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Review Article

Occupational Hazards in Firefighting: Systematic Literature Review

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ABSTRACT

Background: Firefighting involves exposure of firefighters to risks related to this activity, serious injuries, and occupational diseases are recorded. There are other consequences such as thermal and emotional stress. This systematic review is proposed in order to analyze the risks and consequences faced by these workers and thus provide elements to improve safety management systems in institutions.
Method: A descriptive observational study of systematic literature review on the risks and consequences of exposure to firefighters' activity was proposed, and the information was analyzed and described based on the available data and according to the variables determined.
Results: The studies showed data on mechanical, physical, chemical, psychosocial risks, workers' perception and resilience, and epidemiological data. Information related to firefighters' activity on falls and slips, exposure to noise, and high concentrations of carbon monoxide is detailed. In addition, the relationship between burnout, cognitive, and physical fatigue as adverse effects on health and performance is mentioned.
Conclusions: Among the preventive measures, the use of personal protective equipment is suggested, incorporation in prevention programs of information on exposure to risk factors, as well as the implementation of models that can predict the perception of workers, additionally, the generation of management systems with safety climate models for fire departments.

1. Introduction

In firefighting, firefighters are exposed to serious injuries and illnesses related to this activity, in some cases requiring hospitalization and some are forced to take early retirement. It is clear that this activity is dangerous. In the United States, firefighters die at a higher rate than most other workers [1]. This activity involves other consequences such as thermal and emotional stress; there is a relationship between high levels of stress and a high incidence of cardiac deaths. Due to the physical effort, the symptoms that these workers may have are increased heart rate and thermal stress, due to the increase in temperature in combination with dehydration [2].

Exposure to environmental agents such as carbon monoxide, hydrogen cyanide, chemicals such as aerosols and particulate matter suspended in the environment are factors that can cause damage to the health of firefighters. Physical factors, such as exposure to noise, are also analyzed as a risk factor, and studies have indicated that this exposure without hearing protection can pose a threat to cardiovascular health. Firefighters can be exposed to up to 120 decibels of noise from sirens [2].

In the case of fighting forest fires, firefighters face other types of risks. Based on the type of injury, it has been determined that animal attacks, contact with toxic plants, and hot weather are the least common causal factors, while slips, trips, and falls are more frequent. It is important to note that the peak season for forest fires occurs during the hottest months and therefore environmental conditions range from warm to dry, which increases the risk of heat-induced consequences such as heat exhaustion and heat stroke in this activity [3].

The risks to which workers are exposed in this activity are evident, regardless of the scenario they face. In relation to the fight against forest fires and the imminent risks to this activity, the importance of prevention must be considered from the social and institutional point of view; it is essential to carry out comprehensive actions to strengthen the management for the prevention of forest fires in different localities, but as part of these actions, the

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protection of workers and the implementation of prevention systems in the institutions become a necessary complement to fully meet this objective. This systematic review is proposed in order to know the methodologies used for the study and analysis of the exposure of workers to risks in firefighting and the possible consequences, in order to provide convenient elements for the management of safety in these institutions.

2. Material and methods

A systematic literature review aims to provide the best literary evidence to support scientific development on a specific topic, rigorously analyzing the context, presenting new trends in the scientific field. A systematic literature review is conducted to analyze the past and its results in order to prepare for the future by identifying, evaluating and interpreting studies [4]. Conventionally, these reviews are not constantly updated, which can lead to an increased risk of inaccuracies in current research, larger gaps in the literature, new contributions lost in the literature, and increased risk of error in decision-making [5]. This fact should be constantly observed by the researchers involved, in order to encourage the presentation and publication of studies that complement the demand for literature reviews, being one of the most relevant motivations for conducting this research.

The research logical framework adopted presents a systematic review of the literature on occupational hazards to which firefighters are exposed when fighting fires. The methodology to carry out the systematic review is developed by formulating research questions, in order to locate, select, and evaluate scientific articles that may be relevant for the analysis and synthesis of the information. The reason for conducting a systematic review on fire-related occupational hazards is to summarize the main evidence in the literature, so that it can be a robust scientific contribution to be used in future research. Fig. 1 shows the review protocol with a detailed description of the methodological procedures used for the development of the research.

The review protocol refers to the process of identifying the need for the study through the execution of primary readings. Therefore, the procedure presents five steps to conduct the research and thus fulfill the objective of this study. These steps consist of formulating questions, locating studies, selecting of the studies, describing the studies and analysis, and synthesizing the information which are described below.

2.1. Question formulation

Denyer and Tranfield mention that formulating questions is directly related to the fulfillment of the objectives of a systematic literature review [6]. In the end, the information obtained on the occupational hazards to which firefighters are exposed during a fire should form the basis for providing answers to the research questions formulated in this section, as well as serve as support for future research. It is not our interest to give definitive answers to the research questions listed but to serve as a guide in a controlled environment, allowing for a broader and more critical discussion on the subject. Considering the context, the following research question was formulated:

RQ1. What occupational risk factors are firefighters exposed to during a fire?

