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Review

Review and Statistical Analysis of U.S. Structural Firefighting Injuries: Their Causes and Effects

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Abstract: Safety and prevention of injuries should always be considered in a firefighting environment due to the hazardous conditions experienced on the fireground. These hazardous environmental conditions lead to an increased risk of contracting job-related injuries and illnesses. This review article focuses on evaluating from a statistical perspective the potential solutions found in the literature and how they decrease the likelihood and impact of occupational firefighting injuries. Investigating, identifying, and prioritizing the most common activities leading to injury, the nature of injury, and the body parts affected is a vital step in the implementation of preventive solutions. The scientific community has conducted various studies to evaluate the main injuries and injury profiles commonly suffered by firefighters. Researchers have conducted many independent studies on firefighter communities in the United States, while others have referenced national databases from sources such as the National Fire Protection Association, the Bureau of Labor Statistics, and the National Electronic Injury Surveillance System. Unfortunately, the results of these independent studies lacked standardization in survey categories and terminology, impairing the ability to obtain a clear consensus among studies on the primary nature of injuries, the body parts injured, and the activities contributing to these injuries. Consequently, this review article performed a comparative statistical analysis of published data between 1992 and 2020 to define and rank the most common work scenarios where firefighters were likely to be injured, the most common types of injuries, the parts of the body affected, and the activities that most contribute to United States firefighter injuries as documented in both national databases and independent research surveys. The statistical analysis consisted of determining the mean, standard deviation, confidence intervals (95%), and coefficients of variation for the reported data. The present study identified that despite the preventative measures taken by many organizations in the firefighting community, strains and sprains were still the leading type of injury reported from all the databases under this analysis.

Keywords: firefighter injuries; nature of injuries; body site injured; firefighting activities; national databases; review study; comparative analysis

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1. Introduction

Firefighting environments and operations impose hazardous conditions on firefighters (FFs), such as exposure to extremely high temperatures, smoke, and toxic gases; contact with chemical and biological agents; collapsing structures; and high-intensity physical activities. All these hazards increase the risk of job-related injuries for FFs and impact the fatality and non-fatal injury rates for U.S. firefighting communities. Kunadharaju K. et al. [1] reported that the fatality rate for firefighters was three times worse than the general working population. Moreover, organizations, such as the National Fire Protection

Association (NFPA), reported that the number of on-duty fatalities and non-fatal injuries in 2021 were 135 and 60,750, respectively [2]. Defining and prioritizing these risks and their causes and effects on a firefighter's health are vital steps toward implementing solutions to reduce the likelihood and impact of injuries.

For this reason, scientists, engineers, and researchers working on possible solutions have relied on the information reported by national organizations responsible for collecting, analyzing, and reporting injuries in the United States, such as the National Fire Protection Association, the Bureau of Labor Statistics (BLS), and the National Electronic Injury Surveillance System (NEISS), to help guide their efforts. Organizations such as the NPFA and BLS conduct annual surveys, and the NFPA issues nationwide reports of U.S. FF injuries. In the case of NEISS injuries, data is collected through hospital Emergency Department records. While the NFPA collects and reports injury data related only to FFs, the BLS and the NEISS collect and report data for U.S. FFs and other workers. In addition, research studies have been conducted on firefighter injuries and their main causes through independent surveys based on FF communities in specific fire departments in the United States (U.S.). Unfortunately, it can be challenging to interpret and compare the outcomes of these studies due to a lack of standardization in the categories used for various data types, namely, the typical work contexts where FFs are prone to injuries, the specific nature of these injuries, the body parts frequently affected, and the associated activities. This presents a difficulty for this review with respect to comparison and statistical analysis across studies and datasets. Consequently, this study performed a comparative analysis of published data related to FF injuries by national organizations and databases and independent U.S. studies between 1992 and 2020 to identify and rank the most common work scenario, type of injuries, parts of the body affected, and activities leading to injuries for the U.S. firefighting community.

It is imperative to highlight that even though there are different categories of FFs in the U.S., this study was performed mainly using injury data reported for structural FFs at the municipal level. Although some of the national data sources reported data for the multiple types of FFs (e.g., structural, wildland, and maritime), the independent studies primarily focused on professional structural firefighters in municipal settings, with only two studies that reported injury data on wildland FFs. The most significant distinction between structural and wildland FFs is the operational environments. While wildland FFs engage with fires in outdoor and natural environments (e.g., forests, grasslands, and wilderness areas), structural FFs primarily respond to fires in structures such as buildings. This discrepancy in the environments leads to differences in tools, tactics, and training for each category. Wildland FFs utilize specialized hand tools and focus on strategies to control wildfire across expansive areas, such as using scrapers to create fire lines or smoke jumping to access otherwise inaccessible areas. On the other hand, structural FFs employ specialized equipment for use within building contexts, such as Halligan tools for forcible entry or pike poles to perform ceiling breaches and equipment for rescuing people within confined areas [3]. For a comprehensive understanding of the diverse responsibilities of the different FF categories, additional information is available in [4–6]. In Appendix A, a breakdown of the specific population demographics for each independent study is presented, with discussion on the impacts of the different firefighting contexts presented throughout the study.

The lack of standardized categorization among different national organizations made side-by-side comparisons challenging. While the NFPA [7] gathers data through surveys based on a stratified random sample of U.S. fire departments by career and volunteer community size, the BLS performed a Survey of Occupational Injuries and Illnesses (SOII) on a sample of 200,000 U.S. companies, which were required by law to complete the survey. However, the BLS survey excluded federal public sector workers such as volunteer FFs [8]. The BLS only reported injuries and illnesses that involved days away from work, thus excluding many less severe injuries [9]. Independent researchers have made use of other national organizations that report injury data, such as the U.S. Consumer Product Safety Product Commission (CPSC) [4]. The CPSC has operated a statistically valid injury

surveillance and follow-back system known as the National Electronic Injury Surveillance System (NEISS) [10]. The NEISS collects data on customer product-related injuries in the U.S. Furthermore, the CPSC, in collaboration with the National Institute for Occupational Safety and Health (NIOSH), uses the National Electronic Injury Surveillance System–Occupational Supplement (NEISS-WORK) [11] to collect data on non-fatal injuries and illnesses treated at emergency departments in U.S. hospitals for responders affiliated with justice, public order, and health and safety operations, such as EMS personnel, police officers and firefighters [9].

The International Association of Fire Chiefs (IAFC) [12] also gathers and reports worldwide data concerning firefighting injuries. The IAFC contributes to the broader initiative of reducing firefighting injuries by advocating safety standards, providing information and resources, and implementing best practices within worldwide FF communities [12]. Additionally, several research studies have focused on firefighting injuries across multiple countries as an internationally recognized issue in the firefighting profession. For instance, Orr et al. [13] conducted a review study reporting firefighting injuries across Canada, Greece, Poland, Australia, and Korea. Similarly, Nigel et al. (2015) [14] and Nazari et al. (2020) [15] explored findings related to the incidences of musculoskeletal injuries within firefighting communities in Australia and Canada. Furthermore, Wang et al. (2019) [16] and Watkins et al. (2019) [17] have performed studies assessing firefighting injuries across China, the U.S., mainland Europe, Ireland, Australasia, and the United Kingdom. While the aforementioned review studies systematically reported and analyzed injuries on a country-by-country basis, Burgess et al. (2013) [18] conducted a comparative analysis of career and volunteer injury rates in fire departments internationally. This study showed that the U.S. injury rate was higher compared to Commonwealth nations and Japanese fire departments. Although the significance of analyzing the causes of firefighting injuries has been recognized globally, this manuscript focused on utilizing databases and reports that document firefighting injuries in the United States. The scope of this study, which was funded by the National Science Foundation in the U.S., was aligned with the objective of specifically determining the profile of U.S. firefighting injuries.

Independent research studies focused on FF injuries in the U.S. have shown variability in the demographics of the population, sample sizes, and survey types. In addition, each of these studies shows a greater lack of standardization in defining the categories for the types of injuries, body parts affected, and firefighting activities that contribute to injuries when compared to the national databases. For example, a lack of standardization of information on musculoskeletal injuries was reported by Orr et al. in [13], who identified great limitations in defining the injury profile for FFs. Although most studies included injury definitions, body sites affected, and the nature and mechanism of the injuries, these terms were defined differently by different authors. Orr et al. [13] also reported that most of the studies in their review only specified the types of injuries without providing an explanation for the causes and effects of those injuries. In addition, body parts may also be aggregated in some studies, creating a loss of discretization of the data. Their study was able to evaluate musculoskeletal injuries by their nature and the body parts affected. However, the study failed to evaluate and rank the nature of the injuries, the parts of the body injured, and the activities that contributed to those injuries. Considering this lack of standardization of terms in various studies, there was a need to understand better, as part of this review study, the variability of reporting FF injury data in regional studies and to understand if those studies aligned with data reported by national sources in the U.S.

This review study aggregated FF injury data from small studies and from three national organizations: the NFPA, the BLS, and the NEISS. A comparative analysis based on the published data of firefighter injuries reported by these sources was performed to rank the type of work scenarios, the nature of the injuries typically incurred by FFs, the parts of the body injured, and the activities performed when these injuries occurred. The systematic review of the literature focused on job-related injuries during firefighting operations. Once the relevant data was gathered, the dispersion of the data was determined by a statistical

analysis to rank and compare the results from the different sources. Finally, the Pareto principle [19] was applied to rank the most common activities related to FF injuries.

2. Methodology

The primary objective of this review study was to define the profile of injuries for FFs in the U.S. based on four main categories (work scenario, nature of injuries, body parts affected, and contributing activities). The approach used to define this profile of injuries started with the following: (1) The identification of published FF injury data reported by national organizations and papers in the literature. The next step, (2), consisted of cleaning and post-processing the data. Step (3) consisted of performing a statistical analysis to define the dispersion of the data. (4) Finally, a comparative analysis and ranking of categories was performed as outlined in Figure 1. Each step is described in detail in the following subsections.

