud & Meyer, 2011)	Heart rate	Polar vantage
	Globe temperature	Conventional thermometer
	Air speed	anemometer
	Aerobic capacity	Extrapolation through the use of VO2 and an ergometer cycle
	Anaerobic capacity	Ventilatory threshold
	Body composition	Holtain Caliper Method
(Jose A. Rodríguez-Marroyo et al., 2012)	Heart rate	Polar Team, Polar Electro Oy, Kempele, Finland
	Electrocardiogram	Schiller AG, Baar, Switzerland
	Gas exchange in the respiratory	Medical Graphics System CPX-Plus, Medical Graphics Corporation, St. Paul, MN, USA
	Core temperature	JonahTM intestinal temperature capsule
(Miranda et al., 2012)	Lung Function	Espirómetro MicroMedical, modelo MicroLab ML3500
	Carbon monoxid	GasAlertextreme from BW Technologies
	Volatile Organic Compounds	GasAlertMicro 5 PID from BW Technologies
	Nitrogen Dioxide	GasAlertMicro 5 PID from BW Technologies
(Raines et al., 2012)	Ambient temperature	Weather stations
	Hidratation	Blood sample using the vacutainer method
	Heart rate	Polar heart rate monitors
	Movements	Actica Activity Monitor
	Core temperature	Jonah Mini- Mitter, Bend, Oregon
(Hejl et al., 2013)	Biomarkers	Whatman 903 Protein Saver Cards
	Carbon monoxid	Dräager Pac III
	PM2,5	SidePak AM510
	Sociodemographic data	Questionnaires
(Dunn et al., 2013)	Carbon monoxid	Draeger PAC III CO
(Gordon & Larivière, 2014)	Evaluation of accidents with injuries	Data Bases
	Assessment of perceived severity and frequency of work-related stressful events	*Job Stress Survey*
(Shrira et al., 2015)	Post-traumatic stress syndrome	IES-R; 8
	Self-efficacy	*Firefighter Coping Self-Efficacy Scale*
	Positive Affection	Item 6 da *Scale of Positive and Negative Experience*
	Meaning of life	*5 iténs do "presence of meaning" subscale of the MIL Questionnaire*
(Parker et al., 2017)	Heart Rate	GPSports SPI10
	Movements	Video Camera PAL de 65 mmby 20 mm
(Abreu et al., 2017)	Basal deoxyribonucleic acid	Collection of blood samples using the comet assay procedure
(Adetona et al., 2017)	Polycyclic aromatic hydrocarbons	Urine samples

(Gianniou et al., 2018)	Bronchoscopy	BF-1T200; Olympus Corporation
	Lung Function	MasterScreen; Jaeger, Hoechberg, Alemanha
(Sol et al., 2018)	Heart Rate	Equivital
	Core temperature	
(Henn et al., 2019)	Real-time simulated fire characteristics	Fuel model, fire behaviour, flame height, type of fire and fire activity
	Carbon Monoxide	MSA Altair Pro Fire
(Broyles et al., 2019)	Perception of noise exposure	Questionnaires
	Noise	Dosimetry
(West et al., 2019).	Heart Rate	Equivital EQO2 Life Monitor system
	Respiratory frequency	
	Core temperature	
	Ambient temperature and humidity	OMEGA Engineering, Stamford, Connecticut, EUA
(Navarro, Kleinman, et al., 2019)	PM2,5	Use of validated equation
(Navarro, Cisneros, et al., 2019)	Polycyclic aromatic hydrocarbons	XAD2
	PM2,5	*Environmental Beta Attenuation Monitor*
(Cvirn et al., 2019)	Cognitive Function	Stroop test
	Movements	Actiwatch-64
	Hydration	Analysis of specific gravity of urine
(Wu et al., 2020)	Exhaled air	Respiratory condenser RTube ™
	Oxidative stress	Enzyme immune assay kit (ELISA)
	Pro-inflammatory biomarkers	Human V-plex Ultra-Sensitive Kit designed by Meso Scale Discovery (MSD)
(Marks et al., 2020)	Sociodemographic data	Questionnaires
	Movements	Actigraphs (MiniMitter, Bend, OR)

DISCUSSION

In the results of the present study, it is verified that only one study mentioned the evaluation of radioactivity compounds. The assessment of exposure to radionuclides emitted by smoke during a forest fire can be used as an indicator of cancer incidence, in particular lung cancer. However, it is known that the appearance of lung cancer in firefighters can originate from the combination of different variables, such as exposure to smoking and smoking habits (Abreu et al., 2017).

The International Commission on Radiation Units and Measurements (ICRU) provides international recommendations regarding acceptable values, applicable units and radiation measurement techniques. The techniques for assessing radiation exposure have evolved to ensure greater accuracy and assessment of exposure (International Commission on Radiation Units & Measurements, 2021). However, the measurement in real-time in a forest fire proves to have great difficulty in the application of equipment and the innovation of the process of sampling. In this way, some ways of assessing radioactivity are known through the use of autonomous large-volume samplers, portable aerosol samplers (Carvalho et al., 2014), by estimating the effective dose by inhalation using the Gaussian model (Viner et al., 2015) or through the use of other models. These authors use the Linear No-Threshold model to assess the risk to human health of a forest fire in a forest with radiological contamination.

The use of systems to monitor the health status of firefighters in real-time has already begun to be developed. However, these systems have not yet been applied to all activities at greatest risk to firefighters, as they are not yet developed with variables that indicate enough information to assess the health status of firefighters during the execution of the activity. In fact, the assessment of the firefighters' health status and, consequently, their occupational exposure does not always involve a large number of variables, as can be seen through the included studies, where the variables that are mostly included are related to smoke exposure, thermal stress and lung function (Jose A. Rodríguez-Marroyo et al., 2012).

In a study by Raj & Sarath (2019), a prototype was created that allows the assessment of firefighters' stress through the application of wireless sensors on gloves. In fact, physiological monitoring by wireless systems is an important step towards the safety of firefighters. The information that is provided by these systems allows the assessment of the person's health status, as well as their state of readiness (Adetona et al., 2011; Neitzel et al., 2009).

The collection of data related to the environment in which the firefighter is extremely important. Data such as ambient temperature, CO and oxygen levels allow assessing of the physical circumstances that are conditioning the firefighter's safety and can be warning indicators when these conditions are not those recommended for the health of the professional. These telemetry sensors for monitoring firefighters, together with physiological variables, are already known (Henn et al., 2019; Navarro, Kleinman, et al., 2019; Raines et al., 2012; West et al., 2019). The combination of environmental and physiological variables may prove to be the key to the indication of fatigue alerts caused by exposure to the occupational environment of forest fires. In fact, physiological variables are already known which, when exposed to certain environments, represent fatigue indicators. An example of this, lactate, which has been shown to be an important and easy to monitor indicator, has already been verified as an innovation in biotelemetry. Lactate is already used to determine pathologies and determine the bioenergetic consumption of muscle cells. The correlation between the increase in lactate concentration and exposure to environments with high concentrations of CO, allow us to indicate lactate as a good indicator of overload since it is associated with the consumption of oxygen for energy

production, verified that in oxygen-deprived environments the lactate concentration tends to increase. Therefore, lactate is considered an invasive parameter that can be difficult to include in biotelemetry systems. Assuming that the anaerobic threshold can be estimated using heart rate, a parameter that is easy to measure using portable meters and that although it is known the need for more evaluations to determine the agreement of the different variables (Apud & Meyer, 2011).

Note that other variables of physiological stress should also be included in the occupational assessment and in the combination of those previously mentioned, such as, for example, the assessment of cognitive function (Navarro, Cisneros, et al., 2019). Although it is not easy to apply tests to assess cognitive function in real-time, except at the end of firefighting or in a laboratory environment, some tests are already known that allow easy evaluation.

CONCLUSION

As we have seen, innovation in firefighters has proved to be difficult to apply. The fact that firefighters carry out their tasks in diverse scenarios under extreme conditions has made it difficult to apply innovative equipment. In addition, some of the equipment developed is not economically sustainable, making it a major obstacle to acquiring such equipment by the fire brigades, particularly in Portugal, where they are mostly non-profit corporations. The development of this equipment must be thought from the user's perspective, from the perspective of the environment where it will be applied and from an economic perspective. However, it is not always possible to develop innovative equipment that falls within these three perspectives, making it difficult to quickly and effectively apply it on the ground.

References

Abreu, A., Costa, C., Pinho e Silva, S., Morais, S., do Carmo Pereira, M., Fernandes, A., Moraes de Andrade, V., Teixeira, J. P., & Costa, S. (2017). Wood smoke exposure of Portuguese wildland firefighters: DNA and oxidative damage evaluation. *Journal of Toxicology and Environmental Health - Part A: Current Issues*, *80*(13–15), 596–604. https://doi.org/10.1080/15287394.2017.1286896

Adetona, O., Dunn, K., Hall, D. B., Achtemeier, G., Stock, A., & Naeher, L. P. (2011). Personal PM(2.5) exposure among wildland firefighters working at prescribed forest burns in Southeastern United States. *Journal of Occupational and Environmental Hygiene*, *8*(8), 503–511. https://doi.org/10.1080/15459624.2011.595257

Adetona, O., Simpson, C. D., Li, Z., Sjodin, A., Antonia, M., Naeher, L. P., & Sciences, O. H. (2017). *Hydroxylated polycyclic aromatic hydrocarbons as biomarkers of exposure to wood smoke in wildland firefighters*. *27*(1), 78–83. https://doi.org/10.1038/jes.2015.75.Hydroxylated

Almeida, A. G., Duarte, R., Mieiro, L., Paiva, A. C., Rodrigues, A. M., Almeida, M. H., & Bárbara, C. (2007). Pulmonary function in portuguese firefighters. *Revista Portuguesa de Pneumologia*, *XIII*(3), 149–157.

Apud, E., & Meyer, F. (2011). Factors influencing the workload of forest fire-fighters in Chile. *Work*, *38*(3), 203–209. https://doi.org/10.3233/WOR-2011-1124

Betchley, C., Koenig, J. Q., Van Belle, G., Checkoway, H., & Reinhardt, T. (1997). Pulmonary function and respiratory symptoms in forest firefighters. *American Journal of Industrial Medicine*, *31*(5), 503–509. https://doi.org/10.1002/(SICI)1097-0274(199705)31:5<503::AID-AJIM3>3.0.CO;2-U

Broyles, G., Kardous, C. A., Shaw, P. B., & Krieg, E. F. (2019). Noise exposures and perceptions of hearing conservation programs among wildland firefighters. *Journal of Occupational and Environmental Hygiene*, *16*(12), 775–784. https://doi.org/10.1080/15459624.2019.1668001

Carvalho, F. P., Oliveira, J. M., & Malta, M. (2014). Exposure to radionuclides in smoke from vegetation fires. *Science of the Total Environment*, *472*, 421–424. https://doi.org/10.1016/j.scitotenv.2013.11.073

Cvirn, M. A., Dorrian, J., Smith, B. P., Vincent, G. E., Jay, S. M., Roach, G. D., Sargent, C., Larsen, B., Aisbett, B., & Ferguson, S. A. (2019). The effects of hydration on cognitive performance during a simulated wildfire suppression shift in temperate and hot conditions. *Applied Ergonomics*, *77*(January), 9–15. https://doi.org/10.1016/j.apergo.2018.12.018

Dunn, K. H., Shulman, S., Stock, A. L., & Naeher, L. P. (2013). Personal carbon monoxide exposures among firefighters at prescribed forest burns in the Southeastern United States. *Archives of Environmental and Occupational Health*, *68*(1), 55–59. https://doi.org/10.1080/19338244.2011.633126

Gianniou, N., Giannakopoulou, C., Dima, E., Kardara, M., Katsaounou, P., Tsakatikas, A., Roussos, C., Koulouris, N., & Rovina, N. (2018). Acute effects of smoke exposure on airway and systemic inflammation in forest firefighters. *Journal of Asthma and Allergy*, *11*, 81–88. https://doi.org/10.2147/JAA.S136417

Gordon, H., & Larivière, M. (2014). Physical and psychological determinants of injury in Ontario forest firefighters. *Occupational Medicine (Oxford, England)*, *64*(8), 583–588. https://doi.org/10.1093/occmed/kqu133

Hejl, A. M., Adetona, O., Diaz-Sanchez, D., Carter, J. D., Commodore, A. A., Rathbun, S. L., & Naeher, L. P. (2013). Inflammatory effects of woodsmoke exposure among wildland firefighters working at prescribed burns at the savannah river site, SC. *Journal of Occupational and Environmental Hygiene*, *10*(4), 173–180. https://doi.org/10.1080/15459624.2012.760064

Henn, S. A., Butler, C., Li, J., Sussell, A., Hale, C., Broyles, G., & Reinhardt, T. (2019). Carbon monoxide exposures among U.S. wildland firefighters by work, fire, and environmental characteristics and conditions. *Journal of Occupational and Environmental Hygiene*, *16*(12), 793–803. https://doi.org/10.1080/15459624.2019.1670833

International Commission on Radiation Units & Measurements. (2021). *Current Activities of ICRU*.

Marks, A. N., Sol, J. A., Domitrovich, J. W., West, M. R., & Ruby, B. C. (2020). Total Energy Intake and Self-Selected Macronutrient Distribution During Wildland Fire Suppression. *Wilderness and Environmental Medicine*, *31*(2), 188–196. https://doi.org/10.1016/j.wem.2020.01.009

Miranda, A. I., Martins, V., Cascão, P., Amorim, J. H., Valente, J., Tavares, R., Borrego, C., Tchepel, O., Ferreira, A. J., Cordeiro, C. R., Viegas, D. X., Ribeiro, L. M., & Pita, L. P. (2010). Monitoring of firefighters exposure to smoke during fire experiments in Portugal. *Environment International*, *36*(7), 736–745. https://doi.org/10.1016/j.envint.2010.05.009

Miranda, A. I., Martins, V., Casco, P., Amorim, J. H., Valente, J., Borrego, C., Ferreira, A. J., Cordeiro, C. R., Viegas, D. X., & Ottmar, R. (2012). Wildland smoke exposure values and exhaled breath indicators in firefighters. *Journal of Toxicology and Environmental Health - Part A: Current Issues*, *75*(13–15), 831–843. https://doi.org/10.1080/15287394.2012.690686

Navarro, K. M., Cisneros, R., Schweizer, D., Chowdhary, P., Noth, E. M., Balmes, J. R., & Hammond, S. K. (2019). Incident command post exposure to polycyclic aromatic hydrocarbons and particulate matter during a wildfire. *Journal of Occupational and Environmental Hygiene*, *16*(11), 735–744. https://doi.org/10.1080/15459624.2019.1657579

Navarro, K. M., Kleinman, M. T., Mackay, C. E., Reinhardt, T. E., Balmes, J. R., Broyles, G. A., Ottmar, R. D., Naher, L. P., & Domitrovich, J. W. (2019). Wildland firefighter smoke exposure and risk of lung cancer and cardiovascular disease mortality. *Environmental Research*, *173*(November 2018), 462–468. https://doi.org/10.1016/j.envres.2019.03.060

Neitzel, R., Naeher, L. P., Paulsen, M., Dunn, K., Stock, A., & Simpson, C. D. (2009). Biological monitoring of smoke exposure among wildland firefighters: A pilot study comparing urinary methoxyphenols with personal exposures to carbon monoxide, particular matter, and levoglucosan. *Journal of Exposure Science and Environmental Epidemiology*, *19*(4), 349–358. https://doi.org/10.1038/jes.2008.21

Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., Shamseer, L., Tetzlaff, J. M., Akl, E. A., Brennan, S. E., Chou, R., Glanville, J., Grimshaw, J. M., Hróbjartsson, A., Lalu, M. M., Li, T., Loder, E. W., Mayo-Wilson, E., McDonald, S., … Moher, D. (2021). The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. *Systematic Reviews*, *10*(1), 89. https://doi.org/10.1186/s13643-021-01626-4

Parker, R., Vitalis, A., Walker, R., Riley, D., & Pearce, H. G. (2017). Measuring wildland fire fighter performance with wearable technology. *Applied Ergonomics*, *59*, 34–44. https://doi.org/10.1016/j.apergo.2016.08.018

PORDATA. (2018). *Bombeiros*.

Raines, J., Snow, R., Petersen, A., Harvey, J., Nichols, D., & Aisbett, B. (2012). Pre-shift fluid intake: Effect on physiology, work and drinking during emergency wildfire fighting. *Applied Ergonomics*, *43*(3), 532–540. https://doi.org/10.1016/j.apergo.2011.08.007

Raj, J. V, & Sarath, T. V. (2019). An IoT based real-time stress detection system for fire-fighters. *2019 International Conference on Intelligent Computing and Control Systems, ICCS 2019*, 354–360. https://doi.org/10.1109/ICCS45141.2019.9065866

Reinhardt, T. E., & Ottmar, R. D. (2004). Baseline measurements of smoke exposure among wildland firefighters. *Journal of Occupational and Environmental Hygiene*, *1*(9), 593–606. https://doi.org/10.1080/15459620490490101

Reisen, F., Hansen, D., & Meyer, (Mick) P. (2011). Exposure to bushfire smoke during prescribed burns and wildfires: Firefighters' exposure risks and options. *Environment International*, *37*(2), 314–321. https://doi.org/10.1016/j.envint.2010.09.005

Rodríguez-Marroyo, J. A., Villa, J. G., López-Satue, J., Pernía, R., Carballo, B., García-López, J., & Foster, C. (2011). Physical and thermal strain of firefighters according to the firefighting tactics used to suppress wildfires. *Ergonomics*, *54*(11), 1101–1108. https://doi.org/10.1080/00140139.2011.611895

Rodríguez-Marroyo, Jose A., López-Satue, J., Pernía, R., Carballo, B., García-López, J., Foster, C., & Villa, J. G. (2012). Physiological work demands of Spanish wildland firefighters during wildfire suppression. *International Archives of Occupational and Environmental Health*, *85*(2), 221–228. https://doi.org/10.1007/s00420-011-0661-4

Rothman, N., Poirier, M. C., Haas, R. A., Correa-Villasenor, A., Ford, P., Hansen, J. A., O'Toole, T., & Strickland, P. T. (1993). Association of PAH-DNA adducts in peripheral white blood cells with dietary exposure to polyaromatic hydrocarbons. *Environmental Health Perspectives*, *99*(April), 265–267. https://doi.org/10.1289/ehp.9399265

Rothman, Nathaniel, Correa-Villaseńor, A., Patrick Ford, D., Poirier, M. C., Haas, R., Hansen, J. A., O'Toole, T., & Strickland, P. T. (1993). Contribution of Occupation and Diet to White Blood Cell Polycyclic Aromatic Hydrocarbon-DNA Adducts in Wildland Firefighters. *Cancer Epidemiology Biomarkers and Prevention*, *2*(4), 341–347.

Serra, A., Mocci, F., & Sanna Randaccio, F. (1996). Pulmonary function in Sardinian fire fighters. *American Journal of Industrial Medicine*, *30*(1), 78–82. https://doi.org/10.1002/(SICI)1097-0274(199607)30:1<78::AID-AJIM13>3.0.CO;2-5

Shrira, A., Shmotkin, D., Palgi, Y., Soffer, Y., Hamama Raz, Y., Tal-Katz, P., Ben-Ezra, M., & Benight, C. C. (2015). How Do Meaning in Life and Positive Affect Relate to Adaptation to Stress? The Case of Firefighters Following the Mount Carmel Forest Fire. *The Israel Journal of Psychiatry and Related Sciences*, *52*(3), 68–70.

Sol, J. A., Ruby, B. C., Gaskill, S. E., Dumke, C. L., & Domitrovich, J. W. (2018). Metabolic Demand of Hiking in Wildland Firefighting. *Wilderness and Environmental Medicine*, *29*(3), 304–314. https://doi.org/10.1016/j.wem.2018.03.006

Swiston, J. R., Davidson, W., Attridge, S., Li, G. T., Brauer, M., & Van Eeden, S. F. (2008). Wood smoke exposure induces a pulmonary and systemic inflammatory response in firefighters. *European Respiratory Journal*, *32*(1), 129–138. https://doi.org/10.1183/09031936.00097707

Viegas, D. X. (2017). *Cercados pelo Fogo em Águeda* (ADAI (ed.)).

Viner, B., Jannik, T., Stone, D., Hepworth, A., Naeher, L., Adetona, O., Blake, J., & Eddy, T. (2015). Modelling and mitigating dose to firefighters from inhalation of radionuclides in wildland fire smoke. *International Journal of Wildland Fire*, *24*. https://doi.org/10.1071/WF14181

West, M. R., West, M. R., Costello, S., Sol, J. A., & Domitrovich, J. W. (2019). Risk for heat-related illness among wildland firefighters: Job tasks and core body temperature change. *Occupational and Environmental Medicine*, *77*(7), 433–438. https://doi.org/10.1136/oemed-2019-106186

Wu, C.-M., Adetona, A., Song, C. C., Naeher, L., & Adetona, O. (2020). Measuring acute pulmonary responses to occupational wildland fire smoke exposure using exhaled breath condensate. *Archives of Environmental & Occupational Health*, *75*(2), 65–69. https://doi.org/10.1080/19338244.2018.1562413

Assessment of Potential Health Risks of Portuguese Wildland Firefighters' Occupational Exposure: Biomonitoring Approach

Filipa Esteves[1], Joana Madureira[2], João Paulo Teixeira[3], Solange Costa[4]

[1]National Institute of Health, Porto, PT; EPIUnit Institute of Public Health, University of Porto, PT; Laboratory for Integrative and Translational Research in Population Health (ITR), PT and Faculty of Medicine, University of Porto, PT (filipa.esteves3@hotmail.com) ORCID 0000-0001-9187-0279, [2]National Institute of Health, Porto, PT; EPIUnit Institute of Public Health, University of Porto, PT and Laboratory for Integrative and Translational Research in Population Health (ITR), PT (joana.madureira@insa.min-saude.pt) ORCID 0000-0001-5279-877X, [3] National Institute of Health, Porto, PT; EPIUnit Institute of Public Health, University of Porto, PT and Laboratory for Integrative and Translational Research in Population Health (ITR), PT (joao.teixeira@insa.min-saude.pt) ORCID 0000-0001-8693-5250, [4] National Institute of Health, Porto, PT; EPIUnit Institute of Public Health, University of Porto, PT and Laboratory for Integrative and Translational Research in Population Health (ITR), PT (joana.madureira@insa.min-saude.pt) ORCID 0000-0001-5279-877X, [3] National Institute of Health, Porto, PT; EPIUnit Institute of Public Health, University of Porto, PT and Laboratory for Integrative and Translational Research in Population Health (ITR), PT (solange.costa@insa.min-saude.pt) ORCID 0000-0003-4201-1966.
https://doi.org/10.24840/978-972-752-279-8_0031-0036

Abstract

Introduction: Worldwide, forest fires are among the most common forms of natural disasters. In the closing years of the last century there was an increase of the burned area in some parts of the globe, including in Europe. Portugal has been particularly affected by large forest fires and megafires, which have been occurred mainly in the central and northern regions. The proximity of firefighters to fire exposes them to high levels of toxic compounds making this occupation one of the most dangerous and leading International Agency for Research on Cancer to classified occupational firefighting activity as possibly carcinogenic to humans. Up to date, the existing studies are mainly focused on environmental monitoring, existing limited information regarding biomonitoring assessments during real scenarios of wildland fires combat. This study aims to evaluate the impact of firefighting occupational exposure at molecular and cellular levels, considering personal exposure levels. Early-effect biomarkers (e.g., micronucleus, DNA strand breaks and oxidative DNA damage) will be analyzed in order to understand the mechanisms of action through which woodsmoke may impact firefighters' health, including the risk of cancer. Methodology: This ongoing prospective longitudinal study will comprise three different stages, specifically pre-exposure, exposure, and post-exposure to fire season. Around 200 wildland northern Portuguese firefighters will be involved in this study. Characterization of the study population will be conducted via questionnaires. Firefighters' personal exposure levels will be assessed by means of metabolites in exhaled breath, using an artificial olfactory system (e-nose technology). Buccal and urine samples will be used to measure genomic instability through micronucleus test in buccal epithelial cells and urothelial cells. DNA damage and oxidative DNA damage will be evaluated in peripheral blood lymphocytes using the comet assay. Statistical analysis will be performed to determine the relationship between personal exposure levels to toxic compounds and the early-effect biomarkers over the three different phases of the study. Expected results: The obtained results will support a more accurate and comprehensive assessment of occupational risks among wildland firefighters, crucial to prevent/reduce the associated health impacts. This work will contribute to the establishment of recommendations/good practices to improve firefighters' working conditions, allowing better definitions of policies and prevention strategies highly needed in this sector.

Keywords: Biomonitoring, Occupational, Air pollution, Biomarkers, Wildland firefighter.

INTRODUCTION

In the closing years of the 20th century, it was observed an increase of forest burned area, including in European region (Mouillot & Field, 2005). Through the last 3 decades, Portugal has been severely affected by forest fires which have been occurring mostly in the central and northern areas (San-Miguel-Ayanz et al., 2018). Higher drought periods associated with global warming have been increasing the number, duration and severity of fires among forests (Littell et al., 2016).

Firefighters are required to respond to emergency situations, including participation in wildfire combat. During these events, firefighters face continuous exposure to high temperatures and

smoke, a complex mixture of gas-, liquid- and solid phase chemicals (Ward, 2001). Many smoke compounds, such as particulate matter (PM), polycyclic aromatic hydrocarbons (PAHs), volatile organic compounds (VOCs) and toxic metals (e.g., lead, mercury, and cadmium), have well-known adverse health effects on humans (Cascio, 2018; IARC, 2010). For that reason, firefighting is considered one of the most dangerous occupations (IARC, 2010). Exposure to smoke pollutants may occur through different routes, namely inhalation, dermal absorption, and ingestion (Ruby et al., 2002). Growing evidence has suggested an association between wildfire smoke exposure and respiratory diseases (Cascio, 2018; Reinhardt, 2000), cardiovascular problems (Navarro et al.,2019) and all-cause mortality (Reid et al., 2016). In fact, firefighters are exposed to a complex mixture of compounds, and many of them are classified by International Agency for Research on Cancer (IARC) as probable (e.g., ethylbenzene, isoprene, styrene) or known human carcinogens (e.g., benzene, benzo[a]pyrene, formaldehyde, PM) (IARC, 2010). Increased rates of mortality and cancer incidence among firefighters (when compared to the general population) were found by Daniels et al. (2014). Consistently, a recent meta-analysis reported an increased incidence risk of some cancers among firefighters (e.g., colon, testicular, rectum, bladder, and cutaneous melanoma) (Jalilian et al., 2019).

Wildland firefighters face significant exposure to a variety of smoke pollutants through inhalation and dermal absorption, ranging from carbon monoxide, volatile organic compounds (VOCs), and particles. To protect themselves, firefighters are required to wear proper personal protective equipment (PPE), namely: structural helmet, mask, gloves, boots, and fire-resistant clothing. However, there is some reluctance to wear protection since it adds heat stress and physiological demands upon wildland firefighter. In addition, firefighters' skin may be exposed to combustion products through or around PPE or from the cross-transfer of contaminants on PPE to the skin. Moreover, it is important to highlight that firefighting occupational exposure does not end in the field but accompanies professionals in their return to fire stations through different manners (e.g., contaminated equipment and materials). Although firefighting is classified as potentially carcinogenic to humans by IARC, firefighters are still among the least studied occupations in terms of exposure and relationship to occupational diseases, mostly due to the difficulty involved in the collection of data on personal exposure during firefighting events.

Up to date, the majority of the previous studies has been focused on environmental monitoring. Biomonitoring complements the data on environmental firefighter exposure and provides insight into the biological processes related to that exposure. A major advantage of this approach is that biological monitoring can be performed retrospectively what is particularly useful due the difficulty of sampling in the field. Blood and urine have been the most frequently used biological matrices to determine firefighters' smoke exposure. However, other alternatives have been used, such as the measurement of chemical metabolites in exhaled air. Electronic nose (e-nose) system, for example, is a simple, inexpensive and non-invasive tool that allow the analyse gas samples and may be used for monitoring diseases according to specific breathprints (breath profile) (Scarlata et al., 2015). The use of biomarkers of exposure in the assessment of firefighters' occupational exposure should be accompanied of effect biomarkers to better characterize their exposure and the potential health related outcomes. Comet assay is a versatile method to detect DNA damage at the single cell level (Olive & Banáth, 2006); this technique have been commonly used in biomonitoring studies (Azqueta et al., 2020), inclusively in some that involved wildland firefighters (Abreu et al., 2017). Micronuclei assay, other cytogenetic endpoint, is from a great importance to detect early effects of environmental genotoxic carcinogens (Costa et al., 2013). The application of this assay using epithelial cells such

urothelial and buccal cells are of particular relevance because most of the cancers are of epithelial origin (Hinck & Näthke, 2014). The use of both micronucleus assay and comet assay provides information about past and current exposures, respectively.

Biomonitoring of firefighters' occupational exposure during real scenarios of wildland fires combat have been subject of few studies. Thus, the aim of this study is to evaluate the impact of firefighting occupational exposure at molecular and cellular levels, considering personal exposure levels.

METHODOLOGY

This ongoing prospective longitudinal study will comprise three different stages, specifically pre-exposure, exposure, and post-exposure to a whole fire season. Around 200 wildland northern Portuguese firefighters, from different fire stations, will be involved in this study. In a previous phase, subjects will be fully informed on the nature of the study (objectives, risks and benefits); it will be stressed that their participation in this study is totally voluntary and that may be stopped at any point. In case of acceptance, participants will be asked to sign an informed consent already approved by an Ethical Committee. A characterization of study population will be conducted via questionnaires. These will be distributed to participants, in the three phases of the study, to collect data on socio-demographic factors, diet, physical activity, medical and occupational history. Relevant occupational data will be collected at those individuals that are involved in fire activities (e.g., occupational exposure time, usage of PPE, acute health symptoms, etc.). Data on relevant confounding variables as tobacco smoking and grilled or smoked food ingestion will be also collected. This task will run in parallel with the measurement of personal firefighters' occupational exposure and biomonitoring. Firefighters' personal exposure-levels will be assessed though the metabolites in exhaled breath, using an artificial olfactory system (e-nose technology). Exhaled air samples will be collected using Tedlar bags; briefly, subjects will be asked to inhale, hold breath, and consequently exhale into the Tedlar bag. E-nose system incorporates an on-board principal component analysis algorithm that will allow the automatic discrimination of VOCs profiles in each individual breath sample. Early effects may indicate early sub-clinical alterations that may be associated with pathological events. Thus, in the present study early effects will be evaluated at molecular and cellular levels in systemic (peripheral blood) and local target issues (buccal and urothelial cells). Data on genotoxicity and genomic instability associated with wildland firefighters' occupational exposure will be assessed through different techniques, namely comet assay and micronucleus assay. DNA damage will be evaluated in peripheral blood lymphocytes using the comet assay as described in previous works (Esteves et al., 2020; Costa et al., 2008).Oxidative DNA damage will be determined through the enzyme modified version of comet assay where an enzyme incubation step (OGG1) will allow the specific detection of 8-oxoguanine adducts, a biomarker of oxidative stress. Comets will be analyzed through fluorescence microscopy with the Comet Assay V analysis software (Perceptive Instruments). A total of 150 cells will be analyzed per sample, whereas DNA damage and oxidative DNA damage will be expressed as the percentage of DNA in the tail.

Genomic instability will be assessed through the micronucleus assay using buccal and urothelial cells. The analysis of effect biomarkers using epithelial cells (buccal and urothelial) presents several advantages (comparatively with the use of blood lymphocytes) since they are the first-contact tissue of inhaled contaminants that may promote early genotoxic events induced by carcinogenic agents entering the body and because its collection is obtained via minimally invasive methods. For the collection of buccal cells, subjects will be asked to rinse the mouth

with tap water a few times in order to remove unwanted debris. Buccal cells from each subject cheek (left and right), will be collected using a cytobrush and suspended in a proper buffer to be further analyzed. In order to collect urothelial cells, a midstream clean catch collection of urine from the second or third void of the day will be requested to the subjects. All biological samples will be transported in a cooler (4°C) to be further processed. Micronucleus assay will be performed according to the procedure described by previous authors (Thomas et al., 2009; Bolognesi et al., 2013). Two thousand epithelial cells per individual will be registered and scored for micronuclei, nuclear buds and nucleoplasmic bridges. Slides will be stained using a DNA specific staining in order to guarantee a good contrast between nucleus and cytoplasm, avoiding the false positive readings. Cells in apoptotic or necrotic will also be scored; the death parameters evaluated will be condensed chromatin, karyorrhectic, pyknotic, and karyolitic cells. Descriptive statistics will be performed in order to describe the characteristics of the study group. Moreover, additional statistical approaches will be performed to determine the relationship between personal exposure levels to toxic compounds and the early-effect biomarkers over the three different phases of the study. Regression modelling approaches will be performed in order to include possible confounding factors.

EXPECTED RESULTS

The increasing incidence of wildfires episodes and long fire seasons highlight the need for occupational studies among wildland firefighters. Scientific evidence has been contributing to the establishment of some measures related to firefighters' occupational health and safety such as the use of PPE, the quick removal of protective equipment after fire suppression activities followed by showering to reduce the exposure to potentially toxic compounds. However, there are still knowledge gaps in the scientific literature regarding the health effects of woodsmoke exposure among wildland firefighters in real scenarios of exposure, particularly in the evaluation of the effects of a wildfire season at the molecular level (e.g., DNA strand breaks, oxidative DNA damage and micronucleus). This study will explore the biological mechanisms of action of woodsmoke exposure among these professionals to establish possible associations between short- and long-term firefighting occupational exposures with acute and chronic health impacts. Results here obtained will take into account factors that may affect the relationship between environmental exposures and the uptake of toxic compounds, including the different absorption rates within the subjects, the use of PPE and other personal behaviors. The characterization of Portuguese firefighters' occupational exposure and potential health risks are particularly relevant because Portugal is one of the European countries more highly affected by wildfires every year.

Finally, we expect to provide important data from biomarkers of exposure and early-effect biomarkers to a better characterization of firefighters' occupational exposure. This work will contribute to the establishment of recommendations/good practices to improve firefighters' working conditions, as well as allow better definitions of policies and prevention strategies highly needed in this sector.

Acknowledgements

This work received financial support by the project PCIF/SSO/0017/2018 by the Fundação para a Ciência e a Tecnologia (FCT), Ministério da Ciência, Tecnologia e Ensino Superior (MCTES) through national funds. Filipa Esteves, recipient of PhD grant UI/BD/150783/2020, is supported by FCT and by the European Social Fund (ESF). Joana Madureira, under the grant SFRH/BPD/115112/2016, is supported by FCT and by ESF, through Programa Operacional Capital

Humano (POCH). The authors also acknowledge the Instituto de Saúde Pública da Universidade do Porto (ISPUP).

