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Review Article

Work Exposome and Related Disorders of Firefighters: An Overview of Systematized Reviews

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ABSTRACT

Introduction: Firefighters experience many exposures associated with negative health outcomes. Because of this, there are many studies on the subject. Our objective here was to conduct an umbrella review of systematized reviews to identify firefighting activities and related exposures associated with negative health outcomes.

Methods: A comprehensive search of the PubMed, Web of Science, and Scopus (Health) was conducted using all firefighter systematized reviews. We extracted the country and date of the review, type of firefighter, types of exposure, and related health outcomes. Risk of bias was based on AMSTAR-2 checklist.

Results: In 1130 studies, 47 systematized reviews were included, mostly in the last 5 years and from North America and Australia. The topics were diverse, ranging from general aspects to specific exposures, such as polycyclic aromatic hydrocarbons, wildland fires, organizational, traumatic, or psychological stress exposure, and from prevention or surveillance to specific health effects (e.g., cancer, mental health, musculoskeletal disorders, cardiovascular, and pulmonary health, etc.). The risk of bias assessment using the selection grid shows a significant heterogeneity, though some studies were of very high quality.

Discussion: This umbrella review provides a comprehensive description of systematized reviews describing populations of firefighters, including information on exposure, health outcomes, and illness/injury prevention.

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1. Introduction

Many events have demonstrated the crucial role of adequately trained health and safety professionals in responding to health and environmental crises. [1–3]. In addition to healthcare sector workers and security professionals, firefighters represent a significant workforce that is required to respond to numerous exceptional situations [4–6]. Moreover, the nature of their occupation entails tasks that inherently impact their health and well-being [7]. Given the multitude of specific, acute, and chronic forms of exposures from; environmental, occupational, and lifestyle throughout their lifetime, the term “occupational exposome” seems especially appropriate for this population of workers. This concept is based on the “exposome” definition, which emerged following the success in mapping the human genome. The exposome integrates the multiplicity, temporality, and variability of exposures, as well as their interaction with one another [8,9]. For example, firefighters are exposed to chemicals substances during fires, elevated temperatures, noise, and other biomechanical factors. They also face shift work, long working hours [10,11], numerous psychosocial risk factors, including those associated with work organization, culture, and constraints unique to their occupation. [12]. Additionally, there may be variability in the level of exposure depending on the tasks performed, the work organization, the protective equipment, the seniority/rank (or lack thereof), duration of employment, and even their lifestyle individual factors. As such, the resulting health consequences are directly related to this exposome, and requires the translation of such knowledge to those affected. Despite the existence of numerous valuable studies with valuables systematic reviews allowing a high level of evidence, the consistency of data necessitates this review. Since there is no overview of such reviews, our objective was to conduct an umbrella review of systematized publications to identify firefighting activities associated with negative health outcomes, in order to highlight the multifaceted nature of occupational hazards faced by firefighters.

2. Methods

This review was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-analyses statement (PRISMA), see supplemental materials [13]. Four steps were performed in this umbrella review: A. inclusion step (database/syntax, title and abstract, full paper), B. extraction step, C. quality step, and D. synthesis step.

For A. inclusion step, we conducted the review search in three online databases: PubMed, Web of Science, and Scopus (Health) to identify systematic reviews published in peer-reviewed journals. Additional relevant systematic reviews were also searched in databases from NIOSH (National Institute for Occupational Safety and Health), EU-OSHA (European Agency for Safety and Health at Work), and the first 40 references of Google Scholar. The search strategy and inclusion criteria were defined according to the PI/ECO (Population and Intervention/Exposure, Comparison, and Outcome) approach. A librarian assisted in the development of the final search string syntax. The final search work was conducted without date limits until August 2024, with an update on December 1st. In detail, search was based on human studies of firefighters (Population, all type of fire/firefighters). The search strategy employed the truncation of the term “firefight” and aimed to identify the selected keywords within the article titles, abstracts, and keywords/medical subheading fields (for PubMed). The term “review” was considered a keyword rather than a filter to enhance the search’s sensitivity, in order to include systematized reviews (e.g., systematic, scoping, rapid, and umbrella review). Details of exposure relevant to health or health outcomes in this population (exposure/outcome), were checked manually as well as the effect measure (if present, meta-risk or meta-prevalence), without mandatory comparators. PubMed searches included: "fire fight"*[Title/Abstract] OR firefight*[Title/Abstract] OR “firefighters" [MeSH Terms] AND Review [Title/Abstract]; Web of Science: TS=(“ fire fight *" OR " firefight *" AND TS = review*); Scopus (health): ((TITLE-ABS-KEY (firefight*) OR TITLE-ABS-KEY (fire fight*)) AND TITLE-ABS-KEY (review*) AND (LIMIT-TO (SUBJAREA,"MEDI") OR LIMIT-TO (SUBJAREA,"HEAL")). Search results were imported to the web-based systematic review tool, Covidence (Veritas Health Innovation, Australia, https://www.covidence.org/). Duplicate records were removed. During title and abstract screening, all records were assessed independently by two co-authors (AD and HD) according to the previously outlined eligibility criteria. Disagreements regarding which articles should be included were resolved by consensus between the two authors. A similar approach was used for full-text record screening (i.e., those that did not fit the inclusion criteria, including those with irrelevant study designs, populations, or settings).

For B. the extraction step, the first author’s name, the year of publication and nationality of the first author, PI/ECO criteria, country of the review, type of firefighters, types of exposure and health outcomes, and intervention/prevention were extracted.

For C. the quality step, risk of bias was based on AMSTAR-2 [14]. Similarly to the inclusion step, all records were assessed independently by two coauthors (AD and HD). Disagreements were also resolved by consensus between the two authors.