2.1. Identification of Published Data for Firefighter Injuries

The identification of published data was dependent on the accessibility and discretization of the number of injuries and their nature, the part of the body affected, and related activities. For this, the collection of data was carried out using national reports led by organizations responsible for the collection and analysis of information related to injuries and illnesses for workers in the U.S., i.e., the NFPA [20–26], the BLS [27] and the NEISS [9,28]. All these organizations provide annual injury reports in the U.S., and the characteristics of each database are described in Table 1 [29]. For this study, the years for the data identified and used by national organizations for the comparative analysis are outlined in Table 1. It is important to note that the NEISS data for this comparative analysis was provided by two studies from the literature review. The first study was conducted by Marsh et al. [28], who analyzed and reported non-fatal firefighter injuries treated in emergency rooms from 2003 to 2014 using the National Electronic Injury Surveillance System occupational supplement (NEISS-Work). The second study was conducted by Reichard et al. [9], who performed a study of the occupational injuries and illnesses among EMS personnel, FFs, and police treated in U.S. hospital emergency departments from 2000 to 2001. In Reichard et al., the authors collected the data for a geographically stratified sample of 67 U.S. hospitals with emergency departments considering "work-related injuries for civilian (non-military), non-institutionalized workers who were working for compensation or volunteer organizations" [9] (p. 3). Therefore, for this study, the collection of FF injury data from the NEISS, which is a disaggregation of FF injuries from EMS and police personnel, were analyzed. This FF injury data addressed by the authors in [9] included injuries for career and volunteer FFs during fireground operations and training activities. It is important to note that for easier identification of the data through this manuscript, the data reported by Reichard et al. [9] would be identified as "NEISS 2000–2001", and the data reported by Marsh et al. [28] would be identified as "NEISS 2003–2014".

Figure 2 depicts how the search process of the open literature was conducted. This process consisted of three main steps: (1) identification, (2) screening and eligibility, and (3) inclusion. For the identification process, four databases were selected to search the articles related to U.S. firefighter injuries. These databases were PubMed/MEDLINE, Web of Science, CINAHL, and ScienceDirect. Additionally, hand-searching of papers was performed through Google Scholar. The keywords used for the search process are shown in Table 2, where the Boolean operator "OR" was used for keywords within the same group, the "AND" operator for keywords that referred to different groups. The "NOT" operator was used to exclude keywords based on inclusion and exclusion criteria.

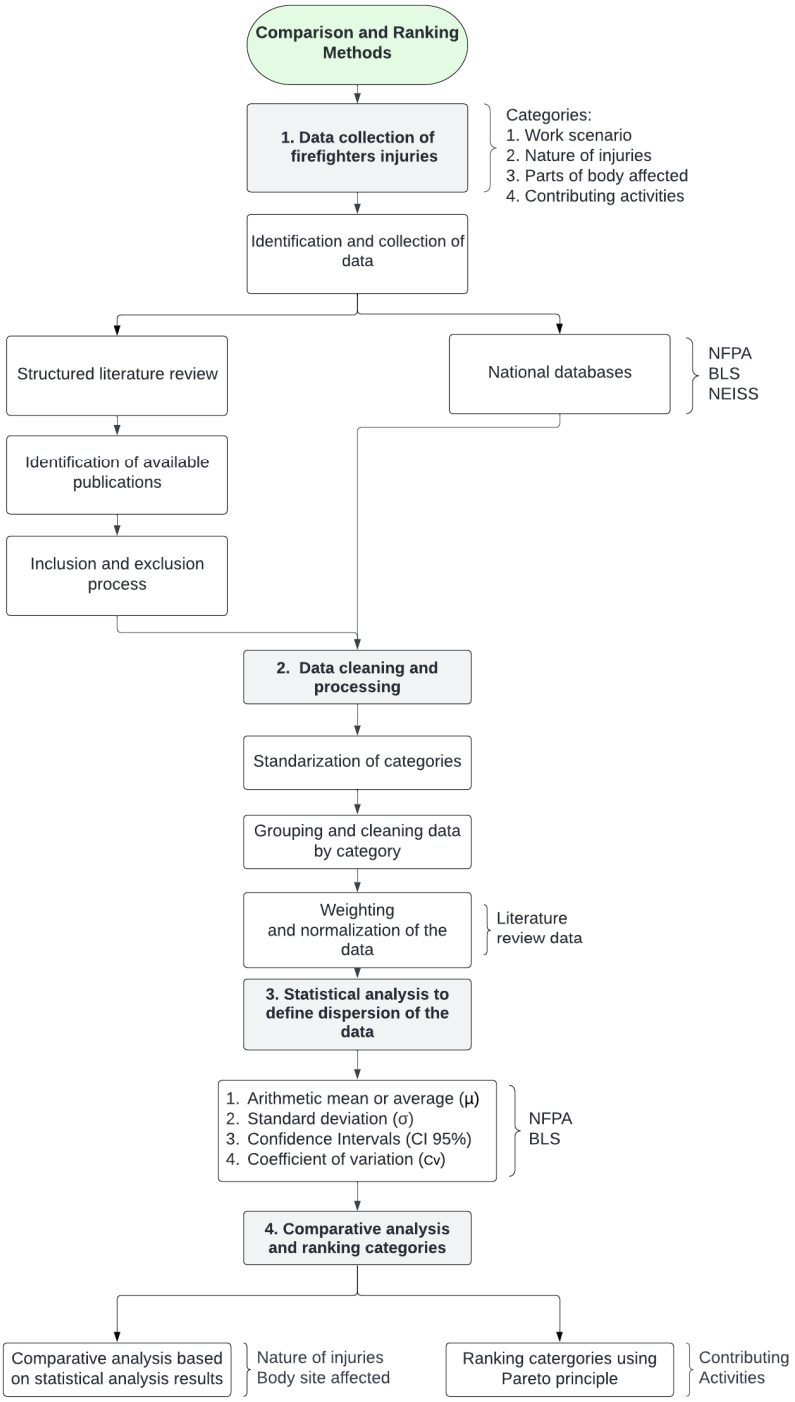

Figure 1. Methodology flowchart for determination of the profile of firefighter injuries.

Table 1. Databases from national organization description [29].

Database from National Organizations	Data Sources	Scope	Inclusion Criteria	Exclusion Criteria
NFPA (2010–2019)	Reports from fire departments Reports from NFIRS Information from state and federal agencies NIOSH Fire Fighter Fatality Investigation Reports Responses to specific data requests	FFs in U.S.	Career and volunteer FFs, local and municipal FFs, state, territory, and federal	FFs at U.S. territorial and overseas military installations and Recreational activities not required by fire department

Table 1. *Cont.*

Database from National Organizations	Data Sources	Scope	Inclusion Criteria	Exclusion Criteria
BLS (2011–2020)	Federal, state, and local sources including: • Death certificates workers' compensations reports • Police reports • News reports • OSHA forms 300/301 • USFA firefighter fatality notices	FFs in U.S.	Employed workers including private, federal, state, local, and government. Workers engaged in legal work activity	Prison workers, military personnel killed outside of U.S. Recreational activities not required by fire department
NEISS (2000–2001) & (2003–2014)	Stratified probability sample of approximately 67 U.S. hospital EDs where case identification occurs via medical chart review [17]	Civilian non-institutionalized workers	FFs treated in EDs for injuries related to on duty functions, and FFs providing patient care [17]	Occupations such as administrator, emergency medical services worker with no indication of concurrent FF employment, clerk, communications operator, dispatcher, mechanic, fire investigator, forest service ranger, lifeguard, maintenance worker, cook, and ambulance driver [17]

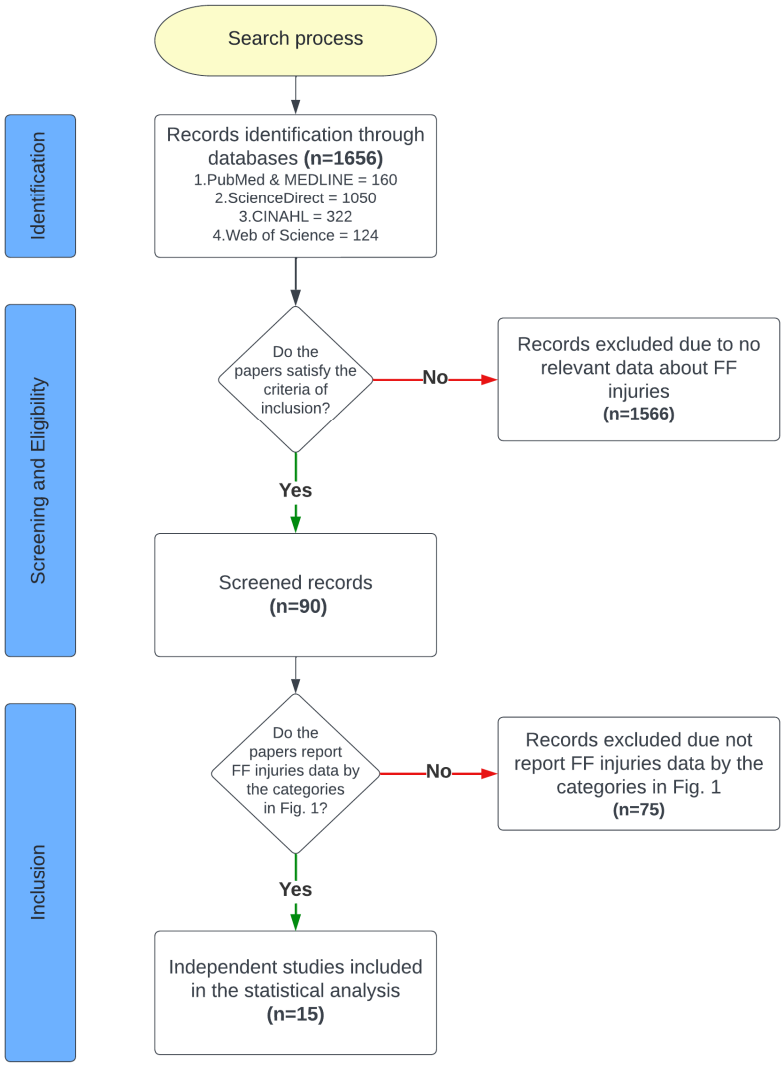

Figure 2. Flowchart for the search and screening processes in the literature review.

Table 2. Keywords for searching process in the literature review.

Database Name	Keywords Used for Searching Process
PubMed MEDLINE	(Firefighters OR firefighter OR fireman or firewoman) AND (injury OR injuries) AND (US, OR United States) AND (Occupational injury) NOT (National Fire Protection Association).
ScienceDirect	("Firefighters") AND) ("injuries OR injury") AND ("United States") NOT ("Mental health").
Web of Science	(((WC = (Public, Environmental & Occupational Health)) AND TS = (firefighter OR fireman OR firewoman OR firefighters)) AND TS = (injury)) AND TS = (occupational injury) NOT ALL = (NFPA OR national fire protection association).
CINAHL	(TX all text = firefighters or fireman or firewoman) AND (TX all text= fire fighters or firefighting) AND (TX all text = United States or America or USA or US) AND (TX all text = injury or injuries or accident or trauma) NOT (AB abstract = National Fire Protection Association).

The inclusion and exclusion criteria used to perform the search process considered all the articles that reported data related to occupational injuries for United States FFs. This review of the literature included all the peer-reviewed studies and reports available using data collection methods that excluded national reports and databases, as shown in Table 2. This search process was focused on physical health, including all the musculoskeletal injuries, while excluding all mental health cases. Additionally, there was an inclusion restriction regarding the country where the sample of the study was applied; in this case the firefighter injuries were only considered for fire communities within the U.S. However, there was no restriction for the year of publication.