References

Abreu, A., Costa, C., Pinho e Silva, S., Morais, S., do Carmo Pereira, M., Fernandes, A., Moraes de Andrade, V., Teixeira, J. P., & Costa, S. (2017). Wood smoke exposure of Portuguese wildland firefighters: DNA and oxidative damage evaluation. *Journal of Toxicology and Environmental Health*, Part A, *80*(13-15), 596-604. https://doi.org/10.1080/15287394.2017.1286896

Azqueta, A., Ladeira, C., Giovannelli, L., Boutet-Robinet, E., Bonassi, S., Neri, M., Gajski, G., Duthie, S., Del Bo, C., & Riso, P. (2020). Application of the comet assay in human biomonitoring: An hCOMET perspective. *Mutation Research/Reviews in Mutation Research*, *783*, 108288. https://doi.org/10.1016/j.mrrev.2019.108288

Bolognesi, C., Knasmueller, S., Nersesyan, A., Thomas, P., & Fenech, M. (2013). The HUMNxl scoring criteria for different cell types and nuclear anomalies in the buccal micronucleus cytome assay–An update and expanded photogallery. *Mutation Research/Reviews in Mutation Research, 753*(2), 100-113. https://doi.org/10.1016/j.mrrev.2013.07.002

Cascio, W. E. (2018). Wildland fire smoke and human health. *Science of the Total Environment, 624*, 586-595. https://doi.org/10.1016/j.scitotenv.2017.12.086

Costa, S., Brandão, F., Coelho, M., Costa, C., Coelho, P., Silva, S., Porto, B., & Teixeira, J. P. (2013). Micronucleus frequencies in lymphocytes and buccal cells in formaldehyde exposed workers. *WIT Transactions on Biomedicine and Health, 16*, 83-94. http://dx.doi.org/10.2495/EHR130081

Costa, S., Coelho, P., Costa, C., Silva, S., Mayan, O., Santos, L. S., Gaspar, J., & Teixeira, J. P. (2008). Genotoxic damage in pathology anatomy laboratory workers exposed to formaldehyde. *Toxicology, 252*(1-3), 40-48. https://doi.org/10.1016/j.tox.2008.07.056

Daniels, R. D., Kubale, T. L., Yiin, J. H., Dahm, M. M., Hales, T. R., Baris, D., Zahm, S. H., Beaumont, J. J., Waters, K. M., & Pinkerton, L. E. (2014). Mortality and cancer incidence in a pooled cohort of US firefighters from San Francisco, Chicago and Philadelphia (1950–2009). *Occupational and Environmental Medicine, 71*(6), 388-397. http://dx.doi.org/10.1136/oemed-2013-101662

Esteves, F., Amaro, R., Silva, S., Sánchez-Flores, M., Teixeira, J. P., & Costa, C. (2020). The impact of comet assay data normalization in human biomonitoring studies outcomes. *Toxicology Letters*, *332*, 56-64. https://doi.org/10.1016/j.toxlet.2020.06.024

Hinck, L., & Näthke, I. (2014). Changes in cell and tissue organization in cancer of the breast and colon. *Current Opinion in Cell Biology, 26*, 87-95. https://doi.org/10.1016/j.ceb.2013.11.003

International Agency for Research on Cancer (IARC). (2010). Painting, firefighting, and shiftwork. *Monographs on the evaluation of carcinogenic risks to humans, 98*, 561. http://www.monographs.iarc.fr/ENG/Monographs/vol98/mono98-7.pdf.

Jalilian, H., Ziaei, M., Weiderpass, E., Rueegg, C. S., Khosravi, Y., & Kjaerheim, K. (2019). Cancer incidence and mortality among firefighters. *International Journal of Cancer, 145*(10), 2639-2646. https://doi.org/10.1002/ijc.32199

Littell, J. S., Peterson, D. L., Riley, K. L., Liu, Y., & Luce, C. H. (2016). A review of the relationships between drought and forest fire in the United States. *Global Change Biology, 22*(7), 2353-2369. https://doi.org/10.1111/gcb.13275

Mouillot, F., & Field, C. B. (2005). Fire history and the global carbon budget: a 1× 1 fire history reconstruction for the 20th century. *Global Change Biology, 11*(3), 398-420. https://doi.org/10.1111/j.1365-2486.2005.00920.x

Navarro, K. M., Kleinman, M. T., Mackay, C. E., Reinhardt, T. E., Balmes, J. R., Broyles, G. A., Ottmar, R. D., Naher, L. P., & Domitrovich, J. W. (2019). Wildland firefighter smoke exposure and risk of lung cancer and cardiovascular disease mortality. *Environmental Research, 173*, 462-468. https://doi.org/10.1016/j.envres.2019.03.060

Olive, P. L., & Banáth, J. P. (2006). The comet assay: a method to measure DNA damage in individual cells. *Nature Protocols*, *1*(1), 23. https://doi.org/10.1038/nprot.2006.5

Reid, C. E., Brauer, M., Johnston, F. H., Jerrett, M., Balmes, J. R., & Elliott, C. T. (2016). Critical review of health impacts of wildfire smoke exposure. *Environmental Health Perspectives, 124*(9), 1334-1343. https://doi.org/10.1289/ehp.1409277

Reinhardt, T. E. (2000). Smoke exposure at western wildfires. *US Department of Agriculture, Forest Service, Pacific Northwest Research Station*, 525, 72 p. https://doi.org/10.2737/PNW-RP-525

Ruby, B. C., Shriver, T. C., Zderic, T. W., Sharkey, B. J., Burks, C., & Tysk, S. (2002). Total energy expenditure during arduous wildfire suppression. *Medicine and Science in Sports and Exercise, 34*(6), 1048-1054. https://doi.org/10.1097/00005768-200206000-00023

San-Miguel-Ayanz, J., Durrant, T., Boca, R., Libertà, G., Branco, A., De Rigo, D., Ferrari, D., Maianti, P., Artés Vivancos, T., & Costa, H. (2018). Forest Fires in Europe, Middle East and North Africa 2017. *Publications Officer of the European Union*. https://doi.org/10.2760/663443

Scarlata, S., Pennazza, G., Santonico, M., Pedone, C., & Antonelli Incalzi, R. (2015). Exhaled breath analysis by electronic nose in respiratory diseases. *Expert Review of Molecular Diagnostics, 15*(7), 933-956. https://doi.org/10.1586/14737159.2015.1043895

Thomas, P., Holland, N., Bolognesi, C., Kirsch-Volders, M., Bonassi, S., Zeiger, E., Knasmueller, S., & Fenech, M. (2009). Buccal micronucleus cytome assay. *Nature Protocols, 4*(6), 825. https://doi.org/10.1038/nprot.2009.53

Ward, D. (2001). Combustion chemistry and smoke. In *Forest Fires* (pp. 55-77). Elsevier. https://doi.org/10.1016/B978-012386660-8/50005-2

The comfort parameters in indoor air of sports facilities with different ventilation regimes

Cátia Peixoto[1], Klara Slezakova [2], Maria do Carmo Pereira [3] and Simone Morais [4]

[1]REQUIMTE-LAQV, Porto School of Engineering, Polytechnic of Porto, PT; LEPABE, Department of Chemical Engineering, Faculty of Engineering, University of Porto, PT (catia.peixoto@graq.isep.ipp.pt) ORCID 0000-0002-2957-7458, [2]LEPABE Department of Chemical Engineering, Faculty of Engineering, University of Porto, PT (slezakok@fe.up.pt) ORCID 0000-0001-5265-4186, [3]LEPABE, Department of Chemical Engineering, Faculty of Engineering, University of Porto, PT (mcsp@fe.up.pt) ORCID 0000-0001-8505-3432, [4]REQUIMTE-LAQV, Porto School of Engineering, Polytechnic of Porto, PT (sbm@isep.ipp.pt) ORCID 0000-0001-6433-5801.
https://doi.org/10.24840/978-972-752-279-8_0037-0042

Abstract

Introduction: In Portugal, during COVID19 pandemic, sport and fitness facilities were closed. When lockdown has been lifted, in order to prevent the spread of infection, indoor sport facilities were subject to specific regulations that limited indoor occupancy as well as manner of air ventilation. This study aims to analyze the impacts of these ventilation restrictions on indoor air comfort parameters in sport fitness facilities. Methodology: Temperature (T; ºC), relative humidity (RH; %), and carbon dioxide (CO_2) were continuously monitored (41 days; spring and autumn) in four fitness centers situated in Oporto metropolitan area: two of them under normal ventilation conditions (i.e. before lockdown; NV1 and NV2) and two of them under temporary restrictions for indoor ventilations and occupancy (RV1 and RV2). Results and Discussion: Under normal ventilation conditions, T in fitness centers slightly varied (in NV1:22-25 ºC; NV2: 20-23 ºC) but in both clubs the comfort recommendations (18-25 ºC) were fulfilled. On contrary, RH were below guideline values (55-75%) in NV1 (47-54%) whereas at NV2 (66-73%) it fulfilled the recommendations. When specific health regulations took place, mean T ranges were similar in both clubs (RV1: 21-23 ºC; RV2:21-23 ºC) but they both exceeded recommended comfort levels (16-21 ºC). Mean RH were in accordance with the legislative values, but the very high temporal maxima (up to 75 and 89%) indicate the possible discomforts the that exercisers might have experienced. Concerning the CO_2, the obtained results showed that indoor levels decreased when specific health restrictions were in force (11-121%) most likely due imposed guidelines for human occupancy. Conclusions: The restrictions for ventilation and human occupancy positively impacted indoor levels of CO_2. However, T and RH were on several occasions outside the recommended comfort levels, especially during group activity classes. As regular exercising in environmental conditions, such as elevated T and increased RH can cause health discomforts, these parameters should be carefully maintained within the recommended ranges even under restricted ventilation scenarios.

Keywords. Indoor air quality (IAQ), Carbon dioxide (CO_2), Comfort parameters, Temperature (ºC), Relative humidity (%HR).

INTRODUCTION

Physical activity is an important factor for quality of life; frequent practice of exercise, such as walking or bicycling, presents great heath benefits (Warburton et al., 2006). A clean environment is also essential for human health and well-being. Considering the environmental perspective, one of the most relevant health concerns is related with air quality in spaces in which people spend their time, both indoor and outdoor (EEA, 2011; Almeida et al., 2014). In Portugal during the SarsCov-2 pandemic, sport and fitness facilities were closed. After the lockdown, in order to prevent a spread of infections, these indoor spaces were subjected to specific health recommendations, namely in terms of type of ventilation and restrictions for occupancy. In sport facilities, this was also applied to occupancy, habits and behaviors during individual trainings as well to group-activity classes. This study aims to analyze the impacts of these restrictions on indoor air comfort parameters, namely temperature (T), relative humidity (RH), and carbon dioxide (CO_2) in four fitness centers, two of them being monitored under normal ventilation conditions (NV1 and NV2) and two after the lockdown under temporary health restrictions (RV1 and RV2).

METHODOLOGY

The data collection for this was carried out in two phases. The first part of sampling was carried out in two fitness centers (NV1 and NV2) before the virus outbreak under normal conditions. The sampling was done continuously, during 21 consecutive days (including weekdays and weekends) in spring season. NV1-NV2 were large, sophisticated health clubs (internationally recognized) and were equipped with pool. The second phase of this work was conducted in autumn season 2020, for 20 consecutive days in fitness centers (RV1 and RV2) with restrictions for ventilation and indoor space occupancies. These clubs belong to a chain of low-cost gyms and, on contrary to the previous, RV1-RV2 did not have pools. However, the indoor layout in four clubs were similar and included: (i) a bodybuilding and cardio fitness area, (ii) two-three studios for group classes, and a cycling class studio. The four clubs were situated Oporto Metropolitan Area; road traffic and local industry were the main sources in ambient air of the respective sites (Pereira et al., 2007; Slezakova, 2013). Mechanical ventilation was provided through HVAC system that controls ventilation and air temperature; at the time of second phase of sampling the system was allowed to provide only ventilation (in a limited manner). The number of people (after lockdown, phase two) in indoor spaces was controlled and reduced. Comfort parameters (T, ºC; and RH, %) and CO_2 were sampled by a multi-gas sensor probe (model TG 502; GrayWolf Sensing Solutions, Shelton, USA) continuously, with 1 min logging interval. Samplers were mounted on supports (1.4±0.2 m) and at least 1.5 m from walls to minimize the influence on pollutant dispersion (Holmberg et al., 1998; Jin et al., 2013), location of samplers was chosen in order to avoid any direct influence (opened windows/doors, mechanical ventilation systems, cleaning product emissions, etc.).

RESULTS AND DISCUSSION

CO_2

Under normal conditions, the overall average CO_2 concentration was 3333 mg/m^3, with values ranging between 1048 - 7671 mg/m^3 in club NV1. The corresponding levels in NV2 were 1304 mg/m^3 (mean) and range of 686-4907 mg/m^3. In club NV1, the averages obtained across indoor spaces (general area, studios) were above the limit value (2250 mg/m^3) of Portuguese legislation thus indicating insufficient ventilation (Slezakova et al., 2018). Furthermore, the stricter recommendation of the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE; 1800 mg/m^3) (Persily, 1997) was exceeded too. Considering human occupancy, the corresponding obtained mean in NV1 was 3770 mg/m^3 (approximately 1.7 times higher than the protection threshold) when people frequented them vs. 2659 mg/m^3 when they were closed. When analyzing different indoor spaces, average concentration (4657 mg/m^3) that was twice higher than the threshold in body building and cardio fitness area; the respective temporal maxima reached value of 7671 mg/m^3, surpassing (3.4 times) the limit. For studios, mean CO_2 was 3299 mg/m^3, exceeding 1.5 times the legal limit. Furthermore, type of activity impacted the indoor CO_2 as the highest levels were recorded during classes with more vigorous exercises. In club NV2, the mean CO_2 levels obtained in different spaces fulfilled the limit value of 2250 mg/m^3, with exception to group studios (when occupied: mean value of 2481 mg/m^3). Although ventilation setups and routines were similar in both gyms, in NV2 its better control, the overall more spacious rooms, and limited occupancy (strict control and registry for group classes) led to lower (about 60% less) overall CO_2 levels. During the second phase, after lockdown when ventilation and occupancy restrictions were applied in indoor spaces, average CO_2 was 1400 mg/m^3 (range 122-2894 mg/m^3) in RV1 and 1543 mg/m^3 (739-6740 mg/m^3) in RV2. When occupied indoor CO_2 were slightly (though not significantly; p=0.05) higher than

when closed. The temporal maxima (RV1: 2660-2894 mg/m^3, RV2: 2798-6740 mg/m^3) exceeded the protection threshold defined in Portuguese legislation in the two gyms, but in RV2 obtained values were 2.3 times higher. Concerning the group activities in RV2, mean CO_2 exceeded the value defined in the legislation in highly intense cardiovascular (bodyjump: 3533 mg/m^3) and cycling classes (cycling: 3742 mg/m^3). Whereas CO_2 is does not pose hazard to human health at the levels detected in clubs, exposure to moderate concentrations can cause changes in human performances and influence decision-making (Persily, 1997; Satish et al., 2012). Thus, despite the restrictions in the number of occupants, CO_2 concentration during the high intensity group activities were still exceeded.

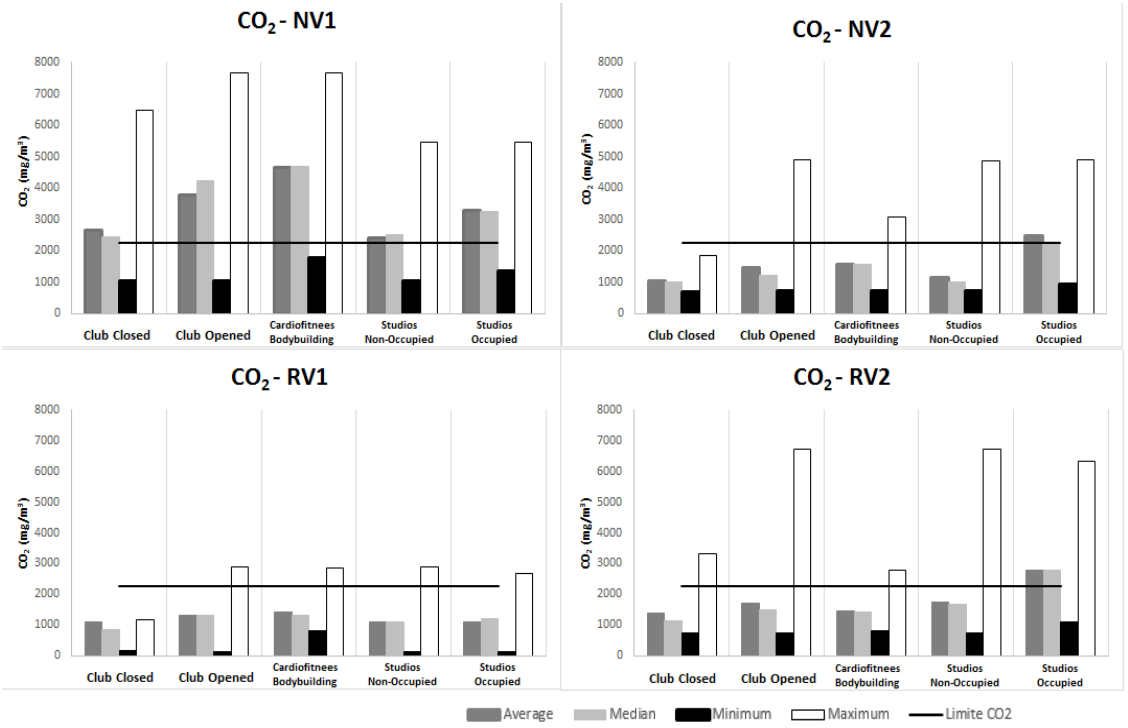

Figure 1. CO_2 levels in four fitness clubs under normal ventilations (NV1, NV2) and under restricted ventilations and occupancy (RV1, RV2).

Temperature and relative humidity

T and RH are parameters that affect thermal comfort of respective occupants. In general, RH levels recommended by different organizations range from 30 to 60%. For RH in range of 30 and 60%, American Society of Heating (ASHRAE) recommends indoor T range of 23.0 – 25.8ºC (ASHRAE, 2017). However, specifically for sport facilities, RH in range of 55-75% and T range of 18-25ºC (summer) and 16-21ºC (winter) are recommended (SEJD, 2008). The spring season was characterized by lower than normal average precipitation (192 mm) of ambient air and higher average air temperature (mean of 14.9 °C). In the respective 20 days of sampling maximum daily temperature were high (>30 °C), with a sharp drop. The autumn season was cold and rainy, with mean of ambient air temperature 15.4 °C (means of 9.9 °C and 20.8 °C for the of minimum and maximum air temperature, respectively; IPMA, 2020). Although NV1 and NV2 were both normally ventilated using HVAC systems, they exhibited different indoor temperature ranges. In NV1, when occupied, T ranged between 22.4-25.4 ºC, while in NV2 it was less, with values of 19.8-22.7 ºC. This fact can be associated with several factors. Firstly, NV1 was located in the

basement of a building (at the level of the garages) whereas NV2 was situated on the top floor of a shopping center. In addition, NV2 has much larger room spaces than NV1 (mainly in the cardio and fitness room, which was almost 4 times larger) thus easily accommodating for T increases due to human body of room occupants, as was previously reported (Žitnik et al., 2016). Finally, the control of the number of people was stricter and more effective in NV2, with a permitted limit for each area. Under the restricted conditions, T was almost unchanged when occupied and closed. Means of 22.8 ºC and 21.6 ºC were observed in RV1 and RV2 when closed, whereas it was 22.6ºC and 22.0 ºC, respectively, when occupied. During group classes at RV1, lower temperature values (17.7 ºC) were obtained due sporadic use of air conditioning system. Nevertheless, it is necessary enhance that mean temperature recorded in both RV1, RV2 did not fulfill the recommendations, being constantly higher than comfort limits, with maxima values up to 24-25.7 ºC in A1 and 23.2-24.6 ºC in RV2.

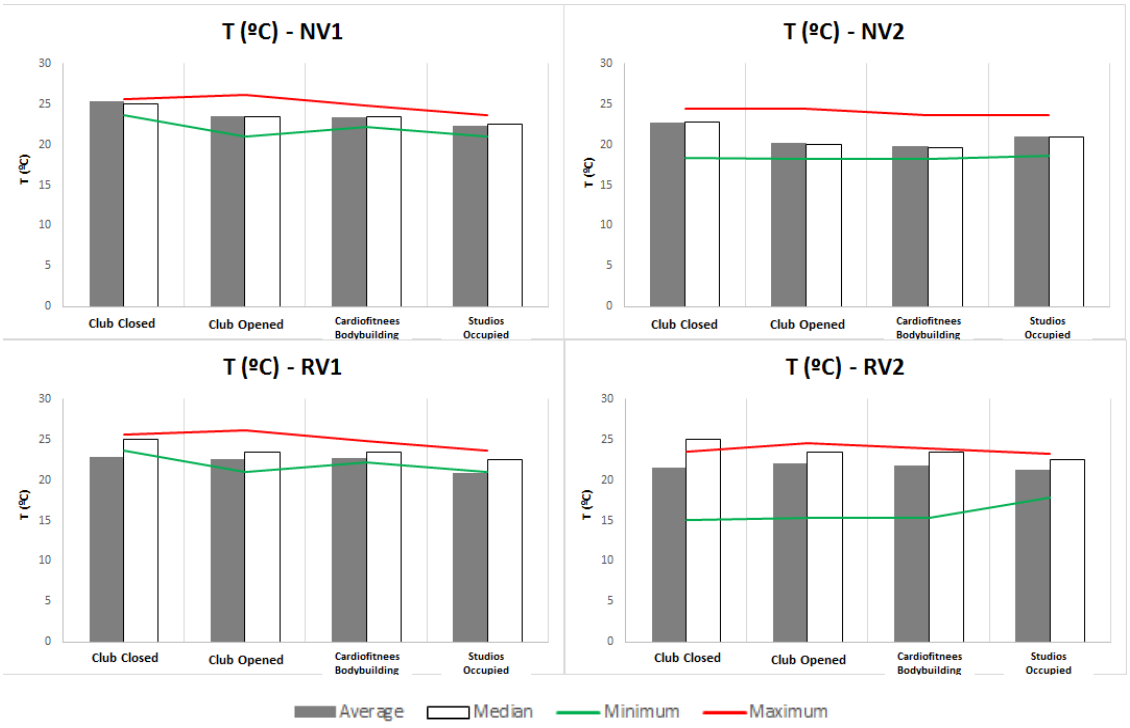

Figure 2. Temperature (ºC) in four fitness clubs under normal ventilations (NV1, NV2) and under restricted ventilations and occupancy (RV1, RV2).

When exercising, breathing and perspiration generate substantial amount of water vapor, which impacts measured RH (Žitnik et al., 2016). Under normal ventilation conditions, the average values of RH recorded at B1 (when occupied, 47–54%), were always below the recommended minimum designated for sport facilities (SEJD, 2008). Somewhat lower RH can cause some discomfort (drying nose, throat, mucous membranes and skin) (Sylvester et al., 2016; Bélanger et al., 2014). In NV2 (both when occupied and non-occupied) RH was within the recommended guidelines (62-73%). Under the restricted conditions, higher RH values were recorded when people exercised, mainly during group classes. The mean RH in bodybuilding and cardio fitness area was 57% in RV1 and 62% in RV2. Furthermore, these values were slightly higher during group activities with average RH of 63% and 66%, respectively. Thus, the average values were in accordance with the comfort guidelines though high temporal maxima (75% in RV1; 89% in RV2)

that were occasionally registered indicate the necessity for comfort parameters monitoring in sport facilities.

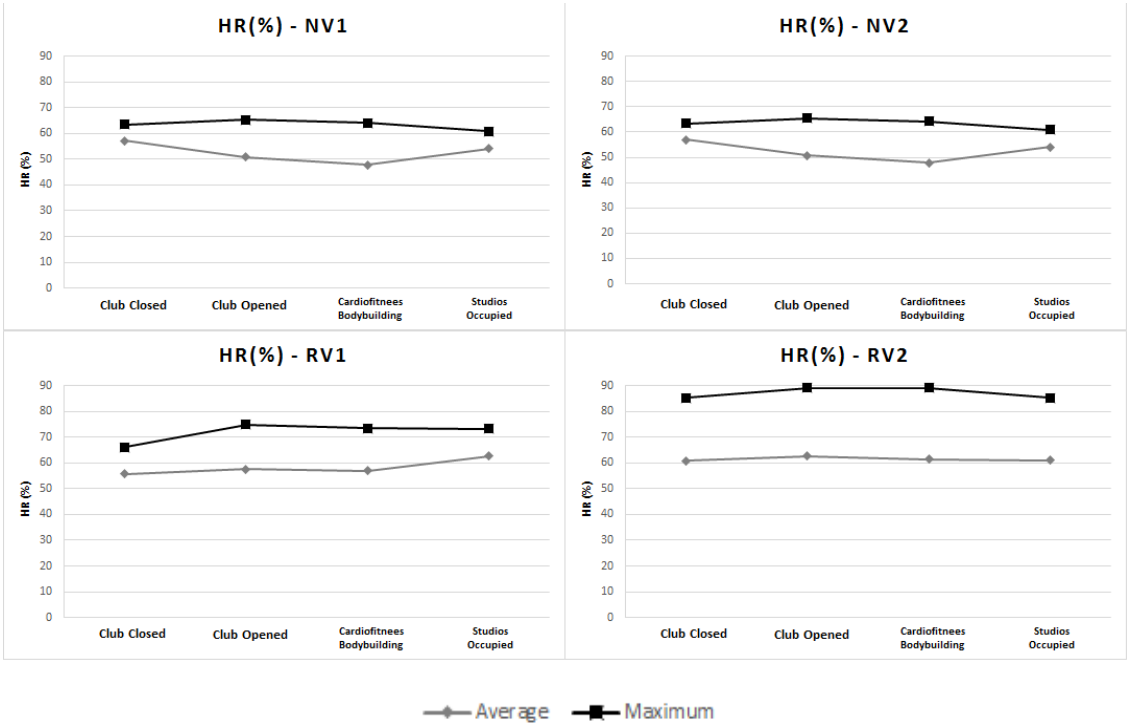

Figure 3. Relative humidity (%) in four fitness clubs under normal ventilations (NV1, NV2) and under restricted ventilations and occupancy (RV1, RV2).

CONCLUSIONS

This study provides information on air quality in indoor (CO_2, T and RH) environments for sport practice, under different ventilations scenarios imposed due to limitation of COVID-19 pandemic. The restrictions in the number of occupants led to improved CO_2 concentration, but the changes in ventilation did not favor the levels of comfort parameters, especially in group classes of greater activity intensity. Since regular exercise in environmental conditions, such as elevated T and increased RH can cause several health consequences (Sylvester et al., 2016; Racinais et al., 2012; Roelands et al., 2015), comfort parameters should be maintained within the recommended ranges by the proper use of air conditioning systems, isolation of the environment, reduction of sun / heat, even during restricted ventilation scenarios.

ACKNOWLEDGMENTS

This work received financial support by UIDB/50006/2020, UIDP/50006/2020, and by UIDB/00511/2020 of the Laboratory for Process Engineering, Environment, Biotechnology and Energy – LEPABE. Further funding was provided through the project PCIF/SSO/0017/2018 by the Fundação para a Ciência e a Tecnologia (FCT), Ministério da Ciência, Tecnologia e Ensino Superior (MCTES) through national funds. C. Peixoto would like to acknowledge FCT for her fellowship SFRH/BD/147185/2019.

References

Almeida, S.M., Silva, A.V., and Sarmento, S. (2014). Effects of Exposure to Particles and Ozone on Hospital Admissions for Cardiorespiratory Diseases in Setúbal, Portugal. Journal of Toxicology and Environmental Health, Part A, 77(14-16), 837–848. http://dx.doi.org/10.1080/15287394.2014.887399

American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), ASHRAE Technical FAQ ID 92, Accessed online December 2019. Available at: https://www.ashrae.org/File%20Library/Technical%20Resources/Technical%20FAQs/TC-02.01-FAQ-92.pdf

Bélanger, D., Gosselin, P., Valois, P., & Abdous, B. (2014). Perceived Adverse Health Effects of Heat and Their Determinants in Deprived Neighbourhoods: A Cross-Sectional Survey of Nine Cities in Canada. International Journal of Environmental Research and Public Health, 11(11), 11028–11053. https://doi:10.3390/ijerph111111028

Castro, A., Calvo, A.I., Alves, C., Alonso-Blanco, E., Coz, E., Marques, L., Nunes, T., Fernández-Guisuraga, J.M., Fraile, R. (2015). Indoor aerosol size distributions in a gymnasium. Science of The Total Environment, 524-525, 178–186. https://doi.org/10.1016/j.scitotenv.2015.03.118

EEA. (2011). Environment and health. http://www.eea.europa.eu/themes/human.intro

Geng, Y., Ji, W., Lin, B., Zhu, Y. (2017). The impact of thermal environment on occupant IEQ perception and productivity. Building and Environment, 121, 158–167. https://doi:10.1016/j.buildenv.2017.05.022

Holmberg, U., Li, Y. (1998) Modelling of the indoor environment e particle dispersion and deposition, Indoor Air 8 113–122. ISSN 090S-6947.

IPMA. (2020). Boletim Climatológico Mensal – outubro 2020. ISSN 2183-1076.

Jin, H., He, C., Lu, L., Fan, J. (2013) Numerical investigation of the wall effect on airborne particle dispersion in a test chamber, Aerosol and Air Quality Research, 13: 786–794. https://doi.org/10.4209/aaqr.2012.04.0106

Pereira, M.C., Santos, R.C., Alvim-Ferraz, M.C.M. (2007). Air quality improvements using European environment policies: A case study of SO2 in a coastal region in Portugal. J. Toxicol. Environ. Health – Part A Curr. Issues 70. 1-5. https://doi.org/10.1080/15287390600884990

Persily, A.K. (1997). Evaluating building IAQ and ventilation with indoor carbon dioxide, ASHRAE Trans. 10 (2).

Racinais, S., Mohr, M., Buchheit, M., Voss, S.C., Gaoua, N., Grantham, J., Nybo, L. (2012). Individual responses to short-term heat acclimatisation as predictors of football performance in a hot, dry environment. British Journal of Sports Medicine, 46(11), 810–815. https://doi:10.1136/bjsports-2012-091227

Ramos, C.A.; Wolterbeek, H.T. and Almeida, S.M. (2014). "Exposure to indoor air pollutants during physical activity in fitness centers". In Building and Environment, 82, 349-360. https://doi.org/10.1016/j.buildenv.2014.08.026

Ramos, C.A.; Reis, J.F.; Almeida, T.; Alves, F.; Wolterbeek, H.T. and Almeida, S.M. (2015). "Estimating the inhaled dose of pollutants during indoor physical activity". In Science of the Total Environment, 527–528, 111–118. https://doi.org/10.1016/j.scitotenv.2015.04.120

Roelands, B., De Pauw, K., Meeusen, R. (2015) Neurophysiological effects of exercise in the heat. Scandinavian Journal of Medicine & Science in Sports, 25, 65–78. https://doi:10.1111/sms.12350

Satish, U., Mendell, M. J., Shekhar, K., Hotchi, T., Sullivan, D., Streufert, S., Fisk, W. (2012). Is CO2 an Indoor Pollutant? Direct Effects of Low-to-Moderate CO2 Concentrations on Human Decision-Making Performance. Environmental Health Perspectives 120 (12) 1671–1677. https://doi:10.1289/ehp.1104789

SEJD, Ginásios: Diploma relativo à construção, instalação e funcionamento, Available at Secretariat of State for Youth and Sport, Lisbon Portugal. Presidency of the Council of Ministers, Secretariat of State for Youth and Sport, 2008, http:// www.cd.ubi.pt/artigos/Gin%C3%A1sios.pdf

Slezakova, K.; Peixoto, C.; Pereira, M.C. and Morais, S. (2018). "Indoor air quality in health clubs: Impact of occupancy and type of performed activities on exposure levels". In Journal of Hazardous Materials, 359, 56-66. https://doi.org/10.1016/j.jhazmat.2018.07.015

Sylvester, J.E., Belval, L.N., Casa, D.J., O'Connor, F.G. (2016). Exertional heat stroke and American football: what the team physician needs to know. The American Journal of Orthopedics 45 (6) 340–348.

Warburton D., Nicol C., Bredin S. (2006). Health benefits of physical activity: the evidence. Canadian Medical Association Journal, 174(6), 801–809. https://doi:10.1503/cmaj.051351

Žitnik, M., Bučar, K., Hiti, B., Barba, Ž., Rupnik, Z., Založnik, A., Žitnik, E., Rodrìguez, L., Mihevc, I., Žibert, J. (2015). Exercise-induced effects on a gym atmosphere. Indoor Air, 26(3), 468–477. https://doi:10.1111/ina.12226

A framework to implement Occupational health and safety innovation

Sara Shahedi[1], Alfredo Augusto Vieira Soeiro[2], Sara Maheronnaghsh[3]

[1]Department of Mining, Faculty of Engineering, University of Porto, PT (s_shahedi@yahoo.com) ORCID 0000-0001-5954-6209, [2]Department of Civil Engineering, Faculty of Engineering, University of Porto, PT (avsoeiro@fe.up.pt) ORCID 0000-0003-4784-959X, [3]Department of Mining, Faculty of Engineering, University of Porto, PT (up201600476@fe.up.pt) ORCID 0000-0002-4966-4292.
https://doi.org/10.24840/978-972-752-279-8_0043-0048

Abstract

Background and objectives: Being able to compete in the market needs sustainable development. Occupational safety and health Innovation process is one of the most important procedures helping companies to achieve their goal and to win the competition as radical change in the workers' environment, enhancing the profitability of companies. However, most research and discussion of innovations are focused on product development and/or process improvement, disregarding workplace and service innovation. This study will outline the general terms related to safety innovation and how the process can get managed using some techniques to implement a framework in a company. In this case, the objectives of the study are to introduce the innovation in OHS and to introduce a model including some techniques for industries to apply innovation in occupational safety and health. Methodology: To apply Innovation in occupational safety and health, the first step is to indicate the importance of innovation. To do so, a major review of studies focusing on occupational safety and health and innovation were required. The second step in this part is to define a frame work for innovation in safety and health, by reviewing those introduced frameworks in both innovation and health and safety researches. Results and conclusions: As a result, the importance of innovation has been searched and emphasized. On the other hand, a 6 step framework has been introduced and the details of applying the framework has been expanded. The frame work employs 6 continues steps starting by TIPS technique which is followed by JTBD. Based on the result, the framework can be applied. The introduced steps are as follow: Identifying Innovation Projects, Scoping and Focusing Innovation Projects, Leveraging Brainpower and Turbo-Charging Creativity, Selecting the Best Ideas for Further Development and Design, Evaluating How New Products/Services Perform Prior to Their Release, Problem Diagnosis and Improvement Prior to Commercialization. Following these steps as a framework may increase the efficiency of the company however, there is a huge need of several case studies in long term to assess the result and to compare the efficiency of the introduced framework.