D. the synthesis step includes a table with the type of work, the main result, the risk of bias map, and a graphical abstract for firefighters.

The review’s protocol was registered in PROSPERO as CRD42024557030.

3. Results

There are a large number of published systematized reviews on this particular population (1127 + 3 added in the update), focusing on firefighter exposures and their related health effects, of which 47 reviews were extracted. (Fig. 1 [15–61]). Notably, one study in the form of a Monograph published by the World Health Organization’s (WHO) International Agency for Research on Cancer (IARC) in 2022 [35], which includes a metaanalysis published as a separate study [27]. The first systematized review included was published in 2003, and half of the included systematized reviews were published in the last four years. North America and Australia were the first regions to publish this type of study, consistent with the countries where the original studies were published. Among the 47 systematic reviews, a total of 1214 studies involving firefighters were included (distribution on number of studies included: median 25.5, minimum 2, maximum 66 [40,41,59]). The number of firefighters included in each individual study also varied depending on its purpose (from 14 in an intervention study to 45,698 in a large cohort study [40,46]).

The topics are diverse (Fig. 2), ranging from general aspects to specific exposures, such as specific chemical agents, such as polycyclic aromatic hydrocarbons (PAH), wildland fires, and indoor air in fire stations, to agents of other types (organizational, traumatic or psychological stress), from prevention or surveillance to specific health effects (cancer, mental health, musculoskeletal disorders, cardiovascular and pulmonary health, etc.). Table 1 lists the main studies and their classification (their abstracts are provided in supplemental materials). The assessment of the risk of bias (RoB) according to the selection grid shows that the heterogeneity of the studies is significant, as shown in Fig. 3, though there are several studies of very high quality [20,27,48].

In terms of synthesis, this review highlights topics that are no longer debated, such as cancer risk in firefighters, but also

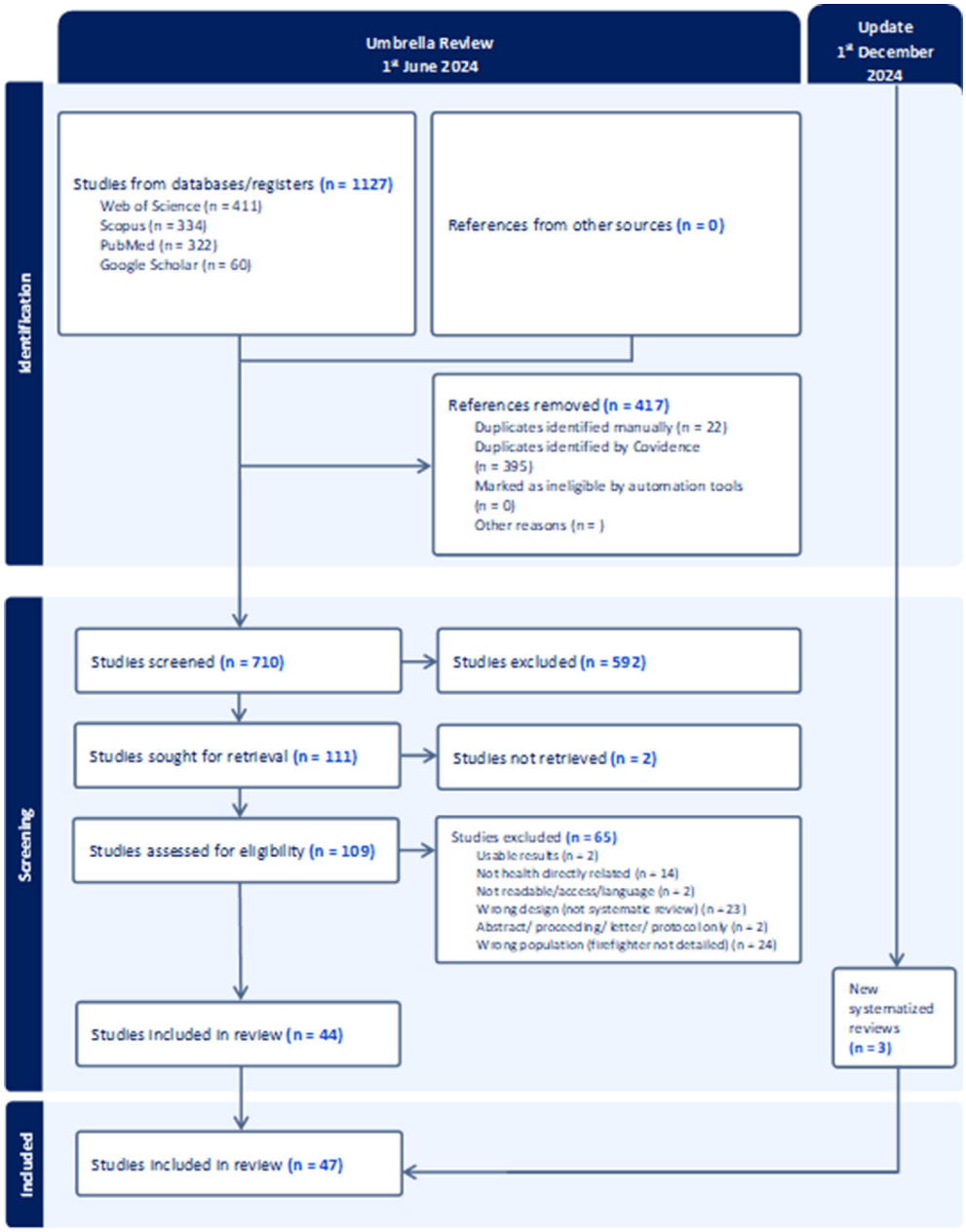

Fig. 1. Flow chart.

musculoskeletal disorders, and mental health disorders (Table 1). Indeed, recent high-quality syntheses with metaanalyses showed consistent increase risk of some cancers, such as mesothelioma and bladder cancer which exhibited low heterogeneity and were largely robust across sensitivity analyses, and relevant exposures of firefighters [27,35]. Furthermore, we found robust results based on metaanalyses from different parts of the world showed consistent high prevalence of musculoskeletal disorders of body area [49,39,55]. Mental health is important with a high proportion of posttraumatic stress disorders and also related to daily occupational stress [21,56,59].