To further explore the systematic literature review, three additional secondary research questions were specified.

RQ1a. What are firefighters' perceptions of occupational hazards?
RQ1b. How does epidemiology relate to the activities performed by firefighters?
RQ3c. What control measures can be implemented to effectively manage the occupational hazards to which firefighters are exposed?

2.2. Locating studies

The location of the studies seeks to find information carried out over time, for which we searched for articles in the ScienceDirect and Scopus databases. The main reason for choosing the databases presented was the large number of journals that contains articles focused on occupational risk prevention, specifically on the control of occupational hazards. In addition to defining the databases, other criteria were listed for the selection of the universe of articles portraying the topic, such as year of publication, keywords, and languages. Fig. 2 shows a summary of the criteria adopted to refine the location of the scientific articles.

Within each database, articles were searched using keywords that were directly related to the objective proposed in this study.

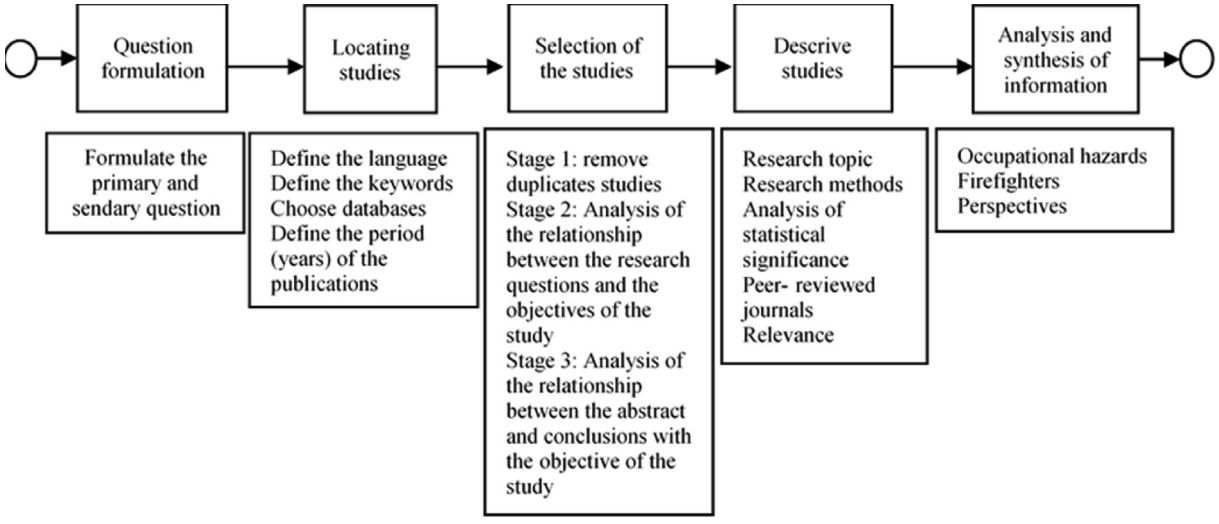

Fig. 1. Review protocol with the methodological procedures adopted.

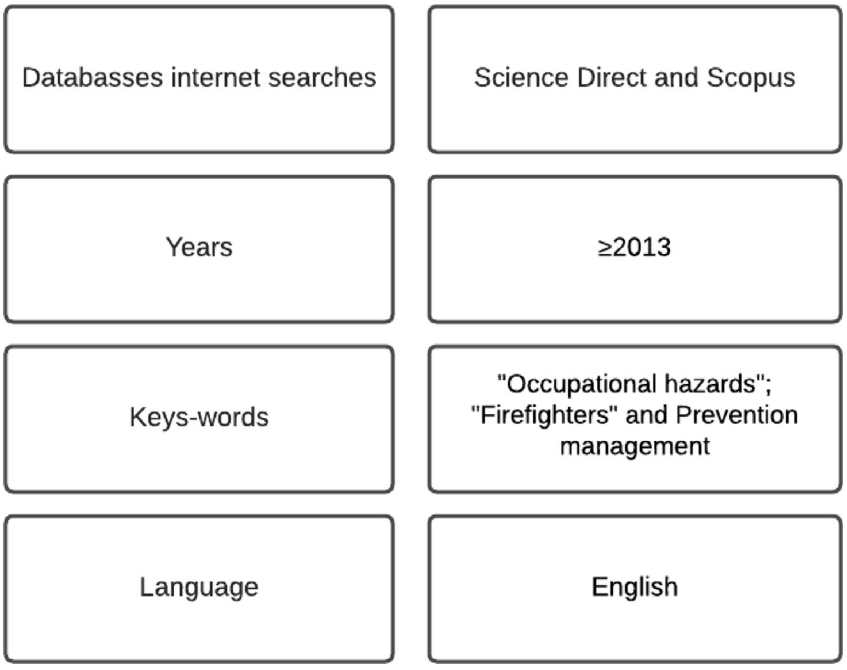

Fig. 2. Criteria adopted to find the articles.