Figure 2 shows that 1656 publications were identified in the search process through the different databases selected. Considering further review of the studies by title, abstract, and keywords, 1566 papers were excluded, and 90 papers satisfied the inclusion criteria to be retrieved and evaluated in detail. The evaluation process focused on the methods, results, and discussion sections of the papers with the objective of selecting papers that presented data related to firefighter injuries during work-related operations. These studies were carefully evaluated to ensure that they reported injury data by the categories indicated in Figure 1 (i.e., work scenario, nature of injuries, parts of body affected, and contributing activities) and that this data was not a duplication of data previously reported by national organizations. Of 90 papers, only 15 satisfied the criteria, i.e., the data collected was for FF injuries during work operations, and the data was not from one of the national data sources. As a result, the 15 papers satisfying the criteria formed the basis of the structured review in this study. The data collection methods in these papers primarily comprised surveys administered to fire departments. The 15 independent studies identified in Figure 2 were evaluated to determine the size of the study, number of injuries, part of the body injured, and activities that caused the injuries.

2.2. Data Cleaning and Preparation

Due to the different terminology used in the databases to describe FF injury profiles, this study standardized and grouped the categories for each injury profile area (i.e., work scenarios, nature of injury, body site injured, and firefighting activities) based on standard terminology used by the NFPA [25] and the BLS [30] (as shown in Table 3). While the categories for nature of injuries and body sites injured were created by combining terminology from national organizations, the categories for work scenarios and firefighting activities only used NFPA terms. It is important to emphasize that for this study, the term "firefighting injury" was defined in alignment with the definition of work-related injuries provided by the BLS [30]. Hence, firefighter injuries broadly include any event or exposure within the firefighting work environment that either caused or contributed to a resulting health condition or significantly aggravated a pre-existing condition [30].

Table 3. Injury profile areas and their associated categories.

Injury Profile Area	Work Scenario	Nature of Injuries	Body Site Injured	Firefighting Activities
Categories	1. Fireground operations 2. Non-fire emergency operations 3. Training activities 4. Responding to an incident 5. Other on duty activities	1. Strains or sprains 2. Only pain 3. Thermal burns 4. Penetrating wounds, cuts, bleeding, bruises 5. Fracture 6. Cardiac symptoms 7. Thermal stress 8. Smoke or gas inhalation 9. Others	1. Lower extremities 2. Upper extremities 3. Internal 4. Neck and shoulders 5. Head 6. Neck and back 7. Trunk 8. Multiple body parts 9. Others 10. Not reported	1. Extinguishing fire and neutralizing incidents 2. Suppression support 3. Other incident scene activity 4. EMS or rescue 5. Operating fire department apparatus 6. Driving or riding vehicle 7. Other known activity

Once the categories were standardized, the data was grouped, cleaned, and prepared for further analysis. When cleaning and preparing the data, we considered that the independent authors had different ranges of data collected. This study normalized the number of injuries per year by dividing the total of injuries reported in the study by the number of years covered by each study. Additionally, the data presented by the 15 independent studies that did not add up to 100% were normalized by dividing the percentage value reported by the authors for each category over the summation of the categories of the injury profile area.

The data from the 15 independent studies showed large differences in the total number of injuries reported and the percentages of injuries related to each category. This was due to the different study objectives, sample size, years of data collected, and population demographics. To account for the variability in the data presented by the 15 papers and to prepare them for comparison with the data reported by the national organizations, the data collected from the 15 studies was weighted and normalized by applying Equation (1) to each injury profile area:

$$X_i = \frac{\sum_{j=1}^{N} w_{ij} I_j}{\sum_{j=1}^{N} I_j} \quad (1)$$

where X_i was the cumulative weighted percentage for each category i (for $i = 1, 2, \ldots, M$, where M is the number of categories within each injury profile area), w_{ij} is the percentage of each category reported by each author, I_j is the total number of FF injuries reported for each study, and N was the number of studies included in the review of the literature.

Equation (1) was applied to all categories of each injury profile area according to the standardization presented in Table 3. The summation of X_i results in the total percentage for each injury profile area, which is equal to 100%, considering that the unreported data by authors was grouped into 'Others' or 'Not reported' categories, as appropriate.

2.3. Statistical Analysis to Define Variability of the Data

A statistical analysis was performed to evaluate the variability of the data to compare between the different databases and rank FF injuries by category. For this study, four dispersion measures were used: average or mean of the data points (μ), standard deviation (σ), confidence coefficient with a 95% confidence interval (CI), and coefficient of variation (c_v). While these four dispersion measures were applied to the NFPA and BLS datasets by applying statistical equations, the CI for the NEISS was reported from the dataset by both authors [9,28]. Since the NEISS data included only a single value for each category of the FF injury profile areas reported during 2000 and 2001, the dispersion measures could not be applied to the NEISS data. Similarly, the four dispersion measures could not be

applied to the 15 independent studies since each had insufficient information to account for the variation in each source accurately. Instead, the cumulative weighted mean for each category, X_i, described in Section 2.2 is used for the comparison of the 15 independent studies with the data reported by the national organizations.

The measures of dispersion were applied to datasets that presented data points of the same injury profile area over the years. For the case of the NFPA, the measures of dispersion were applied to the work scenarios and nature of injuries, while for the BLS dataset, the measures of dispersion were applied to the nature of injuries and body sites injured. Within the NEISS dataset, the number of FF injuries, their corresponding percentage, and a *CI* of 95% by nature and body sites injured were presented.

For the databases reported by national organizations, this study made use of the standard deviation (σ) to quantify the amount of dispersion of the data with respect to the arithmetic mean [31]. Additionally, the confidence intervals were computed as part of this analysis. Confidence intervals were applied as an indicator to estimate the uncertainty present in the datasets reported by each organization in relation to their respective mean (μ). This study considered a confidence coefficient of 95% (z = 1.96), as shown in Equation (2).

$$CI = \mu \pm ‡ \frac{\sigma}{\sqrt{n}} \tag{2}$$

where n was the number of data points reported for each category included in the analysis. Finally, the last dispersion measure was the coefficient of variation (c_v) given by:

$$C_v = \frac{\sigma}{\mu} \tag{3}$$

The coefficient of variation is the ratio of the standard deviation to the mean and is used to establish a normalized and dimensionless measurement of dispersion. For this study, the nature of injury and body site injured were computed to determine how much dispersion was present over 10 years in the national databases (the NFPA and the BLS). The higher the result of the coefficient of variation, the greater the level of dispersion around the mean.

2.4. Comparative Analysis and Prioritization of the Variables

The comparative analysis and ranking of the categories are based on two measurements from the statistical analysis: the cumulative weighted percentage (X_i) for the results of the data provided by the 15 independent studies and the arithmetic mean (μ) for the databases reported by the national organizations. Additionally, to rank the results of the contributing activities for firefighter injuries, the Pareto principle was applied. This principle states that a small group of causes leads to most of the effects and consequences [11]. In other words, for any typical results, 80% of the effects or consequences are the result of 20% of the causes. For the purposes of this study, this rule was applied to determine the 20% of activities that represent a cumulative weighted percentage of 80% of the leading tasks that cause injuries for FFs.

3. Results and Discussion

The results of this study have been subdivided into the following: (i) Results of data identification; (ii) Analysis of the work scenarios related to firefighter injuries; (iii) Analysis and ranking of the nature of firefighter injuries; (iv) Analysis and ranking of body parts injured; (v) Analysis and ranking of activities contributing to firefighter injuries.

3.1. Results of Data Identification

The injury profile areas with data available from the national sources were summarized in Table 4 by year. This data was collected using the official website for each organization except for the NEISS, whose data was obtained from Reichard et al. in [9] for the years 2000 and 2001 and from Marsh et al. [28] for the years from 2003 to 2014. Table 4 identifies

which database reports the number and percentage of injuries by type or nature, body sites injured, and activities. The database with the largest number of injuries was the NFPA, with the caveat that this organization gathers information about all types of injuries, whereas the BLS collected injuries that involved days away from work, and the NEISS only gathered information related to several injuries that are treated in emergency hospitals.Table A1 (Appendix A) summarizes the 15 independent studies used in this analysis and the data collection methods utilized by the studies. All the authors presented data related to the type of injury; four authors presented data related to injuries by body part, and only one author [9] studied injuries by activities grouped in FF work scenarios. The 15 independent studies corresponded to the collection and study of FF injuries in the years between 1992 and 2018.

Table 4. U.S. firefighter injury data available by category from national databases.

National Organization	Period Reported	Total Injuries during Period	Data Available by Injury Profile Area			
			Number of Injuries by Work Scenario	Number of Injuries by Type or Nature	Number of Injuries by Body Site Injured	Number of Injuries by Activities
NFPA	2010–2019	648,675	×	×	×	×
BLS	2011–2020	145,140		×	×	
NEISS	2003–2014	351,800		×	×	
NEISS	2000–2001	37,300		×	×	

3.2. Analysis of the Work Scenario Related to Firefighter Injuries

The NFPA uses a type of duty as one of the injury profile areas for reporting the injuries of FFs. This injury profile area was broken down into five different categories: fireground operations, non-fire emergency operations, training activities, responding to an incident, and other on-duty activities. In this study, these operations were named work scenarios, and the data for analysis was based on the NFPA dataset from 2010 to 2019 [20–25,31]. It is important to clarify that the category of training activities refers to tasks that prepare and assist in obtaining fundamental knowledge, skills, and fitness related to firefighting operations, as opposed to sport-related training. A total of 648,675 FF injuries occurred from 2010 to 2019 during all work scenarios. As shown in Figure 3, the percentage of total injuries in each scenario showed that injuries are more likely to occur during fireground operations, corresponding to 43% of the total injuries, followed by non-fire emergency activities (21%). These two work scenarios corresponded to 64% of all work scenarios where FFs were most likely to be injured. Hazardous operations and conditions, such as rescue calls, hazardous calls, natural disaster calls (non-emergency), structural fires, vehicle fires, brush fires, etc. (fireground operations), increase the likelihood of being injured during these work scenarios. These conditions had contributed to the ranking of fireground operations as the scenario where FFs were most likely to be injured over the years. Although the NFPA reported a reduction of 65% of injuries during fireground operations between 1981 and 2019 due to the decreased number of fires, fireground operations were ranked as the most common work scenario where FFs are most likely to be injured, accounting for the highest percentage of injuries from 2010 to 2019.