Nevertheless, there remain many research gaps where systematic reviews need to be developed:

Nevertheless, there remain many areas where systematic reviews need to be developed, such as:

1. Specific intervention and prevention studies,
2. Studies in different contexts, given the differences that may exist between countries,
3. Differences among sub-populations (type of firefighter, sex, race and age),
4. The importance of questions related to wildland fires (two last review included are on this subject),
5. The impact of training methods,
6. The question of selection effects (as seen for lung disease),
7. The global consideration of exposures or specific exposures (e.g., PFAS),
8. The additive, multiplicative, or interaction effects from agents acting in synergy with each other have not been adequately assessed,
9. Health outcomes, including health effects that are difficult to measure in the short term and within small sample populations, such as endocrine and reproductive effects or other sex-specific or rare subtypes of cancers.

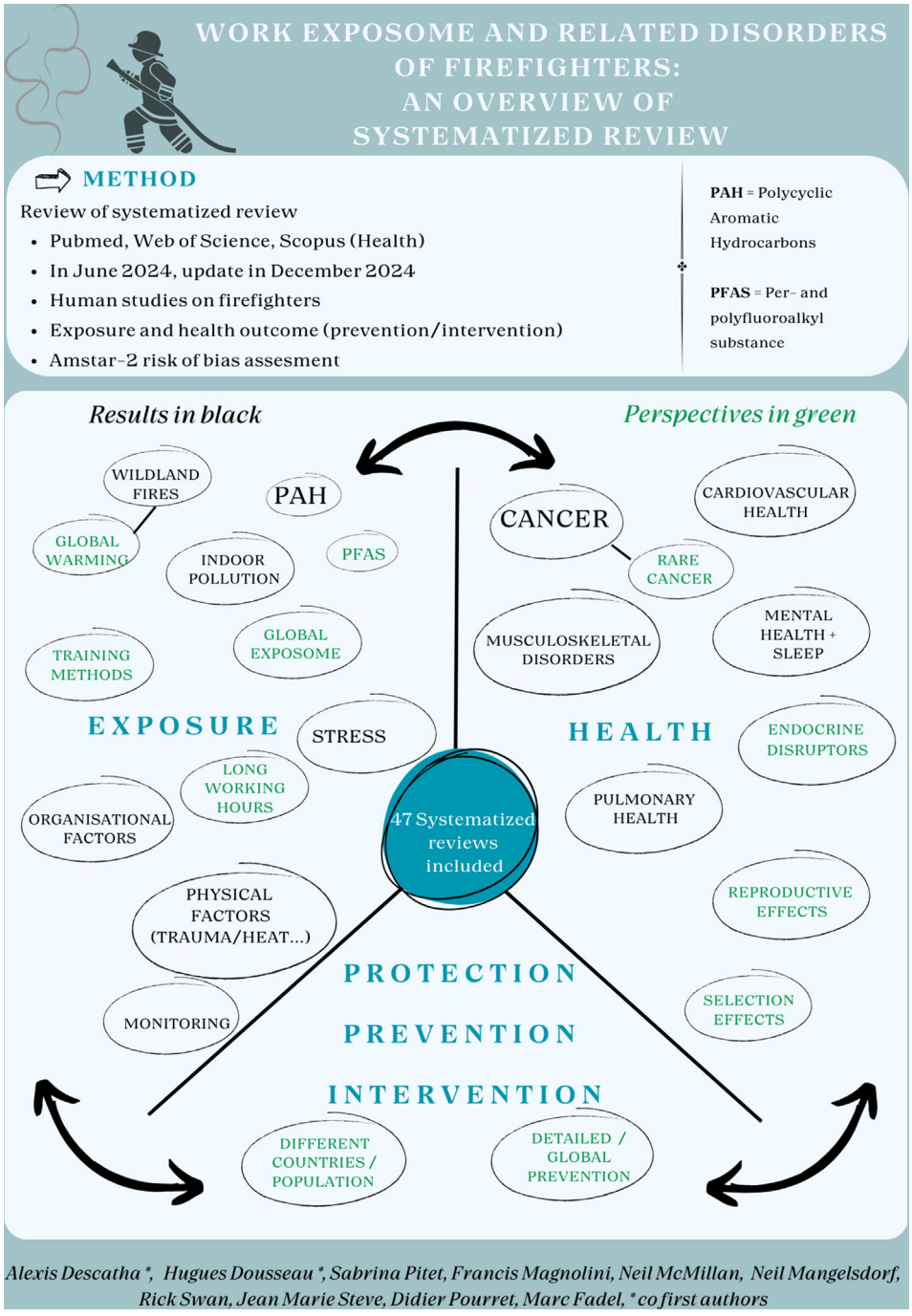

Fig. 2. Translational summary.

4. Discussion

This systematized overview provides a comprehensive description of systematized reviews describing populations of firefighters, including information on exposure, health, and prevention. The health of firefighters is an important topic that has been the subject of numerous systematic reviews, yet the inconsistency of the data and the wide variability of workplace exposures contribute to persistent gaps in the literature. This umbrella review approach makes it possible to select only the highest level of evidence and to provide a synthesis for professionals and researchers alike.