Keywords: Innovation, Innovation management, Occupational safety, consequence analysis, gas refinery.

INTRODUCTION

Over the last few years innovation has turned out to be one amongst the foremost necessary issues for all industries (Khosravi, Newton, & Rezvani, 2019). Baregheh (2009) described the innovation as "the multi-stage process whereby organizations transform ideas into new products, service or processes, in order to advance, compete and differentiate themselves successfully in their marketplace".

Being successful in the marketplace by organizing work to increase productivity and decrease the cost, has been a preeminent concern of business organizations. To attain and maintain competitive advantages by new methods of work organization and systems of operation, all resources and attention have been devoted to commercial and financial concerns rather than well-being, safety and health of employees (Dawson & Zanko, 2009).

Occupational safety and health (OSH) issues recently arisen in some cases; however innovative solutions to OSH problems are absent to a great extent. According to the ILO (International Labor Organization) more than 2 million diseases and 450 million accidents are experienced annually by workplaces (Pillay, 2015). The related social and financial expenses of these accidents and diseases are anticipated to expand further as our subsequent generation of employees continues to face challenges from a range of quarters.

Managing these costs, therefore, continues to be an assignment for policy makers, practitioners and lecturers concerned in accident prevention and security management. A potential reason for this dire state of affairs is that developments in safety management are outpaced by technological advancements, and a lot of innovations are required.

This needs scientists to change the method organizations manage safety. Doing this, however, needs us to possess a far higher understanding of however accidents are caused, how they'll be prevented or how the cost can be decreased after happening the accident, and the way safety may be managed in organizations (Pillay, 2015).

Innovation

Organizations need innovation as a sustainable source of long-term success (Camisón & Villar-López, 2014; Khosravi et al., 2019). Many scientists offer different definitions for innovation. A definition is to transform a new idea into a product, process, object, or service (Jilcha & Kitaw, 2017) (O'Sullivan, 2000)

Innovation management on the other hand is related to increase the creation of knowledge to obtain or improve products, processes or services. Not only that, improving the way jobs are done to achieve the organization's goal is one of the most important ways ends in innovation management.(Simsit, Vayvay, & Oztürk, 2014) managing innovation is a quick and adoptable way in order to overcome competitors and achieve a sustainable competitive advantage (Poolton & Barclay, 1998).

The way to success innovation management process is only when those generated outputs could *conquer* barriers in order to accomplish market needs (Páez-Avilés, Juanola-Feliu, & Samitier, 2018). Hence managers prefer to work on strategies or actions to influence the productivity and impact of their scientists and product development teams. These strategies are even more necessary when managing different technologies increases the complexity of the process (Páez-Avilés et al., 2018).

The process begins with the recognition of a problem or finding an idea, extends over the problem-solving and the creation of productive capacity to the introduction of the new product or service on the market (Tidd & Bessant, 2018).

Occupational Safety and Health Innovation

Occupational safety define as comfort of working environment for employees. It includes, but not limited to, applicability of working methods for the recommended operation and reliability of machine design. (Organization, 2002). Occupational health on the other hand, is the wellbeing of employees that protects workers from any workplace accidents in any circumstance (Jilcha, Kitaw, & Beshah, 2016; Oeij, Dhondt, Kraan, Vergeer, & Pot, 2012).

The research showed that a poor work environment, less pay, weak conducive and weak work environments and less experience, together with stress, tiredness, pain, boredom, demotivation and unhappiness, reduce productivity. Injuries and illnesses increase workers' compensation and retraining costs, absenteeism, and faulty products (Jilcha et al., 2016; Oeij et al., 2012).

Although the positive impact of healthy workplaces on growth is well known, some companies, small enterprises and organizations are still facing challenges in adopting preventive measures (Masi, Cagno, & Micheli, 2014) regarding workplace hazards.

Most of a companies' focus is on the external customer satisfaction with their product or service disregarding worker satisfaction and working environment comfort in economically lagging countries. Consideration of OSH has a great impact for the development of economic growth and organizational productivity improvement (Jilcha et al., 2016). With workplace safety and health improvements, there is an increase in the health and satisfaction of employees (Nuwayhid, 2004) (Organization, 2010) . Many researchers have found that wealth means health (Rufino & Villasor, 2015).

Innovation has been discussed by many researchers with different approaches but the final conclusion brought all ideas to a focal point as being creating new products and services or adopting the existing technology from where it was developed into a new situation. Safety innovation, however, is being disregarded and has not been discussed in many research findings. According to the literature review, occupational safety innovation is the improvement of workplace system. Which is configuring people who work there and their work environment (Beblavý, Maselli, & Martellucci, 2012; Jilcha et al., 2016; Oeij et al., 2012; Podgórski, 2015)

Due to importance of employees' well-being and to decrease the lack of innovation in OSH, the main goal of this paper is 1) to introduce the innovation in OHS and 2) to introduce a model including some techniques for industries to apply innovation in occupational safety and health.

METHODOLOGY

Innovation Management Process

Initiation of innovation process is defining the jobs need to be done and the target group. Phases of the process has shown in the diagram below.

Figure 1. Steps of innovation process.

The first step of the process is to find out and uncover the target group's needs. Following that segments of opportunities need to find, market opportunity sized, competitive analysis conducted, innovation and pricing strategies formulated. Completing these analysis leads the process to define and assess the solution. Following these steps can be done by using some tools and techniques selected based on the structure of the industry, target group and type of the service.

Identifying Innovation Projects

Defining the needs of the target group is the start point of the innovation project. Among several techniques enabling one to create innovation opportunities, job to be done (JTBD) process is a revolutionary concept that guides toward innovation and helps move beyond the norm of only improving current solutions (Silverstein, Samuel, & DeCarlo, 2013). There are 6 steps for JTBD process which are (1) Identify a Focus Market, (2) Identify Jobs Customers Are Trying to Get Done, (3) Categorize the Jobs to be Done, (4) Create Job Statements, (5)Prioritize the Opportunities and (6) Identify Outcome Expectations Regarding the job (Simsit et al., 2014).

Scoping and Focusing Innovation Projects

Scoping and focusing innovation projects can be seen as a redefinition problem. From this point of view "Heuristic redefinition" can help a team to visualize the various elements of a problem as well as its underlying structure (Simsit et al., 2014).

One of the techniques to scope and focus innovation projects is Theory of Inventive Problem Solving (TIPS). This theory is an international system of creativity developed by the Soviet inventor and science-fiction author Genrich Altshuller (1926-1998) (Barry, Domb, & Slocum, 2010).

According to TIPS, universal principles of creativity form the basis of innovation. TIPS identifies and codifies these principles, and uses them to make the creative process more predictable ("A Powerful Methodology for Creative Problem Solving," 2019).

Leveraging Brainpower and Turbo-Charging Creativity

Heuristic Ideation is a very efficient group technique that helps to generate new and innovative ideas. The participants compare two items or concepts that are not apparently related (McFadzean, 2002). In order to implement this technique two items of interest that are already in existence but are not connected need to be chosen.

Selecting the Best Ideas for Further Development and Design

The KJ Method was developed as the Affinity Diagram by Jiro Kawakita in the 1960s and has become one of the Seven Management and Planning Tools used in Total Quality Control. It provides a way to organize and refine innovation ideas, sparking further dialogue and achieving consensus about which ideas are worth developing. In advance of the idea-generating session, participants receive a description of the challenge, posting the JTBD associated outcome expectations so the team can keep these in mind (Simsit et al., 2014).

Forming a team around 4-6 and including the stakeholders or the ones who lives the problem will create better ideas during development stage. After all ideas created and posted by all participants giving more time to the participants will create time to everyone to submit more ideas inspired by the first round of ideas. This is called YES&AND activity.

The next step is sorting the ideas into related categories based on functionality, features, outcome or whatever makes sense and voting on ideas. Each team member gives 3 to 5 votes to place on the same or multiple ideas. The idea with the most votes merit further discussion and/or development. KJ method allows free and creative thinking and frees everyone from problem so that can pursue creative thinking based on facts without any constraints (Simsit et al., 2014).

Evaluating How New Products/Services Perform Prior to Their Release

A prototype is an early sample, model or release of a product built to test a concept or process or to act as a thing to be replicated or learned from. This term used in a variety of contexts, including semantics, design, electronics, and software programming. A prototype is designed to test and trial a new design to enhance precision by system analysts and users (Simsit et al., 2014). Prototyping serves to provide specifications for a real, working system rather than a theoretical one. It also tests the robustness of design and its sensitivity to uncontrollable factors (Hernley, 2011).

One of the most common pitfalls is the tendency to wait until they have everything right before sharing their prototype with others. Ironically, the primary reason of prototyping is to communicate ideas and get feedback to validate project requirements. It's human nature to want that prototype to be "perfect" before showing it to anyone (Simsit et al., 2014).

Prototyping lets visual communication and interactive design concepts to both team members and non-technical stakeholders so that constructive feedbacks can gather earlier in the process when it's most valuable. A prototype to validate existing requirements, uncover missing requirements, help to clients understand exactly what they need, and ensure that correct designing based on correct assumptions. Repeated sharing, gathering feedbacks and refining prototypes through as many cycles are required to reach a right decision. Each cycle turns the dial, bringing the customer's needs, and the project itself, into clearer and clearer focus(Taiwo, 2010).

Problem Diagnosis and Improvement Prior to Commercialization

A Control Plan provides a single point of reference for understanding process characteristics, specifications, and standard operation procedures also known as SOP for the process. A control

plan enables assignment of responsibility for each activity within the process. This ensures that the process is executed smoothly and is sustainable in the long run (Poots & Woodcock, 2012). Control Plan is critical to ensuring that your innovation will be produced or delivered according to your careful design, regardless of location, personnel, environment or other variables that you won't be able to control (Silverstein et al., 2013).

One of the important points to consider in implementing innovation models is that these models are non-linear and may be referred to several previous or subsequent steps at each step. Therefore, implementation of such models cannot easily done step by step and also the margin between different steps cannot be clearly clarified.

RESULTS AND CONCLUSION

In 21th century the importance of innovation is not hidden for anyone specially managers trying to win the market competition. Innovation is not only employing new tools, services and process, but also any changes in a way a process has been done to gain the goal would consider as an innovation.

Innovation management can be used to develop both product and organizational innovation and includes a set of tools that allow managers and engineers to cooperate with a common understanding of goals and processes. It is an obvious necessity that managers need a clear road map in innovation management which is a complex procedure especially because of the characteristic of innovation itself.

Companies who started improvements before and accelerated technology transfer continuously gain advantages among its rivals. On the other hand companies who are just starting their development process in terms of innovation management had to move forward with right steps because there is already a gap between their rivals.

Nowadays, among several industrial challenges, one that clearly stands out in emerging economies is occupational safety and health specifically. These challenges are expected to be reduced through innovative researches and implementation of the research output models. Thus, workplace safety and health consideration has had less attention in developing countries as stated and evidenced by different researches. Most of a company's focus is on the external customer satisfaction with their product or service disregarding worker satisfaction and working environment comfort in economically lagging countries.

Consideration of OSH has a great impact for the development of economic growth and organizational productivity improvement. With occupational safety and health improvements, there is an increase in the health and satisfaction of employees. Many researchers have found that wealth means health. In solving these problems, one of the most important starting points is innovative development of the occupational safety and health improvement systematic approach. Workplace design and hazards interventions have been identified as barriers in manufacturing industries which need innovation.

This study followed a 6-step framework to implement innovation process in any industry by focusing on safety approaches. The framework. Although implementing of safety innovation frame work may increase the efficiency of the company, the framework itself needs a long period of time to get assessed specially for its 2-last step.

References

Baregheh, A. (2009). Towards a multidisciplinary definition of innovation. *Management Decision, 47*(8), 1323-1339. doi:10.1108/00251740910984578

Barry, K., Domb, E., & Slocum, M. (2010). TRIZ-What Is TRIZ? The Triz Journal. Real Innovation Network. In.

Beblavý, M., Maselli, I., & Martellucci, E. (2012). Workplace Innovation and Technological Change. *CEPS Special Reports, Forthcoming*.

Camisón, C., & Villar-López, A. (2014). Organizational innovation as an enabler of technological innovation capabilities and firm performance. *Journal of Business Research, 67*(1), 2891-2902.

Dawson, P. M., & Zanko, M. (2009). Reframing occupational health and safety management: a social innovation approach.

Hernley, L. R. (2011). *An analysis of early stage prototypes using implementation, look and feel, and role.* Massachusetts Institute of Technology,

Jilcha, K., & Kitaw, D. (2017). Industrial occupational safety and health innovation for sustainable development. *Engineering Science and Technology, an International Journal, 20*(1), 372-380. doi:https://doi.org/10.1016/j.jestch.2016.10.011

Jilcha, K., Kitaw, D., & Beshah, B. (2016). Workplace innovation influence on occupational safety and health. *African Journal of Science, Technology, Innovation and Development, 8*(1), 33-42. doi:10.1080/20421338.2015.1128044

Khosravi, P., Newton, C., & Rezvani, A. (2019). Management innovation: A systematic review and meta-analysis of past decades of research. *European Management Journal*. doi:https://doi.org/10.1016/j.emj.2019.03.003

Masi, D., Cagno, E., & Micheli, G. J. (2014). Developing, implementing and evaluating OSH interventions in SMEs: a pilot, exploratory study. *International journal of occupational safety and ergonomics, 20*(3), 385-405.

Nuwayhid, I. A. (2004). Occupational health research in developing countries: a partner for social justice. *American Journal of Public Health, 94*(11), 1916-1921.

O'Sullivan, M. (2000). The innovative enterprise and corporate governance. *Cambridge Journal of Economics, 24*(4), 393-416.

Oeij, P., Dhondt, S., Kraan, K., Vergeer, R., & Pot, F. (2012). Workplace Innovation and its Relations with Organisational Performance and Employee Commitment-www-publicatie.

Organization, W. H. (2002). *The world health report 2002: reducing risks, promoting healthy life*: World Health Organization.

Organization, W. H. (2010). *World health statistics 2010*: World Health Organization.

Páez-Avilés, C., Juanola-Feliu, E., & Samitier, J. (2018). Cross-fertilization of Key Enabling Technologies: An empirical study of nanotechnology-related projects based on innovation management strategies. *Journal of Engineering and Technology Management, 49*, 22-45. doi:https://doi.org/10.1016/j.jengtecman.2018.05.001

Pillay, M. (2015). Accident Causation, Prevention and Safety Management: A Review of the State-of-the-art. *Procedia Manufacturing, 3*, 1838-1845. doi:https://doi.org/10.1016/j.promfg.2015.07.224

Podgórski, D. (2015). Measuring operational performance of OSH management system–A demonstration of AHP-based selection of leading key performance indicators. *Safety science, 73*, 146-166.

Poolton, J., & Barclay, I. (1998). New product development from past research to future applications. *Industrial Marketing Management, 27*(3), 197-212.

Poots, A. J., & Woodcock, T. (2012). Statistical process control for data without inherent order. *BMC Medical Informatics and Decision Making, 12*(1), 86.

A Powerful Methodology for Creative Problem Solving. (2019). Retrieved from https://www.mindtools.com/pages/article/newCT_92.htm

Rufino, C. C., & Villasor, R. S. (2015). Health is Wealth.

Silverstein, D., Samuel, P., & DeCarlo, N. (2013). *The innovator's toolkit: 50+ techniques for predictable and sustainable organic growth*: John Wiley & Sons.

Simsit, Z. T., Vayvay, O., & Oztürk, O. (2014). An Outline of Innovation Management Process: Building a Framework for Managers to Implement Innovation. *Procedia - Social and Behavioral Sciences, 150*, 690-699. doi:https://doi.org/10.1016/j.sbspro.2014.09.021

Taiwo, A. S. (2010). The influence of work environment on workers productivity: A case of selected oil and gas industry in Lagos, Nigeria. *African Journal of Business Management, 4*(3), 299-307.

Tidd, J., & Bessant, J. R. (2018). *Managing innovation: integrating technological, market and organizational change*: John Wiley & Sons.

Fatigue detection through physiological assessment during real-life occupational situations: Preliminary results

D. Bustos[1], J.C. Guedes[2], P. Pratas[3], M.P. Vaz[4], J.C. Torres Costa[5], R.J. Fernandes[6] and J. Santos Baptista[7]

[1]Associated Laboratory for Energy, Transports and Aeronautics - LAETA (PROA), Faculty of Engineering, University of Porto, PT (ldbs@fe.up.pt) ORCID 0000-0002-4942-7625, [2]Associated Laboratory for Energy, Transports and Aeronautics - LAETA (PROA), Faculty of Engineering, University of Porto, PT (jccg@fe.up.pt) ORCID 0000-0003-2367-2187, [3]Faculty of Engineering, University of Porto, PT (up202003606@fe.up.pt) ORCID 0000-0003-3380-5027, [4]Associated Laboratory for Energy, Transports and Aeronautics - LAETA (PROA), Faculty of Engineering, University of Porto, PT; Porto Biomechanics Laboratory, University of Porto, PT (gmavaz@fe.up.pt) ORCID 0000-0002-6347-9608, [5]Associated Laboratory for Energy, Transports and Aeronautics - LAETA (PROA), Faculty of Medicine, University of Porto, PT (zecatoco@sapo.pt) ORCID 0000-0003-3947-8688, [6]Center of Research, Education, Innovation and Intervention in Sport, Faculty of Sport, University of Porto, PT; Porto Biomechanics Laboratory, University of Porto, PT (ricfer@fade.up.pt) ORCID 0000-0002-5811-0443, [7]Associated Laboratory for Energy, Transports and Aeronautics - LAETA (PROA), Faculty of Engineering, University of Porto, PT (jsbap@fe.up.pt) ORCID 0000-0002-8524-5503.

https://doi.org/10.24840/978-972-752-279-8_0049-0055

Abstract

Background: Fatigue is a significant health and safety-related problem among workers. In general, it decreases performance and physical strength, causing incidents and accidents in operational situations. During military activities, soldiers often encounter severe conditions, which combined lead to fatigue manifestations affecting their health and performance. Continuous monitoring of their overall health status would prevent its adverse effects. Objective: This work aimed to present the preliminary results of a retrospective assessment of military training physiological recordings using an alert-based fatigue detection algorithm to validate its accurate functioning. Methods: Three case studies from soldiers participating in military training tests were recruited for evaluation. The referred algorithm was developed to manage fatigue through the combined assessment of physiological variables and determine different fatigue levels warnings to advise timely interventions and prevent potential health impact. Each examined case included the continuous recording of heart rate, breathing rate and core temperature. The algorithm translated physiological sensory data into minute alarms according to fatigue levels determined through the conjunction of normative and related research criteria. Results and Discussion: Outcomes revealed that the algorithm could evidence the different stages of training and the resulting physical demands on soldiers using their physiological response throughout the exercises. Retrieved fatigue alarms showed the high physiological cost of military practices and helped to overview the impact of each training period. Finally, results also demonstrated the importance of individual and contextualised assessment for accurately characterise the subject's fatigue status. Conclusions: It is concluded that the developed decision model can improve the management of real-time fatigue, allowing early detection of potential indicators of further physical impairments. Furthermore, it can lead to the enhancement of work-rest cycles, not only for tactical personnel but also for any safety-sensitive occupation. For future work, its validity will be tested through more participants, and other variables will be added to improve its accuracy.

Keywords: Performance, Physical exertion, Physiological monitoring, Sensors.

INTRODUCTION

Fatigue is a major health and safety-related challenge among workers (Anwer et al., 2021). In general, it can be understood as a reduction in physical and mental capacity to perform activities at the desired level due to exhaustion of mental or physical strength (Hallowell, 2010; Ream & Richardson, 1996). Fatigue degrades performance and well-being, leading to error, incident, and accident in operational settings (Belenky et al., 2014). Because of the potential influence of fatigue on health, safety, and productivity, any organisation in which individuals work extended hours, or hours in which people typically sleep, can experience fatigue in the workplace. This is especially important for safety-sensitive operations such as the transportation, military missions, health care, and energy industries (Lerman et al., 2012).

Fatigue is widely prevalent among military personnel. Besides typical operational stressors, soldiers, potentially more than any other working group, must deal with stressful situations that can lead to a state of fatigue, non-functional overreaching, and eventually overtraining conditions (Friedl, 2012; Parnell et al., 2018). As a result, early detection and real-time monitoring of fatigue play vital roles in the military (Friedl, 2012; Stacey et al., 2018). In general,

literature has evidenced that traditional methods to assess fatigue, such as subjective measurements and self-reported fatigue (Fang et al., 2015; Lee et al., 1991; Rachmawati et al., 2020; Zhang et al., 2015), are biased by situational and individual perceptions and might be limited to some occupational environments (Anwer et al., 2021). On the other hand, biochemical workload markers offer reliable measurements on the individuals' physical exertion (Horta et al., 2019) but do not allow a continuous non-invasive examination during normal working activities.

To overcome these limitations, researchers have attempted to use various physiological variables such as heart rate, skin temperature, electromyography and jerk metrics to monitor real-time fatigue in any occupational setting (Friedl, 2018; Lee et al., 2017). However, this obtained information needs to be translated into actionable data that can actually be used to prevent further physical impairments and improve individuals' performance in the workplace. In this regard, an algorithm for fatigue detection and continuous assessment through physiological monitoring was used, and the preliminary results of its application within military training events are presented in this study.

METHODOLOGY

Participants

Two male subjects were randomly selected to participate in the study and, their anthropometric characteristics are detailed in Table 1. They were regular elements from the Portuguese Army undertaking the 131st Commando Course (from April to June 2018). Before investigative procedures, recruited participants gave their written consent and were briefed on the purpose, potential risks, and benefits of the experiences. Additionally, they underwent a medical examination (as a standard requirement to take part in the course) and did not present cardiac, vascular, pulmonary, or any allergic diseases; they were considered mentally healthy and were not prescribed any regular medication.

Table 1. Participants

Subject	A	B
Age	21,0	24,0
Height (cm)	178	188
Weight (kg)	76,05	86,38
Body fat mass (kg)	11,48	6,78
Body fat (%)	15,09	7,84
Body Mass Index (kg/m^2)	24,03	24,43

Experimental design

Physiological recordings were continuously collected from each volunteer while participating in the three events. Contrarily to a previous laboratory experience (Bustos et al., 2019), in which participants performed a maximal exertion test, in this case, there were not predefined experimental protocols, and recordings were gathered during normal training conditions. After obtaining the results from the algorithm, details about each event were asked and correlated with the performed assessment. Prior to the training events, participants donned the physiological monitoring system, as indicated. The three evaluated events are briefly described lines below.

PIC (April 26th, 2018): Acronym of 'Pista Individual de Combate' (Portuguese words for 'Individual combat track'), this test consists of individual combatant progression under real fire. It is composed of 17 periods, in which activities of wounded displacement, a tunnel passage, lifeguarding, combat, and communication during stressful simulated conditions are included.

MARCOR (June 4th - 5th, 2018): Denominated by combining the Portuguese words: 'Marcha-Corrida' (March-Run), this physical test involves running and marching with loads within a 42km path. Approximate completion duration varies from 4 to 6 hours.

PCC (May 24th, 2018): Similar to the PIC, this test denominated 'Pista Coletiva de Combate' (Portuguese words for 'Collective Combat Track') is composed of various activities divided into 21 periods. However, in this case, individuals are part of different groups, and tasks are oriented to test performance and teamwork. With all, of the three events covered, this one involved the least physical effort for participants.

Since sensors were randomly assigned to participants before each test, it was not possible to obtain data from the same subject during the three tests. As a result, Participant A was monitored during the PIC test, while participant B was assessed while performing both MARCOR and PCC tests.

Equipment

During the three events, physiological measurements were recorded every 15 seconds through a chest belt physiological monitoring system: EquiVital LifeMonitor equipment (Hidalgo Ltd., Cambridge, U.K.), a "wear and forget" system type already validated for research purposes (Liu et al., 2013). For core temperature recordings, ingestible thermometer pills from Vital Sense were used. These pills travel along the digestive tract harmlessly and leave the body naturally within 24 to 72 hours. Finally, body composition was assessed using bioelectrical impedance analysis with the Body Composition Analyzer InBody230 (Karelis et al., 2013).

Data analysis

Physiological monitoring records were assessed using an algorithm (implemented using Python 3.6) that enables analysis and provides an integrated assessment of variables per minute. This algorithm has already been described and tested in a previous study (Bustos et al., 2019). Its main feature lies in classifying received sensory information into health alarm levels that refer from a good overall health status (alarm 1) to four different levels of fatigue (alarms 1.5, 2, 3 and 4). The system also attributes a warning when the sensor is not functioning correctly (alarm -1). The default number of examined physiological variables is three (heart rate, breathing rate, and core temperature), another two referring to body position and the last one determining the validity of the sensor recordings. However, if one or more of these variables are found to be 'noisy' (with unreliable values), they are filtered, and the algorithm assesses the rest of the available information. Nevertheless, the more of these variables are included, the higher the reached accuracy.

RESULTS AND DISCUSSION

The proposed method has been evaluated previously in controlled laboratory conditions, during a short maximal exertion test and proved an overall reliable performance (Bustos et al., 2019). In this study, a retrospective assessment throughout three military training events was performed. In general, outcomes demonstrated that despite the diverse activities covered within each event, the algorithm evidenced the different stages of training and the resulting

physical demands on subjects throughout the exercises. Physiological monitoring files from two subjects participating in three different military events were assessed. In all, the algorithm proved to be a promising approach for detecting physically demanding periods and evidencing the physiological impairment resulting from the most stressful situations, which suggests it can be extrapolated to various occupational and physically intense training settings.

Results were obtained per minute, and Table 2 presents the time percentage under each alarm category for the three cases. Contrary to the referred laboratory experience (Bustos et al., 2019), higher alert levels and a higher percentage of time in those levels were expected since prolonged intermittent exercises are proved to be more physically demanding than short continuous practices (Edwards et al., 1973; Edwards et al., 1972; Kraning 2nd & Gonzalez, 1991), which was corroborated within obtained assessments. Specifically, outcomes from the PIC test showed an alarm 2 (moderate physical intensity) for 10% of the test duration. The participant taking this assessment showed a stable tendency, reporting a very minimum percentage under alarm 3 and approximately 88% of the time under alarm 1 (no fatigue stage). This steadiness could be justified considering his longer experience (compared with the other soldier) in military training practices, which infers the need for assessing fatigue on an individual basis.

Table 2. Time percentage under each alarm level.

Alarm category	Subject A - PIC	Subject B - MARCOR	Subject B - PCC
Alarm 1	88.32	17.41	54.64
Alarm 1.5	0.00	0.00	0.00
Alarm 2	10.58	45.52	44.30
Alarm 3	1.09	29.35	1.06
Alarm 4	0.00	7.71	0.00

Similar to the PIC, the PCC results showed a bigger percentage of alarm 1. However, the level of physical exertion was significantly superior since both alarms 2 and 3 lasted longer than in the previous test. Despite this, no health warning was retrieved, and a maximal exertion was observed only 1% of the time, suggesting the subject was able to deal with all periods of the event. Assessment of more individuals undertaking this test can help validate the physiological cost during this alarm 4 period. On the other hand, from the MARCOR test, it was noted that the highest time percentages under alarms 2 and 3 were retrieved, and the subjects also reported a more significant amount of time under level 4. Since this test involves mostly an extended physical performance evaluation simulating a marathon, it was anticipated to obtain higher alarm levels and higher time percentages under fatigue. Correspondingly, assessments also revealed the lowest rates under a no fatigue condition (alarm 1). From all, this event proved to be the most physically demanding for soldiers.

Furthermore, when referring to the physiological responses determining the alarms, figures 1 and 2 help to observe how the alert-based system accurately represented these physiological outcomes. Core temperature and heart rate were considered the most discriminating factors when performing assessments and, correlation coefficients between them corroborate these positive associations. On the other hand, outcomes also revealed that there were periods in which heart rate values reached 180 bpm, and the breathing rate was above 60 rpm, denoting the high physiological cost associated with these practices. However, the most significant values were observed in core temperature. During the march-run series, there were periods in which they went above 39°C and maintained those high numbers over several minutes. This fact attests

to the severe acute stress under which soldiers are exposed and verifies what is evidenced in literature during military field practices (Lieberman et al., 2005; Lieberman et al., 2016; Ralph et al., 2017).

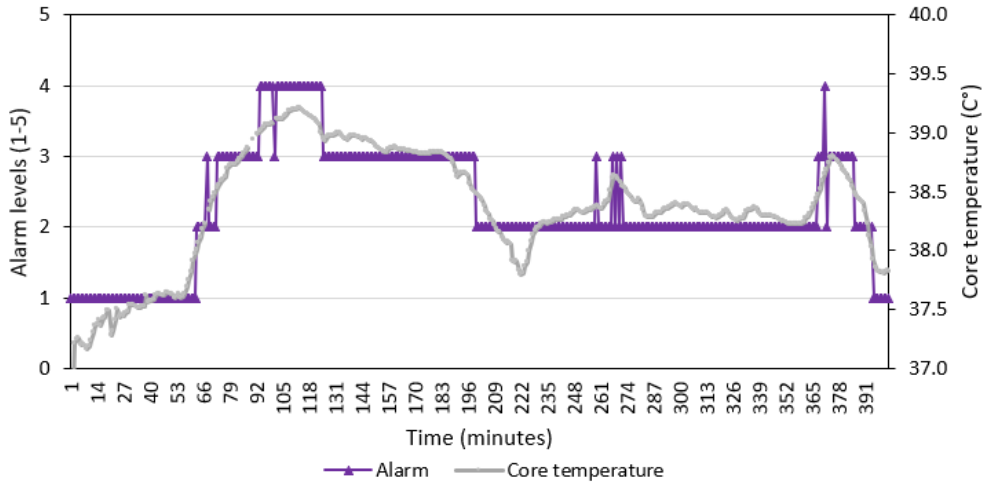

Figure 1. Results vs. core temperature from Subject B during MARCOR test.

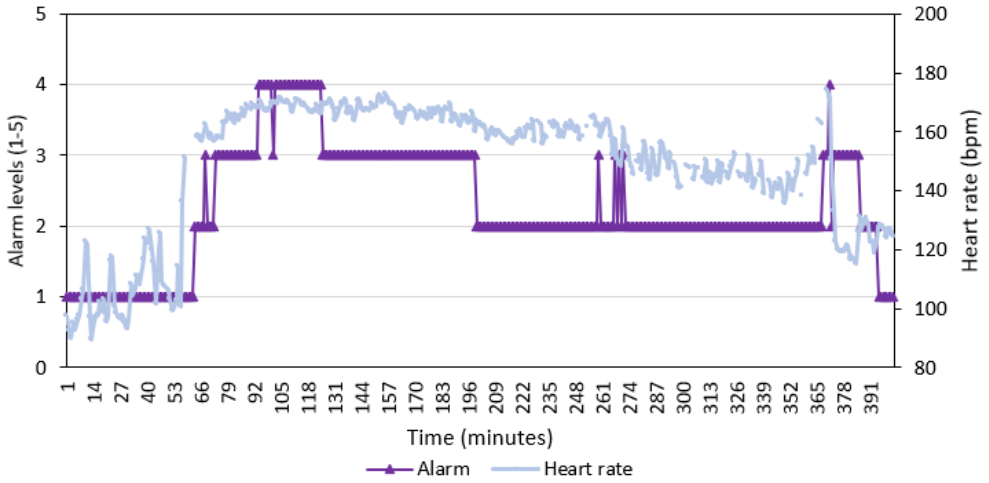

Figure 2. Results vs. heart rate from Subject B during MARCOR test.

Limitations

Since this study refers to field measurements and was not conducted in controlled laboratory settings, some inevitable limitations were observed. There were differences in testing times and quantity of available information, and some recordings had to be dismissed due to their compromised validity, which did not allow a complete overview of all physiological variables. Furthermore, the small sample referred for assessment did not permit the drawing of generalisable conclusions. Finally, the time course for complete recovery from the training could not be determined since there were no follow-up assessments. However, it was possible to collect data for three specific events each with a unique profile, which allowed to test the algorithm's capacity to detect fatigue in different real-life scenarios.

CONCLUSIONS

In this study, the preliminary outcomes from the validation of a decision-based algorithm for fatigue detection within training events are reported. Based on these initial results, it was

demonstrated that the proposed alert-based system was able to provide reliable outcomes and led to the accurate identification of the most physically demanding periods and their direct impact on physiological variables. The assessment of more individuals undertaking these events will help establish the intensity of each training period clearly, leading to a better planning and management of training and work-rest cycles. Overall, by providing a multivariate approach, it is believed that this assessment method, with further modifications, has the potential to improve fatigue management among military populations. For future work, its validity will be tested through a more significant sample, and additional variables will be added to the assessment system for more specificity and robustness.

Acknowledgments

This work was funded by the Foundation of Science and Technology (FCT Portugal) through the PhD studentship SFRH/BD/143608/2019, the Military Academy Research Center (CINAMIL), and the Associated Laboratory for Energy, Transports and Aeronautics (LAETA). The authors would also like to acknowledge the support of the Doctoral Program in Occupational Health and Safety from the University of Porto.

References

Anwer, S., Li, H., Antwi-Afari, M. F., Umer, W., & Wong, A. Y. L. (2021). Evaluation of Physiological Metrics as Real-Time Measurement of Physical Fatigue in Construction Workers: State-of-the-Art Review [Review]. *Journal of Construction Engineering and Management*, *147*(5), Article 03121001. https://doi.org/10.1061/(ASCE)CO.1943-7862.0002038

Belenky, G., Lamp, A., Hemp, A., & Zaslona, J. L. (2014). Fatigue in the Workplace. In *Sleep Deprivation and Disease* (pp. 243-268). Springer.

Bustos, D., Guedes, J., Alvares, M., Vaz, M., & Torres Costa, J. (2019). Real Time Fatigue Assessment: Identification and Continuous Tracing of Fatigue Using a Physiological Assessment Algorithm. *Occupational and Environmental Safety and Health*, In Press. https://doi.org/https://doi.org/10.1007/978-3-030-14730-3_28

Edwards, R., Ekelund, L.-G., Harris, R., Hesser, C., Hultman, E., Melcher, A., & Wigertz, O. (1973). Cardiorespiratory and metabolic costs of continuous and intermittent exercise in man. *The Journal of physiology*, *234*(2), 481-497.