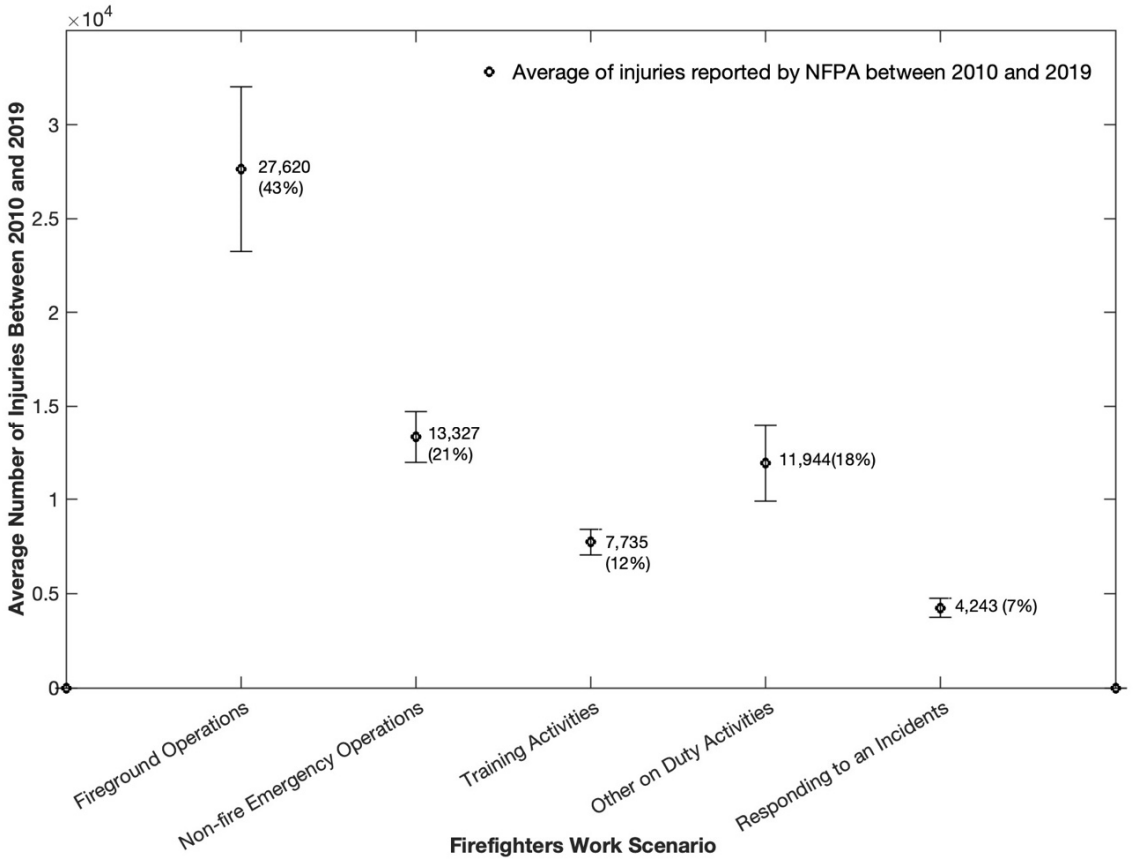

Figure 3. Average of FF injuries by work scenarios between 2010 and 2019.

Other studies have found similar results for fireground operations as the most likely work scenario where FFs were injured [32,33]. Hollerbach et al. [32] conducted a study of occupational injuries in a sample of U.S. career women FFs; results showed that the most common operations related to injuries were during fire rescue activities. Considering the high value of injuries during these activities, the study conducted by Griffin et al. [33] indicated that the University of Arizona had been working with the Tucson Fire Department to implement preventive strategies focusing on reducing injuries that occur during fireground operations, patient transport, and physical training.

3.3. Analysis and Ranking of the Nature of Firefighter Injuries

The results of the statistical analysis of the nature of injuries for FFs are shown in Table 5. This table shows the cumulative weighted percentage (X_i) for the type of injuries reported by the 15 independent studies compared with the analysis of the dispersion of the data presented by the BLS and the NFPA databases over a period of 10 years and the percentages reported by the NEISS for both authors. The dispersion of the data was evaluated to measure the variability of the number of injuries across the years. Additionally, the results of these measurements indicated the efficacy of actions to reduce the different types of injuries for FFs. The variables reported by the NFPA with the lowest dispersion in the data were smoke or gas inhalation (σ = 3%, c_v = 0.45), followed by strains and sprains (σ = 6%, c_v = 0.12). Similar results were found for the data reported by the BLS, for which the variables with the lowest dispersion in the data were strains and sprains (σ = 8%, c_v = 0.16), followed by fracture (σ = 1%, c_v = 0.34). The low spread of the data presented by these organizations showed that these types of injuries were consistently occurring in firefighting communities in the U.S.

Table 5. Statistical analysis results of nature of injuries for FFs *.

Data Source	Ind. Studies	NFPA					BLS					NEISS 2000–2001			NEISS 2003–2014		
Nature of Injuries	X_i (%)	μ (%)	σ (%)	LCB 95%	UCB 95%	c_v	μ (%)	σ (%)	LCB 95%	UCB 95%	c_v	%IR	LCB 95%	UCB 95%	%IR	LCB 95%	UCB 95%
Strains or sprains	54	49.2	6	46	53	0.12	47.9	8	43	53	0.16	33	15	51	34	18	49
Only pain	NR	NR	NR	NR	NR	NR	16.6	4	14	19	0.24	NR	NR	NR	NR	NR	NR
Thermal burns	5	7.9	1	7	9	0.13	2.9	1	2	4	0.03	6	1	11	NR	NR	NR
Penetrating wound, cuts, bleeding, bruises	27.5	13.5	1	13	14	0.07	7.5	2	6	9	0.26	24	11	36.6	23	13	31
Breathing difficulty/Respiratory illnesses	0.5	1.9	0	2	2	0	NR	NR	NR	NR	NR	5	2.30	7.7	NR	NR	NR
Fracture	4	2.6	0	2	3	0	2.9	1	3	3	0.34	4	1.30	6.7	5	3	6
Cardiac symptoms	0.3	0.7	0	1	1	0	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
Thermal stress	NR	6.7	2	6	8	0.30	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
Smoke or gas inhalation	NR	6.6	3	5	8	0.45	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
Others	10	11	1	10	11	0.09	21	8	17	27	0.38	28	0.70	26.8	38	16	26

* Abbreviations and Initialisms: Ind. Studies: Independent Studies, LCB: Lower Confidence Bound, UCB: Upper Confidence Bound, %IR: Percentage of Injuries Reported, NR: No reported data.

Sprain and strain injuries showed a standard deviation of 6% for the data reported by the NFPA and 8% for the data reported by the BLS. These results indicated that the number of injuries reported each year is relatively close to the mean of the injuries evaluated for 10 years for both national organizations (NFPA: μ = 32,112, and BLS: μ = 6875), as shown in Figure 4. This figure indicates the number of injuries reported by year and the dispersion of these values with respect to the mean for each database reported by the organizations. For clarification purposes, Figure 4 shows the actual number of injuries versus the percentage values shown in Figure 4. The authors of this study considered that the actual number was more significant and easier to interpret than their corresponding percentage equivalent. The number of strain and sprain injuries reported by the NFPA has shown a trend to decrease linearly over time, reflected by the result of the coefficient of determination (R^2 = 0.81). Additionally, it was observed that since 2016, the number of injuries significantly deviated from the 10-year mean, as shown in Figure 4. The results of their study showed that the overall total number of injuries had been steadily declining in relation to the declining rate of fire incidents over the same period. One contributing cause of the reduction in injuries over the years was the redefinition of the category for injuries caused by exposure to hazardous conditions and infectious diseases, which previously was classified in the total of injuries reported by the NFPA [34]. Although the overall trend of injuries for FFs has been shown to decrease over the years, the NFPA reported that the number of strain and sprain injuries continued to be high in 2020 (26,000 injuries) and is still considered a significant problem for the firefighting community [26,34,35]. Evans et al., in 2019, explained that the rate of injuries for US FFs per 1000 fire incidents in the years 2016, 2018, and 2019 represented the lowest rate over the past 38 years [26].

The result of the coefficient of determination for the number of injuries reported by the BLS (R^2 = 0.11) showed a large variation of this data over 10 years. Due to the fluctuation of the BLS data over this period, the use of a linear trend line was not reflective of a linear decline in the number of strain and sprain injuries. Although the data points reported by the BLS did not show a linear trend, the number of injuries indicated less deviation with respect to the 10-year mean. One of the contributing factors for the difference between the results of the coefficient of determination shown by the BLS compared to NPFA was the nature of the sample population of each database. While the NFPA reported FF injuries for all severity levels, the BLS only reported those severe injuries that required days away from work. Therefore, the authors in this study could conclude that severe strain and sprain injuries had a nonlinear trend between the years 2011 and 2020, even though these injuries

are relatively close to the average mean evaluated for these 10 years. The trends visualized in Figure 4 are similar even after normalization with respect to the number of FFs and the number of emergency calls.

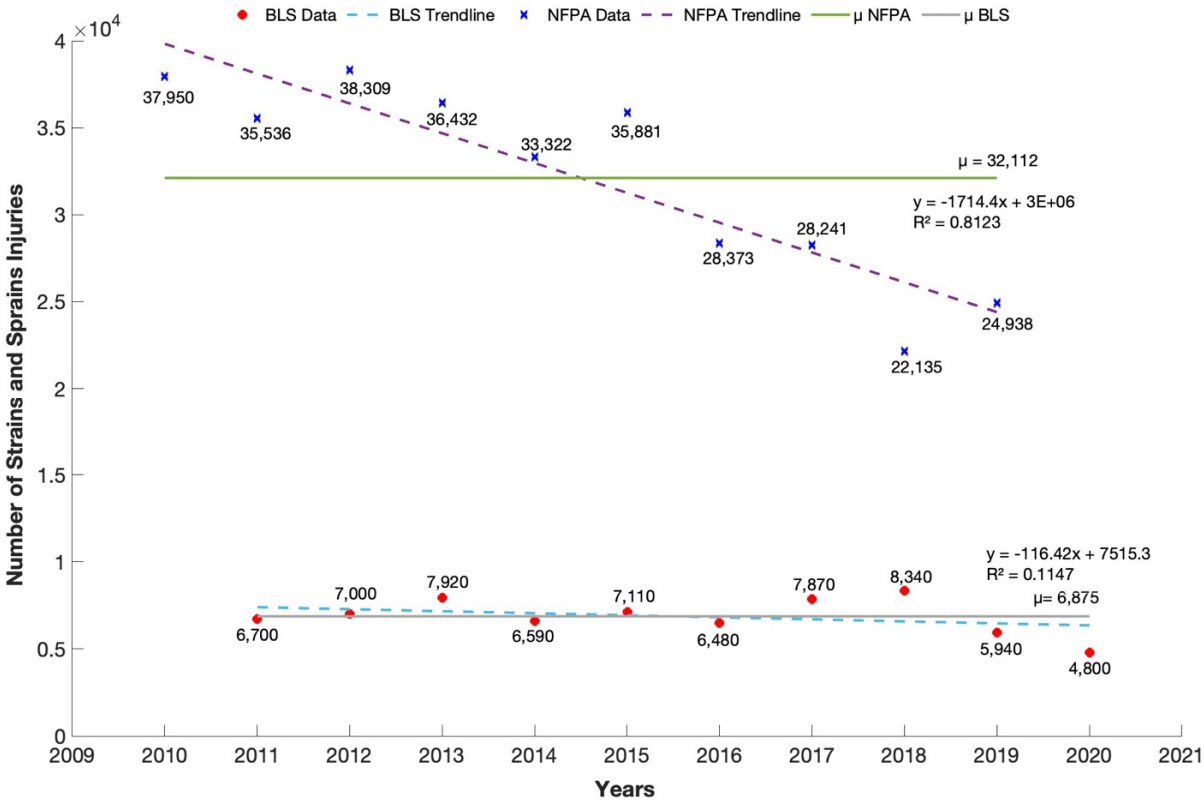

Figure 4. Analysis of strain and sprain injuries over 10 years.