Several limitations need to be discussed: first, there was a deviation from the original protocol regarding the use of the AMSTAR-2 grid, which was considered more operational for assessing the RoB of systematic reviews than the navigation guide or other [62,63]. Additional keywords were checked with the help of the librarian of Angers University to ensure that a systematic review was not overlooked, in particular the two-word term "fire fight*" and “fire personnel”. In addition to these discrepancies, reviews based on exposure and health outcomes did not include general promotion not related to work or even on duty performance [64,65]. Furthermore, conference proceedings and even letters might have been interesting [66]. Moreover, it was decided to extract only systematic reviews and not narrative reviews and books, some of which are of high quality [67]. To limit this bias, systematized reviews extracted were systematic reviews, scoping

Table 1
Included systematic reviews

Study	Title	Topic (exposure/ outcome/ intervention)	Country of first author affiliation	Published Year	Start of study	End of study	Number of firefighter studies included	Metaanalysis? (yes/no)	Main conclusions (with exposure/outcomes)
Adetona 2016	Review of the health effects of wildland fire smoke on wildland firefighters and the public.	Wildfire	USA	2016	1990	2013	37	No	Need of more studies on wildfires exposure
Alves 2023	Exploring clinical trials to manage firefighters' sleep quality: A PRISMA compliant systematic review.	Intervention	Portugal	2023	2011	2021	7	No	Relation between sleep disorders, shift work (exposure), and occupational health outcomes, and education/ intervention/
Andrews 2019	The effects of exercise interventions on health and fitness of firefighters: A meta-analysis	Intervention	Ireland	2019	1983	2015	7	Yes	Exercise interventions (resistance active training) positively improve physiological parameters as proxy of outcome
Barbosa 2022	The effect of fire smoke exposure on firefighters' lung function: A meta-analysis.	Respiratory	Portugal	2022	1990	2018	24	Yes	Fire smoke exposure on firefighters' lung function (outcome), not related (though variation)
Barros 2023	Biomonitoring of firefighting forces: A review on biomarkers of exposure to health-relevant pollutants released from fires.	Monitoring	Portugal	2023	2015	2021	52	No	Chemical exposure (biomonitoring). Urine ++ blood +, all increase by firefighting activities
Beckett 2023	The prevalence of metabolic syndrome and its components in firefighters: A systematic review and meta-analysis.	Cardiovascular	England	2023	2008	2023	25	Yes	Prevalence of metabolic syndrome (outcome) 22.3% (17.7-27.0%) among firefighters
Berger 2012	Rescuers at risk: A systematic review and meta-regression analysis of the worldwide current prevalence and correlates of PTSD in rescue workers.	Mental	Brazil	2012	2008	2011	28	Yes	Among firefighters, high prevalence (7.3%) of posttraumatic stress disorder (outcome)
Bralewska 2024	Air pollution inside fire stations: State-of-the-art and future challenges.	Air pollution inside	Poland	2024	1987	2023	32	No	Air pollution exposure inside fire stations (related to equipment, trucks, and combustion tools)
Carr-Pries 2022	Scoping review of the occurrence and characteristics of firefighter exercise and training injuries.	Physical	Canada	2022	2002	2020	23	No	Physical exposure by exercise and training is associated to injuries (musculoskeletal outcome)
Casjens 2020	Cancer risks of firefighters: A systematic review and metaanalysis of secular trends and region-specific differences	Cancer	Germany	2020	1959	2018	25	Yes	Exposure as firefighters differently associated with cancer around the world and with secular trend (outcome)
Chakr 2024	The role of personal protective equipment (PPE) in reducing firefighter exposure to chemical hazards: A systematic review	Prevention	Australia	2024	2013	2023	21	No	Respirators provide protection, though not complete
Cuenca-Lozano 2023	Occupational hazards in firefighting: systematic literature review.	General	Ecuador	2023	2013	2021	15	No	All exposure/risk of firefighter (bibliometric analyze). Prevention is needed
DeBono 2023	Firefighting and cancer: A metaanalysis of cohort studies in the context of cancer hazard identification.	Cancer	Canada	2023	1959	2022	35	Yes	Evidence to support a causal relationship between occupational exposure as a firefighter and certain cancers (mesothelioma/bladder)
DiNota 2021	Coping among public safety personnel: A systematic review and metaanalysis.	Psychological	Canada	2021	2001	2019	10	Yes	Exposure to psychologically traumatic events can result in posttraumatic stress outcomes

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Table 1 (*continued*)