Edwards, R., Melcher, A., Hesser, C., Wigertz, O., & Ekelund, L. G. (1972). Physiological correlates of perceived exertion in continuous and intermittent exercise with the same average power output. *European journal of clinical investigation*, *2*(2), 108-114.

Fang, D., Jiang, Z., Zhang, M., & Wang, H. (2015). An experimental method to study the effect of fatigue on construction workers' safety performance. *Safety science*, *73*, 80-91.

Friedl, K. E. (2012). Predicting human limits-the special relationship between physiology research and the Army mission. *Friedl KE, Santee WR (Eds) Military Quantitative Physiology: Problems and Concepts in Military Operational Medicine: Problems and Concepts in Military Operational Medicine*, 1-38.

Friedl, K. E. (2018). Military applications of soldier physiological monitoring. *Journal of Science and Medicine in Sport*.

Hallowell, M. R. (2010). Worker fatigue. *Professional safety*, *55*(12), 18.

Horta, T. A. G., Bara Filho, M. G., Coimbra, D. R., Miranda, R., & Werneck, F. Z. (2019). Training Load, Physical Performance, Biochemical Markers, and Psychological Stress During a Short Preparatory Period in Brazilian Elite Male Volleyball Players [Article]. *Journal of strength and conditioning research*, *33*(12), 3392-3399. https://doi.org/10.1519/JSC.0000000000002404

Karelis, A. D., Aubertin-Leheudre, M., Duval, C., & Chamberland, G. (2013). Validation of a portable bioelectrical impedance analyser for the assessment of body composition [Article]. *Applied Physiology, Nutrition and Metabolism*, *38*(1), 27-32. https://doi.org/10.1139/apnm-2012-0129

Kraning 2nd, K., & Gonzalez, R. R. (1991). Physiological consequences of intermittent exercise during compensable and uncompensable heat stress. *Journal of Applied Physiology*, *71*(6), 2138-2145.

Lee, K. A., Hicks, G., & Nino-Murcia, G. (1991). Validity and reliability of a scale to assess fatigue. *Psychiatry Research*, *36*(3), 291-298. https://doi.org/https://doi.org/10.1016/0165-1781(91)90027-M

Lee, W., Lin, K.-Y., Seto, E., & Migliaccio, G. C. (2017). Wearable sensors for monitoring on-duty and off-duty worker physiological status and activities in construction. *Automation in Construction*, *83*, 341-353.

Lerman, S. E., Eskin, E., Flower, D. J., George, E. C., Gerson, B., Hartenbaum, N., Hursh, S. R., & Moore-Ede, M. (2012). Fatigue risk management in the workplace. *Journal of Occupational and Environmental Medicine*, *54*(2), 231-258.

Lieberman, H. R., Bathalon, G. P., Falco, C. M., Kramer, F. M., Morgan, C. A., & Niro, P. (2005). Severe decrements in cognition function and mood induced by sleep loss, heat, dehydration, and undernutrition during simulated combat. *Biological psychiatry*, *57*(4), 422-429.

Lieberman, H. R., Farina, E. K., Caldwell, J., Williams, K. W., Thompson, L. A., Niro, P. J., Grohmann, K. A., & McClung, J. P. (2016). Cognitive function, stress hormones, heart rate and nutritional status during simulated captivity in military survival training. *Physiology & behavior*, *165*, 86-97.

Liu, Y., Zhu, S. H., Wang, G. H., Ye, F., & Li, P. Z. (2013). Validity and reliability of multiparameter physiological measurements recorded by the Equivital LifeMonitor during activities of various intensities. *Journal of occupational and environmental hygiene*, *10*(2), 78-85.

Parnell, N., Rye, K., & Greenberg, N. (2018). Health and well-being management in the military: a systematic review of genetic studies. *Journal of the Royal Army Medical Corps*, *164*(4), 302-308. https://doi.org/10.1136/jramc-2017-000765

Rachmawati, S., Aktsari, M., Suryaningsih, A., Hawali Abdul Matin, H., & Suryadi, I. (2020). Assesment Work Fatigue to Workers in Environment Underground Mining Areas Based on Fatigue Assesment Scale Questionnaires. E3S Web of Conferences,

Ralph, C. S., Vartanian, O., Lieberman, H. R., Morgan, C. A., & Cheung, B. (2017). The effects of captivity survival training on mood, dissociation, PTSD symptoms, cognitive performance and stress hormones. *International Journal of Psychophysiology*, *117*, 37-47.

Ream, E., & Richardson, A. (1996). Fatigue: a concept analysis. *International journal of nursing studies*, *33*(5), 519-529.

Stacey, M. J., Hill, N., & Woods, D. (2018). Physiological monitoring for healthy military personnel. In: British Medical Journal Publishing Group.

Zhang, M., Sparer, E. H., Murphy, L. A., Dennerlein, J. T., Fang, D., Katz, J. N., & Caban-Martinez, A. J. (2015). Development and validation of a fatigue assessment scale for US construction workers. *American journal of industrial medicine*, *58*(2), 220-228.

Work-related musculoskeletal disorder and its costs: a short review

Ana Sophia Rosado[1], J. Santos Baptista[2] and J. C. Guedes[3]

[1]Faculty of Engineering, University of Porto, PT (anasgmr@yahoo.com.br) ORCID 0000-0002-4935-4171, [2]Associated Laboratory for Energy, Transports, and Aeronautics - LAETA (PROA), Faculty of Engineering, University of Porto, PT (jsbap@fe.up.pt) ORCID 0000-0002-8524-5503, [3]Associated Laboratory for Energy, Transports, and Aeronautics - LAETA (PROA), Faculty of Engineering, University of Porto, PT (jccg@fe.up.pt) ORCID 0000-0003-2367-2187.
https://doi.org/10.24840/978-972-752-279-8_0056-0064

Abstract

Introduction: Musculoskeletal disorder can result from extreme physical demands at work. It has risen, mainly due to high muscle demands and static postures and generates a significant economic burden to the companies. This short review aims to point out the statistics of the most affected body parts by work-related musculoskeletal disorders, assess absenteeism and presenteeism costs, and evaluate the effectiveness of the interventions. Methodology: According to the PRISMA Statement, the search was performed in 5 electronic databases (Scopus, Web of Science, Science Direct, Pubmed). Articles selection was made by the title and abstract analysis, especially those aiming to explain and validate the subject. If the abstract fulfils the objective, the articles were read, and studies were considered that met the defined eligibility criteria. Were chosen articles that realised measurements or considered interventions in healthy human beings, especially in the working population, dated from 2015 to 2020. Results and Discussion: The scrutinised articles were conclusive that the most affected part of the body are the upper limbs, the neck and the upper back. The statistics of the affected workers varied according to the country and analysed tasks, but they converge concerning the most affected body parts. It could be noted that women are more affected by musculoskeletal disorders than men, especially older women; the reason, however, is not clearly explained. Muscle injury can lead high economic burden, mostly due to absenteeism and presenteeism. It was noted that the expenditure due to presenteeism is higher comparing to absenteeism in both developed and emergent countries. Conclusions: Due to high costs, companies are deploying strategies to improve work conditions and aware the workers about health and safety. Interventions have shown to be effective in reducing the risk of injuries. Work-related musculoskeletal disorders can be extremely damaging to the workers' health and are costly to the companies. Support supervisor interventions effectively improve work conditions and reduce the risk of damaging outcomes, increasing workers' health, work ability, and, consequently, productivity.

Keywords: Injury, Absenteeism, Presenteeism, Strategies.

INTRODUCTION

The high physical load and repetitive movements are the leading causes of musculoskeletal disorders associated with emotional stress (Atroszko et al., 2020). Physical exhaustion results in muscular frailty and can be aggravated by awkward postures, repetitive tasks, and static position, which propitiate the risk of injury (Hembecker et al., 2017) (Knoop et al., 2019).

Work-related musculoskeletal disorders (WMSD) are a reality in companies worldwide and represent the highest disease rate (Acaröz et al., 2019). It is a crucial factor to be assessed since it directly relates to the employees' health, safety, and productivity (Caldwell et al., 2019).

Illnesses originated from overwork precedes high economic burden to workers companies, especially due to presenteeism and absenteeism (Silva et al., 2018). Musculoskeletal disorder is the leading cause of work absenteeism in Europe, affecting over 40 million workers. It leads to disability around the globe in 20%-33% and represents up to 40% of occupational costs (Moussavi, Zare, Mahdjoub, & Grunder, 2019) (Santos & Mendes, 2020) (Crawford et al., 2020). The World Health Organization (WHO) recognises that an unsuitable working environment precedes physical and mental health problems, raising the risk of sick leave and loss of productivity (Atroszko et al., 2020).

Considering the high associated costs, companies are becoming aware of improving working conditions, as well as reducing productivity losses and sick leave (Jonge et al., 2019) (Atroszko et al., 2020).

Although various factors contribute to the loss of work capacity, WMSD has proved to be one of the most important. This study is a short review to point out the most affected body parts and

evaluate absenteeism and presenteeism as harm outcomes resulting from musculoskeletal disorders.

METHODOLOGY

The review was done by the analysis of articles, which could be reviews and individual researches. The analysis of each article was verified, on the first moment, the title and the abstract. If the abstract fulfils the goal, then the lecture of the full articles was performed. The selection reflected only articles that considered healthy human beings and workers of working age. Articles evaluating outdoor work and measurement methods utilising Rula, Reba, Ocra, Owas, and NIOSH were not considered.

The databases used were: Scopus, Web of Science, Science Direct, Pubmed. The words used in the investigation were:

- cost absenteeism AND employers;
- increase health AND absenteeism;
- loss productivity AND injury;
- musculoskeletal AND absenteeism AND presenteeism AND cost;
- musculoskeletal AND body region;
- musculoskeletal disease AND body part;
- musculoskeletal disorder AND reduce productivity;
- work capacity AND tiredness;
- work capacity AND increase AND health;
- work capacity evaluation AND tiredness;
- work productivity AND absenteeism AND presenteeism.

This systematic review was performed according to the PRISMA Statement (Moher D. et al., 2009), and the research was updated to March 2021. The investigation of the articles resulted in: summary of the collected articles with 33 209 articles pre-selected. Applying the exclusion criteria, 24 648 papers were excluded by “date” (articles published in the period between 2015 and 2020 were included); 3 446 were rejected by “document type” (only articles and review articles were accepted); 11 texts were refused due to “language” (only English was accepted). After articles exclusion according to the explained criteria, were read the titles and abstracts of the remaining ones. 5 073 articles were excluded because they are not consistent with the goal of this Short review. Finally, 31 articles were used for analysis in this work. Of all analysed articles, thirteen exhibited the statistics of the most injured part of the body by WMSD, five articles compared the costs of absenteeism and presenteeism due to musculoskeletal disorder, and the other investigated articles justified this systematic review.

Articles before 2015 were considered due to their importance about the topic.

RESULTS AND DISCUSSION

Most common sites pain

Work-related musculoskeletal disorders can affect workers and companies of different sectors. The consequences can be damaging to the health of the workers and the economy of companies (Acaröz et al., 2019). Due to its severity, several kinds of research have been made to understand the most affected gender, regions of the body, and costs.

It was noted that women are more susceptible to WMSD, and it is twice as common in older women than in man (Pensola et al., 2016; Knoop et al., 2019; Acaröz et al., 2019; Troelstra et al., 2020). However, no author has explained clearly the reason why women are most affected.

Several researchers have scrutinised the part of the body with the highest rate of WMSD. Figure 1 shows the result of thirteen articles (number 1-13 on the X-axis). It is known that musculoskeletal injuries disturb workers from different sectors. Tasks with physical demands and intellectual workers are both touched by bodily injuries. Figure 2 illustrates the result of thirteen analysed articles (numbers 1-13 on the X-axis), concerning the most affected body parts, considering different jobs, such as health workers (nurses, physicians, physical therapists), financial services workers, manufacturing workers, academicians, supermarket cashiers, construction workers.

It must be highlighted that the used methods for the evaluation mainly were the Nordic Musculoskeletal Questionnaire, but also were used the Dutch Musculoskeletal Questionnaire, Work Ability Index, Institute for Medical Technology Assessment Productivity Cost Questionnaire (iPCQ), Work Productivity and Activity Impairment Questionnaire, and health examination. In addition, musculoskeletal pain and disorder from the past twelve months were considered.

Figure 1, illustrates the most affected parts of the body due to WMSD, in indoor activities.

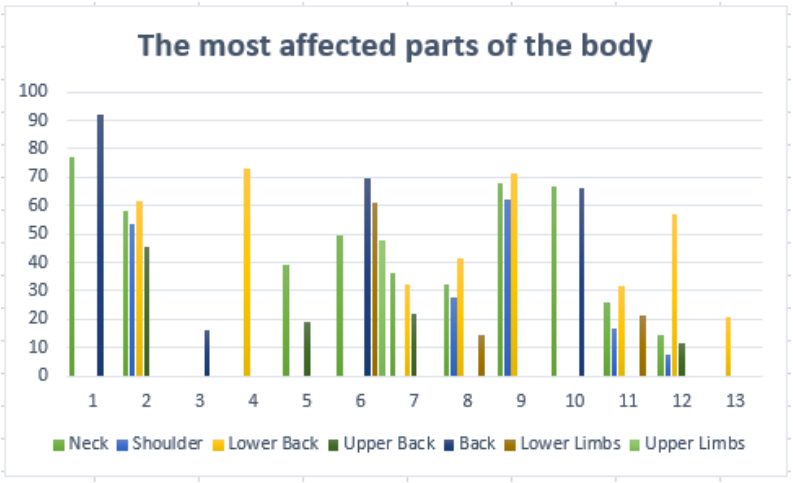

Figure 1. The parts of the body most affected by WMSD.

The evaluation of the articles permits to conclude that the incidence of WMSD is mainly in the neck and back. Figure 2 illustrates the statistics of the three most affected body parts.

It must be underlined that the back pain can be related to the upper back or lower back. Some of the articles did not explain the exact location.

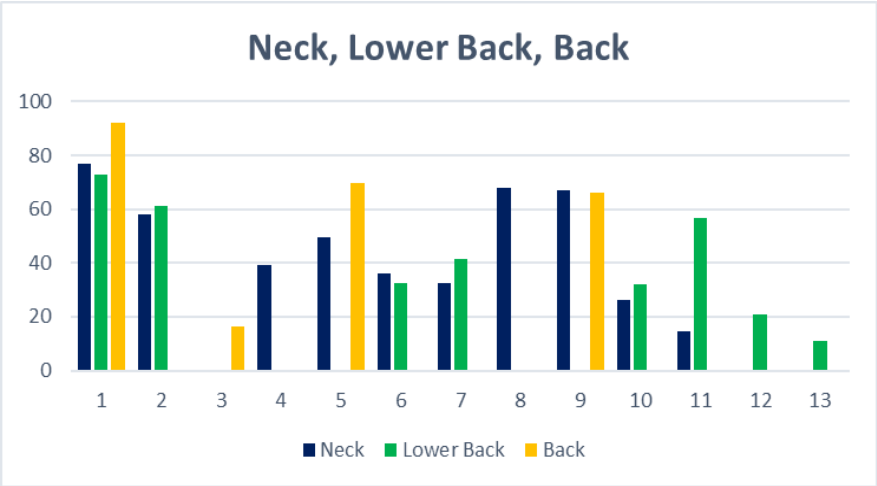

Figure 2. The three most affected body parts by WMSD.

The discrepancies between the statistics results might be attributed to the characteristics of the evaluated population and the work characteristics (Ezzatvar et al., 2020), but there is a consensus on the most affected body parts. In this sense, according to the European Agency for Safety and Health at Work, lower back pain is one of the main causes of disability and sick leave (Algarni, Alkhaldi, et al., 2020; Acaröz et al., 2019).

The severity of WMSD may increase the risk of disability, chronic pain, sick leave, reduced work capability, and early retirement (Miranda et al., 2010; Phongamwong & Deema, 2015; Hallman et al., 2019; Troelstra et al., 2020; Vieira & Sato, 2020).

Costs

It is estimated that an economic burden due to WMSD in Europe is approximately 2% of the Gross Domestic Product (GDP) (Bevan, 2015; Svendsen et al., 2020; Santos & Mendes, 2020; Crawford et al., 2020).

The monetary expenses are mainly due to presenteeism and absenteeism (Nagata et al., 2018). Absenteeism can be easily calculated since it represents sick leave. However, evaluating the cost of presenteeism is more complicated because the loss of productivity is often a hidden cost. It reduces the effectiveness due to pain or disorders (Ammendolia et al., 2016), which usually offers unseen expenses.

Figure 3 reflects the economic burden (percentage) due to presenteeism and absenteeism in five developed and developing countries to illustrate the importance of reducing musculoskeletal disorder.

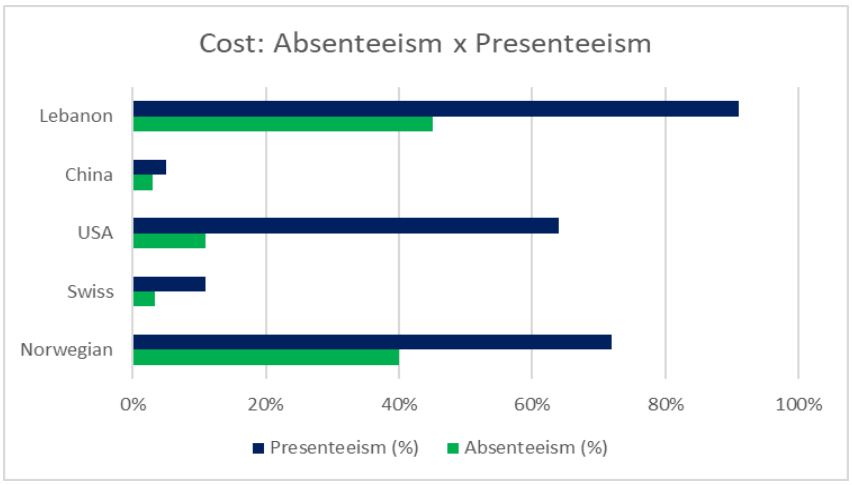

Figure 3. Comparing the total cost of absenteeism and presenteeism in five countries.

It has been assumed that presenteeism costs exceed the costs of absenteeism (van der Burg et al., 2020; Lohaus & Habermann, 2019).

Figure 3 makes it clear that independently of developed and emergent countries, the costs due to sick leave and loss of productivity are high. It can be understood that human beings are equal concerning the body's movements and adoption of postures.

Workers not affected by WMSD symptoms have a higher quality of life (Algarni, Alkhaldi, et al., 2020), which is reflected in positive outcomes and efficiency at work and in private life. It demonstrates that improvements at work, such as awareness of adopting correct postures and reducing stressors, can minimise harmful outcomes (Acaröz et al., 2019).

Causes

Professionals from different sectors are negatively affected by overload, improper ergonomic conditions, and a lack of attention to the principles of biomechanics (Ameer & Ashour, 2020). It can be said that the musculoskeletal system is primarily affected by repetitive work and overload, but static postures also can be damaging to physical health, increasing the risk of WMSD (Hembecker et al., 2017; Algarni et al., 2020).

It must be highlighted that extreme demanding tasks are related to psychological stress, directly associated with functional stress and illnesses (Karnaukh & Shevtsova, 1991; Moussavi, Zare, Mahdjoub, & Grunder, 2019).

Besides the high demand at work, sedentary behaviour and unhealthy eating habits are also detrimental to health. Regarding physical activity (PA), it has been settled that leisure PA promotes health and decreases in 20% the risk of long-term sickness absence. Contrary to leisure PA, a high occupational PA increases the risk of long-term sickness absence (Gupta et al., 2020).

Muscular injuries are caused by the insufficient restoration of energy and strength. In its turn, the first symptom of WMSD is usually muscular pain, which is directly associated with reduced work capacity, loss of productivity, and in most severe cases it can lead to absence due to illness (Jonge et al., 2019; Hallman et al., 2019; Ameer & Ashour, 2020; Skovlund et al., 2020). Other serious consequences of WMSD are turnover intentions, depression (Frone & Blais, 2019), and disability retirement (Pensola et al., 2016). Emphasising this sentence, in Finland, the most common reason for early retirement is musculoskeletal problems (33%) (Söderbacka et al., 2020). These harmful results have a direct impact on workers' health and high costs.

It must be emphasised that workers have been affected by multisite pain. The most common combination is neck and back pain (Pensola et al., 2016). Musculoskeletal disorder in several parts of the body dramatically reduces work ability (Bayattork et al., 2019; Hallman et al., 2019; Ezzatvar et al., 2020), with detrimental effects on workers and companies.

Strategies

Companies have a great challenge to protect workers' health and ensure a safe workplace (Boschman et al., 2015). To improve work conditions and minimise the incidence of WMSD, occupational and hygiene professionals should implement different strategies (Nordstoga et al., 2019).

Well-planned policies can increase workers' health and reduce unnecessary costs (Crawford et al., 2020). Interventions, such as mapping the process considering individual risk factors and productivity demands, are proven efficient to achieve excellent outcomes (Atroszko et al., 2020). Training is also a low-cost and effective measure to minimise hidden productivity losses (Brunner et al., 2019), sickness- absence, and consequently prolong workers careers (Nielsen & Midtsundstad, 2020).

Prevent harm conditions at work is crucial to avoid absenteeism and economic losses, as well as the injuries caused by the muscular response to excessive overwork (McDonald, Mulla, & Keir, 2019). Tactics with supportive supervisors have been demonstrated to be effective to improve work conditions and reduce the risk of damaging consequences (Baral et al., 2018; Brunner et al., 2019; Söderbacka et al., 2020).

However, planning an effective strategy, risk management, and the best strategy to be taken must be evaluated according to the reality and feasibility of each organisation (Ammendolia et al., 2016; Crawford et al., 2020).

CONCLUSIONS

Work-related musculoskeletal disorders reflect a high economic burden to companies around the world, as well as prejudice worker health. The consequences to the individuals can reflect lost productivity and, in most serious cases, sickness absence.

The more significant cost is due to presenteeism, more than absenteeism, although it is difficult to evaluate its cost since it is a hidden cost. It is known that developed and underdeveloped countries have significant losses, which could be minimised with effective and inexpensive strategies.

It is important to aware workers about physical health, especially taking care of the neck and back, which are the most affected body parts. Well-designed strategies are essential to improve work conditions and should be taking according to the reality experienced.

References

Acaröz, S., Sahin, U. K., & Akoglu, S. (2019). The investigation of work-relatedmusculoskeletal disorders among female workers in a hazelnut factory : Prevalence, working posture, work-related and psychosocial factors. *International Journal ofIndustrial Ergonomics*, *74*. https://doi.org/10.1016/j.ergon.2019.102838

Algarni, F. S., Alkhaldi, H. A., Zafar, H., Kachanathu, S. J., Al-Shenqiti, A. M., & Altowaijri, A. M. (2020). Self-Reported Musculoskeletal Disorders and Quality of Life in Supermarket Cashiers. *International Journal of Environmental Research andPublic Health*, *17*(24), 1–14. https://doi.org/10.3390/ijerph17249256

Algarni, F. S., Kachanathu, S. J., & Alabdulwahab, S. S. (2020). A Cross-Sectional Studyon the Association of Patterns and Physical Risk Factors with Musculoskeletal Disorders among Academicians in Saudi Arabia. *BioMed Research International*. https://doi.org/10.1155/2020/8930968

Ameer, M. A., & Ashour, A. A. (2020). Practising physical therapy affects professionals in

Egypt. *Physiotherapy Quarterly*, *28*(4), 42–4 .https://doi.org/10.5114/PQ.2020.96235

Ammendolia, C., Côté, P., Cancelliere, C., Cassidy, J. D., Hartvigsen, J., Boyle, E., … Iii, B. A. (2016). Healthy and productive workers : using intervention mapping to design a workplace health promotion and wellness program to improve presenteeism. *BMC Public Health*, *16*. https://doi.org/10.1186/s12889-016-3843-x

Atroszko, P. A., Demetrovics, Z., & Griffiths, M. D. (2020). Work Addiction, Obsessive- Compulsive Personality Disorder, Burn-Out, and Global Burden of Disease : Implications from the ICD-11. *International Journal of Environmental Research and Public Health*, *17*(2), 660. https://doi.org/doi.org/10.3390/ijerph17020660

Baral, S., Subedi, H. N., Paudel, P., Chand, P. B., Shrestha, M. P., McCullough, A., … Elsey, H. (2018). Implementation research to assess a health workers performance-based management system in Nepal. *Acta Paediatrica*, *107*(471), 24–34. https://doi.org/10.1111/apa.14406

Bayattork, M., Jakobsen, M. D., Sundstrup, E., Seidi, F., Bay, H., & Andersen, L. L. (2019). Musculoskeletal pain in multiple body sites and work ability in the general working population: cross-sectional study among 10,000 wage earners. *Scandinavian Journal of Pain*, *19*(1). https://doi.org/doi.org/10.1515/sjpain-2018- 0304

Bevan, S. (2015). Economic impact of musculoskeletal disorders (MSDs) on work in Europe. *Best Practice & Research Clinical Rheumatology*, *29*(3), 356–373. Retrieved from https://doi.org/10.1016/j.berh.2015.08.002

Boschman, J. S., Nieuwenhuijsen, K., Frings-Dresen, M. H. W., & Sluiter, J. K. (2015). Development of hospital nurses ' work ability over a 2 year period. *Occupational Medicine*, *65*(7), 542–548. https://doi.org/10.1093/occmed/kqv076

Brunner, B., Igic, I., Keller, A. C., & Wieser, S. (2019). Who gains the most from improving working conditions? Health-related absenteeism and presenteeism due tostress at work. *The European Journal of Health Economics*, *20*(8), 1165–1180. https://doi.org/10.1007/s10198-019-01084-9

Caldwell, J. A., Caldwell, J. L., Thompson, L. A., & Lieberman, H. R. (2019). Fatigue and its management in the workplace. *Neuroscience and Biobehavioral Reviews*, *96*(July 2018), 272–289. https://doi.org/10.1016/j.neubiorev.2018.10.024

Crawford, J. O., Berkovic, D., Erwin, J., Copsey, S. M., Davis, A., Giagloglou, E., … Woolf, A. (2020). Best Practice & Research Clinical Rheumatology Musculoskeletalhealth in the workplace. *Best Practice & Research Clinical Rheumatology*, *34*(5). https://doi.org/10.1016/j.berh.2020.101558

Ezzatvar, Y., Calatayud, J., Andersen, L. L., Vinstrup, J., Alarcón, J., & Casaña, J. (2020). Dose-response association between multisite musculoskeletal pain and work ability in physical therapists: a cross-sectional study. *International Archives of Occupational and Environmental Health*, *93*(7), 863–870. https://doi.org/10.1007/s00420-020-01533-6

Frone, M. R., & Blais, A.-R. (2019). Work fatigue in a non-deployed military setting: Assessment, prevalence, predictors, and outcomes. *MDPI - International Journal ofEnvironmental Research and Public Health*, *16*(16), 1–26. https://doi.org/10.3390/ijerph16162892

Gupta, N., Dencker-Larsen, S., Rasmussen, C. L., Mcgregor, D., Rasmussen, D. C. N., Thorsen, S. V., … Holtermann, A. (2020). The physical activity paradox revisited :a prospective study on compositional accelerometer data and long-term sickness absence. *International Journal of Behavioral Nutrition and Physical Activity*, *17*(1),1–9. https://doi.org/10.1186/s12966-020-00988-7

Hallman, D. M., Holtermann, A., Dencker-Larsen, S., Jørgensen, M. B., & Rasmussen, C. D. N. (2019). Are trajectories of neck-shoulder pain associated with sick leave and work ability in workers ? A 1-year prospective study. *BMJ Open*, *9*(3), 1–10. https://doi.org/10.1136/bmjopen-2018-022006

Hembecker, P. K., Reis, D. C., Konrath, A. C., Gontijo, L. A., & Merino, E. A. D. (2017).Investigation of musculoskeletal symptoms in a manufacturing company in Brazil :a cross-sectional study. *Brazilian Journal of Physical Therapy*, *21*(3), 175–183. https://doi.org/10.1016/j.bjpt.2017.03.014

Jonge, J. De, Peeters, M. C. W., & Taris, T. W. (2019). Feeling Vital or Fatigued ? Relations with Demands and Resources in a University Context. *InternationalJournal of Environmental Research and Public Health*, *16*(6), 1–24.https://doi.org/doi.org/10.3390/ijerph16162893

Karnaukh, N., & Shevtsova, V. (1991). Thoughts on the length of the work-shift and efficient work regimens in industry. *Metallurgist*, *34*(12), 30–31. Retrieved from https://link.springer.com/content/pdf/10.1007/BF00750115.pdf

Knoop, V., Costenoble, A., Azzopardi, R. V., Vermeiren, S., Debaina, A., Jansen, B., …Group, G. B. S. (2019). The

operationalization of fatigue in frailty scales: a systematic review. *Ageing Research Reviews*, *53*. https://doi.org/10.1016/j.arr.2019.100911

Lohaus, D., & Habermann, W. (2019). Presenteeism : A review and research directions. *Human Resource Management Review*, *29*(1), 43–58.https://doi.org/10.1016/j.hrmr.2018.02.010

McDonald, A. C., Mulla, D. M., & Keir, P. J. (2019). Muscular and kinematic adaptationsto fatiguing repetitive upper extremity work. *Applied Ergonomics*, *75*, 250–256. Retrieved from https://doi.org/10.1016/j.apergo.2018.11.001

Miranda, H., Kaila-kangas, L., Heliovaara, M., Leino-Arjas, P., Haukka, E., Liira, J., & Viikari-Juntura, E. (2010). Musculoskeletal pain at multiple sites and its effects on work ability in a general working population. *Occupational & Environmental Medicine*, *67*(7), 449–455. https://doi.org/10.1136/oem.2009.048249

Moussavi, S. E., Zare, M., Mahdjoub, M., & Grunder, O. (2019). Balancing high operator's workload through a new job rotation approach : Application to an automotive assembly line. *International Journal of Industrial Ergonomics*, *71*, 136–144. https://doi.org/10.1016/j.ergon.2019.03.003

Nagata, T., Mori, K., Ohtani, M., Nagata, M., Kajiki, S., Fujino, Y., … Loeppke, R. (2018). Total Health-Related Costs Due to Absenteeism, Presenteeism, and Medicaland Pharmaceutical Expenses in Japanese Employers. *Journal of Occupational and Environmental Medicine*, *60*(5), 273–280. https://doi.org/10.1097/JOM.0000000000001291

Nielsen, R. A., & Midtsundstad, T. I. (2020). Do workplace health-promotion interventions targeting employees with poor health reduce sick-leave probability anddisability rates ? *Scandinavian Journal of Public Health*, 1–9. https://doi.org/10.1177/1403494820946543

Nordstoga, A. L., Vasseljen, O., Meisingset, I., Nilsen, T. I. L., & Unsgaard-Tøndel, M. (2019). Improvement in Work Ability, Psychological Distress and Pain Sites in Relation to Low Back Pain Prognosis - A Longitudinal Observational Study in Primary Care. *Spine*, *44*(7), E423–E429. https://doi.org/10.1097/BRS.0000000000002860

Pensola, T., Haukka, E., Kaila-kangas, L., Neupane, S., & Leino-Arjas, P. (2016). Goodwork ability despite multisite musculoskeletal pain ? A study among occupationallyactive Finns. *Scandinavian Journal of Public Health*, *44*(3), 300–310. https://doi.org/10.1177/1403494815617087

Phongamwong, C., & Deema, H. (2015). The impact of multisite musculoskeletal pain on work ability among health care providers. *Journal of Occupational Medicine andToxicology*, *10*(21), 1–5. https://doi.org/10.1186/s12995-015-0063-8

Santos, M. R. dos, & Mendes, C. (2020). Manual therapy and its role in occupational health : Reducing absenteeism and presenteeism by treating chronic pain with spinalmanipulation and mobilization in the workplace. *European Journal of Integrative Medicine*, *35*. https://doi.org/10.1016/j.eujim.2020.101078

Silva, T. P. D. da, Araújo, W. N. de, Stival, M. M., Toledo, A. M. de, Burke, T. N., & Carregaro, R. L. (2018). Musculoskeletal discomfort, work ability and fatigue in nursing professionals working in a hospital environment. *Journal of School of Nursing - University of São Paulo*, *52*(e03332), 1–8. https://doi.org/doi.org/10.1590/S1980-220X2017022903332

Skovlund, S. V., Bláfoss, R., Sundstrup, E., & Andersen, L. L. (2020). Association between physical work demands and work ability in workers with musculoskeletal pain : cross-sectional study. *BMC Musculoskeletal Disorders*, *21*(166), 1–8. https://doi.org/doi.org/10.1186/s12891-020-03191-8

Söderbacka, T., Nyholm, L., & Fagerström, L. (2020). Workplace interventions that support older employees ' health and work ability - a scoping review. *BMC Health Services Research*, *20*(1), 1–9. https://doi.org/10.1186/s12913-020-05323-1

Svendsen, M. J., Schmidt, K. G., Holtermann, A., & Rasmussen, C. D. N. (2020). Expert panel survey among occupational health and safety professionals in Denmark for prevention and handling of musculoskeletal disorders at workplaces. *Safety Science*,*131*. https://doi.org/10.1016/j.ssci.2020.104932

Troelstra, A. S., Straker, L., Harris, M., Brown, S., Beek, A. J. vand der, & Coenen, P. (2020). Multimorbidity is common among young workers and related to increased work absenteeism and presenteeism: results from the population–based Raine Studycohort. *Scandinavian Journal of Work, Environment and Health*, *46*(2), 218–227. https://doi.org/10.5271/sjweh.3858

van der Burg, L., Sepriano, A., Landewé, R., Geuskens, G., Ottenheijm, R., Dinant, G.- J., & Boonen, A. (2020). Comparative construct validity of three presenteeism instruments in workers with musculoskeletal

complaints : a prospective cohort study. *RMD Open - Rheumatic & Musculoskeletal Diseases*, *6*(2), 1–8. https://doi.org/10.1136/rmdopen-2020-001281

Vieira, L. M. S. M. de A., & Sato, T. de O. (2020). Prevalence of multisite pain and association with work ability – Cross-sectional study. *Musculoskeletal Science andPractice*, *50*. https://doi.org/10.1016/j.msksp.2020.102279

The occurrence of accidents and injury in mining shift worker influenced by food intake, a short review

Gentil A. Andaque [1], Olivia Pinho [2], J. Santos Baptista [3], J. Castelo Branco [4], Elizabete Nunes [5]

[1]Faculty of Engineering, University of Porto, PT (gentilandaque@gmail.com) ORCID 0000-0001-9882-8735, [2]Associated Laboratory for Green Chemistry (LAQV/REQUIMTE), Faculty of Nutrition and Food Science, University of Porto, PT, (oliviapinho@fcna.up.pt) ORCID 0000-0001-9477-8638, [3]Associated Laboratory for Energy, Transports and Aeronautics - LAETA (PROA), Faculty of Engineering, University of Porto, PT (jsbap@fe.up.pt) ORCID 0000-0002-8524-5503, [4]Associated Laboratory for Energy, Transports and Aeronautics - LAETA (PROA), Faculty of Engineering, University of Porto, PT (jcb@fe.up.pt) ORCID 0000-0002-9254-4384, [5]Faculty of Medicine, University Eduardo Mondlane, Moçambique (dra.elizabete.nunes@gmail.com) ORCID 0000-0002-1736-1473.
https://doi.org/10.24840/978-972-752-279-8_0065-0072

Abstract

Introduction: Identifying factors that contribute to occupational accidents has been a general concern of companies in the present millennium. One of the factors identified is the quality and quantity of food, as well as meals times. In this context, the present systematic review aimed to identify how food intake influences the occurrence of accidents in shift work, with some focus, although not exclusive, on the mining industry. Methodology: The research-based literature was carried out in four electronic databases: Medline/PubMed, Science Direct, Scopus and Web of Science. Have been combined the following words "occupational accident" and "food intake"; "mining injury" and "food choice"; "meal timing" and "workplace"; "eating at night" and "mining injury"; "Circadian rhythm" and "diet shift"; "Food safety" and " Health risk"; "workplace accidents" and "food choice". Results: It was possible to identify 24 articles related to food intake. To better understand the analysis, the results were organized into five groups: Author surname and year, Study type, Accidents/injury causes, risk factor, Conditions for accidents/injuries to occur. Through the groups of causes, it was possible to regrouped on three, which facilitated the discussion of the topic; food choice n=10 (42%) articles, eating habits n=9 (37.5%), and emotional commitment n=5 (20.5%), showed the relativity of food intake causes for the occurrence of accidents and illnesses in shift workers. Discussion: The reviewed articles demonstrated that the materialisation of accidents was due to the relationship between food intake and consumption of nutrient-poor foods in shift work. That can develop chronic diseases, metabolic disorders such as blood pressure abnormalities, blood sugar fluctuation (dyslipidemia, dysglycemia), and obesity, neurobehavioural performance. Foods contain high content As, Cd, Cr, Hg, Fe, and Mn above the recommended standards by the FAO/WHO. Sleep disturbance during the 12-hour shift interferes with circadian rhythm and, consequently, with performance. These factors can be related to food and the precarious physical environment, increased workload, fatigue and poor diet, especially at night. Conclusion: In conclusion, the study demonstrated how food intake impacted workers' health on shifts but did not determine the causes or risk factors contributing to accidents/injuries. Further studies are needed to demonstrate a direct relationship which the risk factor of food intake and causes accidents/injuries.