These keywords were “Occupational hazards”; “Firefighters”; and “Prevention management,” and only scientific articles published since 2013 in English language were analyzed.

2.3. Studies selection

The selection of articles to be included in the literature review is done to contextualize and support the research, which consists of finding studies related to the purpose of the study and whose main premise is to answer the questions formulated in Section 2.1. Three stages make up the article selection process, called Stage 1, Stage 2, and Stage 3. In Stage 1, all repeated articles identified in the universe of studies were removed. In Stage 2, the titles of all the articles submitted were read and only those directly related to the research questions formulated were selected. Finally, in Stage 3, the abstracts and conclusions were read to define the articles that will make up the final database.

3. Results description

This section presents a compilation of information on the selected articles. As shown in (Table 1), after applying the search criteria, a total of 86 scientific articles were found. In Stage 1, a total of 66 articles are defined, 51 articles in Stage 2, and finally in Stage 3, 15 scientific articles are established, which make up the final database.

The detailed description of the characteristics of the 15 selected articles is stratified according to the following aspects:

Table 1
Number of articles filtered at each step

Selections of studies	Articles
Articles located	86
Stage 1	66
Stage 2	51
Stage 3	15

a. Research topic
b. Research methods
c. Analysis of statistical significance
d. Peer-reviewed journals
e. Relevance

A systematic reading of the selected scientific articles was carried out, with the aim of grouping them into research topics, research methods, analysis of statistical significance, peer-reviewed journals, and relevance. The first three aspects to be considered are detailed in (Table 2).

For the peer-reviewed journals, as shown in (Table 3), 15 selected articles are distributed in 11 journals, leading to a high dispersion in the relationship between the total number of articles published and the number of journals used to disseminate the research. This fact can be explained by the scope of the study topics explored over the years.

According to the journals used to perform this systematic review, it can be highlighted that there is a predominance of journals covering topics related to occupational hazards, safety, rehabilitation, quality, and occupational health; with this, it can be evidenced that there is a strong relationship between the topics of the journals and the research questions that were formulated. It can also be highlighted that the 11 journals have a JCR score, with a variation between 0.640 and 8.431.

The last aspect shown in this section is a comparison of the relevance of the publications. For each article, the number of citations (based on the Google Scholar citation index) and the total number of years since the year of publication were counted, considering November/2022 as the cutoff. Table 4 shows all the articles used with the number of citations and the average number of citations per year since publication.

Using their vast experience in occupational hazards associated with firefighters, with 66 citations, Britton et al [3] developed an investigation into the epidemiology of injuries sustained by wildland firefighters, highlighting that the most common injury mechanisms are caused by falls/slips/trips followed by equipment/

Table 2
Overview of the literature used

Author	Research topic	Methodology	Statistical significance analysis	Result
Neitzel et al, 2015 [7]	Physical	Logistic regression model (surveys and noise measurement).	Statistically significant variables within a 95% confidence interval (CI) are shown.	Dose–response relationship between injuries and near misses and increased noise.
Wu et al, 2021 [8]	Chemical	Measurements of PM2.5 (Particles with a diameter of 2.5 μm), CO (Carbon Monoxide) and black carbon (BC) in smoke particles during prescribed burns. Survey application.	Statistically significant variables within a 95% confidence interval (CI) are shown.	A total of 28 personal carbon monoxide exposure concentrations above the Recommended Exposure Limit (REL).
Caban-Martinez et al, 2020 [9]	Chemical	Management of epidemiological data exposing a high risk of skin cancer in firefighter groups during fire response activities.	No statistical significance analysis is presented.	Mechanisms of dermal absorption of carcinogenic compounds or harmful chemicals found in polycyclic aromatic hydrocarbons (PAHs) during fire. Personal protective equipment (PPE) used by firefighters can promote dermal absorption and increase the risk of cancer.
Kong et al, 2013 [10]	Mechanical	Review on the incidence and economic cost of accidental slips, trips, and falls in firefighter activities.	No statistical significance analysis is presented.	Evidence affirms that the mass of boots worn by firefighters is associated with an increased risk of slips and falls, as well as increased fatigue.
Yung et al, 2021 [11]	Psychosocial	Review on fatigue in workers.	No statistical significance analysis is presented.	Burnout, cognitive fatigue, and physical fatigue caused adverse effects on workers' health and performance.
Haddock et al, 2017 [12]	Psychosocial	Online survey. Snowball sampling technique. Worked with female professionals.	Statistically significant variables within a 95% confidence interval (CI) are shown.	There is a relationship between those diagnosed with depression or posttraumatic stress disorder and problem drinkers. 40% more likely to suffer an accident at work.
Heydari et al, 2021 [13]	Psychosocial	Application of unstructured and semi-structured interviews.	No statistical significance analysis is presented.	Resilience assessment can improve firefighter decision-making.
Fullagar et al, 2021 [14]	Perception	Prospective survey applied to 473 firefighters.	No statistical significance analysis is presented.	Firefighters believe that passive techniques or strategies that are easier to apply are the most effective versus advanced ones such as cooling systems.
Coehoorn et al, 2020 [15]	Perception	Incremental test application (39.5°C for 2 hours) with and without firefighting equipment. Bayesian hypothesis test.	Statistically significant variables within a 95% confidence interval (CI) are shown.	Rapid heat stress and increased physiological stress lead to decreased control in decision making which can affect firefighter rescue and firefighting activities.
Rodríguez-Garzón et al, 2021 [16]	Perception	Psychometric instrument to measure risk perception. Multivariate linear model and linear regression analysis.	Statistically significant variables within a 95% confidence interval (CI) are shown.	Significant differences between volunteer firefighters evidencing lower levels of risk perception compared to career firefighters.