Study	Title	Topic (exposure/ outcome/ intervention)	Country of first author affiliation	Published Year	Start of study	End of study	Number of firefighter studies included	Metaanalysis? (yes/no)	Main conclusions (with exposure/outcomes)
Engelsman 2020	Biomonitoring in firefighters for volatile organic compounds, semivolatile organic compounds, persistent organic pollutants, and metals: A systematic review	Monitoring	Australia	2020	1982	2019	34	No	Exposure to volatile organic compounds, semi-volatile organic compounds, persistent organic pollutants, and metals (biomonitoring) due to smoke
Frost 2021	The effects of sleep on firefighter occupational performance and health: A systematic review and call for action	Organizational	USA	2021	2005	2021	15	No	Poor sleep exposure and cognitive performance/overall health
Golka 2008	Fire fighters, combustion products, and urothelial cancer	Cancer	Germany	2008	1977	2005	20	No	Exposure as firefighters is not associated with urothelial cancer (outcome)
Groot 2019	A systematic review of the health impacts of occupational exposure to wildland fires	Wildfire	Canada	2019	1985	2016	32	No	Wildfire exposure and need for future research
Hwang 2021	Health risks of structural firefighters from exposure to polycyclic aromatic hydrocarbons (PAH): A systematic review and meta-analysis.	PAH	USA	2021	1997	2020	20	Yes	Structural firefighters from exposure to PAH. Location/duration.
Hwang 2022	Urinary metabolites of polycyclic aromatic hydrocarbons in firefighters: A systematic review and metaanalysis.	Monitoring	USA	2022	1997	2021	27	Yes	Hydroxylated PAH (biomonitoring) increase after fire activities
WHO IARC 2022	Occupational Exposure as a Firefighter	Cancer (Exposure)	Canada	2022	1959	2022		No (DeBono)	Evidence to support a causal relationship between occupational exposure as a firefighter and certain cancers (mesothelioma/bladder)
Igboanugo 2021	Health outcomes of psychosocial stress within firefighters: A systematic review of the research landscape	Psychological	Canada	2021	2006	2020	29	No	Psychosocial stressors exposure and health and well-being outcomes
Jahnke 2024	Metaanalysis of incidence and mortality of firefighter cancer: An update on emerging science	Cancer	USA	2024	2008	2020	24	Yes	Exposure as firefighters differently associated with incidence/mortality of cancer (outcome) in/outside United States
Khoshakhlagh 2023	Global prevalence and associated factors of sleep disorders and poor sleep quality among firefighters: A systematic review and metaanalysis.	Mental	Iran	2023	2000	2022	47	Yes	Among firefighters, sleep disorders (outcome) 30.5% (25.9%-35.1%)
Khoshakhlagh 2024	The global prevalence of musculoskeletal disorders among firefighters: A systematic review and metaanalysis	Musculoskeletal	Iran	2024	1993	2021	31	Yes	High prevalence of musculoskeletal disorders (outcome)
Kim 2022	Noncancer health risks in firefighters: A systematic review	General	Republic of Republic of Korea	2022	1978	2021	66	Yes	Description of all noncancer diseases, with variations on job type, years of service, rank, country)
Kyron 2021	Prospective risk and protective factors for psychopathology and wellbeing in civilian emergency services personnel: A systematic review.	Psychological	Australia	2021	1988	2019	66	No	Psychological risk and protective factors (including workplace exposure) and mental health outcomes
Lee 2023	Cancer risk and mortality among firefighters: A metaanalytic review	Cancer	USA	2023	1978	2022	38	Yes	Exposure as firefighters associated with skin and prostate cancer (outcome)
LeMasters 2006	Cancer risk among firefighters: A review and metaanalysis of 32 studies.	Cancer	USA	2006	1975	2003	32	Yes	Exposure as firefighters associated with multiple myeloma (outcome)

Li 2022	Efficacy of cooling garments on exertional heat strain recovery in firefighters: A systematic review and metaanalysis	Intervention	China	2020	1999	2021	12	No	Interventions using cooling garments are an effective adjunct therapy to mitigate exertional heat stress (outcome) though more studies are needed
Lyra 2021	Occupational exposure to suicide: A review of research on the experiences of mental health professionals and first responders.	Mental	New Zealand	2021	2010	2019	3	No	Between 34%-92.4% of firefighters had been exposed to suicide, and mental health (outcome)
Macmillan 2021	Systematic review of randomized control trial health promotion intervention studies in the fire services: Study characteristics, intervention design and impacts on health	Intervention	Australia	2020	1986	2019	11	No	Health promotion intervention studies in the fire services are possible and effective on health outcome
McEntire 2013	Mitigation and prevention of exertional heat stress in firefighters: A review of cooling strategies for structural firefighting and hazardous materials responders.	Physical	USA	2013	1989	2011	27	No	In term of exertional heat stress as exposure management, still considerable work needed
Murphy 2022	Musculoskeletal injury epidemiology in law enforcement and firefighter recruits during physical training: A systematic review	Musculoskeletal	Australia	2022	2003	2020	8	No	Among firefighters (including in law officers) prevalence and incidence rates for musculoskeletal injuries (outcome) is high though large variation
Nazari 2020	Prevalence of musculoskeletal disorders among Canadian firefighters: A systematic review and metaanalysis	Musculoskeletal	Canada	2020	2015	2018	5	Yes	Simulated physical exertion exposure during firefighting tasks are physiologically demanding
Nazari 2021	Quantifying physiological responses during simulated tasks among Canadian firefighters: A systematic review and metaanalysis	Physical	Canada	2021	1999	2019	10	Yes	Structural and wildfire firefighting exposure can cause dehydration (outcome)
Serrano-Ibáñez 2023	Psychological variables associated with posttraumatic stress disorder in firefighters: A systematic review.	Mental	Spain	2023	2011	2020	19	No	Among firefighters, work factors (e.g. operational stress, job duration) associated with posttraumatic stress disorder (outcome)
Slattery 2018	The long-term rate of change in lung function in urban professional firefighters: A systematic review	Respiratory	Australia	2018	1974	2016	22	No	Change in lung function (outcome) among urban professional firefighters only significant for “nonroutine” severe exposures
Sousa 2022	Exposure to PAHs during firefighting activities: A review on skin levels, in vitro/in vivo bioavailability, and health risks.	PAH	Portugal	2022	1991	2021	13	No	HAP exposure of firefighters’ skin, mainly on the neck
Sritharan 2017	Prostate cancer in firefighting and police work: a systematic review and metaanalysis of epidemiologic studies.	Cancer	Canada	2017	1980	2017	31	Yes	Exposure as firefighters moderately associated with prostate cancer (outcome)
Tahernejad 2024	A systematic review and metaanalysis of musculoskeletal disorders among firefighters	Musculoskeletal	Iran	2024	1998	2022	26	Yes	Among firefighters (exposure), high prevalence of musculoskeletal disorders (outcome)
Wagner 2021a	Systematic review of mental health symptoms in firefighters exposed to routine duty-related critical incidents	Mental	Canada	2021	1980	2017	40	No	Impact of potentially traumatic exposure in firefighting personnel on mental health symptoms (outcome)
Wagner 2021b	Mental disorders in firefighters following large-scale disaster	Mental	Canada	2021	1980	2017	32	No	Impact of disaster exposure in firefighting personnel on posttraumatic stress disorders (outcome)