Table 5 and Figure 5 show that the most common type of injury for FFs reported by all the databases and the independent authors were strains and sprains. This type of injury accounted for a cumulative weight of 54% of the total number of injuries reported by the different studies between 1992 and 2020. From this, 14 of the 15 examined independent studies, i.e., [16,32,36–44] agreed that strains and sprains were the leading type of injury suffered by FFs. Only one of the independent studies, namely [16], reported breathing difficulty and respiratory illnesses corresponding to 26% of the total as the primary injury. This latter report was based on data gathered from the Fire Department of the City of New York (FDNY) for FFs and emergency medical service (EMS) personnel injured during the World Trade Center (WTC) terrorist attack on 11 September 2001. Although this study reported injuries of one crucial event in 2001, this report assessed the injury type of 240 workers in FDNY. The report evaluated injuries from 24 h to 11 months after the attack. The structural collapse of the World Trade Center caused the death of 343 FDNY workers, and 240 workers (158 FFs and 82 EMS) were injured and treated in hospital emergency rooms. The highest percentage of injuries was respiratory infections, which comprised a combination of symptoms (i.e., respiratory irritation, dehydration, eye irritation, mild exhaustion) caused by the considerable number of toxic substances transmitted through the air after the attack.

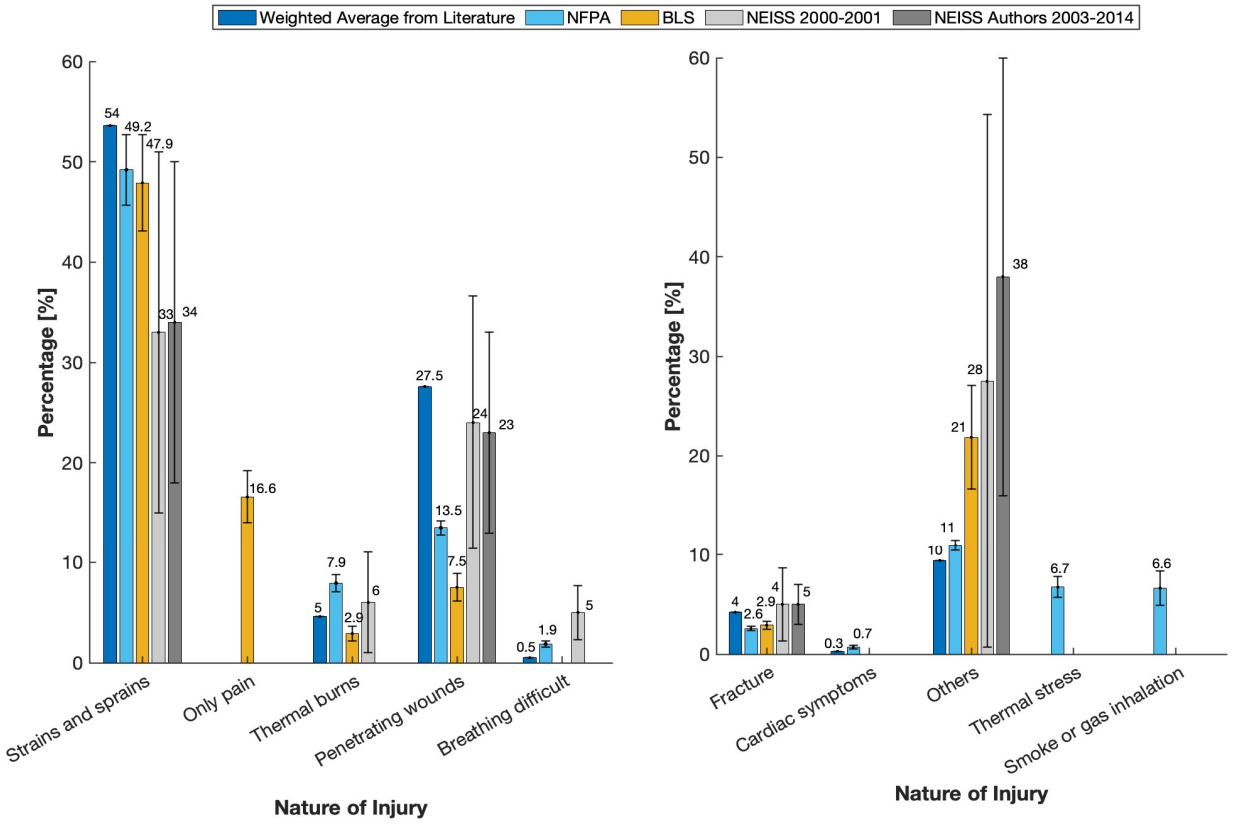

Figure 5. Comparative analysis on the nature of injuries for U.S. FFs.

From the data reported by the national organizations, strains and sprains were also considered the leading type of FF injuries. As shown in Table 5 and Figure 5, this "nature of injury" category accounted for 49.2% of total injuries reported by the NFPA, 47.9% of total injuries reported by the BLS, and 33% of total injuries reported by the NEISS 2000–2001 and 34% reported by the NEISS 2003 2014. Databases from national organizations such as the NFPA and the BLS showed very similar results for the mean of strain and sprain injuries between 2010 and 2020. On the other hand, the result reported by the NEISS between 2000 and 2001 and 2003–2014 is slightly lower than the average injury number reported by the BLS and NFPA. One of the contributing factors for this result was the limitation of the data collection used by the NEISS. The data collection for this national database was limited to injuries treated in emergency departments (ED), which might result in the omission of injuries that were less severe or did not require instant medical attention [9]. Thus, some less severe strain and sprain injuries may have been excluded. Furthermore, injuries with the primary nature of penetrating wounds, bleeding, cuts, and bruises reported by the NEISS 2000–2001 (24%) and the NEISS 2003–2014 (23%) showed a higher percentage in comparison to other data sources. Among the ED injuries, career FFs reported higher occurrences of strains and sprains than volunteer FFs (34% vs. 28%, respectively) but fewer bleeding wound and cut injuries (8% vs. 17%, respectively) [9]. It was important to note that all these reported injuries did not consider injuries from the World Trade Center (WTC) terrorist attack on September 11, 2001, in New York City. It is also important to highlight that despite the NEISS data being sourced from different authors and evaluated across different years, it consistently reflected a similar trend in the percentage of injuries by nature reported by FFs in emergency departments, as shown in Figure 5 and Table 5.

Among the national organizations that report firefighting injuries, the NFPA performs a deep analysis of these injuries by type of duty, nature, gender, age, activity, and body parts affected. As an illustrative example, the NFPA report in 2021 indicated that firefighters aged between 30 and 49 are at a higher risk of sustaining injuries during firefighting operations.

Additionally, the NFPA report noted that this age group has reported more incidents of injuries among career firefighters than volunteers. However, the NFPA authors also identified that the number of career firefighters aged over 60 years was less than 1%. According to their analysis, this could be attributed to the reduced participation in firefighting activities as individuals age [2]. The fact that there are very few career firefighters aged over 50 years indicates a longevity problem within the firefighting community.

Figure 6 demonstrates the correlation between percentages of strain and sprain injuries reported by each of the 15 independent studies and the average percentage of the three databases from the national organizations. This comparison allowed the authors of the study to identify the level of similarity between the percentage of injuries reported by individual authors and those from the data reported by national organizations. As shown in Figure 6, the authors in [4,32,37,41,42,44,45] presented similar percentages of strain and sprain injuries to those reported by the databases from national organizations. The authors in [37] conducted the evaluation of occupational injuries among 435 FFs from three different states, for which sprains and strains were the most common injury type (74%) reported. The data reported in [37] considered individuals with one or multiple injuries. As such, this author double-counted the number of injuries grouped by category.

