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# Firefighting Gloves: a Literature Review on Ergonomic Issues

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**Abstract:** Gloves are an important item of firefighting protective equipment and must provide adequate hand protection while allowing firefighters to conduct operations in hazardous environments. However, among the diverse personal protective equipment items worn by firefighters, gloves are considered the most challenging. Studies point out several shortcomings in gloves currently used in firefighting and other related missions, directly impacting firefighters' performance. This paper provides a literature review with the objective of offering a better understanding of how ergonomics of firefighting protective gloves has been addressed. The main purpose is to identify the issues faced by firefighters when wearing gloves based on previous research and describe how identified issues are being assessed by researchers. Selected research papers highlight performance issues such as limited dexterity and lack of grip as common disadvantages of current gloves. Authors also identified difficulties when donning and doffing of gloves and a reduction of thermal protection when gloves become wet. Current firefighting protective gloves are still considered bulky and thick, impairing mobility and hand function. Moreover, design issues such as fit and sizing appear as common complaints of firefighters. Furthermore, studies advocate that glove sizing systems may not be the most appropriate. Additionally, construction aspects and interfaces with other equipment and tools seem to be aspects to be investigated. It is also worth mentioning that, according to some studies, fit and sizing is a special constraint for female firefighters, who usually have smaller hands. It is possible to notice that although research has been focusing on issues related to the use and interaction of firefighters with their personal protective equipment, few authors relate such aspects to the Ergonomics discipline. The development of new methods and the availability of relevant data would facilitate the application of ergonomic principles in the design of protective gloves and contribute to the protection, comfort and operational performance of firefighters.

*Keywords:* Dexterity, Fit and Sizing, Grip, Human Factors, Personal Protective Equipment, Sizing systems

## 1. Introduction

Personal protective equipment (PPE) is critical in firefighting, allowing firefighters to perform different missions in hazardous environments. Gloves are an important element among the diverse firefighting PPE[1] items, including clothing, boots, hoods, helmets, face masks and self-contained breathing apparatus (SCBA). However, gloves figure as one of the most challenging firefighting PPE items.

Firstly, gloves are considered as having minor importance when compared to other protective ensemble items. Durability may be an important factor, as gloves are subject to faster wear and tear. According to Stull and Stull (2007), gloves are perhaps the most misunderstood, usually considered a commodity or throwaway item, of the protective ensemble and are often given little consideration when purchased.

[1] Also referred to as turnout gear, turnout ensemble or protective ensemble.

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Secondly, it is highlighted that there is not much research concerning gloves in comparison to other firefighting PPE items such as turnout clothing. Approximately a decade ago, Park et al. (2014) pointed out that although some studies investigated firefighters' perceptions concerning their turnout clothing, none gathered specific insights regarding gloves, boots, helmet and SCBA.

And thirdly, the proper nature of the hands. Hands are complex 'tools' central to the performance of many tasks such as gripping, pulling or pushing objects (Griffin et al. 2019). However, the high rate of exposed surface area to volume of body mass (Stull and Stull 2007) associated with multifaceted dimensions and shapes (Hsiao et al. 2015) brings difficulties to glove design.

Several shortcomings are still identified in the existing gloves used in firefighting and other related missions[2] performed by firefighters, impacting their operational performance. Gloves appear as one of the worst evaluated PPE items according to participant firefighters of many studies (Boorady et al. 2013a; Moraes et al. 2019; Son, Lee, and Tochihara 2013). There are relevant trade-offs between protection and comfort. The need for combining high-performance protection and comfort is considered a technical challenge in firefighting glove design (An et al. 2016; Boorady et al. 2013b).

Aiming to bring light to some of these challenges, this paper provides a review with the objective of offering a better understanding of how ergonomics of firefighting protective gloves has been addressed in the literature. The main performance and design issues faced by firefighters when wearing their gloves based on previous research are identified. Moreover, it is described how researchers have been addressing such issues. Suggestions and recommendations presented by authors as well as recent developments on firefighting gloves are offered. Furthermore, the following subsection briefly describes the common features of gloves used in firefighting.