(*continued on next page*)

Table 1 (*continued*)

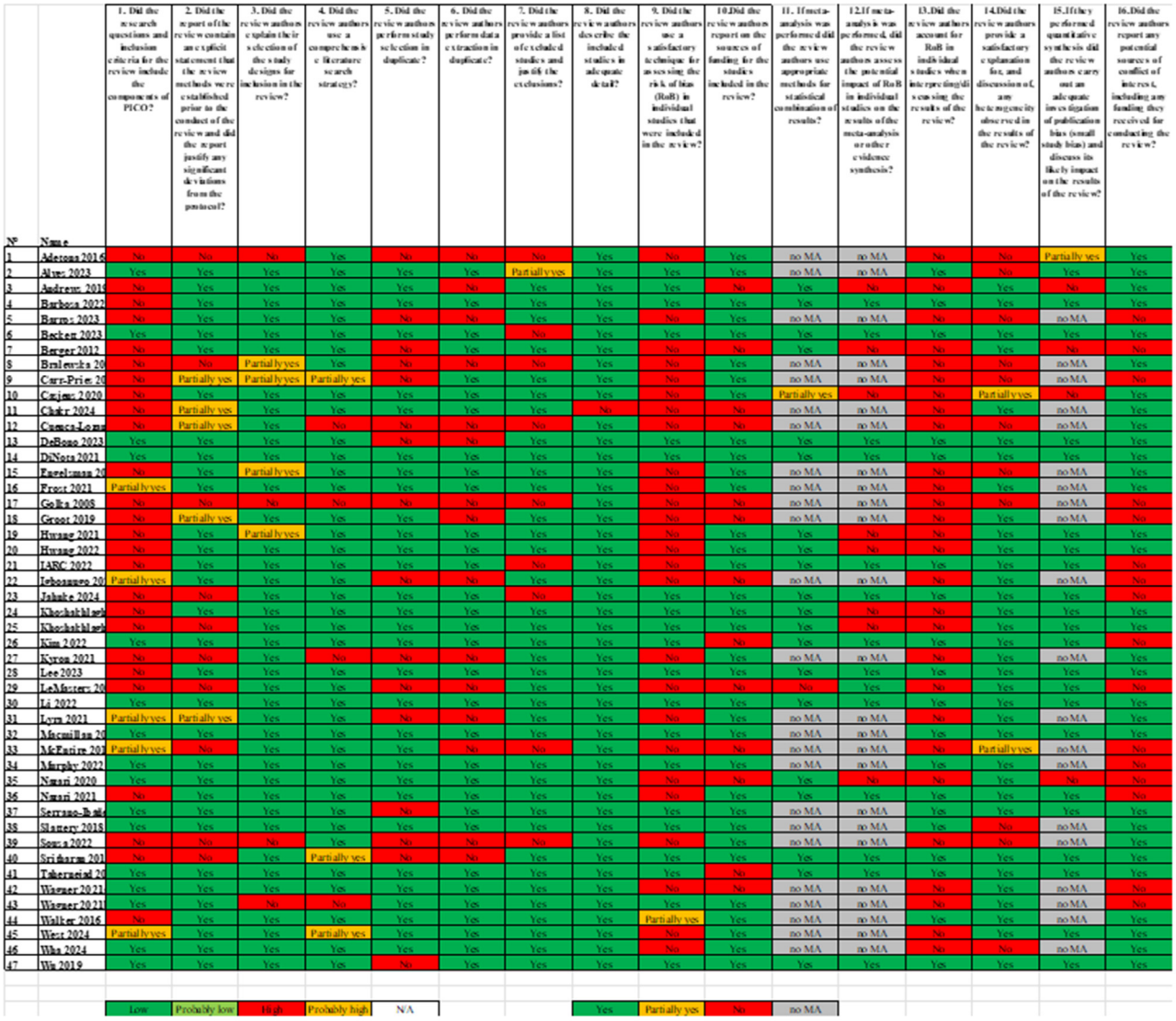
Study	Title	Topic (exposure/ outcome/ intervention)	Country of first author affiliation	Published Year	Start of study	End of study	Number of firefighter studies included	Metaanalysis? (yes/no)	Main conclusions (with exposure/outcomes)
Walker 2016	The impact of fire suppression tasks on firefighter hydration: A critical review with consideration of the utility of reported hydration measures.	Physical	Australia	2016	2000	2015	10	No	Structural and wildfire firefighting can cause dehydration (outcome). Ad libitum drinking may be sufficient but not for during intense, longer duration, hot structural fire operations
West 2024	A review of occupational exposures to carcinogens among wildland firefighters.	Wildfire	USA	2024	1992	2022	49	No	Wildland firefighters are regularly exposed to carcinogens.
Wah 2024	Systematic review of impacts of occupational exposure to wildfire smoke on respiratory function, symptoms, measures and diseases.	Wildfire	Australia	2024	1991	2023	26	No	Wildfires (exposure) or prescribed burns has both respiratory outcome
Wu 2019	The prevalence of moderate-to-high posttraumatic growth: A systematic review and metaanalysis	Mental	China	2019	2006	2017	2	Yes	Level of posttraumatic stress growth (outcome), among persons (including firefighters)

reviews, and metaanalyses. The heterogeneity visible in the bias assessment table highlights this limitation and makes it possible to meet the objective of providing an "overview" of reproducible reviews.