Britton et al, 2013 [3]	Epidemiology	Logistic regression model.	Statistically significant variables within a 95% confidence interval (CI) are shown.	The most important mechanism of injury was slips/trips/falls.
DeJoy et al, 2017 [1]	Risk management	Safety climate model for the fire department. Focus groups. Logistic regression model.	No statistical significance analysis is presented.	Guidance is provided with specific measures for a safe firefighting climate and interventions to improve safety.
Hard et al, 2019 [17]	Risk management	Review of fatality investigations between 2006 and 2014.	No statistical significance analysis is presented.	There were changes in traumatic injury recommendations, strategies, and tactics by firefighters.
Bui et al, 2019 [18]	Risk management	Interrupted time series analysis.	Statistically significant variables within a 95% confidence interval (CI) are shown.	Risk management programs have a potential benefit in reducing fire department accidents and associated costs.
Eastlake et al, 2015 [2]	Risk management	Logistic regression model.	Statistically significant variables within a 95% confidence interval (CI) are shown.	Respiratory protection could help with the reduction of inhaled particles. Dermal protection to prevent absorption of soot contaminants through the skin. Limiting exposure to avoid adverse health effects.

Table 3
List of peer-reviewed journals classified by number of articles published

Journal	Articles	JCR
Environmental Research	1	8.431
Safety Science	3	6.392
Journal of Safety Research	3	4.264
American Journal of Emergency Medicine	1	4.093
Applied Ergonomics	1	3.940
Fire Safety Journal	1	3.780
Annals of Work Exposures and health	1	2.779
Annals of Occupational Hygiene	1	2.241
WORK: A Journal of Prevention, Assessment & Rehabilitation	1	1.803
Women's Health	1|	0.84
Chinese Journal of Traumatology	1	0.640

tools/machinery. With 54 citations, the second most cited article is a key article proposed by Kong et al [10] on the incidence of risk factors of accidental slips, trips, and falls, in which they highlight the relationship of intrinsic and extrinsic factors that cause the occurrence of this type of injury. Finally, the third most relevant article deals with safety climate and firefighting, proposed by DeJoy et al [1], with 50 citations, in which they highlight that safety climate is multidimensional, and these dimensions affect when fighting fires.

4. Analysis and synthesis of information

This section presents an analysis and synthesis of the information found by each of the studies determined to answer the research questions formulated; this information is divided according to the findings according to the risk factor (physical, chemical, mechanical, and psychosocial), the epidemiology of firefighters, and risk management.

4.1. Physical risk

Neitzel and his team studied the relationship between noise exposure and injuries suffered by firefighters. Information is collected from firefighters who train in a training campus that simulates different stages where they form emergency response teams for collapsed structures, vehicle rescue, among others. In addition, information is collected on demographic data, health

Table 4
List of scientific articles by number of citations and average number of citations per year

Reference	Number of citations	Citations per year
Britton et al (2013) [3]	66	7.33
Kong, Suyama & Hostler (2013) [10]	54	6
DeJoy, Smith & Dyal (2017) [1]	50	10
Haddock et al (2017) [12]	42	8.4
Eastlake et al (2015) [2]	38	5.42
Neitzel et al (2015)	18	3
Hard et al (2019) [17]	11	3.67
Fullagar et al (2021) [14]	11	5.5
Yung et al (2021) [11]	9	4.5
Wu et al (2021) [8]	6	3
Rodríguez et al (2021) [16]	5	2.5
Bui et al (2019) [18]	5	1.67
Coehoorn et al (2020) [15]	5	1.7
Heydari et al (2021)	2	2
Caban-Martinez et al (2020)	1	0.5

status of the subjects, age, body mass index, and a history of serious injuries, in case they have required treatment from any health or first aid entity. The evaluation was carried out by means of surveys and noise measurement by means of an acoustic dosimeter for 24 hours. A logistic regression model was used to estimate accidents and near misses associated with noise exposures as an independent variable [7].