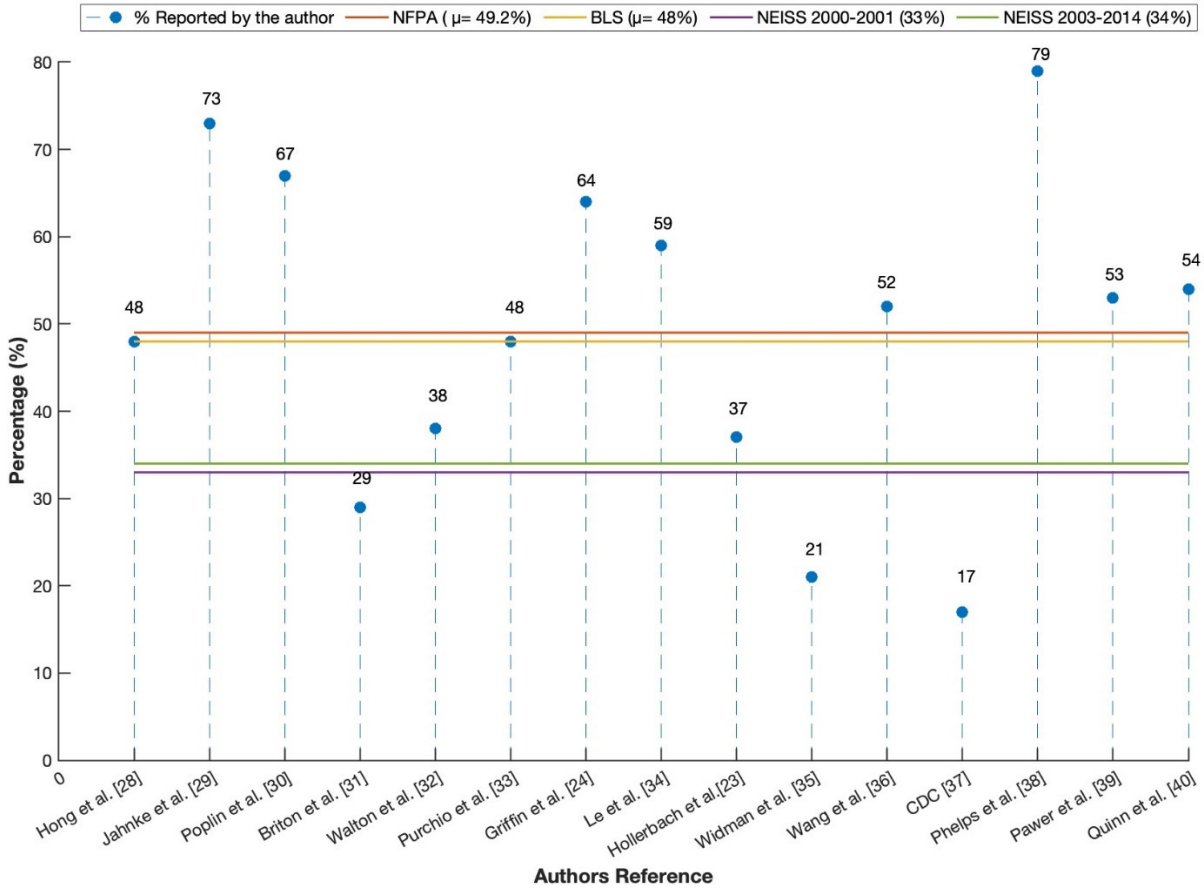

Figure 6. Correlation analysis of strain and sprain injuries reported by independent authors and databases from national organizations [23,24,28–40].

Figure 6 also indicated that the authors in [36,38,39,46] reported higher values for strain and sprain injuries compared with the databases from the national organizations. These results could be affected by the characterization of the sample population considered in each study. For example, Jahnke et al. in [38] and Poplin et al. in [39] focused on injuries among FFs in fire departments during training operations. A higher percentage of strain

and sprain injuries (73%) were reported among the studied population versus other types of injuries such as fractures, penetrating wounds, cuts, bleeding, and thermal burns.

The authors in [40,42] conducted studies with wildland FFs, for which the results presented by Britton et al. in [40] indicated a lower percentage of sprains and strains compared with the data from the national sources. Considering the demographic of the population and working environment of wildland FFs, the factors associated with injuries reported by the authors in [40] were poisoning or environmental exposure. Although injuries related to poisoning reported high values (21.6%), slips, trips, and falls were considered the most common factors resulting in strain and sprain injuries for wildland FFs, i.e., accounting for 29.4% of the total of injuries reported in the study conducted by Britton et al. [40]. This result is supported by Purchio et al. in [42], who reported that the most common factor related to wildland FF injuries was attributed to slips, trips, and falls, resulting in sprains and strains of the lower back, knees, and ankles. These types of injuries were reported as the most common among wildland FFs, accounting for 48% of the total of injuries, which results for the percentage of strain and sprain injuries were similar compared to the average percentage reported by national databases (i.e., the NFPA and the BLS) as shown in Figure 6.

The comparative analysis of the nature of injuries obtained from all data sources, as depicted in Figures 5 and 6, clearly shows that strains and sprains ranked as the leading type of injury for FF communities. This type of injury results from overexertion of joints and muscles of the body. Thus, the next section of this manuscript focuses on determining the primary body sites injured during firefighting operations to understand the correlation between the nature of these injuries and body location.

3.4. Analysis and Ranking of Body Parts Injured

The statistical analysis of the body parts injured for FFs is shown in Table 6. The evaluation of the data reported in the open literature was based on six of the fifteen independent studies, which identified and evaluated information related to body parts injured during firefighting activities [36,40,42,43,46,47]. Additionally, considering that the NFPA-published data on injuries was just discretized and reported since 2015, the data collected and analyzed in this study for the NFPA only considered the percentage of body parts injured from 2015 to 2019 [48]. On the other hand, the data reported by the BLS only considered occurrences from 2011 to 2020. This combination of data sources limited the evaluation of the variability of these injuries to a period of 10 years for the NFPA and NEISS data reported by Reichard et al. [9]. The dispersion measurements were applied to the BLS dataset to analyze the dispersion of body sites injured from 2011 until 2020. The categories with the lowest dispersion and, thus, the most frequently injured were internal (σ = 9%, c_v = 1.12), followed by neck and shoulders (σ = 3%, c_v = 0.33), and upper extremities (σ = 3%, c_v = 0.21). Additionally, the cumulative weighted percentage (X_i) value for the lower and upper extremities reported by this review coincided with the percentage reported by the NFPA and the NEISS and the average (μ) reported by the BLS, as shown in Table 6 and Figure 7.

Figure 7 showed a slight difference between the data presented by the NEISS 2000–2001 with respect to the NFPA, the BLS, and the independent studies. While the NFPA, the BLS, and the independent studies reported that the most common body sites injured were the lower extremities, the NEISS 2000–2001 reported that the upper extremities accounted for the most occurrences, with 31% of the total number of injuries of FFs from 2000 to 2001. Additionally, the data provided for this organization considered injuries for "neck and back" as an independent category, accounting for 18% of the total number of injuries. This standardization did not allow the present study to compare neck, back, and shoulder injuries to data provided by the NEISS 2000–2001 with the other data sources. Another factor that obscured the data from the NEISS 2000–2001 was the "not reported" category, which accounted for only 3% of the data reported by Reichard et al. [9]. The "not reported" category was used to sum the data reported by the authors up to 100%, considering that the data provided [9] considered two

categories that did not meet the minimum reporting requirements. Opposite to this result, the NEISS data reported by Marsh et al. [28] indicated that the most common injured body site was lower extremities (21%), followed by upper extremities (20%) and trunk (19%). The percentages reported by the NEISS 2003–2014 were like the rest of the national organizations and the 15 independent authors as shown in Figure 7.

Table 6. Statistical analysis of body sites injured for U.S. FFs.

Data Source	Ind. Studies	NFPA	BLS					NEISS 2000–2001			NEISS 2003–2014		
Body Site Injured	X_i (%)	%IR	μ (%)	σ (%)	LCB 95%	UCB 95%	c_v	%IR	LCB 95%	UCB 95%	%IR	LCB 95%	UCB 95%
Lower extremities	27	20	24	4	21.89	26.83	0.16	24	12.20	35.80	21	13	28
Upper extremities	15	18	14	3	11.88	15.2	0.21	31	10.89	51.11	20	13	26
Internal	5	17	8	9	1.93	13.44	1.12	NR	NR	NR	NR	NR	NR
Neck and shoulders	6	13	10	3	8.59	12.11	0.33	NR	NR	NR	13	4	23
Head	5	12	4	1	3.61	5.28	0.25	11	5.10	16.90	12	8	16
Neck and back	NR	NR	NR	NR	NR	NR	NR	18	5.94	30.06	NR	NR	NR
Trunk	18	12	26	3	23.91	28.1	0.11	NR	NR	NR	19	10	27
Multiple body parts	14	8	13	6	8.89	16.14	0.46	13	2.81	23.19	NR	NR	NR
Others	10	NR	1	1	0.57	1.64	1	NR	NR	NR	15	11	20
Not reported	NR	NR	NR	NR	NR	NR	NR	3	NR	NR	NR	NR	NR

Abbreviations and Initialisms: Ind. Studies: Independent Studies, LCB: Lower Confidence Bound, UCB: Upper Confidence Bound, %IR: Percentage of Injuries Reported, NR: No reported data.

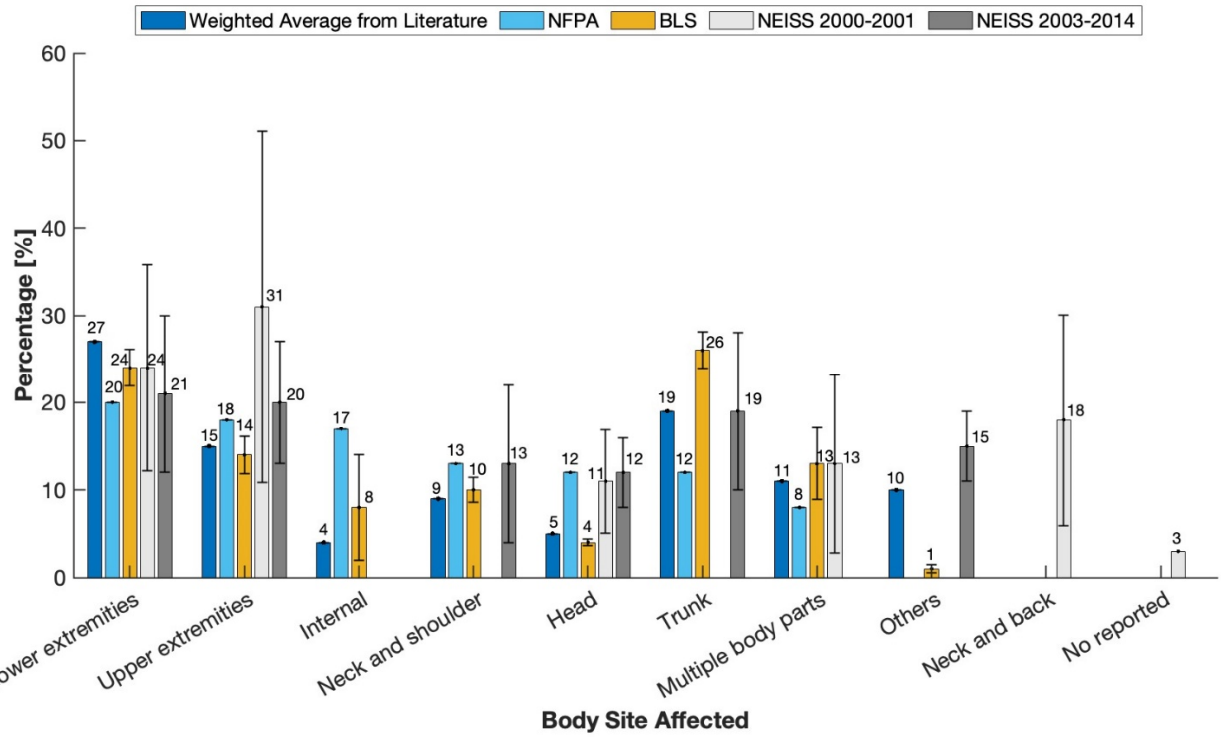

Figure 7. Comparative analysis of body sites injured for U.S. FFs.