Nevertheless, the systematic approach of this umbrella review provides an important global overview in a societal context of recognition, professionals feedback (health literacy), and research development for firefighters, who have a particular exposome and health effects that require singular surveillance. Indeed, the review covers a wide range of exposures and health outcomes relevant to firefighters, including chemical exposures, physical strain, and psychological stress. This breadth is valuable in understanding the multifaceted nature of occupational hazards faced by firefighters.

Cancers among firefighters have long been discussed. Previously (in 2010), IARC concluded that "Occupational exposure as a firefighter is possibly carcinogenic to humans (Group 2B)" [68]. It was only in 2023, that sufficient evidence among human and strong mechanistic evidence allowed IARC to conclude "Occupational exposure as a firefighter is carcinogenic to humans (Group 1), and causes mesothelioma and bladder cancer in humans" [35]. These associations vary temporally and regionally; however, consistencies among those highest-powered studies make this relationship clear. Different other cancers have also been suggested, such as blood cancer (multiple myeloma, non -Hodgkin lymphoma), skin cancer (melanoma and other skin cancer), prostate cancer. Physical strain leads to musculoskeletal disorders among firefighters with prevalence depending on definition and body areas. Exercise and training, as well as injuries are involved. Mental health disorders with posttraumatic stress disorders are also no longer debatable, with interaction between personal and work factors, though further research is needed to evaluate the potential contribution from physical and psychological trauma that predates employment in the fire service.

However, this umbrella review also highlighted some research perspectives that require national and international collaboration to be addressed. These include the type of firefighters, sex, age, type of duties, and training methods. With climate change driven events, wildland fires and urban interface fires have become a growing concern for governmental and health authorities. Monitoring and protection (neither too much nor too little, given the immediate side effects) require large-scale (both in time and participant size) studies according to international standards. In terms of protection methods, for example, we could model standards similar to those used in drug development. Consequently, in addition to a preclinical phase of laboratory tests, a clinical phase could be conducted on a non-firefighter population with similar "healthy worker" characteristics (equivalent to healthy volunteer phase studies), on firefighters with random selection in terms of efficacy and tolerance (equivalent to phases 2 and 3), including tolerance adapted to protection (for example, where "perfect airway protection" might be too heavy/hot/unbreathable/expensive), and a real-life post-marketing evaluation (vigilance) could be carried out. In the short, medium, and long term, systematic but also original studies need to be carried out, taking into account exposures in different contexts and in the different comparative populations mentioned above, and while integrating different exposures within an overall exposome framework (e.g., endocrine disruptors and PFAS (Per- and polyfluoroalkyl substances), long working hours, etc.). It is also important to provide an operational translation for all stakeholders to avoid over-pessimistic interpretations in the absence of interventions proven to improve health outcomes. At the same time, we must promote the importance of global prevention in the face of excessive risks associated with the occupation of firefighting. Fig. 2 is an illustration of the main results of this overview, which can be spread to the firefighting community, though details and