The models indicated that there is a dose–response relationship between injuries and near misses and increasing noise levels. For noise levels above 90 dBA, there was a significant increase in the likelihood of a near miss or injury when exposure occurred within the previous 30 minutes. The logistic regression models used showed that age was significantly associated with a higher risk of injury, while experience showed a significant preventive effect. Regarding accidents or near misses, body mass index (BMI), job demands, and perceived hearing difficulty were associated with an increased risk of accident. However, Model 1 indicates a nonsignificant trend in the probability of accident or near-accident when the task is set with a shorter time (first hour of the training session). This model also shows a significant increase in the probability of an accident or near-accident at higher noise levels (90 dBA $\leq$ LEQ $<$ 95 dBA, and LEQ $\geq$ 95 dBA). In relation to Model 2, no significant risk of accident associated with higher perceived noise levels was identified; this leads to establish that the difference may be due to personal perceptions of noise exposure. It is also determined that the risk of injury varies with the demands and time of work, a recommendation is included to perform this study in a real setting, not simulated. Among the measures suggested in the study are hearing protection and the incorporation of noise exposure in firefighters' injury prevention programs [7].

4.2. Chemical risk

A study by Wu et al characterized by the concentrations of exposure to air pollutants in smoke emissions from forest fires. Prescribed burns of a given area composed mainly of oak (63%), maple (21%), and aspen (9%) were conducted. A total of 35 firefighters, 31 men and 4 women, participated in the study between 2016 and 2019. Information was provided to the firefighters who participated in the study so that they could make a voluntary and informed decision. A questionnaire was used to obtain demographic data, work history, and information on the health status of the subjects [8].

Measurements of PM2.5 (2.5 μm diameter particles), CO (carbon monoxide), and black carbon (BC) in smoke particles were performed during prescribed burns. During the measurements, the firefighters carried a MicroPEM sensor (Lightweight MicroPEM aerosol sensor) (RTI International, RTP, NC), in addition a carbon monoxide meter was used and the BC level was determined by the light transmission technique using the SootScan™ optical transmissometer model OT21. Finally, for the quantification of trace metals, it was analyzed by inductively coupled plasma mass spectrometry (ICP-MS) [8].

The results determined that a total of 28 personal carbon monoxide exposure concentrations were above the National Institute for Occupational Safety and Health (NIOSH) Recommended Exposure Limit (REL). PM2.5 and CO concentrations were 2 to 7 times higher in one of the study regions (Midwest) than in the other regions. In clamping duties firefighters undergoing the study had higher carbon monoxide exposure concentrations compared to concentrations in firefighters performing lighting duties ($p < 0.01$), in the case of firefighters performing ignition they were exposed to a higher level of black carbon in smoke particles ($p < 0.01$). PM2.5 exposure shows no differences in concentration between tasks ($p = 0.08$); however, significant differences are observed during prescribed burning shifts (95% CI: 2.84–5.31 ppm) for CO, 111.05 μg/m^3 (95% CI: 81.38–151.55 μg/m^3) for BC, and 9.55% (95% CI: 6.90–13.22%) for BC/PM during prescribed burning shifts. The levels of (trace metals) in wildfire smoke particles were well below those corresponding to occupational exposure limits; no task-related differences were determined. The study concludes that adequate respiratory protection is necessary for firefighters against exposure to wildfire smoke [8].

Related to chemical risk, another study published by Caban-Martinez and his team highlights the need for the integration of regular occupational health and safety with workplace wellness programs. They emphasize the approach provided by the Total Worker Health (TWH) program developed by the National Institute for Occupational Safety and Health and its support in skin cancer prevention with actions at the organizational level and skin protection. The study is supported by epidemiological data exposing a higher risk of skin cancer in groups of firefighters during fire response activities; this is supported by the mechanisms of dermal absorption of carcinogenic compounds or harmful chemicals found in polycyclic aromatic hydrocarbons (PAH) that are formed as by-products of the combustion of materials that burn during the fire, it is indicated that the personal protective equipment (PPE) used by firefighters may favor dermal absorption and increase the risk of cancer [9].

The proposal is to generate strategies by occupational hygienists and that incorporate organizational leadership commitment initiatives, elimination of workplace hazards and promotion of worker wellness, worker participation in program design and implementation, assurance of confidentiality and privacy in participation, and effective integration of systems [9].

Suggested measures within the program include support for annual skin cancer screening activities and monitoring of environmental exposures through the use of skin swabs or silicone wristbands to document personal exposures in firefighters. In addition, digital technologies that allow the recording of personal exposure, the type of PPE, as well as the frequency and duration of an exposure to carcinogens [9].

4.3. Mechanical hazard

For the analysis of this aspect, a study by Kong et al is proposed in which a review is consolidated including the incidence and economic cost of accidental slips, trips, and falls in the activities of firefighters. In relation to falls suffered by firefighters, the study proposes an analysis including individual or intrinsic factors and factors related to the external or extrinsic environment. In the case of internal factors, balance, age, experience, muscle strength, muscle mass, and fatigue were analyzed. For the external factors, equipment, reduced vision, surface condition, and heat were analyzed [10].