The study conducted in this manuscript analyzed in more detail the body site categories described in the methodology section. Therefore, lower extremities include the following body parts: knees, upper and lower legs, feet and toes, ankles, and multiple lower body extremity locations. The NFPA reported that the most common body part affected by firefighting activities were knees, which accounted for 8% of the total number of injuries, followed by ankles (6%), lower and upper legs (4%), and feet and toes (2%). Similar findings were reported by the BLS, for which the body parts most affected for FFs

were knees with 10.21% of the total number of injuries, followed by ankles (6.37%), feet and toes (3.17%), and multiple lower body parts (3.74%).

As shown in Figure 7, the trunk was the category with the second-highest number of injuries reported by all the sources. The trunk category was grouped using the BLS standardization, for which the body parts considered were the chest, back, abdomen, pelvic region, external and internal reproductive tract structures, and multiple trunk locations. Of these, the most common body part affected by firefighting operations reported by the BLS was the back, which accounted for 73% of the total number of injuries within the trunk category from 2011 to 2020. It was important to note that internal body sites showed the highest data variability. The dispersion of this data was affected by the number of injuries reported in 2020.

The number of injuries to internal systems reported in 2020 was 6070, which accounted for 33% of the total. This percentage value was quite high compared to the values reported in 2011 and 2019 at 3% and 6%, respectively. Internal systems included circulatory systems, gastrointestinal systems, nervous systems, and respiratory systems. According to the BLS, the number of injuries and illnesses for all these body systems was significantly affected by the global pandemic caused by Coronavirus disease 2019 (COVID-19) in 2020. COVID infections were reported only if the worker was infected while performing work activities [49]. The SOII-BLS reported an increment of 43.5% of cases per 10,000 full-time equivalent workers from 2019 to 2020. The SOII gathers injuries and illness data under Occupational Safety and Health Administration (OSHA) requirements, for which COVID-19 was considered to be a part of the respiratory illness category. Similar results were reported by the NFPA, which estimated 20,900 exposures to infectious diseases, including COVID-19, in 2020, doubling the exposures reported in 2019.

The results of the literature review assessment were in line with the results presented by Orr et al. [13], that the lower extremity (knee, ankle, and foot) and back were the two most affected body sites, cited by three of the six authors evaluated in their review study [13]. These results were supported by the study conducted by Jahnke et al. [38], who reported that the lower extremity (21%) and trunk (19%) were the most common injury sites for FFs in fire departments located in the Missouri Valley Region of the U.S. Additionally, fire departments located in states such as California, Illinois, and Indiana reported that the most common body parts injured for FFs in their communities were the upper and lower extremities, accounting for 60% of the total number of injuries [37].

The comparative analysis of body sites injured obtained from all data sources, as illustrated in Figure 7 and Table 6, showed that the lower and upper extremities are the most common body sites injured during firefighting activities. While the trunk, knees, and ankles were the most common body parts within the lower body category, hands and fingers represented the most common body parts for the upper body category. The nature of injuries and body parts affected were related to the activities performed by FFs in the work context. Therefore, the next section analyzed and ranked those activities that contributed the most to the injuries of FFs reported by the NFPA.

3.5. Analysis and Ranking of Contributing Activities for Firefighter Injuries

Since the databases reported by the BLS and the NEISS in 2000–2001 and the NEISS 2003–2014 did not present information related to FF injuries by activity, only the data provided by the NFPA between 2015 and 2019 were used in the analysis performed in this section of the review. The percentage of injuries reported by the NFPA is found in [50]. In this reference, the NFPA showed eight subcategories grouping activities where FFs are likely to be injured. In these categories, extinguishing fire or neutralizing incidents accounted for more than half (56%) of the total injuries. The relevant activities that contributed to FF injuries within this category were handling charged hose lines (21%) and using hand tools for extinguishing fires (6%). The second most common category reported by the NFPA was suppression support activities, which accounted for 22% of the injuries. The set of activities contributing the most, 9% of the total 22%, to this category was "overhaul",

i.e., the group of operations to control and reduce damage caused by fire during pre-control (fire under control) and post-control (after the fire is under control) firefighting phases. This included salvage operations such as opening walls, ceilings, voids, and partitions to check for fire extension. These results were supported by the NFIRS, which established that the largest percent of firefighting injuries occurred during fire neutralizing incidents, which accounted for 52% of the total number of injuries, followed by suppression support (23%), for the years 2015 through 2017. These activities were the main causes of injuries related to strain and sprain, dizziness, exhaustion, and burns. Additionally, 8% of the total number of injuries were penetrating wounds, and bleeding type of injuries were caused by incidents during fire scenes (e.g., picking and moving equipment and tools, laying hose, catching hydrant, and unclassified incidents) [51]. Only one author presented information related to the number of injuries of FFs categorized by activities. Jahnke et al. [38] presented information related to firefighter injuries during work. Fireground operations accounted for 28% of the total number of injuries, from which the main activities related to FF injuries were handling charge hose lines (50%), followed by overhaul (16.7%) and forcible entry (10%). These main findings were similar to the data reported by the NFPA for this category.

Activities related to fire suppression were reported by authors from the NFPA as one of the main causes of injuries for FFs in the U.S. over time. Karter et al. [52] conducted a study of the primary patterns of FF injuries during 2009. The results of this study showed that fire suppression and extinguishing or neutralizing fire were the leading causes of minor FF injuries. It was important to note that these fire suppression activities accounted for 62% of the total number of injuries. On the other hand, the results carried out by the authors in [52] indicated that access or egress activities (i.e., carrying or raising ground ladders, climbing ladders, and escaping from fire hazards) were the most common category that contributed to 49% of the moderate and severe FFs injuries. The Pareto principle was applied to this information to rank the most common activities that contribute to FF injuries. Figure 8 shows that 20% of the activities that caused 86% of the total number of injuries for U.S. FFs during 2015 and 2019 were extinguishing fire or neutralizing incidents, suppression support, and other fire incidents. The results of the Pareto principle indicated that focusing on these three activities to implement preventive measures has the potential to reduce the risk of FF injury by up to approximately 80% and promote the well-being of U.S. FFs during fireground operations.

Data provided by NPFA and from the open literature review indicated the need to study potential prevention opportunities focusing on activities such as carrying hoses and heavy equipment, performing forcible entry, climbing ladders, and contending with uneven and slippery surfaces [34], which contributed to strain and sprain injuries of FFs. Campbell, in [53], mentioned that training techniques to reduce mechanical loads on body parts of the musculoskeletal system involved during risky postures (bending and lifting) have been proposed.

3.6. Strengths and Limitations

This review article presents a comprehensive categorization scheme of four categories aiming at analyzing the patterns of injuries sustained by firefighters (FFs) in the United States. The primary objective of this manuscript was to review, analyze, and compare the data published by national organizations (the NFPA, the BLS, and the NEISS) and by authors in the scientific community. By defining the work context, the types of injuries, the specific body sites affected, and the activities precipitating injuries within the firefighting community, further research should be focused on proposing preventive solutions to reduce the repetitive number of injuries for firefighters.

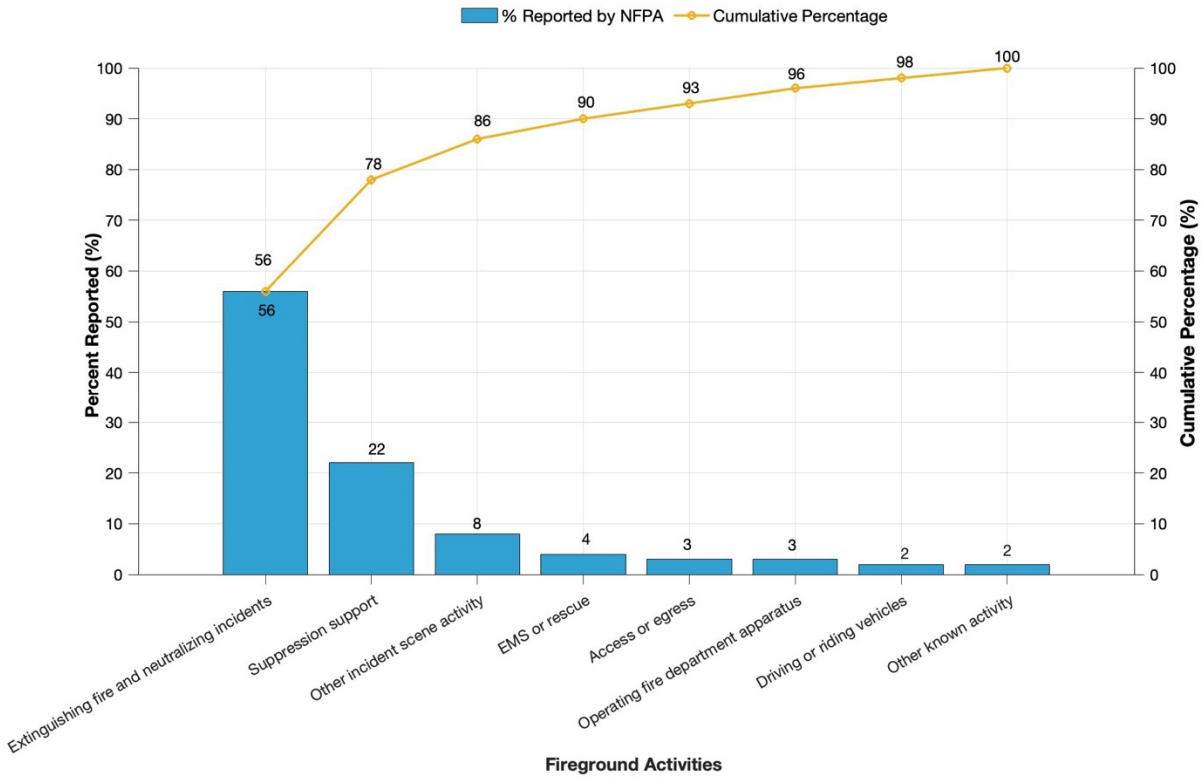

Figure 8. Ranking of activities that contribute to FF injuries applying Pareto principle.

While the data used for this study was sourced from national organizations and scholarly publications included in the literature review, a noteworthy limitation lies in the absence of a comprehensive differentiation and categorization of the data attributed to the different specialized categories of FFs in the United States. The primary focus of this paper is on injury data of municipal FFs. However, it is important to recognize that the firefighting community has different specialized categories, such as industrial firefighters, military firefighters, airport firefighters, and wildland firefighters. These specialized firefighters operate within distinctive environments, encounter unique hazards, and participate in work activities that often diverge significantly from those of municipal firefighters. Therefore, the profile of injuries for these FF categories could potentially deviate from those observed among municipal firefighters. It is important to emphasize that while certain studies within the dataset sourced from the literature included injuries within specialized firefighting communities (e.g., wildland FFs), the available data proved insufficient for creating a comprehensive profile of the injuries, their impacts, and their underlying causes within this specific category of firefighters. Future research should aim to integrate the distinctions in injury patterns among different specialized firefighting categories that have not been undertaken in this study.