Keywords: Food intake, Accidents, Shift work, Poor food.

INTRODUCTION

The reason that influences occupational accidents and diseases related to workplace food intake in workplaces is a fact to be explored. The causes that influence occupational accidents related to food intake have been demonstrated (Stothard et al., 2020; Strzemecka et al., 2014; Geaney et al., 2016; Bonnell et al., 2017; Nea et al., 2018;). They are linked with factors such as shift work (Boivin & Boudreau, 2014; Gupta et al., 2019; Heath et al., 2016; Reid, 2001;). The interaction of workplace food intake with other causes has adverse effects on the performance of activities, which in many cases can influence the occurrence of accidents and injures (Gifkins et al., 2018; Leung et al., 2010). The food intake in shift work has been considered responsible for the increase in body mass index (BMI) due to the imbalance of glycemia in the body (Di Lorenzo et al., 2003; Stothard et al., 2020), which has caused obesity problems, resulting from increased intake of snacks on a night shift and saturated fat diet (Heath et al., 2016)(Geaney et al., 2013). In addition, the first hours of the daily meal have adverse effects on ensuing processes of regulating worker chron-nutrition (Della Torre et al., 2020). Irregular food consumption interferes with the adjustment of insulin secretion (responsible for regulating the sugar in the organism needed for energy in the cells), which interferes with workers' performance

(Strzemecka et al., 2014; Gupta et al., 2019;). The insulin secretion in the body depends on dietary habits when taking a meal irregularly, which will influence the fluctuation of insulin production, which can compromise the metabolic process in the balance of nutrients in the body (Azmi et al., 2020; Heath et al., 2016).

Several research reports that the intake of food in shift workers influences the metabolic processes and has implications in work performance (Arble et al., 2009; Lowden et al., 2010). In shift work, workers are subject to tiredness and stress associated with work activities, consequently more food intake than normal. This is worsened with an increase in the consumption of poor quality food. In general, poor foods do not have micronutrients and the regulated vitamins in the desirable properties for consumption; have high-level sugar, fat and sodium. In most cases, these low-quality food options are considered calorie-rich foods, which are nutritionally inadequate and contain more calories than nutrients like vitamins and minerals. (Fletcher, 2010; Azmi et al., 2020).

In addition, more studies on the causes of accidents at work with food intake in the industries are necessary. It becomes a greater challenge when talking about mining (Nawab et al., 2016) since many studies refer to the effect of food intake in the vicinity of mines (Zhuang et al., 2009; Bempah & Ewusi, 2016; Huang et al., 2017; Rahmdel et al., 2018; Fitzgerald et al., 2018;).

The work in several industries, like mining, is many times subject to shift work. This short literature review (SLR) shows evidence of food influencing accidents in shift work. This possibility motivates the deepening of research on accidents at work-related food intake. Moreover, the SLR intends to answer the following question; how food intake influences accidents?

So, the purpose of this short review is to systematize articles that indicate how food intake can influence accidents or injury in shift work, with some focus, although not exclusive, on the mining industry.

METHODOLOGY

Literature search strategy

In proposing this review, priority was given to peer-reviewed journals in the area under study and published in scientific journals. The research-based literature was conducted in four electronic databases: MEDLINE / PubMed, Science Direct, Scopus, and Web of Science.

The screening of the articles was through the combination of several key terms, such: “occupational accident” and “food intake”; “mining injury” and “food choice”; “meal timing” and “workplace”; “eating at night” and “mining injury”; “Circadian rhythm” and “diet shift”; “Food safety” and “ Health risk”; “workplace accidents” and “food choice”. This short review is based on PRISMA Statement guidelines (Kirtley et al., 2021) shown below (figure1).

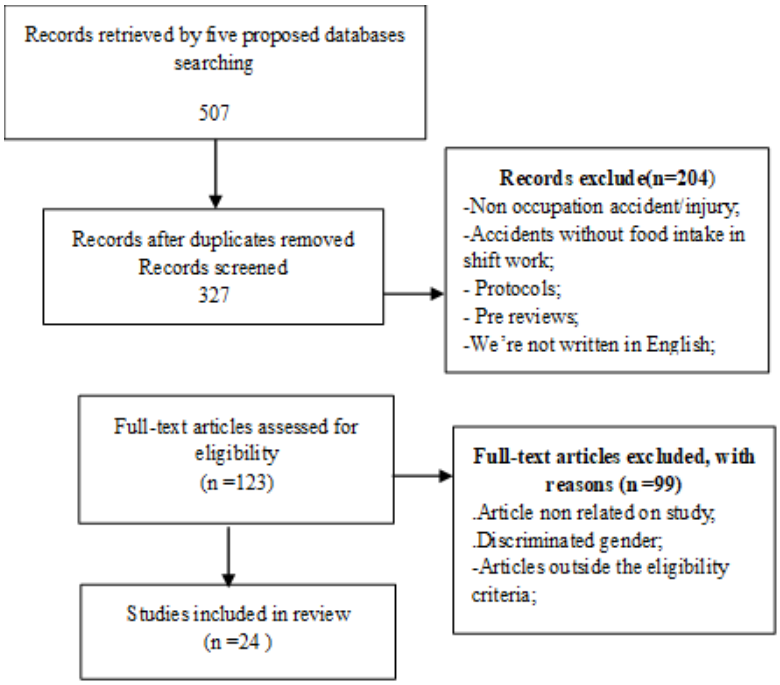

Figure 1. Flow chart illustrating the steps of literature selection.

Eligibility criteria

To inclusion and exclusion criteria based on review goals, i.e. systematize how food intake influences the accident or injury in mining shift work. Were included i) published journals articles, papers which refer impact of food intake in mining shift worker or related to it, ii) intervention and observation study with measures, iii) full text written in English. Were excluded from the review if; i) did not mention food intake at workplace on shift work, ii) not published, iii) does not meet eligibility criteria, iv) not full teste available, v) between 2000 and 2020.

RESULTS

Data items/characteristics

In order to provide an insight into how food intake influence on accidents or injuries in shift work, variables were designed with specific characteristics such as Surname of principal author & year, accident's or injury causes, risk factor, Conditions for accidents and injuries to occur in shift work that allowed the discussion.

Food intake and accident/injury on shift work

Findings of food intake reports in work shifts were obtained through a table organized by the author & year, study types, causes, risk factors, and Conditions for accidents/injuries in shift work. The table 1 presents 24 articles, presents 24 articles, which analyze the causes of propensity to the occurrence of accidents/injury in the mines. They were organized according to the factors that interfere on this effect, such food choice (n=10) 42%; eating habits (n=9) 37.5% and Emotional impairment (n=5) 20.8%. In general, studies report the effects of shift work as making regular meals consumption difficult (Strzemecka et al., 2014)

The systematization of the present articles through the screening of the possible causes of accidents allowed to identify the following risk factor: accidents influenced by behavioural impairment due to long working hours, after ingesting poor food, i.e. rich in sugar, fats devoid of essential micronutrients, developing chronic diseases like the development of metabolic

disorders such as blood pressure abnormalities, blood sugar fluctuation (dyslipidemia, dysglycemia), and obesity, neurobehavioral performance, during shift work and particularly night work, creating changes in the circadian and behavioural cycle. Fatigue in the night-time, beginning of the first food intake from the day, all linked with greater emphasis on eating behaviour in shift work, were identified as the main conditions for accidents and injuries at work (Gupta et al., 2019 Azmi et al., 2020). Furthermore, in shift work in mines, there is high food consumption with a high content of heavy metals, e.g., water and vegetable intake above the standards established by various organizations such as FAO/WHO (Rahmdel et al., 2018).

Table 1. Study items/characteristics

autor & year	Study type	Accidents/ injury causes	Risk factor	Conditions for accidents / injuries to occur
Huang et al. 2017	Prospective cohort study	Food choice	Intake vegetables with high heavy metals	The Pb level exceeded the permissible limit of 0.3 mg/kg in 44.7% of vegetable samples according to FAO/WHO standards
Zhuang et al., 2009	Prospective cohort study	Food choice	Drinking water & vegetable higher than permissible limit standards	Toxicity through to Drinking other and consumption;
Rahmdel et al., 2018	Prospective cohort study	Food choice	Consumption of heavy metals in food	The target hazard quotient (THQ) for Cd & Pb of rice and vegetables the average is 11% daily intake exceeded the (PCL) of FAO/WHO,
Nawab et al., 2016	Prospective cohort study	Emotional impairment	Accidents caused by irregular working hours and night work	Combination of a higher workload, fatigue and too little food night shift 18%; the fatigue and lack of concentration, caused **62 critical accidents** are noted
Fletcher, 2010	Descriptive study	Emotional impairment	Fatigue in the nighttime sleep-night work	Impairment Truck Drive 30- 40% of accidents occur in night shift work; Human error 30-50% after a meal
Lowden et al., 2010	descriptive study	Eating habits	Dietary habits;	The type of food to be consumed during shift duties was 86% overweight, 66% obese;
Di Lorenzo et al., 2003	Prospective cohort study	Eating habits	Obesity has a greater impact on work	Prevalence of obesity in shift work was 37/185 = 20% than day worker 9/134 = 9,7%
Geaney et al., 2013	Prospective cohort study	Emotional impairment	Emotional Stress	Poor physical environment was 62.5%
Leung et al., 2010	descriptive study	Eating habits	work overload, poor physical environment	Injury incident
Gifkins et al., 2018	Retrospective case-control	Eating habits	Eating during the night shift	Shift work increases the fat meal and snack was 38% and 56%
Boivin & Boudreau, 2014	Retrospective case-control	Food choice	Shift work and sleep	With fewer meals and more snacks a day; causes tired drivers;
Heath et al., 2016	prospective cohort study	Food choice	dietary profile in shift workers and findings	Reduced sleep duration may result in changes to fat, and potentially carbohydrates, in the diet was compared daily energy intake was (15-25)% & night (20-35)%.
Gupta et al., 2019	descriptive study	Emotional impairment	Eating behaviour of shift workers	About 50% do not eat because of shift work
Reid, 2001	Prospective cohort study	Emotional impairment	Reductions in neurobehavioral performance in night work	Sleep disruption during a 12-hour shift; circadian rotation rhythm of performance-related a (food), comparing two group's older & young it is 53% & 24,5%
Bonnell et al., 2017	Prospective case-control	Food choice	Food choice and dietary intake	Night shift cooked meal was 78%, ice creams, and chocolates, sweet pastries were 33% than day shift 48% and 23% respectively

Nea et al., 2018	Prospective cohort study	Eating habits	Negatively impacting on eating and lifestyle behaviours	Almost half (48%) were overweight or obese & while 30% were physically active once or less weekly
Stothard et al., 2020	Prospective cohort study	Eating habits	Impact of food intake in the early morning on metabolism	Glucose level ~ 5% higher was observed 80 min in shift workers compared to non-shift workers; observed obesity and diabetes that may be related to food intake in the adverse circadian cycle
Strzemecka et al., 2014	Prospective cohort study	Eating habits	Food in Shift worker	About (66.0%) of workers admitted that shift work hampers regular consumption of meals.
Geaney et al., 2016	Prospective cohort study	Food choice	Dietary intakes	**Employer improves nutrition program** reduction of 32% compared to those who did not participate, which was 78%.
Fitzgerald et al., 2018	Prospective case-control	Food choice	Food choice at work	The incidence was observed at 20 % of obese
Della Torre et al., 2020	Prospective cohort	Eating habits	Shift work is associated with an increased risk of chronic diseases due to circadian rhythm disruptions and behavioural changes	About 49% were overweight, and 13% were obese. Using the percentage of body fat mass (BMI).
Bempah & Ewusi, 2016	Prospective cohort	Food choice	Foods containing high content As, Cd, Cr, Hg, Fe, and Mn above the allowed standards	Analytical procedures were verified by suitable certified reference materials (CRMs) and an average of 10% of the certified value.
Azmi et al., 2020	Descriptive study	Eating habits	Development of metabolic disorders such as hypertension, dyslipidemia, dysglycemia, and abdominal obesity	Metabolic syndrome, Cardiovascular disease, Gastrointestinal disorders, Breast cancer, Psychological disorder
Arble et al., 2009	Prospective Cohort stud	Food choice	The circadian phase of food consumption in weight gain	There was calorie consumption in (80%) during the dark phase (night) in relation to the light phase (day).

The research demonstrates the evidence of food intake in relation to the accidents/injury in the shift work. There are factors such as higher workload, fatigue, bioaccumulation of heavy metals in food content As, Cd, Cr, Hg, Fe, and Mn; percentage of body fat mass was higher than average compared with non-shift workers, in an expressive number among workers; was observed potentially carbohydrate in night shift than the day. Therefore, shift work is considered to have a higher impact on the diet. Shift work is a service preferred in many industries because it accelerates the workforce's production and flexibility to optimize productivity and business in competitive companies.

DISCUSSION

Accidents and injuries have been addressed in various themes. The convergence is that there must be causes, risk factors, and conditions necessary for the occurrence in all cases. In this review, these variables were demonstrated concerning food intake in shift work. There are about 42% of studies, the causes of the accidents are related to the food choice at night shifts that have higher calorie consumption than during the day Arble et al.,(2009). Night shifts have a higher consumption of cooked meal, ice cream, chocolates, sweets pastries than the day Bonnell et al., (2017), higher incidence of obesity in workers assigned to shift work than regular work (Fitzgerald et al., 2018). If the mining activity considered dangerous, then it needs a lot of attention in the execution. It was demonstrated that eating foods with a low micronutrient content affects workers' performance. The choice of food for workers must be the companies' responsibility and preparation to safeguard the nutritional demand needed for the job. That increase sleep, fatigue, stress, blood pressure abnormalities and sugar fluctuation. So the food choice in this activity has to be enhanced. Foods in shift work affect about 15 to 30% of adults in the European population (Boivin & Boudreau, 2014). Most mining works are carried out in

areas other than the habitual residence of workers. Many of them take their food. This possibility makes them buy local food, can put in cause their health since, in the mining areas food, the water consumed has verified the bioaccumulation of heavy metals as As, Cd, Cr, Hg, Fe, and Mn, which is not acceptable for human consumption according to FAO/ WHO (Zhuang et al., 2009; Bempah & Ewusi, 2016; Huang et al. 2017 Rahmdel et al., 2018). Food choice can be a significant factor for the performance of daily activities influencing accidents/injuries in workplaces.

Other causes of accident in the systematic review were linked with eating habits at 37.5% in all articles. Eating habits are associated with the consumption behaviour of certain foods in shift work. Evidence shows that there are workers who consume more food and, on the other hand, those who have difficulties in feeding, this associated body mass index (BIM) regardless of age and duration of work (Di Lorenzo et al., 2003; Gupta et al.,2019). Consequently, cardiovascular disease, Gastrointestinal disorders, Breast cancer, Psychological disorder, i.e. development of chronic diseases affect a relatively young population, conditions put debilitated worker minded to accidents and injuries (Azmi et al., 2020; Nea et al., 2018; Della Torre et al., 2020). Eating habits also influenced by circadian rhythms, the process by which every man needs to adjust every 24 hours, which has been greatly affected by shift work in the process of food intake. What impacts work performance due to the quality of rest and meals during this work period (Leung et al., 2010; Gifkins et al., (2018).

Likewise, emotional impairment was the accident causes related a food intake, there correspond 20.8% of studies, to the extent that it contributed to the commitment of shift work specifically night work caused sleep disruption during a 12-hour shift; circadian rotation rhythm of performance-related a (food) (Reid, 2001). What influenced the emotional behaviour of the shift work in food intake is also noted the difficulties in their regular consumption (Gupta et al., 2019). These conditions associated with stress due to the difficulty in food intake created a working environment impacted 62.5% of work performance (Geaney et al., 2013). Consequently, necessary conditions were formed to the occurrence of occupational accidents. Irregular and nocturnal schedules and increased workload, tiredness and little nighttime feeding were responsible for 62 critical accidents in mines resulting from fatigue and lack of concentration (Nawab et al., 2016).

CONCLUSIONS

In a nutshell, the present systematic literature review (SLR) aimed to systematize articles indicating how food intake can influence accidents or injury in shift work. Were extracted 24 articles eligible for the present study from four databases. The SLR reveals that food intake in shift work has numerous impacts on the health and well-being of workers, mainly in the ingestion of foods with low macronutrients associated with inadequate daily rest. Responsible for development of chronic diseases in workplace, their effect can impact the ability to perform daily tasks. Features like; food choice, food habits and emotional commitment were crucial in establishing the relationship. Specific study in mines related to food intake with accidents and injuries in shift work in the industry are scarce. The few that exist are inconclusive. Further studies are needed to demonstrate a direct relationship which the risk factor of food intake and causes accidents/injuries.

References

Azmi, N. A. S. M., Juliana, N., Teng, N. I. M. F., Azmani, S., Das, S., & Effendy, N. (2020). Consequences of circadian disruption in shift workers on Chrono nutrition and their psychosocial well-being. *International Journal of Environmental Research and Public Health*, *17*(6). https://doi.org/10.3390/ijerph17062043

Bempah, C. K., & Ewusi, A. (2016). Heavy metals contamination and human health risk assessment around Obuasi gold mine in Ghana. *Environmental Monitoring and Assessment*, *188*(5). https://doi.org/10.1007/s10661-016-5241-3

Boivin, D. B., & Boudreau, P. (2014). Impacts of shift work on sleep and circadian rhythms. In *Pathologie Biologie* (Vol. 62, Issue 5, pp. 292–301). Elsevier Masson SAS. https://doi.org/10.1016/j.patbio.2014.08.001

Bonnell, E. K., Huggins, C. E., Huggins, C. T., McCaffrey, T. A., Palermo, C., & Bonham, M. P. (2017). Influences on dietary choices during day versus night shift in shift workers: A mixed methods study. *Nutrients*, *9*(3). https://doi.org/10.3390/nu9030193

Della Torre, S. B., Wild, P., Dorribo, V., Danuser, B., & Amati, F. (2020). Energy, nutrient and food intakes of male shift workers vary according to the schedule type but not the number of nights worked. *Nutrients*, *12*(4). https://doi.org/10.3390/nu12040919

Di Lorenzo, L., De Pergola, G., Zocchetti, C., L'Abbate, N., Basso, A., Pannacciulli, N., Cignarelli, M., Giorgino, R., & Soleo, L. (2003). Effect of shift work on body mass index: Results of a study performed in 319 glucose-tolerant men working in a Southern Italian industry. *International Journal of Obesity*, *27*(11), 1353–1358. https://doi.org/10.1038/sj.ijo.0802419

Fitzgerald, S., Murphy, A., Kirby, A., Geaney, F., & Perry, I. J. (2018). Cost-effectiveness of a complex workplace dietary intervention: An economic evaluation of the Food Choice at Work study. *BMJ Open*, *8*(3). https://doi.org/10.1136/bmjopen-2017-019182

Fletcher, A. (2010). Staying safe in the jungles of borneo: Five studies of fatigue and cultural issues in remote mining projects. *Industrial Health*, *48*(4), 406–415. https://doi.org/10.2486/indhealth.MSSW-04

Geaney, F., Kelly, C., Di Marrazzo, J. S., Harrington, J. M., Fitzgerald, A. P., Greiner, B. A., & Perry, I. J. (2016). The effect of complex workplace dietary interventions on employees' dietary intakes, nutrition knowledge and health status: A cluster controlled trial. *Preventive Medicine*, *89*, 76–83. https://doi.org/10.1016/j.ypmed.2016.05.005

Geaney, F., Scotto Di Marrazzo, J., Kelly, C., Fitzgerald, A. P., Harrington, J. M., Kirby, A., McKenzie, K., Greiner, B., & Perry, I. J. (2013). The food choice at work study: Effectiveness of complex workplace dietary interventions on dietary behaviours and diet-related disease risk - study protocol for a clustered controlled trial. *Trials*, *14*(1). https://doi.org/10.1186/1745-6215-14-370

Gifkins, J., Johnston, A., & Loudoun, R. (2018). The impact of shift work on eating patterns and self-care strategies utilised by experienced and inexperienced nurses. *Chronobiology International*, *35*(6), 811–820. https://doi.org/10.1080/07420528.2018.1466790

Gupta, C. C., Coates, A. M., Dorrian, J., & Banks, S. (2019). The factors influencing the eating behaviour of shiftworkers: What, when, where and why. In *Industrial Health* (Vol. 57, Issue 4, pp. 419–453). National Institute of Industrial Health. https://doi.org/10.2486/indhealth.2018-0147

Heath, G., Coates, A., Sargent, C., & Dorrian, J. (2016). Sleep duration and chronic fatigue are differently associated with the dietary profile of shift workers. *Nutrients*, *8*(12). https://doi.org/10.3390/nu8120771

Huang, Y., He, C., Shen, C., Guo, J., Mubeen, S., Yuan, J., & Yang, Z. (2017). Toxicity of cadmium and its health risks from leafy vegetable consumption. *Food and Function*, *8*(4), 1373–1401. https://doi.org/10.1039/c6fo01580h

Leung, M. Y., Chan, Y. S., & Yuen, K. W. (2010). Impacts of stressors and stress on the injury incidents of construction workers in Hong Kong. *Journal of Construction Engineering and Management*, *136*(10), 1093–1103. https://doi.org/10.1061/(ASCE)CO.1943-7862.0000216

Lowden, A., Moreno, C., Holmbäck, U., Lennernäs, M., & Tucker, P. (2010). Eating and shift work - Effects on habits, metabolism, and performance. In *Scandinavian Journal of Work, Environment and Health* (Vol. 36, Issue 2, pp. 150–162). Nordic Association of Occupational Safety and Health. https://doi.org/10.5271/sjweh.2898

Nawab, J., Li, G., Khan, S., Sher, H., Aamir, M., Shamshad, I., Khan, A., & Khan, M. A. (2016). Health risk assessment from contaminated foodstuffs: a field study in chromite mining-affected areas northern Pakistan. *Environmental Science and Pollution Research*, *23*(12), 12227–12236. https://doi.org/10.1007/s11356-016-6379-9

Nea, F. M., Pourshahidi, L. K., Kearney, J. M., Livingstone, M. B. E., Bassul, C., & Corish, C. A. (2018). A qualitative exploration of the shift work experience: the perceived effect on eating habits, lifestyle behaviours and psychosocial well-being. *Journal of Public Health (Oxford, England)*, *40*(4), e482–e492. https://doi.org/10.1093/pubmed/fdy047

Persson, M., & Mårtensson, J. (2006). Situations influencing habits in diet and exercise among nurses working night shift. *Journal of Nursing Management*, *14*(5), 414–423. https://doi.org/10.1111/j.1365-2934.2006.00601.x

Rahmdel, S., Rezaei, M., Ekhlasi, J., Hossein Zarei, S., Akhlaghi, M., Maryam Abdollahzadeh, S., Sefidkar, R., & Mohammad Mazloomi, S. (2018). *Heavy metals (Pb, Cd, Cu, Zn, Ni, Co) in leafy vegetables collected from production sites: their potential health risk to the general population in Shiraz, Iran*. https://doi.org/10.1007/s10661-018-7042-3

Reid, K. (2001). Comparing performance on a simulated 12 hour shift rotation in young and older subjects. *Occupational and Environmental Medicine*, *58*(1), 58–62. https://doi.org/10.1136/oem.58.1.58

Seychell, J., & Reeves, S. (2017). The effect of shift work on the diet of accident and emergency nurses at a general hospital in Malta. *Nutrition and Food Science*, *47*(2), 165–174. https://doi.org/10.1108/NFS-05-2016-0059

Stothard, E. R., Ritchie, H. K., Birks, B. R., Eckel, R. H., Higgins, J., Melanson, E. L., Wright, K. P., & McHill, A. W. (2020). Early morning food intake as a risk factor for metabolic dysregulation. *Nutrients*, *12*(3). https://doi.org/10.3390/nu12030756

Strzemecka, J., Bojar, I., Strzemecka, E., & Owoc, A. (2014). Dietary habits among persons hired on shift work. *Annals of Agricultural and Environmental Medicine*, *21*(1), 128–131.

Zhuang, P., McBride, M. B., Xia, H., Li, N., & Li, Z. (2009). Health risk from heavy metals via consumption of food crops in the vicinity of Dabaoshan mine, South China. *Science of the Total Environment*, *407*(5), 1551–1561. https://doi.org/10.1016/j.scitotenv.2008.10.061

Dor lombar na operação em equipamentos pesados de carga e transporte, nas indústrias de mineração a céu-aberto e de construção – Breve revisão

Jane Paula de Souza [1], Tatiana Teixeira [2], Joana C. Guedes [3], J. Santos Baptista [4], J. Castelo Branco [5]

[1]Associated Laboratory for Energy, Transports and Aeronautics - LAETA (PROA), Faculty of Engineering, University of Porto, PT (janepaulasouza@gmail.com) ORCID 0000-0001-5455-7232, [2]Associated Laboratory for Energy, Transports and Aeronautics - LAETA (PROA), Faculty of Engineering, University of Porto, PT (tati.teixeira.30@gmail.com) ORCID 0000-0001-5636-1030, [3]Associated Laboratory for Energy, Transports and Aeronautics - LAETA (PROA), Faculty of Engineering, University of Porto, PT (jccg@fe.up.pt) ORCID 0000-0003-2367-2187, [4]Associated Laboratory for Energy, Transports and Aeronautics - LAETA (PROA), Faculty of Engineering, University of Porto, PT (jsbap@fe.up.pt) ORCID 0000-0002-8524-5503, [5]Associated Laboratory for Energy, Transports and Aeronautics - LAETA (PROA), Faculty of Engineering, University of Porto, PT (jcb@fe.up.pt) ORCID 0000-0002-9254-4384.
https://doi.org/10.24840/978-972-752-279-8_0073-0080

Resumo

Introdução: Os operadores de equipamentos pesados de carga e transporte, nas indústrias de mineração e construção estão sujeitos a dores lombares, decorrentes da atividade profissional. Os operadores estão expostos a diferentes tipos de riscos ocupacionais, sendo considerado o de maior intensidade as vibrações de corpo inteiro, as quais podem causar diversos tipos de lesões musculoesqueléticas, em particular a dor lombar. Este artigo objetiva apresentar uma revisão sobre a prevalência de dor lombar nos operadores. Pretende-se analisar os equipamentos de maior utilidade na indústria extrativa a céu aberto e de construção que produzem maior índice de vibração, a relação das atividades que intensificam a vibração, o ambiente e os fatores que contribuem de forma direta, assim como as ações preventivas que as empresas estão implementando para manter a integridade física dos operadores de máquinas e equipamentos móveis desses setores. Metodologia: A presente revisão foi realizada de acordo com os pressupostos definidos pelo Preferred Reporting Items for Systematic Reviews and MetaAnalyses: The PRISMA Statement. Foram consultadas as seguintes bases de dados: "Scopus", "Web of Science", "Engineering Village", "ScienceDirect", "Scielo", "CurrentContents", "Dimensions", "SpringerLink" e "Taylon&Francis", onde foram aplicados os diferentes critérios de exclusão, tais como: intervalo de pesquisa, tipo de documento, tipo de fonte e idioma. Foram utilizadas 35 palavras-chave por meio de combinações. Resultados e Discussões: Na totalidade da pesquisa realizada foram obtidos 591 artigos, tendo sido excluídos 580. Através da técnica da "Snowballing" foram acrescentados mais 7 artigos à revisão sistemática, dado apresentarem informação relevante para o objetivo principal desse estudo, assim totalizando 18 artigos nesta revisão. Os principais resultados demonstraram que os equipamentos pesados de carga e transporte como os caminhões de transporte, basculantes, bulldozers, escavadeiras, pás niveladoras, motoniveladoras, carregadeiras, retroescavadeiras, perfuradoras, raspadores e tratores comumente utilizados nas indústrias da construção e mineração. Estes podem produzir níveis de vibração de corpo inteiro acima do valor limite de exposição, derivados de fatores como terrenos instáveis nas vias de circulação em minerações e construção, relatados em 27,78% dos estudos e 72,22% desses evidenciam a prevalência de dor lombar nos operadores. Conclusão: A implementação de programas de treinamentos, ergonômicos, medidas de segurança, rotação de equipamentos, gestão do risco, manutenções e melhorias no projeto dos equipamentos podem atenuar a intensidade de vibração aos operadores, assim ajudando a conservar a integridade física destes profissionais.

Palavras-chave: Dor lombar, Equipamentos pesados de transporte, Mineração, Construção.

INTRODUÇÃO

A indústria da construção e da mineração é caracterizada pelo elevado risco de acidente ocupacional e de doenças profissionais, em âmbito global, por estar intimamente relacionada ao próprio processo produtivo (OSHA, 1989; Mcphee et al., 2017; Abbaspour et al., 2018). Por este fator, os operadores de máquinas pesadas estão mais expostos a fatores de risco para o potencial desenvolvimento de lesões e distúrbios musculoesqueléticos (Langer et al., 2015). Em contraste, Kuijer et al (2014) estimam que 15% do número total de dias de licença médica por ano é devido a dor lombar, a qual é caracterizada por qualquer dor ou distúrbio musculoesquelético não traumático que afete a região lombar.

Estudos anteriores relatam a associação entre fatores ocupacionais e a dor lombar entre os operadores do setor da mineração e da construção, afirmando que o principal fator contribuinte para o desencadeamento dessas é a vibração de corpo inteiro (VCI) (Mandal e Srivastava, 2010; Xu et al., 2012). A exposição constante à vibração de corpo inteiro é caracterizada como fator de risco primordial para modificações degenerativas na coluna vertebral (Yassierli, 2017; Kim et

al., 2018). No que diz respeito à condução de equipamentos pesados de carga e transporte, verifica-se a existência da prevalência de diferentes tipos de lesões musculoesqueléticas, principalmente, a dor lombar (Groves et al., 2007; Weston et al., 2016).

Burgess-Limerick e Lynas (2016) constataram que os equipamentos pesados de carga e transporte, tais como: buldozers, carregadeiras, escavadeiras, basculantes, pás niveladoras e caminhões de transporte, são classificados como grandes geradores de fontes vibratórias. Estas vibrações são originadas pelo próprio motor e pelas vias de circulação, devido às irregularidades de terreno, sendo as vibrações repassadas ao condutor pelo equipamento (Langer et al., 2015; Madhavie e Silva, 2019). A exposição à vibração de corpo inteiro e outros tipos de vibrações em níveis superiores aos definidos pelas normas internacionais de padronização e realizados em longas jornadas de trabalho, com carga de 8 a 12 horas por dia, podem causar efeitos negativos ao funcionamento do corpo, como por exemplo no sistema musculoesquelético, digestivo, cardiovascular, endócrino, e também no metabolismo, além de propiciar aumento e desencadeamento de dor lombar nos operadores de equipamentos pesados (Wilder; Pope, 1996; Bernard, 1997; Robb; Mansfield, 2007). O nível de vibração que esteja entre as frequências de 0,5 e 80 Hz são considerados os mais preocupantes em relação à saúde do operador. (Paschold; Mayton, 2011).

A revisão tem como objetivo principal identificar a prevalência da dor lombar nos condutores de equipamentos pesados de carga e transporte nas indústrias da construção e de mineração a céu aberto, de modo a analisar os equipamentos, atividades e fatores envolvidos no processo.

METODOLOGIA

A metodologia de pesquisa foi realizada de acordo com os pressupostos do *Preferred Reporting Items for Systematic Reviews and Meta-analysis: The PRISMA Statement* (Page et al., 2021). Para isto, foram consultadas as seguintes bases de dados: "*Scopus*", "*Web of Science*", "*Engineering Village*", "*ScienceDirect*", "*Scielo*", "*CurrentContents*", "*Dimensions*", "*SpringerLink*" e "*Taylor&Francis*".

Foram consideradas as palavras-chave relacionadas com a prevalência de dor lombar em operadores de equipamentos pesados de carga e transporte nas indústrias da construção e mineração, nomeadamente*: mine, mining, open-pit-mine, open-cast-mine, quarry, extractive industry, construction, earthmoving, earthwork, low back pain, ergonomic hazard, musculoskeletal injuries, musculoskeletal disorder, musculoskeletal disease, equipment, machinery, machine, vibrations, dumper, loader, dragline excavator, excavator shovel, bucket wheel excavator, wheel tractor scraper, bulldozer, mining truck, mining drill, earth mover, hydraulic excavator, wheel loader, backhoe loader, earth mover, haul truck e conveyor*.