The possibility of using balance tests to predict accidents related to falls is considered. Although there is no agreement among studies that support this cause, it is concluded that more studies are needed to be able to reduce these accidents related to firefighting. In addition, it is mentioned that these aspects (slips and falls) should be analyzed not only reviewing the simple description of the incidence or the cost that this meant but all aspects integrally. Regarding experience, it is necessary to evaluate independently the case of trainees/volunteers and experienced firefighters and to improve strength and muscle power training [10].

Finally, the conclusions of the study detail that there is evidence that the mass of boots worn by firefighters is associated with an increased risk of slips and falls, as well as increased fatigue. Based on the evidence presented for the analysis, it is stated that typical rest periods of 20 minutes are insufficient to bring heart rate and

body temperature back to baseline, and it is important that sufficient firefighter teams are formed so that all workers can be guaranteed rest [10].

4.4. Psychosocial risk

On this aspect, Yung et al conducted a literature review that examines how fatigue has been conceptualized in workers, based on three occupations to identify differences and similarities according to the type of risk and outcomes, in order to develop a fatigue risk management standard for workers who provide first response actions in an emergency. Further research on cognitive fatigue in paramedics is obtained by compiling the information. In relation to firefighting, the studies focused on physical fatigue and in terms of risk factors, personal, social, cultural, as well as work organization were predominant. The results of the studies collected on physical health were mainly related to firefighters [11].

Subsequent to the review, it is analyzed the fact that for the development of a fatigue risk management standard for workers performing first response action, the risk factors in the workplace must be considered, in addition to the personal, social, and cultural ones, with the objective that the application serves for prevention in the short and long term. It was found that all three occupations, burnout, cognitive fatigue, and physical fatigue caused adverse effects on health and performance; therefore, the importance of controlling these risk factors becomes evident. There were more similarities between the results associated with police and firefighter activity; it is recommended to focus management on multiple types of fatigue [11].

Haddock et al conducted a study related to the consequences of high stress levels in firefighters, and the prevalence of medical and mental disorders associated with this activity was highlighted. This research examined alcohol consumption among female firefighters. To meet the objective of the study, the researchers conducted an online survey of female workers, which included informed consent. The snowball sampling technique was used to identify the study population and only worked with career female firefighters; volunteers were excluded. The survey was carried out with 2,022 women, 94.6% of whom answered the questions on alcohol consumption. In addition, a history of anxiety or depressive disorder was evaluated, as well as the presence of current symptoms of depression, for which the Brief Depression Scale of the Centers for Epidemiological Studies (CES-D) was used, and cases of post-traumatic stress, work trauma, and job satisfaction were also included in the evaluation [12].

Forty percent of the women reported binge drinking, 4.3% reported driving while intoxicated, and of the female firefighters in the study who reported drinking, 16.5% were classified as problematic drinkers. It was determined that there is a relationship between those diagnosed with depression or post-traumatic stress disorder and problem drinkers in 2.5 times more likely (odds ratios 2.55, CI 1.89−3.44), also they were 40% more likely to suffer an accident at work. Finally, it is concluded that excessive alcohol consumption is associated with negative occupational outcomes [12].

Other studies investigated the criteria that could affect resilience in firefighters by performing an analysis of each subject's experience. Through unstructured and semi-structured interviews, it was determined that personality, firefighters' physical condition, behavior and psychological characteristics can affect resilience or the ability to recover from an experience. In addition, organizational and safety management factors of the workers are detailed. This study concludes that developing tools for safety managers to assess resilience can improve decision making in the face of real data on firefighters' work capabilities [13].

4.5. Firefighters' perception of risks

Firefighting involves workers going through a recovery and heat mitigation phase. If firefighters do not perform this phase properly, the main consequences can be heat stress and elevated fatigue levels. Fullagar and his team conducted a study in 2021 that assessed firefighters' current perceptions of heat stress, fatigue, and recovery practices. The study used a prospective survey administered to 473 firefighters. Body areas associated with increased heat stress, as well as activities associated with mental and physical demands and fatigue levels were assessed. Additionally, firefighters were consulted on the use and importance of recovery and cooling practices, as well as the effectiveness of the established strategies [14].

According to the survey data, 62% of the firefighters indicated that the hottest activity was related to structural fires, followed by 51% who stated that the hottest activity was related to forest fires and 38% to rescue operations. The head (58%) is identified as the area of the body that gets the hottest in these activities, followed by the "whole body" (54%) and the "upper back" at 40%. According to the study, this could be due to the use of the protective uniform, and this creates a thermal environment that raises their body temperature. The 93% of the firefighters indicated that they proceed to "sit in the shade," the 90% indicated that they drink water, and the 89% of the firefighters indicated that they remove their helmet, hood, and jacket. The responses to the survey indicate that the firefighters included in the study consider that passive techniques or strategies, which are easier to apply, are the most effective against advanced ones such as cooling systems. The conclusions call for policy and operational interventions involving improvements in protective equipment and clothing, training and resources for firefighter recovery processes [14].