N°	Name	1. Did the research questions and inclusion criteria for the review include the components of PICO?	2. Did the report of the review contain an explicit statement that the review methods were established prior to the conduct of the review and did the report justify any significant deviations from the protocol?	3. Did the review authors explain their selection of the study designs for inclusion in the review?	4. Did the review authors use a comprehensive literature search strategy?	5. Did the review authors perform study selection in duplicate?	6. Did the review authors perform data extraction in duplicate?	7. Did the review authors provide a list of excluded studies and justify the exclusions?	8. Did the review authors describe the included studies in adequate detail?	9. Did the review authors use a satisfactory technique for assessing the risk of bias (RoB) in individual studies that were included in the review?	10.Did the review authors report on the sources of funding for the studies included in the review?	11. If meta-analysis was performed did the review authors use appropriate methods for statistical combination of results?	12.If meta-analysis was performed, did the review authors assess the potential impact of RoB in individual studies on the results of the meta-analysis or other evidence synthesis?	13.Did the review authors account for RoB in individual studies when interpreting/discussing the results of the review?	14.Did the review authors provide a satisfactory explanation for, and discussion of, any heterogeneity observed in the results of the review?	15.If they performed quantitative synthesis did the review authors carry out an adequate investigation of publication bias (small study bias) and discuss its likely impact on the results of the review?	16.Did the review authors report any potential sources of conflict of interest, including any funding they received for conducting the review?
1	Adetona 2016	No	No	No	Yes	No	No	No	Yes	No	Yes	no MA	no MA	No	No	Partially yes	Yes
2	Alves 2023	Yes	Yes	Yes	Yes	Yes	Yes	Partially yes	Yes	Yes	Yes	no MA	no MA	Yes	No	Yes	Yes
3	Andrew 2019	No	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	No	Yes	No	No	Yes	No	Yes
4	Barbosa 2022	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
5	Barros 2023	No	Yes	Yes	Yes	No	No	Yes	Yes	No	Yes	no MA	no MA	No	No	no MA	No
6	Becker 2023	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
7	Berger 2012	No	Yes	Yes	Yes	No	Yes	Yes	Yes	No	No	Yes	No	No	Yes	No	No
8	Brzeznska 20	No	No	Partially yes	Yes	No	No	No	Yes	No	Yes	no MA	no MA	No	No	no MA	Yes
9	Curt-Prie 20	No	Partially yes	Partially yes	Partially yes	No	Yes	Yes	Yes	No	Yes	no MA	no MA	No	No	no MA	No
10	Cuijpe 2020	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Partially yes	No	No	Partially yes	No	Yes
11	Choi 2024	No	Partially yes	Yes	Yes	Yes	Yes	Yes	No	No	No	no MA	no MA	No	Yes	no MA	Yes
12	Cuenca-Lorn	No	Partially yes	Yes	No	No	No	No	Yes	No	No	no MA	no MA	No	No	no MA	Yes
13	DeBono 2023	Yes	Yes	Yes	Yes	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
14	DiNota 2021	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
15	Engelsman 20	No	Yes	Partially yes	Yes	Yes	Yes	Yes	Yes	No	Yes	no MA	no MA	No	No	no MA	Yes
16	Frost 2021	Partially yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	no MA	no MA	No	Yes	no MA	Yes
17	Golka 2008	No	No	No	No	No	No	No	Yes	No	No	no MA	no MA	No	No	no MA	No
18	Groot 2019	No	Partially yes	Yes	Yes	Yes	No	Yes	Yes	No	No	no MA	no MA	No	Yes	no MA	No
19	Hwang 2021	No	Yes	Partially yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	No	No	Yes	Yes	Yes
20	Hwang 2022	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	No	No	Yes	Yes	Yes
21	IARC 2022	No	Yes	Yes	Yes	Yes	Yes	No	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	No
22	Iehoaugeo 20	Partially yes	Yes	Yes	Yes	No	No	Yes	Yes	No	No	no MA	no MA	No	Yes	no MA	No
23	Jahabe 2024	No	No	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No
24	Khochaklarb	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes	Yes	Yes
25	Khochaklarb	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes	Yes	Yes
26	Kim 2022	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	No
27	Kyron 2021	No	No	Yes	No	No	No	Yes	Yes	No	Yes	no MA	no MA	No	Yes	no MA	Yes
28	Lee 2023	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
29	LeMasters 20	No	No	Yes	Yes	No	No	Yes	Yes	No	No	No	Yes	No	Yes	Yes	No
30	Li 2022	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
31	Lyn 2021	Partially yes	Partially yes	Yes	Yes	No	No	Yes	Yes	No	Yes	no MA	no MA	No	No	no MA	Yes
32	Macmillan 20	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	no MA	no MA	Yes	Yes	Yes	Yes
33	McEntire 203	Partially yes	No	Yes	Yes	Yes	No	No	Yes	No	No	no MA	no MA	No	Partially yes	no MA	No
34	Murphy 2022	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	no MA	no MA	Yes	Yes	no MA	No
35	Nnaji 2020	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes	No	No	Yes	No	No
36	Nnaji 2021	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	No
37	Serrano-Bak	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	no MA	no MA	Yes	Yes	Yes	Yes
38	Slattery 2018	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	no MA	no MA	Yes	No	no MA	Yes
39	Sousa 2022	No	No	No	Yes	No	No	No	Yes	No	Yes	no MA	no MA	No	No	no MA	Yes
40	Sridharan 201	No	No	Yes	Partially yes	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
41	Tskeraeid 20	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes	Yes	Yes	Yes	Yes
42	Wiesner 2021	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	no MA	no MA	No	Yes	no MA	No
43	Wiesner 2021	Yes	Yes	No	No	Yes	Yes	Yes	Yes	Yes	Yes	no MA	no MA	No	Yes	no MA	No
44	Walker 2016	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Partially yes	Yes	no MA	no MA	Yes	Yes	no MA	Yes
45	West 2024	Partially yes	Yes	Yes	Partially yes	Yes	Yes	Yes	Yes	No	Yes	no MA	no MA	No	Yes	Yes	Yes
46	Wha 2024	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	no MA	no MA	No	No	no MA	Yes
47	Wu 2019	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Low	Probably low	High	Probably high	NA	Yes	Partially yes	No	no MA

Fig. 3. Risk of bias, AMSTAR-2 evaluation.

applications need to be explained by practitioners working for improving occupational health and safety of firefighters locally.

In conclusion, this study confirms the health impacts associated with firefighters' occupational exposures and presents a synthesis of numerous systematic reviews of this population of workers. This study also highlights the prospects for international collaborative and integrated research. This work also translates general ideas for the fire service, although appropriation by prevention researchers remains necessary to ensure adequate benefits to the studied population. Such research, including updated ones, remain crucial for guiding awareness, prevention, and legislative/regulatory changes necessary to better protect this worker group from the harms associated with their occupation. Open documentation centers (and translated) in each region are examples of translational work, providing the necessary literacy and awareness for firefighters and related professionals, such as epidemiologists, occupational hygienists, and exposure scientists. The appropriate integration of artificial intelligence also holds potential benefits, as for other medical areas, and also comes with drawbacks that require attention [69,70]).

CRediT authorship contribution statement

Alexis Descatha: Writing – original draft, Supervision, Investigation, Conceptualization. **Hugues Dousseau:** Writing – original draft, Investigation, Formal analysis. **Sabrina Pitet:** Writing – review & editing, Supervision, Investigation, Formal analysis. **Francis Magnolini:** Formal analysis, Investigation, Supervision, Writing – original draft. **Neil McMillan:** Writing – review & editing, Supervision, Investigation, Formal analysis. **Neil Mangelsdorf:** Writing – review & editing, Supervision, Investigation, Formal analysis. **Rick Swan:** Writing – review & editing, Supervision, Investigation, Formal analysis. **Jean-Marie Steve:** Writing – review & editing, Supervision, Investigation, Formal analysis. **Didier Pourret:** Writing – review & editing, Supervision, Investigation, Formal analysis. **Marc Fadel:** Writing – review & editing, Supervision, Conceptualization.

Disclaimer

The views expressed in this paper are those of the authors and do not necessarily reflect the views of the aforementioned

institutions. An oral presentation has been given by Alexis Descatha in France to ISO TC94/SC14 group.

Declaration of competing interest

The authors are paid by their institution.

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Appendix A. Supplementary data

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