Ao realizar a busca bibliográfica, uma triagem foi realizada, nomeadamente por: data de publicação dos artigos, tipo de documento, tipo de fonte, idioma de publicação e aplicação dos critérios de elegibilidade, incluindo artigos relacionados a mineração a céu aberto, construção, riscos ergonômicos e dor lombar. Nesta busca, não foram considerados elegíveis para o estudo artigos de opinião e estudos que não abordassem a prevalência de dor lombar em condutores de equipamentos móveis nas indústrias de construção e mineração.

RESULTADOS E DISCUSSÕES

Na totalidade da busca bibliográfica, foram recolhidos 591 artigos. Uma triagem inicial foi realizada por: data de publicação, onde foram considerados os artigos compreendidos entre os anos de 2016 e 2020, tendo sido excluídos 379 artigos; tipo de documento, onde foram considerados só artigos científicos, excluídos 55 artigos; tipo de fonte, onde foram considerados somente artigos publicados em revistas científicas, tendo sido excluídos 3 artigos; por fim, apenas considerados os artigos escritos na língua inglesa, excluindo 2 artigos neste critério. Após

a realização da leitura do título e resumo dos artigos, foram excluídos 126 artigos que não eram compatíveis com o escopo proposto por este estudo. Como critérios de elegibilidade, foram consideradas todas as situações que abordassem a temática da dor lombar associadas aos condutores de equipamentos móveis de carga e transporte, na indústria construtiva e extrativa a céu aberto.

Não foram considerados elegíveis artigos de opinião, revisões sistemáticas e estudos onde não abordassem a prevalência de dor lombar em condutores de equipamentos pesados. Por fim, foram incluídos 7 artigos através da técnica de "Snowballing", tendo sido incluídos para análise qualitativa detalhada, resultando em 18 artigos (Wohlin, 2014).

Essa revisão evidenciou diferentes tipos de equipamentos pesados de carga e transporte no setor da mineração e construção presentes no desenvolvimento de dor lombar. Os mais citados pelos autores, foram os equipamentos pesados e caminhões de transporte, apresentados em 55,56% dos estudos analisados (Smets et al., 2007; Pollard et al., 2016; Yassierli, 2017; Marin et al., 2017; Mayton et al., 2018; Othman et al., 2019; Vitharana et al., 2019a; Iope et al., 2019; Vitharana et al., 2019b; Kia et al., 2020).

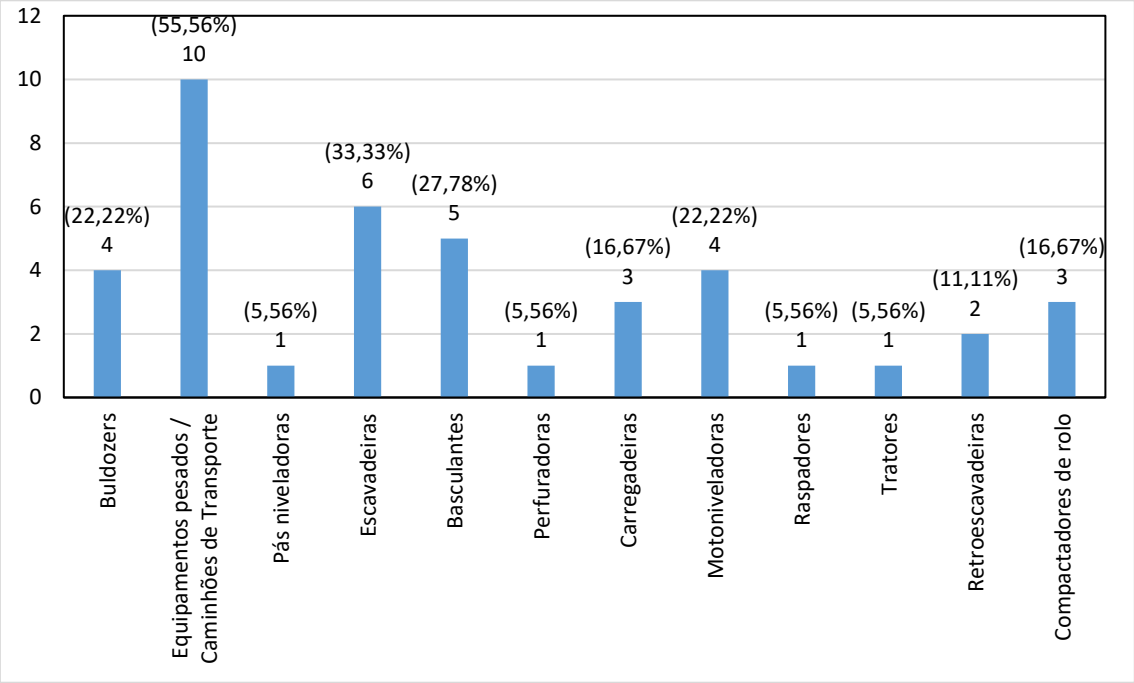

Figura 1. Maquinários mais relatados em estudos analisados.

As escavadeiras foram abordadas em 33,33% dos artigos analisados, seguido dos basculantes em 27,78%, bulldozers e motoniveladoras foram relatados em 22,22% dos estudos em análise; já as carregadeiras e os compactadores de rolo estiveram presentes em 16,67% dos estudos, seguido da retroescavadeira mencionada em 11,11% dos estudos. Por fim, pás niveladoras, perfuradoras, raspadores e tratores estiveram presentes em 5,56% dos estudos, descritos na figura 1. No entanto, alguns autores retratam os basculantes como o equipamento que mais proporciona níveis elevados de vibração de corpo inteiro prejudicial à saúde do operador, resultando na maioria das vezes em dor lombar, mencionados na figura 2 (Mandal; Srivastava, 2010; Raffler et al., 2017; Chaudhary et al., 2020; Atal et al., 2020).

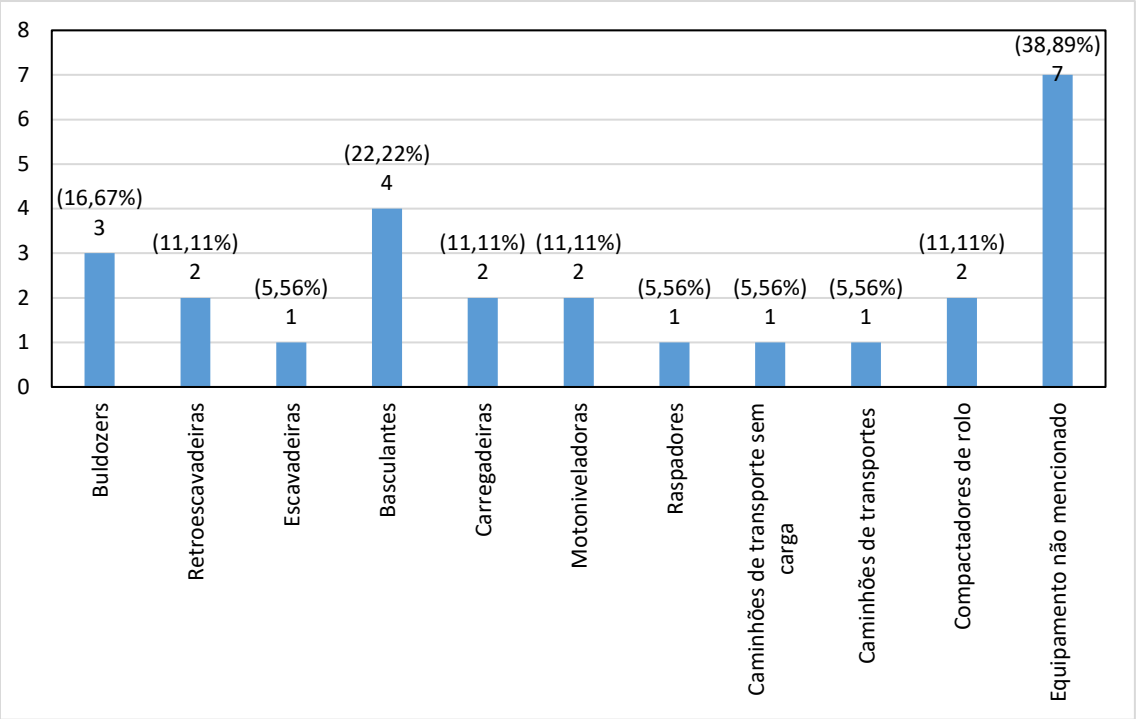

Figura 2. Maquinários com maior índice de vibração nos estudos analisados.

De acordo com o National Institute for Occupational Safety and Health (NIOSH) dos Estados Unidos da América (EUA), verificaram que as viagens com e sem carga podem provocar diferentes níveis de vibração aos operadores, principalmente quando associados aos fatores adjacentes, como o assento da máquina e vias de circulação (Mayton et al, 2014, 2018). Parte dos estudos não conseguiram identificar quais equipamentos foram possíveis de obter um maior índice de vibração com danos à saúde dos operadores, resultando em 38,89% dos estudos analisados (Pollard et al., 2016; Vitharana et al., 2019a; Othman et al., 2019; Vitharana et al., 2019b; Iope et al, 2019; Kia et al., 2020; Jeripotula et al., 2020b).

Por outra óptica, os artigos analisados prevalentes se referenciam às atividades de transporte de equipamentos com carga (33,33%) e atividades diversas, podendo ser em transporte de terras, despejo, escavações e extração, relatados em 33,33% dos estudos (Smets et al., 2007; Pollard et al., 2016; Raffler et al., 2017; Yassierli, 2017; Marin et al., 2017; Mayton et al., 2018; Othman et al., 2019; Vitharana et al., 2019b; Iope et al., 2019; Jeripotula et al., 2020a; Jeripotula et al., 2020b; Chaudhary et al., 2020). Ademais, foram mencionadas atividades de despejo em 22,22% dos estudos, seguidas dos transportes sem carga em 16,67% dos estudos analisados; escavação, terraplanagem e movimentação de terra foram relatados em 11,11%; por fim, extração, manutenção de estrada e construção e atividades não mencionadas estiveram presentes em 5,56%, destacadas na figura 3.

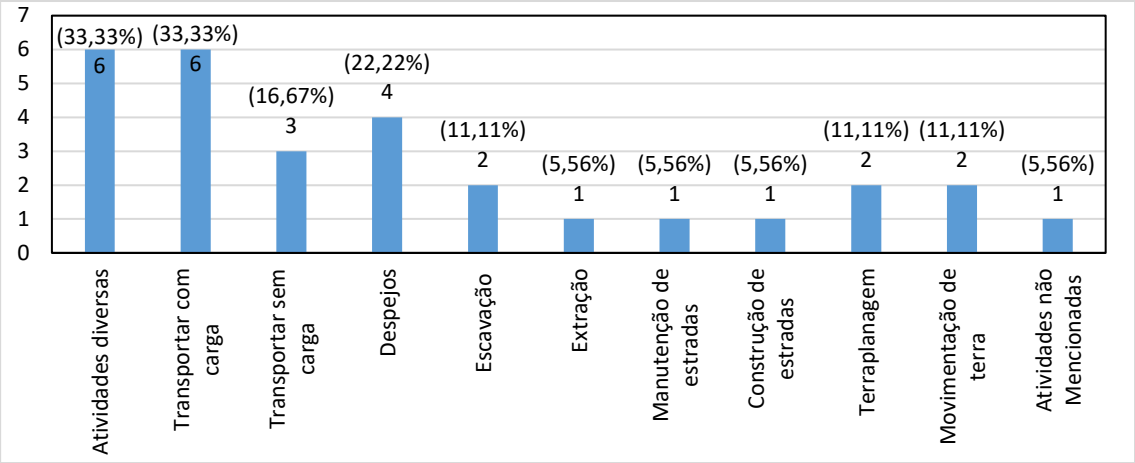

Figura 3. Atividades mais prevalentes nos estudos analisados.

Estudos afirmam que a presença de um conjunto de fatores pode causar o aumento do risco de exposição a níveis de vibração capazes de desencadear dor lombar. Fatores estes caracterizados pelos fatores adjuvantes que contribuem para tal desenvolvimento, como por exemplo, os terrenos instáveis, a falta de manutenção dos equipamentos, o assento inadequado, ambiente de trabalho, fatores de maquinários, fatores de carga, pneus e fatores pessoais. O nível vibracional dos equipamentos é elevado normalmente pela associação destes fatores, que implicam de forma direta no desenvolvimento de dor lombar nos operadores de equipamentos móveis (Raffler et al., 2017; Yassierli, 2017; Akinnuli et al., 2018; Mayton et al., 2018; Iope et al, 2019; Madhavie; Silva, 2019; Vitharana et al., 2019b; Atal et al, 2020; Chaudhary et al., 2020). Dentre os artigos analisados, 72,22% desses evidenciam a prevalência de dor lombar nos operadores (Smets, et al., 2007; Mandal; Srivastava, 2010; Raffler et al., 2017; Yassierli, 2017; Mayton et al., 2018; Akinnuli et al., 2018; Vitharana et al., 2019a; Othman et al., 2019; Vitharana et al., 2019b; Iope et al, 2019; Atal et al, 2020; Jeripotula et al., 2020a; Chaudhary et al., 2020).

A dor lombar não pode ser considerada apenas decorrente de um único fator, caracterizando-se como multifatorial. A alteração da exposição ao operador dos tipos de vibrações, incluem o tipo do veículo e suas características (como a suspensão, tamanho, projeto do assento, manutenção e condições dos pneus), a natureza dos operadores, as questões organizacionais, fatores pessoais e contexto social ao qual os operadores de equipamentos pesados estão envolvidos (Milosavljevic et al., 2010).Tal afirmativa, é relatada por Vitharana et al (2019a) e Othman et al (2019), no qual afirmam que esses fatores são primordiais no desenvolvimento de dores lombares.

Mediante os estudos realizados, os autores propõem ações preventivas, tais como: programas de controle de vibração, melhoramento nas vias de circulação, plano de manutenção e melhorias relacionadas ao projeto do equipamento, ambas com a finalidade de minimizar esses riscos vibracionais aos operadores de equipamentos pesados de carga e transporte, e por consequência o desenvolvimento de dor lombar. Dentre essas, é predominante a criação de programas de controle de vibração direcionados aos operadores (Mandal; Srivastava, 2010; Yassierli, 2017; Marin et al., 2017; Vitharana et al., 2019a; Othman et al., 2019; Vitharana et al., 2019b; Iope et al, 2019; Jeripotula et al., 2020a).

Em contraste, a *International Organization for Standardization* (ILO) afirma que exposição a VCI em longas jornadas provocam choques decorrente da vibração, que levam a efeitos prejudiciais à região lombar do operador, afetando os discos intervertebrais, ligamentos paravertebrais e músculos (ISO 2631-5, 2018).

Este trabalho de revisão aponta que empresas do setor de construção e mineração a céu aberto deve ter como foco principal a preocupação em minimizar as situações possíveis que causam dor lombar em seus operadores, as quais podem colocar a integridade física dos trabalhadores em operações com equipamentos pesados de carga e transporte em risco. Tal problemática poderá ser minimizada por meio de ações que são derivadas de projetos adequados às tarefas dos operadores e ao assento de máquinas (Gallagher, 2011).

CONCLUSÃO

Foi evidenciado que a dor lombar surge devido a exposição à VCI. Em muitos dos equipamentos pesados de carga e transporte na indústria extrativa a céu aberto e construção, os operadores estão expostos a elevados índices de vibração de corpo inteiro, que ocorrem na sua maioria em atividades de transporte de carga, como por exemplo, despejos, escavação, extração, manutenção e construção de estradas, principalmente em operações com caminhões basculantes. Esta exposição é potencializada quando se associada aos fatores envolvidos, como por exemplo, os terrenos instáveis e o projeto do maquinário, focado no melhoramento de assento da máquina, haja visto que proporciona ao operador níveis elevados de vibração. Portanto, é necessário que haja a criação de medidas preventivas a fim de minimizar o desencadeamento da dor lombar, como: programas de controle de vibração e alterações no maquinário.

Bibliografia

Abbaspour, H., Drebenstedt, C., & Dindarloo, S. R. (2018). Evaluation of safety and social indexes in the selection of transportation system alternatives (Truck-Shovel and IPCCs) in open pit mines. Safety Science, 108, 1–12. https://doi.org/10.1016/j.ssci.2018.04.020

Akinnuli, B. O., Dahunsi, O. A., Ayodeji, S. P., &Bodunde, O. P. (2018). Whole-body vibration exposure on earth moving equipment operators in construction industries. Cogent Engineering, 5(1), 1–14. https://doi.org/10.1080/23311916.2018.1507266

Atal, MK et al. (2020). Occupational exposure of dumper operators to whole-body vibration in open cast coal mines: an approach for risk assessment using a Bayesian network. International Journal of Occupational Safety and Ergonomics, p. 1-8.

Bernard BP (1997). Musculo skeletal disorders and workplace factors: a critical review of epidemiologic evidence for work – related disorders of the neck, upper extremities, and low back. Cincinnati,OH: US Department of Health and Human Services, National Institute of occupational safety and health. DHHS (NIOSH). Publication no. 97–141

Burgess-Limerick, R., Lynas, D., 2016. Long duration measurements of whole-body vibration exposures associated with surface coal mining equipment compared to previous short duration measurements. J. Occup. Environ. Hyg. 13, 339–345. https://doi.org/10.1080/15459624.2015.1125486.

Chaudhary, D. K., Palei, S. K., Kumar, V., &Karmakar, N. C. (2020). Whole-body vibration exposure of heavy earthmoving machinery operators in surface coal mines: a comparative assessment of transport and non-transport earthmoving equipment operators. International Journal of Occupational Safety and Ergonomics, 1-10.

US Department of Labor [Internet] (OSHA) (1989). Safety at work & Health administration. Occupational injuries and illnesses in the United States from injury, 1989, Bulletin.

Gallagher, S. (2011). Reducing low back pain and disability in mining. U.S. Department of Health and Human Services, CDC/NIOSH Office of Mine Safety and Health.

International Organization of Normalization. (2018). ISO 2631-5 Mechanical vibration and shock- evaluation of human exposure to whole-body vibration (ISO Standard).

Jeripotula, S. K., Mangalpady, A., & Mandela, G. R. (2020a). Ergonomic Assessment of Musculoskeletal Disorders Among Surface Mine Workers in India. Mining, Metallurgy and Exploration. https://doi.org/10.1007/s42461-020-00200-

Jeripotula, S. K., Mangalpady, A., & Mandela, G. R. (2020b). Musculoskeletal Disorders Among Dozer Operators Exposed to Whole-Body Vibration in Indian Surface Coal Mines. Mining, Metallurgy and Exploration, 37(2), 803–811. https://doi.org/10.1007/s42461-01900170-z

Kia, K., Fitch, S. M., Newsom, S. A., & Kim, J. H. (2020). Effect of whole body vibration exposures on physiological stresses: Mining heavy equipment applications. Applied Ergonomics, 85(February), 103065. https://doi.org/10.1016/j.apergo.2020.103065

Kuijer, PPF, Verbeek, JH, Visser, B.,Elder, LA, Van Roden, N.,VandenWittenboer, ME, Lebbink, M.Burdorf, A.,Hulshof, CT. (2014). Uma diretriz de prática multidisciplinar baseadas em evidências para reduzir a carga de trabalho devido ao levantamento para prevenir a dor lombar relacionada ao trabalho.Ann.Occup.Environ.Med.26

Langer TH, Ebbesen MK, Kordestani A. (2015) Experimental análise da exposição ocupacional à vibração de corpo inteiro em trator agrícola com enfardadeira de fardos quadrados. Ergonomia Int J Ind; 47: 79–83

Madhavie, M.K.J., De Silva, G.H.M.J.S., (2019). Whole body vibration exposures of roller compactors: characteristics and effect of waste rubber in damping the vibration. Int. J. Occup. Saf. Ergon. 0, 1–28. https://doi.org/10.1080/10803548.2019.1631546

Mandal, B. B., & Srivastava, A. K. (2010). Musculoskeletal disorders in dumper operators exposed to whole body vibration at Indian mines. Internation al Journal of Mining, Reclamation and Environment, 24(3), 233-243.

Marin, L. S., Rodriguez, A. C., Rey-Becerra, E., Piedrahita, H., Barrero, L. H., Dennerlein, J. T., & Johnson, P. W. (2017). Assessment of whole-body vibration exposure in mining earth-Moving equipment and other vehicles used in surface mining. Annals of Work Exposures and Health, 61(6), 669–680. https://doi.org/10.1093/annweh/wxx043

Mayton, AG, Jobes, CC, Gallagher, S., 2014. Avaliação da vibração de corpo inteiro exposições e em fatores determinantes para motoristas de caminhão de transporte em pedreira e operadores de carregadeira. Int. J. Heavy Veh. Syst. 21 (3), 241 e 261

Mayton, A. G., Porter, W. L., Xu, X. S., Weston, E. B., & Rubenstein, E. N. (2018). Investigation of human body vibration exposures on haul trucks operating at US surface mines/quarries relative to haul truck activity. International journal of industrial ergonomics, 64, 188-198.

Mcphee B, Foster G, Long A. Badvibrations: a handbook on whole-body vibration exposure in mining. 2nd ed Sydney (NSW): Coal Services Health and Safety Trust;2009

Milosavljevic S, Bergman F, Rehn B et al. (2010) Uso de veículos todo-o-terreno na agricultura: exposição a vibrações de corpo inteiro e choques mecânicos. ApplErgon; 41: 530–35

Othman, N., &Jiar, Y. K. (2019). Low back pain risk assessment for construction industry personnel. Indian Journal of Public Health Research and Development, 10(4), 1399–1404. https://doi.org/10.5958/0976-5506.2019.00909

Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D & Moher, D. (2021). Updating guidance for reporting systematic reviews: development of the PRISMA 2020 statement. Journal of Clinical Epidemiology, 134, 103-112.

Paschold, H. W., &Mayton, A. G. (2011). Whole-body vibration: Building awareness in safety. American Society of Safety Engineers, 56(4): 30-35.

Pollard, J., Porter, W., Mayton, A., Xu, X., & Weston, E. (2016). The effect of vibration exposure during haul truck operation on grip strength, touch sensation, and balance. International Journal of Industrial Ergonomics, 57, 23–31. https://doi.org/10.1016/j.ergon.2016.11.009

Raffler, N., Rissler, J., Ellegast, R., Schikowsky, C., Kraus, T., & Ochsmann, E. (2017). Combined exposures of whole-body vibration and awkward posture: a cross sectional investigation among occupational drivers by means of simultaneous field measurements. Ergonomics, 60(11), 1564-1575.

Robb, M. J., & Mansfield, N. J. (2007). Self-reported musculoskeletal problems amongst professional truck drivers. Ergonomics, 50(6), 814-827.

Vitharana, V. H. P., & Chinda, T. (2019a). Structural equation modelling of lower back pain due to whole body vibration exposure in the construction industry. International Journal of Occupational Safety and Ergonomics, 25(2), 257–267. https://doi.org/10.1080/10803548.2017.1366119

Vitharana, V. H. P., &Chinda, T. (2019b) Development of a low er back pain prevention index for heavy equipment operators in the construction industry: system dynamics modelling. International Journal of Construction Management, p. 1-17.

Wilder DG, Pope MH (1996) Epidemiological and a etiological aspects of low back pain in vibration environments - an update. ClinBiomech (Bristol, Avon) 11:61–73

Wohlin, Claes. Guidelines for snowballing in systematic literature studies and a replication in software engineering. In: Proceedingsof the 18th international conference on evaluation and assessment in software engineering. 2014. p. 1-10.

Xu, G., Pang, D., Liu, F., Pei, D., Wang, S., Li, L., 2012. Prevalence of low back pain and associated occupational factors among Chinese coal miners. BMC Publ. Health 12, 149. http://dx.doi.org/10.1186/1471-2458-12-149.

Yassierli. (2017). Implementation of ergonomic programs to reduce sick leave due to low back pain among nickel mining operators. International Journal of Industrial Ergonomics, 61, 81–87. https://doi.org/https://doi.org/10.1016/j.ergon.2017.05.013

Acidentes ocupacionais em operações com equipamentos pesados de carga e transporte, nas indústrias de extração a céu aberto e de construção – Breve revisão

Jane Paula de Souza [1], Soraya Wingester Vasconcelos [2], J. Santos Baptista [3], J. Castelo Branco [4]

[1]Associated Laboratory for Energy, Transports and Aeronautics - LAETA (PROA), Faculty of Engineering, University of Porto, PT (janepaulasouza@gmail.com) ORCID 0000-0001-5455-7232, [2]Associated Laboratory for Energy, Transports and Aeronautics - LAETA (PROA), Faculty of Engineering, University of Porto, PT (sorayawingester@gmail.com) ORCID 0000-0003-2137-1591, [3]Associated Laboratory for Energy, Transports and Aeronautics - LAETA (PROA), Faculty of Engineering, University of Porto, PT (jsbap@fe.up.pt) ORCID 0000-0002-8524-5503, [4]Associated Laboratory for Energy, Transports and Aeronautics - LAETA (PROA), Faculty of Engineering, University of Porto, PT (jcb@fe.up.pt) ORCID 0000-0002-9254-4384.
https://doi.org/10.24840/978-972-752-279-8_0081-0087

Resumo

Introdução: As operações nas indústrias extrativas a céu aberto e construção são reconhecidas pelos elevados índices de sinistralidade, devido às características dos próprios processos produtivos e em função da forte presença de máquinas e equipamentos pesados. Os trabalhos realizados ao ar livre, em condições meteorológicas adversas e vias de circulação inadequadas e com falta de manutenção, são alguns dos fatores que caracterizam os dois setores. As quedas foram identificadas como os principais fatores desencadeadores de risco de acidentes ou tipos de acidentes. O presente artigo visa apresentar uma breve revisão sistemática sobre a ocorrência de acidentes ocupacionais na utilização de equipamentos pesados, nas indústrias de construção e mineração. Metodologia: A revisão seguiu os requisitos do PRISMA *Statement*. Foram consultadas 7 bases de dados e utilizadas 33 palavras-chave. Foram aplicados vários critérios de exclusão, nomeadamente: intervalo de pesquisa, tipo de documento, tipo de fonte e idioma. Com critérios de elegibilidade foram considerados apenas os artigos que abordassem acidentes ocupacionais com equipamentos pesados de carga e transporte. Considerou-se ainda e a técnica de *Snowballing*, para a adição de outros artigos. Resultados e Discussões: A partir dos 4.546 artigos originários das bases de dados e dos 6 por *Snowballing*, 16 foram incluídos nesta revisão. Os acidentes ocupacionais decorrentes da utilização de equipamentos móveis, nas indústrias de mineração e construção, estão relacionados com os processos produtivos. O setor de mineração a céu aberto se destacou com maior incidência de acidentes ocupacionais. As operações com caminhões de transporte, escavadeira, tratores, retroescavadeira, raspadores e carregadeira frontal evidenciaram a ocorrência de quedas, atropelamento, capotamento e colisões, na indústria mineradora. 43,75% dos artigos apontaram que os operadores de máquinas móveis sofrem mais acidente ao entrar ou sair das cabines dos equipamentos, e que os fatores de risco mais importantes na ocorrência de escorregões, tropeções e quedas são os contaminantes nas escadas e os projetos inadequados de acesso às máquinas. Conclusões: Medidas corretivas nas escadas que dão acesso aos equipamentos móveis das indústrias extrativa a céu aberto e na construção civil, bem como o melhoramento de acesso aos maquinários e manutenções frequentes, são essenciais para diminuir os acidentes ocupacionais nas atividades de ambas as indústrias, mantendo-se a integridade física do operador.

Palavras-chave: Acidentes, Equipamentos móveis, Mineração, Construção civil.

INTRODUÇÃO

Os acidentes ocupacionais relacionados à utilização de equipamentos pesados de carga e transporte, nas indústrias de mineração a céu aberto e de construção, estão intimamente relacionados, ao próprio processo produtivo e às condições operacionais. Na utilização de equipamentos pesados móveis, as atividades realizadas ao ar livre estão sujeitas a condições meteorológicas adversas, exposição a partículas, ruído, vibrações e vias instáveis de circulação nas indústrias (Pollard et al, 2017; Mayton et al, 2018; Nasarwanji; Sun, 2019; Rahimdel; Mirzaei, 2020).

Em ambos os setores, as quedas estão presentes em parte significativa das lesões fatais, as quais também são a segunda principal causa de lesões não fatais na indústria extrativa a céu aberto (*Mine Safety and Health Administration*, 2015). O risco de queda é o que mais se destaca na bibliografia, principalmente nas entradas e saídas das cabines de máquinas e equipamentos (Nasarwanji et al, 2016; Pollard et al, 2017; Mayton et al, 2018; Mayton et al, 2020). Adicionalmente, destaca-se a iluminação insuficiente como um fator importante associado ao desenvolvimento de acidentes nessas indústrias, sendo insuficiente nas atividades realizadas

nos períodos noturnos nas minas a céu aberto, com a iluminação inadequada no local de realização das atividades, pode-se ocasionar acidentes como colisões e atropelamentos nas indústrias (Nasarwanji et al, 2018).

De acordo com o *National Institute of Occupational Health and Safety* (NIOSH), ao realizar um estudo sobre lesões fatais e não fatais relacionadas às máquinas na indústria de mineração dos Estados Unidos da América (EUA), concluíram que 46% dos acidentes ocorreram em atividades de operações de máquinas e 25% na manutenção e reparo de máquinas. Entretanto, mesmo com a quantidade de medidas preventivas existentes e implementadas, o número de acidentes ainda é crescente anualmente (Ruff et al., 2011).

Dados obtidos da *US Bureau of Labor Statistics* relatam que houve um aumento significativo no número de acidentes fatais no setor trabalhista em 2019. Dos acidentes relatados, é evidente o aumento expressivo em 6% anuais de acidentes na indústria extrativa a céu aberto (*Bureau of Labor Statistics*, 2019).

O presente trabalho de revisão sistemática tem como principal objetivo identificar e caracterizar os principais riscos ocupacionais relacionados com equipamentos de carga e transporte nos setores da construção civil e da mineração a céu aberto.

METODOLOGIA

A metodologia proposta para a realização deste estudo baseou-se na aplicação dos pressupostos de uma revisão sistemática indicados na metodologia *Preferred Reporting Items for Systematic Reviews and Meta-analysis* (PRISMA) (Page et al., 2021). A pesquisa foi realizada nas seguintes bases de dados: *Scopus, Web of Science, Engineering Village* (Inspec), *ScienceDirect*, Scielo, *CurrentContents* e *Dimensions*.

Foram consideradas as palavras-chave relacionadas com a incidência de acidentes ocupacionais na utilização de equipamentos pesados de carga e transporte nas indústrias de mineração e construção, nomeadamente: *mine, mining, open-pit-mine, open-cast-mine, quarry, extractive industry, construction, earthmoving, earthwork, risk assessment, occupational accidents, occupational risks, occupational hazards, equipment, machinery, machine, dumper, loader, dragline excavator, excavator shovel, bucket wheel excavator, wheel tractor scrape, bulldozer, mining truck, mining drill, earth mover, hydraulic excavator, wheel loader,backhoe loader, haul truc* e *conveyor.*

RESULTADOS E DISCUSSÃO

No total, foram obtidos 4.546 artigos, ao qual foram aplicados vários critérios de exclusão, nomeadamente:

- Data de publicação - apenas artigos dos últimos cinco anos (2016-2020), com a exclusão de 2725 artigos;
- Tipo de documento - apenas os artigos científicos, tendo sido excluídos 746;
- Tipo de fonte - somente artigos publicados em revistas científicas, totalizando 14 artigos excluídos;
- Idioma de publicação - apenas os artigos escritos em inglês, com a exclusão de 80 artigos. Além desses, outros critérios de inclusão foram aplicados:
- Os artigos só eram selecionados se abordassem os setores de construção e mineração. Mais 184 artigos foram excluídos.

Como critérios de elegibilidade foram considerados todas as situações relacionadas com a mineração a céu aberto, construção em terraplanagem, máquinas móveis, acidentes e riscos ocupacionais. Após realizar a leitura do título e resumos dos artigos, foram excluídos 767 artigos, os quais não estavam em concordância com o objetivo do estudo. Ao final do processo de

seleção, 36 artigos foram classificados como elegíveis e submetidos à leitura completa. Desse total, 6 artigos são provenientes da pesquisa realizada pelo critério de "Snowballing", de forma a incluir a bibliografia relevante (Wohlin, 2014). Por fim, apenas 16 artigos atenderam a todos os critérios para participar dessa revisão sistemática.

Na análise dos artigos, diferentes tipos de equipamentos de carga e transporte nas minerações a céu aberto e de construção envolvidos em riscos de acidentes ocupacionais foram identificados, sendo que os caminhões de transporte se destacaram e foram abordados em 7 artigos, ou seja, 43,75% dos analisados (McCann, 2006; Santos; Porter; Mayton, 2010; Hinze e Teizer, 2011; Horberry et al., 2016; Abbaspour et al., 2018; Mayton et al., 2020). Seguido das escavadeiras, com 25%, sendo abordadas em 4 artigos (McCann, 2006; Hinze e Teizer, 2011; Horberry et al., 2016; Kazan; Usmen, 2018). Já os equipamentos móveis não especificados foram abordados em 5 artigos. A distribuição da abordagem por artigos dos demais tipos de maquinários encontra-se detalhada na Figura 1.