A relationship between heat stress and cognitive and neural function is known to exist in the decision making of firefighters under heat stress. Coehoorn and his team in 2020 conducted a study in which they hypothesized that a rapid increase in heat stress would lead to a decrease in decision-making ability. Fifteen firefighters were subjected to an incremental test to a maximum of 39.5°C in a 2-hour buffer time, some with firefighting equipment and some without [15].

The tests were performed in a laboratory that maintained a temperature of 25 to 26°C, subsequently the workers were subjected to an attention and concentration stimulation test (Go/No-Go) incorrect responses were observed in the subjects wearing the fire extinguishing equipment; however, no change was observed without the use of this equipment. In relation to the physiological impact of the thermal acquisition rate, at the end of the exercise, a mean = 1.74 was calculated, with a 95% CI of 0.67−2.82. Electroencephalograms (EEG) showed a decrease in Theta power comparing data with or without firefighting equipment, and no differences were observed in this aspect. It is concluded that rapid heat stress and the resulting increase in physiological tension cause a decrease in control in decision-making, and this, consequently, may affect firefighting and rescue activities in firefighters [15].

There are some risks that are undoubtedly present in firefighting, but what is the perception of volunteer and career firefighters about these risks? Rodriguez-Garzon and other researchers in 2021 analyzed the perception of firefighters on this aspect, a psychometric instrument was used to measure risk perception. The results show that there are significant differences between volunteer firefighters who evidence lower levels of risk perception compared to career firefighters or experience variable (CI −0.16951−3.05263). In addition, a Hierarchical Linear Model is used, which analyzed the levels of volunteerism as it is suggested that this may help predict risk perception [16].

4.6. Firefighter epidemiology

Britton et al hypothesize in their study the characteristics (type of injury, body part injured) and severity of firefighter injuries and indicate that this can be predicted based on the mechanism of injury. Using a logistic regression model, the researchers first analyzed firefighter injuries recorded between 2003 and 2007 by grouping and coding injuries by type, using Centers for Disease Control and Prevention (CDC) matrix. The probability of mechanism-related disabling injury was then assessed. A total of 1301 nonfatal wildland firefighter injuries were analyzed during the established period. The mechanism of injury was significantly associated with the type of injury and body part injured ($p \leq 0.001$), and it was determined that the most important mechanism of injury was slips/trips/falls (odds ratio 0.45; 95% confidence interval, 0.21–0.95); in second place, equipment/tools/machinery was defined; in addition that injuries from poisoning or environmental exposure were less likely to result in serious injury [3].

4.7. Risk management

The management for risk prevention, in the different situations in which a fire develops, involves concrete actions focused on prevention with the objective of identifying risks and minimizing the possible consequences. As part of this objective, DeJoy and his research group in 2017 develops and tests a safety climate model for the fire department whose methodology was based on the use of focus groups to identify the important dimensions that generate a safety climate. A 15-question online survey was administered on occupational risk factors, lifestyle-related risk factors, and demographic characteristics [1].

For the analysis, a logistic regression model was used to determine the relationship between the disease outcome variable and possible risk factors. Nine general aspects were revealed: competence and professionalism; physical and psychological readiness in which it is indicated that positive traits sometimes produce negative consequences in the sense that the same motivation, commitment, and pride that often contribute to good performance can lead the worker to make poor safety decisions. Cohesion and supervisor leadership/support at the work group level is another issue identified, as well as politics/bureaucracy, resources, and leadership and finally hiring and promotion at the organizational level. As mentioned above, this study concludes that a safe firefighting climate appears to have several dimensions; the study provides guidance for the development of specific measures and interventions to improve safety [1].

In the same line of prevention, the National Institute for Occupational Safety and Health (NIOSH), through its Firefighter Fatality Investigation and Prevention Program, conducts investigations of firefighter fatalities and updates on causes and risks. According to this study conducted between the years 2006 and 2014, a summary of recommendations for the improvement of prevention and care of workers is offered. Data on fatalities between the aforementioned years were selected for the study; other variables such as characteristics of the fire department, characteristics of the event, information on the victims, and information on contributing factors are taken into account. The reports are then classified according to cause of death (medical or traumatic), type of fire department, and career or volunteer firefighters [17].

After the application of the criteria raised in the methodology, priorities were determined; in the case of trauma, incidents with multiple fatalities are considered as top priority, followed by structure fires, and finally, incidents involving motor vehicles. It is indicated that by determining these aspects as the priorities of the research would probably have influenced the kind of recommendations raised; for this reason, it is possible that in the database of recommendations is prioritized on the strategy and tactics of extinguishing fires than on the operation of motor vehicles [17].