4. Conclusions and Recommendations

This review article involves a comprehensive examination of published firefighter injury data from diverse sources, encompassing three national organizations and fifteen independent studies, all pertaining to firefighter injuries within the United States. This review article highlighted that sprains and strains consistently emerged as the most prevalent types of injuries among U.S. firefighters. This conclusion was supported by the outcomes of the statistical comparative analysis, which reveals a consistently high mean percentage of strain and sprain injuries across all the databases incorporated into this study. Furthermore, the minimal variance in the data presented by the national organizations underscores the recurrent nature of these injuries within U.S. firefighter communities. Despite occasional fluctuations in injury rates for strains and sprains, the dispersion of reported percentages

remained relatively close to the mean of the analyzed data. These results showcased the need to perform more research focused on preventative solutions that aim to reduce the impact and probability of firefighter injuries during fireground operations. While the studies propose physical rehabilitation and training programs, the persistently high percentage of these injuries and the heightened risk with increased years of service among aging firefighters require urgent attention. Future investigations into emerging robotic and assistive technologies, such as exoskeletons, should also be considered. This study further underscores the critical priority of focusing on potential solutions to reduce strains and sprains within the U.S. firefighting community. It is important to note, however, that the lack of standardization in the data and the frequent use of musculoskeletal categories with respect to injuries may have unintentionally biased the collection and reporting process to underrepresent injuries and long-term conditions resulting from other factors, such as exposure to hazards (e.g., heat, smoke, gas inhalation, and deposits of carcinogens), as found in [54]. Recent efforts related to the implementation of decontamination procedures and awareness surrounding the increased risks of cancer may be a recommended starting point for future mitigation and prevention studies related to musculoskeletal firefighting injuries.

The most likely body sites injured by U.S. FFs were the lower and upper extremities and trunk. For the lower body parts, the highest percentage of injuries were in the knee and ankle. For the trunk category, the most common body part injury reported was the back. In the upper body extremity, the most injuries for FFs were hands and shoulders. These results are clearly shown by the analysis and ranking of the data presented by all data sources. The low values of the dispersion measurements for the data presented by the BLS also indicated that these body parts had been frequently injured during firefighting activities over the years. Considering the outcomes of this study, the authors suggest directing future research efforts toward assessing the evaluation of the incorporation and use of external devices to prevent injuries in the mentioned body parts, e.g., exoskeletons.

The three main categories of activities contributing to U.S. firefighter injuries were extinguishing fire/neutralizing incidents, suppression support, and incidents during fireground operations. The most common fireground activities causing injuries among FFs are the following: (i) Handling charged hose lines; (ii) Handling tools for fire extinguishing; (iii) Overhaul. The ranking of these specific activities evaluated by a Pareto principle allowed the authors of this study to propose that preventive actions focused on these three activities could decrease by approximately 80% the probability and severity of injuries that occur during fireground operations. To address this, recommended preventive actions may include adherence to training programs aimed at reinforcing safe movements during firefighting activities.

The results presented in this study showcase the need to perform enhanced research focused on preventive solutions that aim to reduce the impact and probability of firefighter injuries during fireground operations. Although research studies have proposed implementing physical rehabilitation and training programs as preventive and corrective actions, the high percentage of strain and sprain injuries reported over the years by the different data sources as well as the increased likelihood of injury with greater years of service among the aging FFs population show that this is still an area of major concern. Based on this study, a focus on potential solutions to reduce strain and sprain injuries should be a critical priority within the firefighting community.

Additionally, it is expected that the findings of this review study may be of general interest to the broader international firefighting community, with future work recommended that would consider a review of injury data within firefighting contexts internationally. Firefighting injuries are prevalent and are a significant issue globally, and a future study investigating trends and contextualizing differences internationally would help provide a comprehensive understanding of the causes and effects of firefighting injuries worldwide.

Further, through the execution of this study, it has become evident that the absence of standardization in terminology and categories for work context, nature of injury, body part affected, and activities leading to injury presented a significant challenge for comparing

firefighter injury data. Thus, it is recommended that additional efforts to standardize the categories and increase the granularity of firefighter injury data be undertaken, broadly informed by a combination of stakeholders, including scientific researchers, national organizations, such as the NFPA or the BLS, and the larger firefighting community.

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Conflicts of Interest: The authors declare no conflicts of interest.

Appendix A

Table A1. Key points regarding the results of papers included in the review study.

Authors (Year) and Reference	Title of Paper	Aim/Objective	Data Collection Method	Years of Data Collection	Total Number of FF Injuries Reported	Population Demographic	Injury Profile Area Reported
Hong et al. (2012) [37]	Occupational injuries, duty status, and factors associated with injuries among FFs	To evaluate the type of FF job-related injuries, duty status, and contributing factors	A survey of three U.S. state fire departments	2010–2011	285	Demographic characteristics included age, gender, ethnicity, and years in fire services (California, Illinois, and Indiana)	Nature of injury
Jahnke et al. (2013) [38]	Injury among a population-based sample of career FFs in the central USA	To study occupational FF injuries due to physical exertion during operations	Survey	2008–2010	115	Career FFs from Missouri Valley Region of the U.S.	Nature of injury Work scenario
Poplin et al. (2011) [39]	Beyond the fireground: injuries in the fire service	Study occupational FF injuries due to physical exertion	Database	2004–2009	902	Tucson Fire Department personnel, which includes 650 career Emergency Service Employees, operating 21 fire stations	Nature of injury
Britton et al. (2013) [40]	Epidemiology of injuries to wildland FFs	Study of factors leading to FF injuries to determine their nature and severity	Reports from the Safety Management Information System (SMIS)	2003–2007	1301	Records included in this analysis were those associated with wildfire or prescribed in the FMAR (Fire Management Accident Report)	Nature of injury Body parts affected
Walton et al. (2003) [41]	Cause, type, and workers' compensation costs of injury to FFs	To understand the cost related to FF injuries, its causes, and nature, to assist in the making of policy decisions related to occupational health and safety	Survey	1992–1999	1343	The data was provided by a large non-profit organization that reports worker compensation with a scope of 77 municipalities located in northeastern Illinois.	Nature of injury
Purchio et al. (2017) [42]	Descriptive analysis of injuries and illnesses self-reported by wildland FFs.	The aim of this study was to identify the types of job injuries for wildland FFs and the contributing factors for defining areas of concern for this community.	Survey	2005–2010	453	The demographic characteristic of this study included wildland FFs older than 18 years old who had worked for at least five years for the U.S. Forest Service (USFS) in all crew types across all geographic area coordinating centers.	Nature of injury Body parts affected

Table A1. *Cont.*

Authors (Year) and Reference	Title of Paper	Aim/Objective	Data Collection Method	Years of Data Collection	Total Number of FF Injuries Reported	Population Demographic	Injury Profile Area Reported
Griffin et al. (2016) [36]	Evaluation of a fitness intervention for new FFs: injury reduction and economic benefits	This paper studies the main injuries, body parts affected, and mechanism of injuries in a sample of 22 fire departments in Tucson to evaluate the effects of fitness programs on improving health conditions.	Survey	2007, 2008 2009, 2012	84	The TFD is a medium-sized metropolitan department that operates 22 fire stations and employs nearly 600 career FFs. Data for four recent classes of the TFD Recruit Academy FFs were used: the 2007, 2008, and 2009 classes served as historical controls, and the 2012 class received the PFF-Fitness intervention.	Nature of injury Body parts affected
Le et al. (2020) [43]	Firefighter overexertion: A continuing problem found in an analysis of non-fatal injury among career FFs	This study aimed to provide an update on injury occurrence among career FFs	Survey	2014–2016	914	FF injury data and records were collected from two large metropolitan fire departments, one in the western U.S. and one in the eastern U.S., each serving populations greater than half a million people.	Nature of injury Body parts affected
Hollerbach et al. (2020) [32]	Injury correlates among a national sample of women in the U.S. fire service.	To examine occupational injuries among career women FFs	Survey	2017	674	Carrier women FFs, 38.8 years old company officers, and chiefs from every U.S. state, the District of Columbia, and the U.S. Territories	Nature of injury Work scenario
Widman et al. (2016) [44]	The benefits of data linkage for firefighter injury surveillance	Maximize case detection and extend injury description for the U.S. Fire Service using data linkage.	Survey	2005–2013	1916	FFs from the Philadelphia Fire Department (PFD)	Nature of injury
Wang et al. (2019) [16]	Cross-cultural comparison of FFs' perception of mobility and occupational injury risks associated with personal protective equipment.	The objective of this study was to compare the effects of personal protective equipment (PPE) used by Chinese and U.S. FFs on mobility and occupational injury risks.	Survey	2018	109	U.S. FFs from Colorado State	Nature of injury
Center for disease control and prevention report (2012) [45]	Injuries and illnesses among New York City Fire Department rescue workers after responding to the World Trade Center (WTC) attacks.	This report describes morbidity and mortality in FDNY rescue workers during the 11-month period after the WTC attacks	Filtering information from the Fire Department New York City-Bureau of Health Services (FDNY-BHS) computerized medical database	2001	158	New York City Fire Department rescue workers who required emergency attention during the 24 h after the collapse of the World Trade Center towers in New York City	Nature of injury
Pawer et al. (2022) [47]	Female firefighter work-related injuries in the United States and Canada: an overview of the survey responses	This study describes work-related injuries among the career and volunteer female population in the firefighting community in Canada and the U.S.	Survey	2019–2020	242	Career and volunteer female firefighters from Canada and the U.S.	Nature of injury Body parts affected

Table A1. *Cont.*

Authors (Year) and Reference	Title of Paper	Aim/Objective	Data Collection Method	Years of Data Collection	Total Number of FF Injuries Reported	Population Demographic	Injury Profile Area Reported
Quinn et al. (2023) [55]	Workers' compensation injury claims among firefighters in Ohio, 2001–2017	This study evaluated existing non-fatal injuries through a detailed examination of workers' compensation injury claims originating from the state of Ohio.	Public and private firefighter claims	2001–2017	25,697	Career and volunteer firefighters at Ohio State	Nature of injury
Phelps et al. (2018) [46]	Characteristics and predictors of occupational injury among career firefighters	This study analyzed the characteristics of occupational injuries for career FFs from central Texas and northern California	Cross-sectional survey	2015–2016	80	Fire departments from Central Texas and Northern California	Nature of injury Body parts affected

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