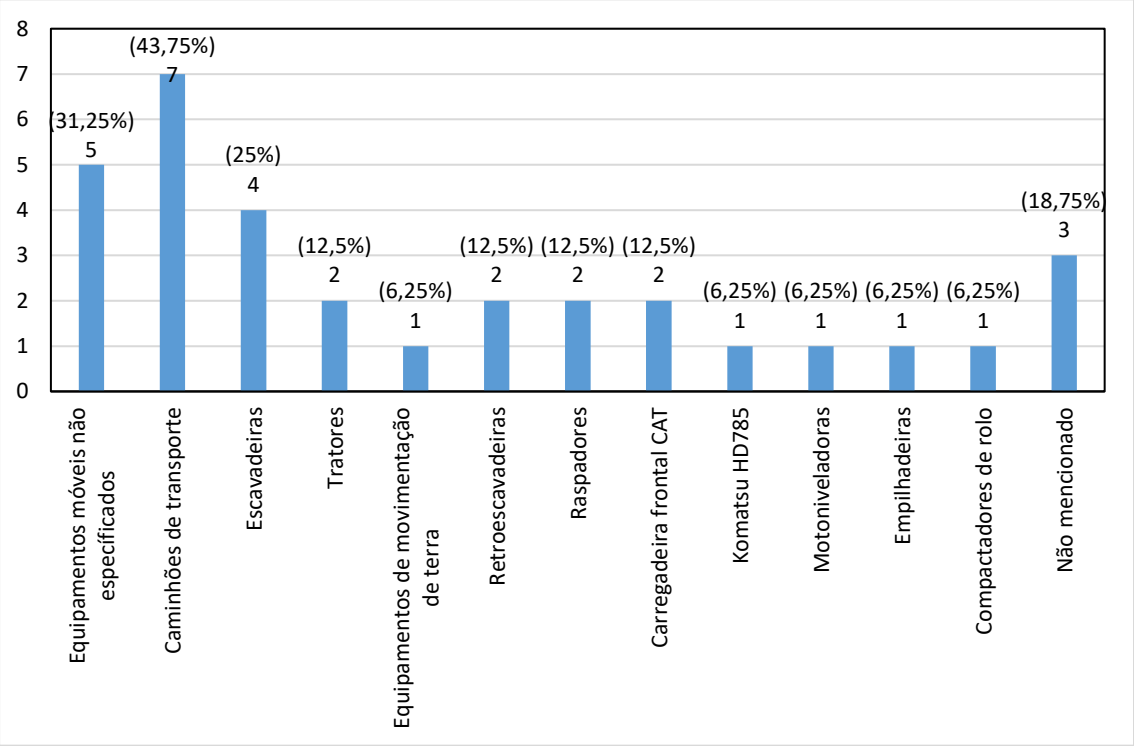

Figura 1. Distribuição dos artigos por tipo de maquinários citados.

Entre os estudos analisados, 9 deles mencionam diferentes tipos de riscos de acidentes e fator desencadeador de risco, como por exemplo as quedas dos equipamentos de mineração e/ou construção (Santos; Porter; Mayton, 2010; Nasarwanji, 2016; Pollard et al., 2017; Nowrouzi-Kia et al., 2017; Nasarwanji et al., 2018; Nasarvwanji et al., 2019; Pollard et al., 2019; Hrica et al., 2020; Mayton et al., 2020). As atividades com maior índice de ocorrências de acidentes são as quedas na entrada e saída das cabines dos equipamentos, conforme 7 dos estudos analisados (Santos; Porter; Mayton, 2010; Horberry et al., 2016; Pollard et al., 2017; Nasarwanji et al., 2018; Pollard et al., 2019; Hrica et al., 2020; Mayton et al., 2020). Seguidos de atropelamentos, em 2 artigos, logo após o capotamento e colisões em 1 dos estudos, descritos detalhadamente abaixo na Figura 2.

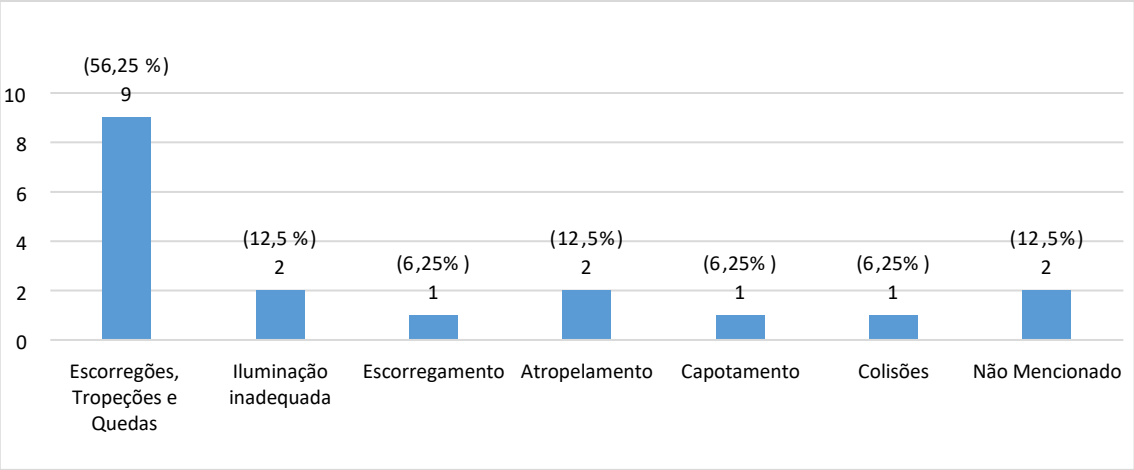

Figura 2. Distribuição dos artigos de acordo com a descrição dos riscos e fatores desencadeador de risco de acidentes ocupacionais.

Em seguida, manutenções e reparos em equipamentos e operações de equipamentos foram mencionados em 4 dos estudos. As operações em equipamentos em marcha à ré e operações de mineração foram abordadas em 2 dos estudos. Outros fatores considerados adjuvantes tornam a saída mais perigosa que a entrada nos equipamentos, como exemplo desses fatores têm-se a gravidade, que torna mais rápido o processo de saída do equipamento e a diminuição da propriocepção dos trabalhadores com maior idade, os quais apresentam redução da capacidade de observar os degraus da escada sob os pés ou utilizar o corrimão de maneira adequada (Robbins et al., 1995; Pollard et al., 2017; Nasarwanji et al., 2018).

Estudos anteriores corroboram essa revisão por apontarem que as quedas de altura nas operações com equipamentos pesados móveis nos setores da mineração e construção foram responsáveis por aproximadamente 60% dos casos relacionados a quedas, escorregões e tropeções, além de colaborarem para o desenvolvimento de distúrbios musculoesqueléticos em operadores (Nasarwanji, 2016; Weston et al., 2016).

Os fatores de risco predominantes que contribuíram para os acidentes identificados foram a visibilidade reduzida do operador, contaminantes em escadas dos equipamentos, como por exemplo a areia e barro, os quais potencializam o risco de quedas na entrada e saída dos equipamentos, além disso, o projeto inadequado de acesso aos maquinários (Hinze e Teizer, 2011; Horberry et al., 2016; Pollard et al., 2017; Nasarwanji et al., 2018; Pollard et al., 2019). O uso incorreto ou a ausência do sistema de proteção contra quedas em alturas, flexibilidade dos trilhos, iluminação insuficiente, fatores pessoais, ambientais e do projeto, bem como a ausência do cinto de segurança foram abordados em 2 dos estudos. A altura dos degraus inferiores, condições perigosas do solo, impossibilidade de visualizar os pés na hora da descida, saída de uma superfície escorregadia, com o escorregamento do pé ou mão, problemas de equilíbrio que podem contribuir para as quedas dos operadores, instalações de saída do equipamento, treinamento de segurança em não conformidade, alarme reserva com defeito e falta de manutenção, foram mencionados em 2 dos estudos em análise. No entanto, 4 dos estudos não chegaram a mencionar tipos de fatores específicos que impliquem no desencadeamento de acidentes, relatados na Figura 3.

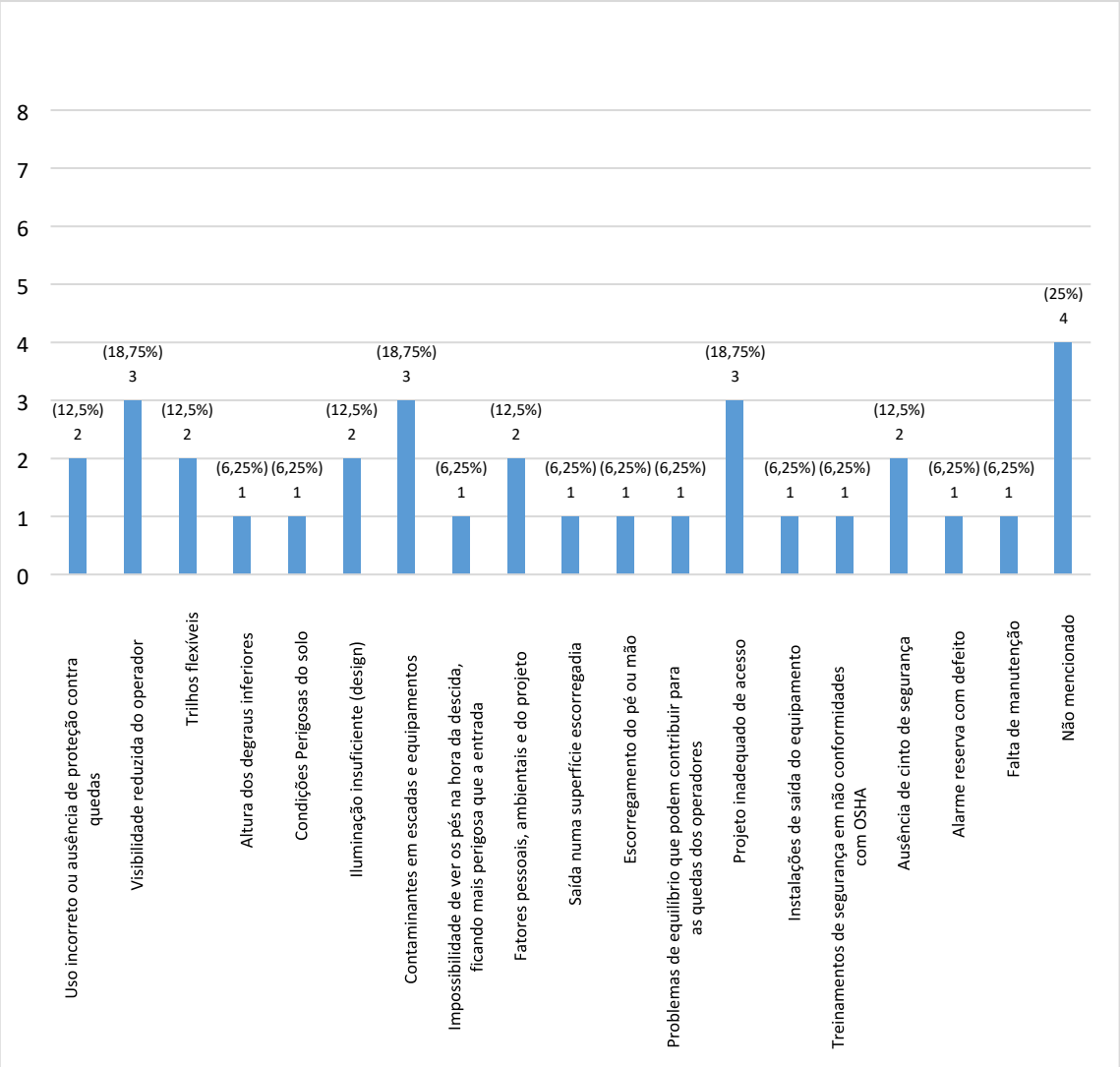

Figura 3. Resultados dos artigos que descreveram os fatores de riscos envolvidos nos acidentes.

Estudos já realizados mostraram que os operadores de equipamentos acreditam que a falta de iluminação adequada se torna um elemento fundamental no desencadeamento de acidentes, seja na entrada ou saída das cabines (Pollard et al., 2019). Em contraste, outros estudos relatam o desencadeamento de acidentes derivados de fatores ambientais, condições de solo, mudança no ambiente de trabalho e falta de manutenção de máquinas (Smets et al., 2010; Langer et al., 2015).

A escavadeira é um equipamento complexo que envolve um processo sinérgico de giro, braço e caçamba, por isso exige uma maior atenção por parte dos operadores em sua utilização. Além disso, está sujeita a fatores desfavoráveis no ambiente de trabalho, como o espaço limitado nas indústrias para as atividades com as escavadeiras, o que aumenta a probabilidade de acidentes nas indústrias, devido às vias de circulação instáveis (Liu et al., 2020). Dados obtidos do *Korean Construction Safety Institute* (2015), apontam que das 632 mortes no setor da construção, no período de 2009 a 2015, 121 delas foram por acidentes na utilização de escavadeiras, assim determinando o maior número de acidentes fatais causados por algum tipo de equipamento da indústria extrativa a céu aberto e construção civil. Esse relato, contribui como os achados desta revisão, a qual afirma o envolvimento das escavadeiras em maioria dos acidentes relatados.

CONCLUSÃO

Diversos equipamentos móveis das minerações e construções estão relacionados ao elevado índice de acidentes do trabalho, a exemplo dos caminhões de transporte, equipamentos móveis em geral, escavadeiras e outros. Na utilização desses equipamentos deve-se observar as normas de segurança para que atividades como a entrada e/ou saída dos operadores das cabines dos maquinários, operações, manutenções e reparos possam ser realizadas sem riscos à saúde dos trabalhadores. Os principais acidentes e riscos relacionados às atividades mencionadas são os quedas, atropelamentos, capotamento e colisões. Os fatores potenciam a ocorrências de acidentes são a visibilidade reduzida do operador, contaminantes (areia, barro) em escadas dos equipamentos e projetos inadequados de acesso. O uso incorreto ou a ausência de proteção contra quedas, flexibilidade dos trilhos, fatores pessoais e ambientais, relacionados ao projeto, bem como a ausência do cinto de segurança são outros fatores associados ao risco de acidentes.

Percebe-se que os setores de mineração e construção, apesar de serem bastante representativos do ponto de vista econômico-financeiro, demonstram realizar investimentos em saúde e segurança do trabalho de forma insignificante, ao se considerar a frequência e gravidade dos acidentes que foram identificados nessa revisão e a elevada taxa de acidentes nessas indústrias.

Bibliografia

Abbaspour, H., Drebenstedt, C., &Dindarloo, S. R. (2018). Evaluation of safety and social indexes in the selection of transportation system alternatives (Truck-Shovel and IPCCs) in open pit mines. Safety Science, 108, 1–12. https://doi.org/10.1016/j.ssci.2018.04.020

Bureau of Labor Statistics. (2019). National census of fatal occupational injuries in 2019. Disponível em: https://www.bls.gov/news.release/pdf/cfoi.pdf. Acesso em: 12. Abr 2021.

Hinze, J. W., &Teizer, J. (2011). Visibility-related fatalities related to construction equipment. Safety Science, 49(5), 709–718.

Horberry, T., Burgess-Limerick, R., Cooke, T., & Steiner, L. (2016). Improving Mining Equipment Safety Through Human-Centered Design. Ergonomics in Design, 24(3), 29–34. https://doi.org/10.1177/1064804616636299

Hrica, J. K., Eiter, B. M., Pollard, J. P., Kocher, L. M., &Nasarwanji, M. (2020). Analysis of Fall-Related Imminent Danger Orders in the Metal/Nonmetal Mining Sector. Mining, Metallurgy and Exploration, 37(2), 619–630. https://doi.org/10.1007/s42461-020-00186-w

Korean Construction Safety Institute. (2015). [Graph] Number of Industrial Accident Deaths Caused by Construction Machines, I-dbNewsletter.

Langer TH, Ebbesen MK, Kordestani A (2015). Experimental analysis of occupational whole-body vibration exposure of agricultural tractor with large square baler. Int. J. Industrial Ergonomics. 2015;47:79–83

Liu, G., Yang, L., Wu, D., Wu, G., & Chen, H. (2021). Development and experimental investigation of an automatic control system for an excavator. Proceedings of the Institution of Mechanical Engineers, Part C: Journal of Mechanical Engineering Science, 235(4), 758-773.

Kazan, E., & Usmen, M. A. (2018). Worker safety and injury severity analysis of earthmoving equipment accidents. Journal of safety research, 65, 73-81.

Mayton, A. G., Demich, B., &Nasarwanji, M. F. (2020). Investigation of Machine-Mounted Area

Lighting to Reduce Risk of Injury from Slips-Trips-Falls for Operators of Mobile Surface Mining Equipment. Mining, Metallurgy and Exploration. https://doi.org/10.1007/s42461-020-00239-0

Mayton, A. G., Porter, W. L., Xu, X. S., Weston, E. B., & Rubenstein, E. N. (2018). Investigation of human body vibration exposures on haul trucks operating at US surface mines/quarries relative to haul truck activity. International journal of industrial ergonomics, 64, 188-198.

McCann, M. (2006). Heavy equipment and truck-related deaths on excavation work sites. JournalofSafetyResearch, 37(5), 511–517

Mine Safety and Health Administration. (2015). Acidentes, lesões, estatísticas e relatórios de produção e acidentes na indústria de mineração. https://www.cdc.gov/niosh/ mining / data / default.html

Nasarwanji MF, Pollard J, Porter W (2018) An analysis of injuries to frontend loader operators during in gress and egress. Int J IndErgon 65:84–92

Nasarwanji, M. F., & Sun, K. (2019). Burden associated with nonfatal slip and fall injuries in the surface stone, sand, and gravel mining industry. Safety Science, 120, 625–635. https://doi.org/10.1016/j.ssci.2019.08.007

Nasarwanji, M.F., 2016. Contributing factors to slip, trip, and fall fatalities at surface coal and metal/nonmetal mines. In: Paper presented at the Proceedings of the Human Factors and Ergonomics Society Annual Meeting

Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., ...&Moher, D. (2021). Updating guidance for reporting systematic reviews: development of the PRISMA 2020 statement. Journal of Clinical Epidemiology, 134, 103-112.

Pollard, J., Kosmoski, C., Porter, W. L., Kocher, L., Whitson, A., &Nasarwanji, M. (2019). Operators' views of mobile equipment ingress and egress safety. International Journal of Industrial Ergonomics, 72, 272–280. https://doi.org/10.1016/j.ergon.2019.06.003

Pollard, J., Porter, W., Mayton, A., Xu, X., & Weston, E. (2017). The effect of vibration exposure during haul truck operation on grip strength, touch sensation, and balance. International Journal of Industrial Ergonomics, 57, 23–31. https://doi.org/10.1016/j.ergon.2016.11.009

Rahimdel, M. J., &Mirzaei, M. (2020). Prioritization of practical solutions for the vibrational health risk reduction of mining trucks using fuzzy decision making. Archives of Environmental & Occupational Health, 75(2), 112-126.

Robbins, S., Waked, E., &McClaran, J. (1995). Proprioception and stability: foot position awareness as a function of age and footware. Age and Ageing, 24(1), 67-72.

Ruff, T., Coleman, P., & Martini, L. (2011). Machine-related injuries in the US mining industry and priorities for safety research. International journal of injury control and safety promotion, 18(1), 11-20.

Santos, B. R., Porter, W. L., & Mayton, A. G. (2010, September). An analysis of injuries to haul truck operators in the US mining industry. In Proceedings of the Human Factors and Ergonomics Society Annual Meeting (Vol. 54, No. 21, pp. 1870-1874). Sage CA: Los Angeles, CA: SAGE Publications.

Smets M, Eger TR, Grenier SG. Whole-body vibration experienced by haulage truck operators in surface mining operations: a comparison of various analysis methods utilized in the prediction of health risks. Appl. Ergon. 2010;41(6):763–770

Weston, E., Nasarwanji, M.F., Pollard, J.P., 2016. Identification of work-related musculoskeletal disorders in mining. J. Saf., Health Environ. Res. 12 (1), 274–283.

Wohlin, Claes. Guidelines for snowballing in systematic literature studies and a replication in software engineering. In: Proceedings of the 18th international conference on evaluation and assessment in software engineering. 2014. p. 1-10.

Aspectos ergonômicos da adaptação de estudantes de engenharia ao regime remoto de ensino na pandemia de Covid-19

Nilberto Rocha Neto [1], André Duarte Lucena [2], Fabrícia Nascimento de Oliveira [3]

[1] Universidade Federal Rural do Semi-árido, Mossoró, Brasil (nilbertoneto-@hotmail.com) ORCID 0000-0002-2121-5567, [2] Departamento de Engenharia e Ciências Ambientais, Universidade Federal Rural do Semi-árido, Mossoró, Brasil (andrelucena@ufersa.edu.br) ORCID 0000-0003-0181-4260, [3] Departamento de Engenharia e Ciências Ambientais, Universidade Federal Rural do Semi-árido, Mossoró, Brasil (fabricia@ufersa.edu.br) ORCID 0000-0002-0333-0035.
https://doi.org/10.24840/978-972-752-279-8_0088-0094

Resumo

Introdução: A pandemia de Covid-19 modificou várias atividades, dentre elas o ensino nas universidades. A adaptação das atividades dos professores para a modalidade de ensino remoto foi discutida e realizada intensa e sistematicamente por várias instituições. Mas as adaptações dos estudantes ao estudo remoto dependem das condições de cada indivíduo e estão sujeitas à autonomia de cada estudante. O objetivo do presente artigo foi identificar aspectos ergonômicos das condições de estudo remoto de um grupo de estudantes de engenharia durante a pandemia de Covid-19. Metodologia: Os dados da pesquisa foram coletados com um questionário enviado por email e respondido na internet por 22 dos 186 estudantes de engenharia de produção de uma universidade brasileira. As questões abordaram as posturas adotadas pelos alunos no momento de estudo; percepção sobre o nível de conforto em relação ao ruído, cômodo adotado para estudar, temperatura, luminosidade, e adequação da mobília do local de estudo. Além disso, questionou-se sobre a carga horária de atividades e incorporou-se ao inquérito o Questionário Nórdico de Sintomas Osteomusculares. Resultados e discussão: Os principais resultados mostram que pescoço, ombros, coluna, punhos e mãos são regiões com maior frequência de dores ou incômodos; sendo as regiões dorsal, lombar e do pescoço as indicadas com maior frequência de incapacitações e com maiores níveis de dor. Também foi identificado que uma parcela dos estudantes usa o quarto como principal cômodo e as posições sentada e deitada para estudar. Conclusões: Longos períodos de estudo em telas, as dores e incômodos corporais, as restrições e incapacitações indicadas nas regiões do pescoço, ombros, punhos, mãos, dorso e lombar possivelmente têm relação com as posturas adotadas pelos estudantes para assistirem as aulas remotas e realizarem suas atividades acadêmicas. São necessárias ações ergonômicas educativas em relação a essa nova configuração de ensino e para o cenário pós-pandêmico.

Palavras-chave: Ensino remoto, Adaptações ergonômicas, Estudantes, SARS-CoV-2.

INTRODUÇÃO

A pandemia do Covid-19 forçou a rápida adaptação de várias atividades ao formato remoto. Nas universidades, os professores precisaram modificar aspectos pedagógicos e técnicos do ensino (Giovannetti et al., 2020) e os alunos tiveram que adaptar seus métodos de estudo a um modelo de ensino remoto emergencial e ao ambiente de casa (Rodríguez-Nogueira et al., 2021).

A mudança repentina trouxe demandas para os estudantes, tais como má interpretação dos conteúdos dos cursos, falta de orientação por parte das universidades, pouca flexibilidade dos professores e estressores por causa da sobrecarga de tarefas (Rosario-Rodríguez et al., 2020).

A pandemia também proporcionou níveis mais significativos de problemas psicossociais comparativamente ao período anterior à pandemia, tais como ansiedade, estresse, depressão, sintomas de estresse pós-traumático, ideação suicida e problemas de qualidade de sono (Cobo-Rendón et al., 2020; Maia & Dias, 2020), em universitários de vários países (Batra et al., 2021).

Atividades a partir de casa podem ser uma alternativa para equilibrar a vida profissional e familiar, entre outros benefícios (Naddeo et al., 2021). Por outro lado, há críticas tais como períodos prolongados de atividades sem considerar a carga mental de trabalho, a transferência de custos, o isolamento domiciliar e a fusão do espaço familiar com o trabalho (Macêdo et al., 2020).

O domicílio nem sempre é um ambiente favorável ao estudo ou trabalho intelectual por várias razões, dentre elas fatores de distração e os aspectos ambientais como níveis de iluminação, sons, ruídos, temperatura e mobília; podendo influenciar a aprendizagem, o humor, o

desempenho dos alunos, os níveis percebidos de conforto (Naddeo et al., 2021). O uso de dispositivos também pode ser uma fonte de distração pelo seu uso intenso para lazer, ao mesmo tempo em que é ferramenta de trabalho e estudo.

Alunos usam dispositivos móveis por longos períodos, sobretudo no ensino remoto (Morais et al., 2019), sendo o tempo de uso um dos principais fatores responsáveis pelos riscos musculoesqueléticos de usuários desses dispositivos (Jain et al., 2021). O tempo de tela aumentou no período da pandemia de Covid-19 (Ganne et al., 2020), e o uso de portáteis é maior do que o de computadores de mesa em ambientes de trabalho móvel (González-Menéndez et al., 2019). O uso do laptop agrava as posturas não neutras observadas no uso do computador de mesa (A. J. Werth & Babski-Reeves, 2012) e podem causar dores e transtornos musculoesqueléticos (González-Menéndez et al., 2019), principalmente nos membros superiores (Obembe et al., 2013) e coluna (Morais et al., 2019).

Passar a maior parte do tempo sentado é outro aspecto da rotina de alunos que pode afetar o aprendizado, bem como proporcionar risco adicional, especialmente à região do pescoço (Kanchanomai et al., 2011; Naddeo et al., 2021). Considerando ainda o grande número de atividades acadêmicas esse grande tempo sentado pode levar uma sobrecarga musculoesquelética nos estudantes (Caromano et al., 2015), podendo provocar também dor ou desconforto na região dorsal (Intolo et al., 2019).

O regime de ensino remoto também favorece o uso dos dispositivos portáteis nos vários cômodos da casa e assumindo posturas não convencionais de trabalho. Nesse sentido, estudar com laptop no sofá, por exemplo, considerando carga muscular, posturas e performance pode ter maior potencial de desenvolvimento de lesões e distúrbios musculoesqueléticos (A. Werth & Babski-Reeves, 2014). Também deve-se levar em consideração que o uso nessas posturas já acontecia e, pelo isolamento social os dispositivos também são utilizados para outras atividades não acadêmicas, tais como filmes, jogos, comunicação, dentre outros.

O uso de laptop na cama também apresenta riscos musculoesqueléticos, pois nesse caso, a postura prona é caracterizada por ombros, cotovelos e punhos comparativamente não neutros e extensão pronunciada do pescoço, com intensidade significativamente maior e mais regiões de desconforto indicadas por estudantes universitários para essa postura durante os estudos do que para a postura sentada (Gold et al., 2012). Durante o uso de laptop na cama a posição de ombros, pescoço e pulsos, somado ao tempo prolongado e à configuração do trabalho são elementos importantes das posturas da parte superior do corpo, pois aumentam a contração muscular estática e consequentemente a fadiga (A. J. Werth & Babski-Reeves, 2012).

Diante do exposto, esse trabalho teve como objetivo identificar aspectos ergonômicos das condições de estudo remoto de um grupo de estudantes de engenharia de uma universidade brasileira durante a pandemia de Covid-19; especificamente as posturas adotadas, carga horária de estudo, cômodos utilizados e percepção de conforto sonoro, lumínico, térmico e da mobília utilizada pelos estudantes nesse contexto de repentina mudança de estratégia de ensino convencional para o ensino remoto devido à pandemia de Covid-19.

METODOLOGIA

A aquisição dos dados foi feita por questionário disponibilizado em formulário do Google, enviado por email aos estudantes e respondido digitalmente na primeira quinzena de dezembro de 2020. Foi composto por um termo de consentimento e outras três seções: 4 questões de caracterização dos estudantes, 10 questões sobre atividades e ambientes de estudo e as 27 perguntas das 9 partes corporais do questionário nórdico. Responderam ao questionário de forma válida 22 estudantes de engenharia de produção de uma universidade brasileira, voluntários, com média de 26 ± 4,9 anos de idade, sendo 13 do sexo masculino e 9 do sexo

feminino. A amostra foi não probabilística e de conveniência. Todos preencheram virtualmente o termo de concordância e consentimento livre e esclarecido de participação na pesquisa.

A percepção do conforto ambiental foi avaliada com uma escala de 5 pontos abordando a percepção do nível de ruído do local de estudo, o cômodo adotado para estudar, a percepção do conforto térmico, conforto em relação à luminosidade e adequação da mobília, considerando que tais aspectos influenciam o desempenho de atividades em regime de home office (Naddeo et al., 2021).

Sobre as posturas, utilizou-se o questionário nórdico de análise de sintomas musculoesqueléticos, proposto por Kuorinka et al., (1987), e validado em versão brasileira por Amaral et al., (2002), para se identificar quais partes do corpo os estudantes sentiram dor ou incômodo, e se nos últimos 7 dias tiveram restrições ou incapacidades de executar atividades rotineiras por causa desses sintomas. As respostas foram fornecidas em escalas de 5 pontos. Os participantes que indicaram dor e /ou desconforto avaliaram-nas atribuindo um valor numa escala de dez pontos que, posteriormente, foi normalizada para uma escala de 5 pontos.

A partir dos dados obtidos foi feita uma análise estatística descritiva buscando identificar os aspectos ergonômicos de maior relevância da adaptação dos estudantes ao estudo remoto, confrontando os resultados com a literatura consultada.

RESULTADOS E DISCUSSÕES

A carga horária média de aulas dos participantes é de 17,3 ± 5,3 horas semanais. Os estudantes declararam dedicar em média 9,5 horas semanais para resolução das atividades assíncronas, e em média 11,9 ± 8,6 horas semanais de estudos dos conteúdos, totalizando uma carga horária média de 38,7 horas de dedicação semanal. Essa carga é elevada, ampliando os riscos pelo longo tempo de trabalho sentado, conforme apontam Caromano et al., (2015), e com o extenso uso de telas, como indicado por Ganne et al., (2020); Jain et al., (2021); Morais et al., (2019).

Em relação aos cômodos utilizados para o estudo o quarto foi apontado por 50% dos participantes, seguido do escritório indicado por 14% dos estudantes, a sala de estar é utilizada por 10% dos estudantes e a sala de jantar por 7%. Os espaços de varanda, terraço, quintal, área de serviços e cozinha foram apontados como utilizados para estudos por 3,6% dos participantes. Vale ressaltar que 4 participantes declararam que alternam os cômodos utilizados para estudar.

Quanto às posturas adotadas nos períodos de estudo remoto 14 estudantes afirmaram estudar sentados, 6 estudam tanto sentados como deitados, 1 estuda sempre deitado e 1 afirmou variar de tal modo a postura para estudar que não sabia especificar a predominante. Dos que estudam deitados; 4 estudantes alternam entre a posição sentada e decúbito dorsal; 1 estudante alterna entre sentado, decúbito dorsal, decúbito ventral e deitado de lado; e 1 estuda sempre na posição de decúbito dorsal. A constatação de que 32% dos estudantes participantes estudam no quarto e deitados, considerando a carga horária média dedicada aos estudos levanta uma hipótese de relação com os desconfortos e dores musculares apontadas pelos participantes, corroborando com o que afirmam Gold et al., (2012); A. J. Werth & Babski-Reeves, (2012) Além disso, os quartos são concebidos com a finalidade primeira de descanso, e nesses casos o uso do mesmo ambiente para estudo pode ter efeitos negativos, como por exemplo a diminuição da qualidade do sono, que está em ascensão entre universitários durante a pandemia de Covid-19, conforme Cobo-Rendón et al., (2020).Em relação à percepção de adequação dos aspectos ambientais, o ruído teve média de avaliação de 3,41, a temperatura teve média 3,27, a iluminação foi avaliada com média 3,64 e a mobília com média 3 de adequação. Aparentemente os valores médios da percepção de conforto ambiental indicam satisfação razoável dos estudantes, não representando fatores de inadequação ao estudo, conforme indicado por Naddeo et al. (2021). Vale salientar que o ambiente de casa proporciona alguma sensação de bem-estar e permite estratégias de adaptação para melhoria de conforto como o uso de

ventiladores ou condicionadores de ar, luminárias, almofadas, entre outros. Mas há um risco de viés de resposta devido à desejabilidade social, ou seja, respostas socialmente aceitas que não representam necessariamente a realidade para essas variáveis de conforto quando se trata da casa do próprio participante.

Em relação às dores, desconforto ou dormência em partes do corpo, 16 participantes indicaram ocorrência na região do pescoço, dos quais 4 apontaram restrição ou incapacitação de execução de atividades rotineiras. Em relação à região dos ombros 14 participantes indicaram dor, mas apenas 2 indicaram restrições ou incapacidades relacionadas. Quanto à região dos cotovelos 3 participantes indicaram dor nessa região e 1 indicou incapacitação por esta razão. Sobre a região dos punhos e mãos, 13 respondentes indicaram dor ou desconforto, e 3 pessoas indicaram restrições ou incapacitações. Já em relação à região da coluna dorsal, 19 participantes indicaram ter sentido dor ou desconforto e 6 participantes indicaram restrição ou incapacitação por esta razão. Registraram ocorrência de dor na região lombar 16 participantes, dos quais 5 reportaram restrição por causa dessas ocorrências. Apenas 2 participantes indicaram dor na região do quadril e coxas, mas sem restrições por esta causa. Na região dos joelhos 7 pessoas apontaram dor e 3 destes tiveram incapacidades por esta causa. Quanto à região dos tornozelos e pés 4 pessoas reportaram dor, sem declarantes de incapacidade por esta razão. Os dados sobre as dores e desconforto musculares estão representados na Figura 1 com valores percentuais.

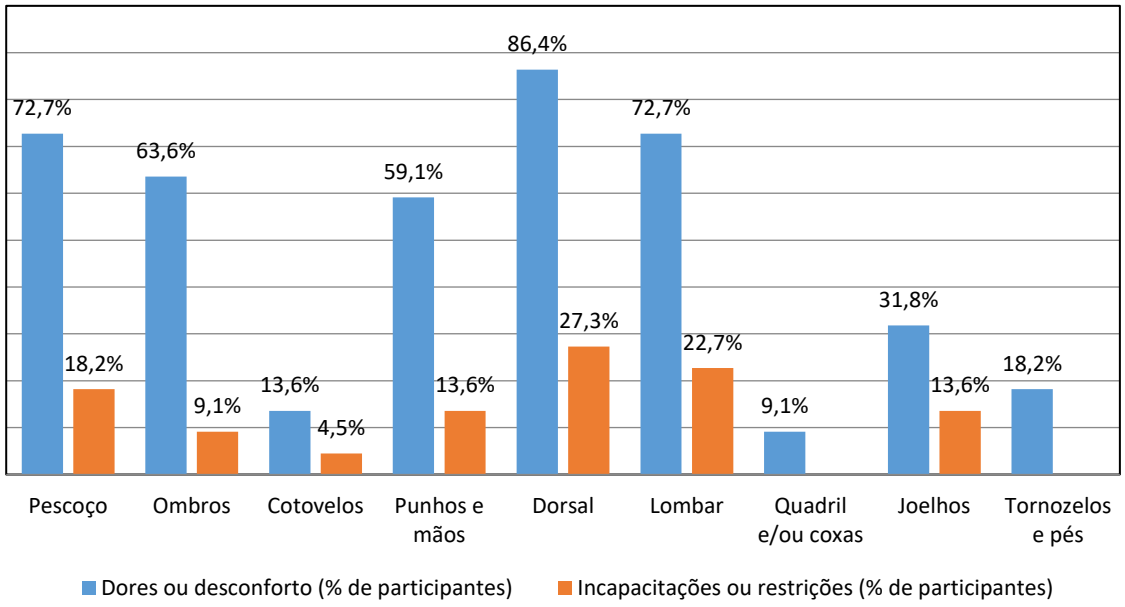

Figura 1. Percentuais de ocorrências de dor ou desconforto e respectivas incapacitações ou restrições de atividades dos participantes por áreas corporais.

