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.
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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	45	34
Pubmed	171	169	169	161	33		
Web Of Science	74	65	65	65	11		
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.

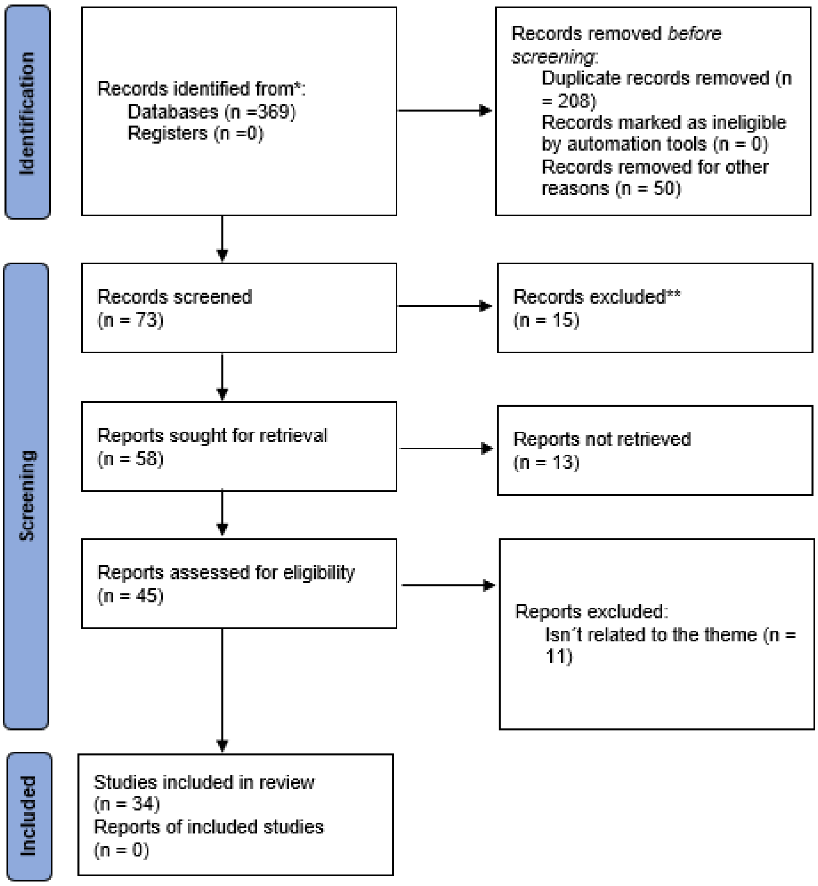

Figure 1. PRISMA flow diagram (Page et al., 2021)

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