There are 1,067 recommendations for the period described (2006–2014). According to the findings of the study, there were changes in the main recommendations on traumatic injuries, being the main change for program improvement the training, which was identified as the main recommendation for that period to deal with these injuries, regarding the strategy and tactics used by firefighters the recommendations for improvement were prioritized, going up two positions according to the list of previous periods, the recommendations on motor vehicles and intervention equipment go down two positions, probably due to the priority criteria handled in the study. On communication, these recommendations are down on the list from previous periods [17].

Other studies, such as Bui et al, propose Proactive Risk Management against one of the leading causes of death associated with this activity, vehicle accidents, including rollovers and collisions with other vehicles and fixed objects; the purpose of the researchers was to evaluate the effect of management with a decrease in accidents. The teams created a risk register of the most common accident types, risks, and hazards; prioritized each of them using a risk matrix; and collected data on the controls and interventions currently in place for the high-priority risks and hazards and data related to additional interventions to be adopted and implemented [18].

Interrupted time series analysis was used to evaluate the effect of the programs on monthly rates; Poisson regression was used to estimate the number of crashes avoided; and as important data, economic data were analyzed to estimate cost savings. It is concluded that risk management programs present a potential benefit for the reduction of accidents in the fire department and associated costs; it is important to note that the results may vary depending on the interventions and how they are employed; however, as a practical application, it is mentioned that risk management can be an effective intervention to reduce accidents in firefighters' emergency activities [18].

As a final contribution to this section, we mention another study on lifestyles and safety practices in a group of firefighters and their relationship with cardiovascular risk factors. Based on a logistic regression analysis, it shows the relationship between variables such as health, high cholesterol or hypertension and risk factors such as occupational exposure and work lifestyle factors, the use of ear protection, respirators, skin exposure to soot or occupational stress. This study shows a statistical significance between high cholesterol, Muscle Mass Index, and alcohol consumption; however, this significance is higher with age (<0.01 CI 1.08 ± 0.04). Age was significantly related to blood sugar (<0.01 CI 1.24 ± 0.17) and arterial hypertension (<0.01 CI 1.06 ± 0.05). It is analyzed the fact that smoke inhalation, without the analysis of other factors, is not a predictive factor of subsequent heart disease; there are other variables such as physical exertion; therefore, it is shown that respiratory protection could help with the reduction of inhaled particles; it is recommended, in addition, to dermal protection to avoid the absorption of soot pollutants through the skin as well as decrease or limit exposure to avoid adverse health effects [2].

5. Conclusions

Research focused on the analysis of worker exposure in firefighting employs methodologies to generate a relationship between risk factors and determine intervention mechanisms to avoid or minimize the consequences to which workers are exposed. Among the methodologies used in the field, studies in this

systematic review include, for example, measurements of PM2.5 (particles with a diameter of 2.5 μm), CO (carbon monoxide), and black carbon (BC) in smoke particles; review on the incidence and economic cost of accidental slips, trips, and falls in firefighting activities; or the application of an incremental test up to 39.5°C. The data obtained were supported by some models such as logistic regression, epidemiological data handling, snowball sampling technique, Bayesian hypothesis testing, multivariate linear model, linear regression model, or interrupted time series analysis.

The application of the field work and the applied methods allowed to evidence some variables that are related to each other; it was evidenced that firefighters are exposed to a higher risk of skin cancer during fire response activities, by mechanisms of dermal absorption of carcinogenic compounds or harmful chemicals found in Polycyclic Aromatic Hydrocarbons (PAH) as by-products of the combustion of the materials that burn during the fire, in addition, the existence of evidence related to the mass of the boots used by firefighters and which is associated with a higher risk of slips and falls. On the other hand, it is shown that increased fatigue, burnout, cognitive fatigue, and physical fatigue cause adverse effects on health and performance in firefighters. The relationship between those diagnosed with depression or post-traumatic stress disorder and problem drinkers in firefighting institutions and consequently the probability of suffering a work-related accident is highlighted. The behavior and psychological characteristics of workers may affect resilience or ability to recover from an experience, as well as, rapid heat stress and increased physiological stress, cause a decrease in control in decision making in firefighters.

Implementing measures such as hearing protection and incorporating noise exposure into firefighter injury prevention programs is one of the measures proposed based on the analysis of the studies, as well as adequate respiratory protection for firefighters against exposure to smoke from forest fire. The monitoring of environmental exposures to avoid harmful effects, in addition, digital technologies that allow the recording of personal exposure, the type of PPE, as well as the frequency and duration of exposure to carcinogens are other measures proposed. Additionally, increasing rest periods to bring heart rate and body temperature back to baseline, assessing resilience to improve decision-making against real data on firefighters' work capabilities, together with the implementation of models that can predict the perception of risks to implement management systems and safety climate models, with the development of specific measures and interventions, in addition to the implementation of research and prevention programs for firefighter fatalities.

Conflicts of interest

The authors declare no conflicts of interest.

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