Identificou-se que as partes do corpo onde os participantes apontam maior frequência de dores e/ou incômodos são: dorso, apontado por 86,4% dos entrevistados; pescoço e região lombar, ambos indicados por 72,7% dos participantes; ombros, indicados por 63,6% dos participantes; e punhos e mãos que foram apontados por 59,1% dos respondentes. Essas mesmas partes do corpo foram as mais indicadas pelos participantes como as áreas cujas dores ou incômodos provocaram incapacitações ou restrições de execução de atividades rotineiras: 27,3% indicaram ocorrência na região da coluna dorsal; 22,7% na região da coluna lombar; 18,2% na região do pescoço; 13,6% na região dos punhos e mãos; e 9,1% na região dos ombros.

Já a classificação das dores teve valores médios e desvios padrões distribuídos da seguinte forma: 3,33 ± 0,73 para as dores da região do pescoço; 2,87 ± 0,82 para a região dos ombros; 3,37 ± 1,12 para a área dos cotovelos; 2,88 ± 1,06 para a região dos punhos e mãos; 3,57 ± 0,76 para a área da coluna dorsal; 3,64 ± 0,88 na região da coluna lombar; 3,67 para as dores da área do quadril e/ou coxas; 3,86 ± 0,76 na área dos joelhos; e 2,67 ± 0,56 na região dos tornozelos e pés. Os valores médios da avaliação das dores estão representados na Figura 2.

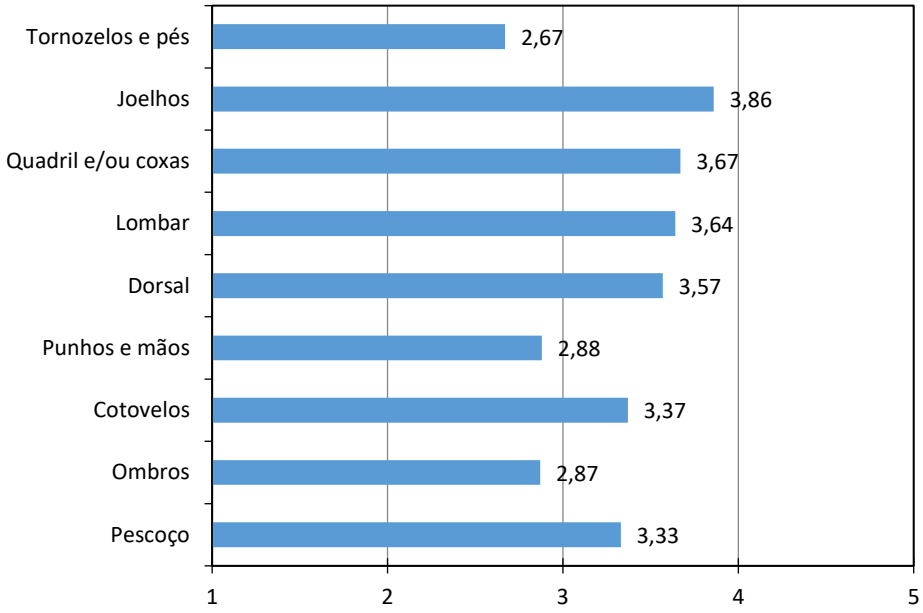

Figura 2. Valores médios da classificação das dores e /ou incômodos por região corporal dos participantes.

As regiões com maior frequência de dores ou incômodos concordam com a literatura que aponta para ombros, pescoço, coluna, punhos e mão (Caromano et al., 2015; Morais et al., 2019; Obembe et al., 2013). Apesar das avaliações das dores apresentarem valores maiores para outras partes do corpo, a frequência em cada área corporal deve ser considerada. Sendo assim, entre as partes do corpo com maior frequência de incômodos e dores as regiões dorsal e lombar foram indicadas com maiores valores de dor, corroborando com os resultados de (Intolo et al., (2019); Kanchanomai et al., (2011); Naddeo et al., (2021); e Obembe et al., (2013). Somado a isso, tais regiões foram as que promoveram mais incapacitações aos participantes.

CONCLUSÕES

O objetivo deste trabalho foi alcançado ao se identificar aspectos ergonômicos das condições de estudo remoto de um grupo de estudantes de engenharia, nomeadamente o tempo médio de atividades semanais, os cômodos da casa utilizados para estudar, as posturas adotadas para tal atividade. As atividades relacionadas ao regime de ensino remoto devido à pandemia de Covid-19, na configuração encontrada entre os participantes desta pesquisa, tem o potencial de ampliar riscos musculoesqueléticos de estudantes universitários.

Percebe-se a necessidade de educar estudantes em relação ao uso de dispositivos de tela em regime de trabalho de casa, bem como a necessidade de políticas pós-pandemia das universidades para tratar da saúde física e mental da comunidade universitária.

Este estudo é preliminar e permitiu identificar os próximos passos da pesquisa que serão relacionados às posturas com maior detalhamento das posições de cada parte do corpo, o tempo em cada posição, os dispositivos móveis utilizados e as consequências desse uso, a

adoção de outros recursos para incrementar o conforto ambiental e elementos que indiquem relação dos aspectos ergonômicos com o desempenho acadêmico de estudantes.

Referências

Amaral, F., Torres, B., & Carvalho, V. De. (2002). Validação do Questionário Nórdico de Sintomas Osteomusculares como medida de morbidade Validity of the Nordic Musculoskeletal Questionnaire as morbidity measurement tool. Revista de Saúde Pública, 36(3), 307–312. http://www.scielosp.org/scielo.php?script=sci_arttext&pid=S0034-89102002000300008

Batra, K., Sharma, M., Batra, R., Singh, T. P., & Schvaneveldt, N. (2021). Assessing the Psychological Impact of COVID-19 among College Students: An Evidence of 15 Countries. Healthcare, 9(2), 222. https://doi.org/10.3390/healthcare9020222

Caromano, F. A., Amorim, C. A. P. de, Rebelo, C. de F., Contesini, A. M., Fávero, F. M., Frutuoso, J. R. C., Kawai, M. M., & Voos, M. C. (2015). Prolonged sitting and physical discomfort in university students. Acta Fisiátrica, 22(4). https://doi.org/10.5935/0104-7795.20150034

Cobo-Rendón, R., Vega-Valenzuela, A., & García-Álvarez, D. (2020). Consideraciones institucionales sobre la Salud Mental en estudiantes universitarios durante la pandemia de Covid-19. CienciAmérica, 9(2), 277. https://doi.org/10.33210/ca.v9i2.322

Ganne, P., Najeeb, S., Chaitanya, G., Sharma, A., & Krishnappa, N. C. (2020). Digital Eye Strain Epidemic amid COVID-19 Pandemic–A Cross-sectional Survey. Ophthalmic Epidemiology, 00(00), 1–8. https://doi.org/10.1080/09286586.2020.1862243

Giovannetti, A. C. V. P., Fontana, P., Suzuki, E. V., Cucinelli, A. do E. S., & Moreira, A. R. (2020). Pandemia Do Covid-19 E O Ensino De Engenharia: Desafio Enfrentado Pelos Professores. Anais Do Cobenge 2020. https://doi.org/10.37702/cobenge.2020.2973

Gold, J. E., Driban, J. B., Yingling, V. R., & Komaroff, E. (2012). Characterization of posture and comfort in laptop users in non-desk settings. Applied Ergonomics, 43(2), 392–399. https://doi.org/10.1016/j.apergo.2011.06.014

González-Menéndez, E., López-González, M. J., Menéndez, S. G., González, G. G., & Bayona, T. Á. (2019). Major health consequences a rising from the continued use of new eletronic devices qith visual display units. Revista Española de Salud Públicaública, 93(Agosto), 1–11.

Intolo, P., Shalokhon, B., Wongwech, G., Wisiasut, P., Nanthavanij, S., & Baxter, D. G. (2019). Analysis of neck and shoulder postures, and muscle activities relative to perceived pain during laptop computer use at a low-height table, sofa and bed. Work, 63(3), 361–367. https://doi.org/10.3233/WOR-192942

Jain, R., Rana, K. B., & Meena, M. L. (2021). An integrated multi-criteria decision-making approach for identifying the risk level of musculoskeletal disorders among handheld device users. Soft Computing, 0123456789. https://doi.org/10.1007/s00500-021-05592-w

Kanchanomai, S., Janwantanakul, P., Pensri, P., & Jiamjarasrangsi, W. (2011). Risk factors for the onset and persistence of neck pain in undergraduate students: 1-year prospective cohort study. BMC Public Health, 11. https://doi.org/10.1186/1471-2458-11-566

Kuorinka, I., Jonsson, B., Kilbom, A., Vinterberg, H., Biering-Sorensen, F., Andersson, G., & Jorgensen, K. (1987). Standardised Nordic questionnaires for the analysis of musculoskeletal symptoms. Applied Ergonomics, 18(3), 233–237. https://doi.org/10.1016/0003-6870(87)90010-X

Macêdo, T. A. de M., Cabral, E. L. D. S., Silva Castro, W. R., De Souza Junior, C. C., Da Costa Junior, J. F., Pedrosa, F. M., Da Silva, A. B., De Medeiros, V. R. F., De Souza, R. P., Cabral, M. A. L., & Másculo, F. S. (2020). Ergonomics and telework: A systematic review. Work, 66(4), 777–788. https://doi.org/10.3233/WOR-203224

Maia, B. R., & Dias, P. C. (2020). Anxiety, depression and stress in university students: The impact of COVID-19. Estudos de Psicologia (Campinas), 37, 1–8. https://doi.org/10.1590/1982-0275202037e200067

Morais, B. X., Dalmolin, G. de L., Andolhe, R., Dullius, A. I. dos S., & Rocha, L. P. (2019). Dor musculoesquelética em estudantes de graduação da área da saúde: prevalência e fatores associados *. Revista Da Escola de Enfermagem Da Usp, 1–8.

Naddeo, A., Califano, R., & Fiorillo, I. (2021). Identifying factors that influenced wellbeing and learning effectiveness during the sudden transition into eLearning due to the COVID-19 lockdown. Work, 68(1), 45–67. https://doi.org/10.3233/WOR-203358

Obembe, A. O., Johnson, O. E., Tanimowo, T. O., Onigbinde, A. T., & Emechete, A. A. (2013). Musculoskeletal pain among undergraduate laptop users in a Nigerian University. Journal of Back and Musculoskeletal Rehabilitation, 26(4), 389–395. https://doi.org/10.3233/BMR-130397

Rodríguez-Nogueira, Ó., Leirós-Rodríguez, R., Benítez-Andrades, J. A., Álvarez-álvarez, M. J., Marqués-Sánchez, P., & Pinto-Carral, A. (2021). Musculoskeletal pain and teleworking in times of the COVID-19: Analysis of the impact on the workers at two Spanish universities. International Journal of Environmental Research and Public Health, 18(1), 1–12. https://doi.org/10.3390/ijerph18010031

Rosario-Rodríguez, A., González-Rivera, J. A., Cruz-Santos, A., & Rodríguez-Ríos, L. (2020). Demandas Tecnológicas, Académicas y Psicológicas en Estudiantes Universitarios durante la Pandemia por COVID-19. Revista Caribeña de Psicología, 4(2), 176–185. https://doi.org/10.37226/rcp.v4i2.4915

Werth, A., & Babski-Reeves, K. (2014). Effects of portable computing devices on posture, muscle activation levels and efficiency. Applied Ergonomics, 45(6), 1603–1609. https://doi.org/10.1016/j.apergo.2014.05.008

Werth, A. J., & Babski-Reeves, K. (2012). Assessing posture while typing on portable computing devices in traditional work environments and at home. Proceedings of the Human Factors and Ergonomics Society, October 2012, 1258–1262. https://doi.org/10.1177/1071181312561223

Análise das condições ergonômicas na atividade de execução de alvenaria utilizando o método RULA

Carolina Mendes Lemos [1], Fabrícia Nascimento de Oliveira [2], André Duarte Lucena [3]

[1] Universidade de Brasília, Brasília, Brasil (carolinamendees@hotmail.com) ORCID 0000-0002-1872-2226, [2] Departamento de Engenharia e Ciências Ambientais, Universidade Federal Rural do Semi-árido, Mossoró, Brasil (fabricia@ufersa.edu.br) ORCID 0000-0002-0333-0035, [3] Departamento de Engenharia e Ciências Ambientais, Universidade Federal Rural do Semi-árido, Mossoró, Brasil (andrelucena@ufersa.edu.br) ORCID 0000-0003-0181-4260.
https://doi.org/10.24840/978-972-752-279-8_0095-00101

Resumo

Introdução: A atividade de execução de alvenaria está presente em praticamente todas as obras da construção civil, por isso, é importante conhecer os cuidados necessários para evitar futuros problemas ergonômicos com os colaboradores. Assim, várias técnicas ou métodos de avaliação postural tem sido empregados para analisar as situações de trabalho e identificar problemas musculoesqueléticos. Este estudo teve como objetivo realizar análises ergonômicas das posturas dos trabalhadores na atividade de execução de parede de alvenaria, assim como identificar as etapas de maior grau de risco e elaborar recomendações ergonômicas para a melhoria das atividades estudadas. Metodologia: Para a coleta de dados utilizou-se máquina fotográfica para registrar as fotos e fazer as filmagens. A partir dos dados coletados, realizou-se análise ergonômica com base nas posturas e movimentos adotados pelos trabalhadores durante à execução de alvenaria aplicando-se o método RULA. Participaram do estudo 14 funcionários envolvidos no processo produtivo de construção de alvenaria, sendo as etapas observadas: pegar areia para peneirar, peneirar areia, pegar areia peneirada, carregar areia peneirada, preparar argamassa, carregar argamassa, construir parede de alvenaria e chapiscar parede. Resultados e Discussão: Observou-se que das oito etapas analisadas, três delas obtiveram pontuação máxima, que foram: pegar areia para peneirar, pegar areia peneirada e chapiscar parede. Sendo a pontuação máxima 7, com grau de risco 4, onde a intervenção é introduzir mudanças imediatamente. As demais etapas apresentaram pontuação 5 ou 6, onde o grau de risco é 3 e a intervenção é do tipo investigação e mudanças na postura ao realizar as atividades. Conclusões: Para melhorar o ambiente de trabalho objeto desse estudo recomenda-se o revezamento de tarefas, pausas, prática de ginástica laboral, treinamentos e que as posturas e movimentos inadequados sejam corrigidos por meio de modificações no método de trabalho, com o intuito de adotar as posturas mais seguras, saudáveis e confortáveis para os trabalhadores envolvidos na atividade de execução de alvenaria.

Palavras-chave: Construção civil, Ergonomia, Avaliação postural, Movimentos repetitivos.

INTRODUÇÃO

A indústria da construção civil destaca-se por ser uma atividade econômica com alto índice de contratação de mão de obra, porém as estatísticas mostram que o número de acidentes de trabalho ainda são significativos nesse setor (Ensslin et al., 2014). Em geral, é possível detectar um nível considerável de riscos para a segurança e a saúde dos trabalhadores na construção civil, pois as máquinas, ferramentas e materiais usados nesses ambientes facilitam a realização de atividades gerando sobrecargas físicas e riscos biomecânicos (Oliveira, Bakke, & Alencar, 2009).

Existem várias técnicas e métodos de avaliação postural na literatura visando determinar e quantificar a exposição a fatores de risco por causa da sobrecarga biomecânica dos membros superiores, entre eles aqueles que mostram de forma qualitativa a existência de características ocupacionais que podem levar o avaliador em direção à possível presença de um risco (Pavani & Quelhas, 2006). Entre alguns dos métodos, destaca-se o RULA (Rapid Upper-limb assessment) que foi desenvolvido para analisar a exposição dos trabalhadores aos fatores de riscos relacionados aos distúrbios dos membros superiores (Iida & Buarque, 2016). Este método foi criado por McAtamney & Corlett (1993), os quais propuseram uma avaliação rápida dos danos potenciais aos membros superiores, em função da postura adotada, avaliando a postura do pescoço, tronco e membros superiores (braço, antebraço e mãos), relacionando com a atividade muscular e a força aplicada (Vasconcelos, 2017).

O método RULA é recomendado para avaliação ergonômica da postura em inúmeras atividades, inclusive já foi aplicado em várias pesquisas, tais como as conduzidas por Silva, Silva & Oliveira (2021); Paul, Gnanaraj, & Paul (2019); Röhm & Tirelli (2019); Kong, Lee, Lee & Kim (2018); Paim, Peraça, Sapper, Moreira, & Moreira (2017); Kohammadi, Sohrabi, Poursadeghiyan, Rostami, Tabar, Abdollahzadeh, & Tabar (2016); Patel & Patel (2016); Vazquez-Cabrera (2016); Rivero, Rodríguez, Pérez, Mar, & Juárez (2015); Rahman (2014); Ansari & Sheikh (2014); Singh & Kocher (2012); Serranheira & Uva (2000), entre outras.

Já para a indústria da construção, algumas pesquisas relacionadas com aplicação do método RULA têm sido desenvolvidas, com foco em atividades diversas que são desempenhadas nesse setor, como por exemplo, os trabalhos de Benedito et al. (2019) que analisou a tarefa de reabastecimento da máquina de fabricação de blocos de concreto, após a retirada da massa da betoneira; Silva, Santos, & Silva (2018) que estudou a postura do trabalhador ao executar três fases da pintura em uma residência; Morales & Rando Júnior (2015) que avaliou a interferência das condições ergonômicas no tempo de execução de paredes de alvenaria de blocos cerâmicos, identificando os problemas causadores de riscos ergonômicos na atividade; Silva Netto (2015) que realizou uma análise das condições ergonômicas de trabalho em atividades típicas na execução de revestimentos em superfícies verticais de edificações; Raffo (2014) que fez uma análise ergonômica baseada na observação dos diferentes movimentos e posições exercidos pelos operadores de retroescavadeira em uma empresa da área do saneamento ambiental; Saad, Xavier, & Michaloski (2006) que avaliou o risco ergonômico durante a tarefa de levantamento de paredes; entre outros.

Apesar de já existirem esses estudos, faz-se necessário realizar outros para verificar as posturas dos profissionais da construção civil a fim de prevenir a ocorrência de acidentes e doenças ocupacionais. Assim, essa pesquisa teve por objetivo realizar análises ergonômicas das posturas dos trabalhadores na atividade de execução de parede de alvenaria, assim como identificar as etapas de maior grau de risco e elaborar recomendações ergonômicas para a melhoria das atividades estudadas.

METODOLOGIA

A pesquisa foi aplicada em um dos canteiros de obras de uma empresa de construção civil localizada na cidade de Mossoró-RN, no Brasil.

Esse estudo caracteriza-se como um estudo de caso com análise qualitativa e quantitativa dos dados. A escolha do local da pesquisa se deu de forma intencional pois a pesquisadora decidiu pelo canteiro de obras em que estava estagiando para realizar a aplicação do método RULA na atividade de execução de alvenaria. A coleta de dados foi feita através de registros fotográficos, filmagens e observações diretas.

Participaram do estudo 14 funcionários envolvidos no processo produtivo de construção de alvenaria, sendo 5 pedreiros, 7 serventes, 1 armador e 1 mestre de obra. O mestre de obra coordena e orienta a equipa e o armador produz armações de aço quando essas não são pré-fabricadas. No entanto, os dois também realizam as atividades de pedreiro quando estão desocupados de suas tarefas. A função do pedreiro é construir de modo geral todas as etapas de uma edificação e o servente os ajuda preparando e carregando materiais para o pedreiro, entre outras atividades. O horário de trabalho é das 7 às 11 horas e das 13 às 17 horas, totalizando 8 horas por dia. As vezes ocorre dos trabalhadores ultrapassar as 8 horas diárias para finalizarem alguma atividade, recebendo hora extra quando isso acontece.

Para a aplicação do método RULA, foi utilizado o Software Ergolândia® versão 6.0, onde pode-se inserir as posturas críticas exercidas pelo trabalhador e, com isso obter um valor global que indica o grau de risco da atividade. A partir deste foi possível elaborar um diagnóstico sobre a atual situação da atividade de execução de alvenaria, sendo as etapas observadas: pegar areia

para peneirar, peneirar areia, pegar areia peneirada, carregar areia peneirada, preparar argamassa, carregar argamassa, construir parede de alvenaria e chapiscar parede.

Os resultados foram mostrados em figuras e quadro resumindo as pontuações obtidas em cada uma das etapas.

RESULTADOS E DISCUSSÕES

Observou-se que para executar a atividade de alvenaria ocorrem oito etapas e que os resultados da avaliação postural dos trabalhadores pelo método RULA é apresentado no Quadro 1. Verifica-se que nenhuma postura assumida nas atividades analisadas teve pontuação inferior a 5, merecendo atenção dos profissionais da área de ergonomia, saúde e segurança do trabalho para implementar intervenções que visem minimizar as inadequações correspondentes às más posturas adotadas pelos trabalhadores.

Tabela 1. Resultado da análise postural pelo método RULA.

Etapa da atividade de execução de alvenaria	Posturas adotadas na atividade de execução de alvenaria	Pontuação RULA	Grau de risco	Intervenção
Pegar areia para peneirar		7	4	Introduzir mudanças imediatamente
Peneirar areia		5 ou 6	3	Investigação e introduzir mudanças
Pegar areia peneirada		7	4	Introduzir mudanças imediatamente
Carregar areia peneirada		5 ou 6	3	Investigação e introduzir mudanças
Preparar argamassa		5 ou 6	3	Investigação e introduzir mudanças

Carregar argamassa		5 ou 6	3	Investigação e introduzir mudanças
Construir parede de alvenaria		5 ou 6	3	Investigação e introduzir mudanças
Chapiscar parede de alvenaria		7	4	Introduzir mudanças imediatamente

Fonte: Dados da pesquisa (2018).

Na etapa de pegar areia para peneirar foi possível perceber que o funcionário realiza sua atividade em pé, curvado, com inclinação lateral no tronco e com movimentos repetitivos. Observa-se que o tronco tem 20° a 60° de inclinação lateral, o pescoço tem uma inclinação de 10° a 20º, pernas apoiadas e equilibradas e carga entre 2 e 10 kg.

A atividade de peneirar areia é uma atividade repetitiva, onde o funcionário realiza os movimentos de levantar e abaixar os braços com 20°+ de inclinação e antebraços com 0° a 60°. O pescoço e o tronco levemente inclinado para frente com respectivamente 0° a 10° e 0° a 20° de inclinação, respectivamente.

Ao pegar a areia peneirada e colocar no carro de mão, o funcionário realiza uma atividade repetitiva com o tronco curvado com mais que 60° com inclinação lateral e rotação no pescoço de 0° a 10°. Para carregar areia peneirada, o funcionário conduz o carro de mão cheio de areia, com braço de 20° a 45°, o pescoço com uma inclinação de 0° a 10°, pernas apoiadas e equilibradas e carga acima de 10 kg.

A atividade de preparar argamassa consiste em colocar água, cimento e areia na betoneira. O funcionário realiza operações com o tronco de 20° a 60° com inclinação lateral e no braço movimentação de 20° a 20°. Ao pegar e carregar a argamassa, o funcionário inicialmente abaixa-se para pegar o carro de mão e depois aplica uma força para movimentá-lo. Nessa etapa a carga é acima de 10 kg, além disso o funcionário inclina o tronco até 60° para pegar o carro de mão, realizando esse movimento de forma incorreta, pois a maneira adequada seria se agachar e levantar o peso.

Para construir a parede de alvenaria, o funcionário pega a argamassa do carro de mão com a colher de pedreiro colocando-a sobre o tijolo anteriormente assentado, depois ele passa a massa na lateral do tijolo, coloca este no local do assentamento e bate duas vezes com a colher de pedreiro em cima do bloco. Nessa atividade a carga é inferior a 2 kg e em alguns momentos do processo, o funcionário apresenta rotação de pescoço e rotação e inclinação lateral do tronco.

Já na etapa de chapiscar a parede, o funcionário realiza a atividade com rotação, inclinação lateral do tronco e pescoço. Com relação ao braço e antebraço, este apresentou alta variação

angular e abdução e operações exteriores ao tronco. De acordo com a altura da parede este vai realizar posturas diferentes, no momento que ele chapisca na parte inferior da parede se curva e quando é na parte superior ele levanta o braço para atingir as partes mais elevadas. A atividade é considerada intermitente com carga menor que 2 kg.

Foi possível perceber que das oito etapas analisadas, três delas obtiveram pontuação máxima, que foram: pegar areia para peneirar, pegar areia peneirada e chapiscar parede. Sendo a pontuação máxima 7, com grau de risco 4, onde a intervenção é introduzir mudanças imediatamente no canteiro de obras. Também foram encontrados os mesmos resultados, na etapa de chapiscar parede, na pesquisa de Silva Netto (2015) na qual constatou que seria necessário intervenção de caráter iminente em todas as posturas assumidas para essa tarefa, pois a pontuação foi 7 com grau de risco 4, reforçando os achados do presente trabalho.

As outras cinco etapas apresentaram pontuação 5 ou 6, onde o grau de risco é 3 e a intervenção é do tipo investigação e mudanças na postura ao realizar as atividades. Essas etapas foram: peneirar areia, carregar areia peneirada e argamassa, preparar argamassa e construir parede de alvenaria. Os resultados dessa pesquisa corroboram os estudos de Xavier, Michaloski & Saad (2009) que obtiveram para o levantamento de paredes, pontuação que variou de 6 a 7.

No presente estudo, os resultados mostram que todas as etapas da construção de uma alvenaria precisam de intervenção do tipo investigação e mudanças na postura ao realizar as atividades no canteiro de obras. São necessárias correções, principalmente no caso das que exigem a inclinação e torção da região das costas.

Para melhorar o ambiente de trabalho objeto deste estudo recomenda-se: revezamento de tarefas; realização de pausas; inclusão da prática de ginástica laboral; realização de treinamentos sobre posturas e movimentos adequados; uso de adesivo de base mineral que substitua o cimento no assentamento de blocos; utilização de máquina de chapisco e reboco, que assegura ganho de tempo e evita o trabalho manual que, nesta atividade, costuma representar risco ergonômico; uso de carrinho de mão ergonômico com travão de pé fácil de acionar, com pegas de borracha natural adaptadas à forma das mãos, duas pegas altas para manobrar o carrinho de mão e duas pegas baixas para inclinar e esvaziar o carrinho de mão.

CONCLUSÕES

A partir do método RULA observa-se que as posturas adotadas estão inadequadas para a atividade de execução de alvenaria, mostrando que as mudanças no posto de trabalho devem ocorrer de modo imediato ou investigar e introduzir mudanças.

A carga que os trabalhadores transportam e a repetitividade são variáveis com a etapa a ser executada na alvenaria, no entanto, as posturas adotadas no trabalho podem ser as principais causas de problemas de diminuição de produtividade e aumento de doenças e acidentes no trabalho.

Como melhoria para o canteiro de obra, recomenda-se a introdução de correções nas posturas inadequadas através de alterações no método de trabalho, bem como estabelecer uma rotina para que os colaboradores possam participar de treinamentos custeados pela empresa, com o objetivo de apresentar posturas mais seguras, saudáveis e confortáveis. Recomenda-se também a utilização de materiais, ferramentas e equipamentos inovadores da construção civil de modo a aumentar a produtividade e diminuir os riscos ergonômicos.

Para a elaboração desse estudo, ocorreram algumas limitações, tais como: não foi possível a participação de mais de uma empresa para realização da pesquisa; dificuldade em encontrar uma obra que possuísse atividades na fase de alvenaria e que concordasse em aceitar o estudo; o tempo disponível para coleta de dados foi exíguo.

Portanto, com o método RULA, é possível avaliar a atividade de execução de alvenaria e verificar se a postura está aceitável ou é necessário mudar imediatamente. Este é um método ergonômico que investiga a exposição dos trabalhadores aos fatores de risco, e o mesmo tem como vantagem uma avaliação inicial rápida de um elevado número de trabalhadores.

Referências bibliográficas

Ansari, N. A., & Sheikh, M. J. (2014). Evaluation of work Posture by RULA and REBA: A Case Study. IOSR Journal of Mechanical and Civil Engineering, 11(4), 18-23. https://doi.org/10.9790/1684-11431823

Benedito, I. B., Alves, I. S., Castro, B. O. P., Castro, L. F., & Barbosa, S. B. (2019). Avaliação ergonômica no setor de construção civil: aplicação do método RULA em uma fábrica de pré-moldados. REP - Revista de Engenharia de Produção, 1(1), 143-157.

Ensslin, S. R., Ensslin, L., Moreira, A. C. S., & Pereira, V. L. D. V. (2014). Evidenciação do estado da arte da avaliação da segurança do trabalho em empreendimentos da construção civil. Interciencia [en linea], 39(1), 6-23. https://www.redalyc.org/articulo.oa?id=33930067003

Iida, I., & Buarque, L. I. A. (2016). Ergonomia: projeto e produção. Editora Blucher.

Kohammadi, H. Y., Sohrabi, Y., Poursadeghiyan, M., Rostami, R., Tabar, A. R., Abdollahzadeh, D., & Tabar, F. R. (2016). Comparing the posture assessments based on RULA and QEC methods in a carpentry workshop. Research Journal of Medical Sciences, 10(3), 80-83.

Kong, Y. K., Lee, S. Y., Lee, K. S., & Kim, D. M. (2018). Comparisons of ergonomic evaluation tools (ALLA, RULA, REBA and OWAS) for farm work. International journal of occupational safety and ergonomics, 24(2), 218-223. https://doi.org/10.1080/10803548.2017.1306960

McAtamney, L., & Corlett, E. N. (1992). Reducing the risks of work related upper limb disorders: a guide and methods. Institute for Occupational Ergonomics, University of Nottingham.

Morales, G., & Rando Jr, A. M. (2015). Redução do tempo de execução de alvenaria decorrente de intervenções ergonômicas. Revista Eletrônica de Engenharia Civil, 12(3), 56-65. https://doi.org/10.5216/reec.v12i3.37189

Oliveira, A. G. S., Bakke, H. A., & Alencar, J. F. (2009). Riscos biomecânicos posturais em trabalhadores de uma serraria. Fisioterapia e Pesquisa, 16(1), 28-33. https://doi.org/10.1590/S1809-29502009000100006

Paim, C., Peraça, D., Sapper, F., Moreira, I., & Moreira, T. (2017). Análise Ergonômica: Métodos Rula e Owas aplicados em uma Instituição de ensino superior. Revista Espacios, 38(11), 22-31.

Patel, P., & Patel, T. (2016). Ergonomic modification in study bench with validation through RULA method and EEA. International Journal for Research & Development in Technology, 5(5), 112-115.

Paul, B. P., Gnanaraj, D., & Paul, S. (2019). Ergonomic design and rula analysis of a motorised wheelchair for disabled and elderly. International Journal of Mechanical Engineering and Technology (IJMET), 3(1), 1014-1025.

Pavani, R. A., & Quelhas, O. L. G. (2006). A avaliação dos riscos ergonômicos como ferramenta gerencial em saúde ocupacional. Anais... XIII Simpósio de Engenharia de Produção. Bauru, SP, 1-9.

Raffo, S. C. (2014). Avaliação dos níveis de ruído e aplicação do método RULA no posto de trabalho do operador de retroescavadeira. Especialização de Engenharia de Segurança do Trabalho, Universidade Tecnológica Federal do Paraná, Brasil.

Rahman, C. M. (2014). Estudo e análise da postura de trabalho de trabalhadores de uma indústria cerâmica através da avaliação rápida do membro superior (RULA). International Journal of Engineering , 5(03), 14-20.

Rivero, L. C., Rodríguez, R. G., Pérez, M. D. R., Mar, C., & Juárez, Z. (2015). Fuzzy logic and RULA method for assessing the risk of working. Procedia Manufacturing, 3, 4816-4822. https://doi.org/10.1016/j.promfg.2015.07.591

Röhm, D. G., & Tirelli, M. A. (2019). Aplicação da ferramenta ergonômica RULA: estudo de caso em uma indústria automobilística. Multiciência, 18, 159 – 178.

Saad, V. L., Xavier, A. A. P., & Michaloski, A. O. (2006). Avaliação do risco ergonômico do trabalhador da construção civil durante a tarefa do levantamento de paredes. In: SIMPÓSIO DE ENGENHARIA DE PRODUÇÃO, 13., Bauru/SP. Anais... Bauru/SP, UNESP, 8 p.

Serranheira, F., & Uva, A. S. (2000). Avaliação do risco de lesões musculo-esqueléticas do membro superior ligadas ao trabalho (LMEMSLT): aplicação dos métodos RULA e Strain Index. Saúde & Trabalho, 3, 43-60.

Silva, F. C., Santos, B. S., & Silva, A. (2018). Análise ergonômica em três fases da pintura utilizando o método RULA. In: CONGRESSO BRASILEIRO EM ENGENHARIA DE PRODUÇÃO, 8., Ponta Grossa/PR. Anais... Ponta Grossa/PR, APREPRO, 9 p.

Silva, T. A. M. D., Silva, R. J. R. D., & Oliveira, R. B. D. (2021). Análise dos riscos ergonômicos e posturais dos funcionários da secretaria acadêmica de uma faculdade privada de saúde do Recife. http://tcc.fps.edu.br:80/jspui/handle/fpsrepo/982

Silva Netto, E. P. (2015). Análise das condições ergonômicas de trabalho em atividades típicas na execução de revestimentos em superfícies verticais de edificações. Mestrado em Engenharia Civil, Universidade Tecnológica Federal do Paraná, Brasil. http://repositorio.utfpr.edu.br:8080/jspui/handle/1/2002

Singh, J., Lal, H., & Kocher, G. (2012). Musculoskeletal disorder risk assessment in small scale forging industry by using RULA method. International Journal of Engineering and Advanced Technology, 1(5), 513-518.

Vasconcelos, G. B. T. (2017). Análise ergonômica da fabricação de estruturas de sofá em uma indústria moveleira. Curso de Ciência Florestal, Universidade Federal de Viçosa, Brasil.

Vazquez-Cabrera, F. J. (2016). Ergonomic evaluation, with the RULA method, of greenhouse tasks of trellising crops. Work, 54(3), 517-531.

Xavier, A. A. P., Michaloski, A. O., & Saad, V. L. (2009). Avaliação da existência de DORT de membros superiores através de testes musculares específicos e relatos de dor em pedreiros na tarefa do assentamento de tijolos. Revista Gestão Industrial, 5(4), 115-129. https://periodicos.utfpr.edu.br/revistagi/article/view/494/389

DCE21

4th DOCTORAL CONGRESS IN ENGINEERING

28 - 29 JUNE 2021
FEUP
PORTO - PORTUGAL