### 1.1 Types of firefighting gloves

Firefighters must wear different types of gloves for different missions, according to the hazards to which they are exposed. Moreover, must be compatible to wearer's anthropometric characteristics, climates and performance needs (Lee et al. 2014). The main types of gloves worn by firefighters are described in the TechNote of the U.S. Department of Homeland Security (U.S. Department of Homeland Security 2013). Work gloves provide puncture protection and are used for maintenance tasks. Extrication or rescue[3] gloves provide protection from cuts, punctures, bodily fluids and chemicals and must be compatible with rescue tools. Proximity gloves have a metallic outer layer and are used in extreme heat environments such as aircraft and some chemical fires. Structural gloves must be resistant to flame, conductive heat, liquid penetration, cuts and punctures and are used in fighting structural fires, including residential and commercial structures.

At the same time, all these types of gloves must ensure comfort and hand function. Protective firefighting gloves must cover hands and wrists, overlapping the coat sleeves to create a secure barrier. Structural firefighting gloves follow the same principles of layering materials applied to structural firefighting clothing, usually employing a functional three-layer construction comprised of an outer shell, a moisture barrier (or barrier layer), and a separate or combined thermal lining (Stull and Stull 2007). Different cuff lengths are offered depending on the glove style and manufacturer (Boorady et al. 2013b). Structural gloves interface with the coat sleeves through an attached knit gauntlet or strap which loops over the thumb to hold coat sleeves securely in place (Boorady et al. 2013b). Protective gloves for firefighting missions should meet certification requirements[4].

## 2. Methods

Research papers addressing ergonomics of firefighting gloves were selected for the present review. Searches were initially made in the Scopus and ISI Web of Science subscribed databases. The first search included the following search terms and Boolean operators: (firefight*) AND (glove*) AND (ergonomic*), appearing in the article title, abstract or keywords. Later, as the number of returned references was too small[5] a second search was made in the Google Scholar database using the same search terms[6]. Furthermore, references cited within all relevant retrieved papers were examined for finding additional

[2] Including recuse and protection of people in emergencies, including emergency medical response, hazardous materials response, extrication from road traffic collision, among others.
[3] Also named as RTC (road traffic crash) gloves.
[4] It is possible to mention the NFPA 1971 Standard on Protective Ensembles for Structural Fire Fighting and Proximity Fire Fighting (National Fire Protection Association 2018) and the European Standard EN 659:2003+A1:2008 – Protective Gloves for Firefighters (European Committee for Standardization 2008).
[5] Initial searches in the Scopus and ISI Web of Science databases resulted in 5 and 2 research papers, respectively.
[6] In this case, 1.670 research papers and academic thesis were identified. The most 30 relevant references were selected for analysis.

papers. Applicable references such as standards and guidelines were also collected. Additional searches on websites were performed aiming to find further relevant references. All duplicates were excluded as well as papers in any language other than English[7]. Literature searches were conducted between 01-15 of May 2022.

## 3. Results and Discussion

A total of 15 references specifically addressing firefighting gloves were selected. The following subsections present the main results of the literature review grouped in performance issues – dexterity, grip, donning/doffing and protection, and design issues – fit, sizing and construction. Moreover, an overview of the main methods applied by authors is offered. Furthermore, a subsection containing recommendations, suggestions and recent developments is presented.

### 3.1 Objectives and Research Methods

Methods used by authors varied from qualitative to quantitative, depending on the research objectives. An overview of authors, year, country, methods, and number of participants of the main selected papers is summarized in Table 1.

Table 1. Selected research papers and thesis related to Ergonomics of firefighting gloves

| Authors | Year | Country | Method | Participants (no. and gender) |
|---|---|---|---|---|
| Sotiriadis and Fletcher | 2010 | U.K | Semi-structured interviews | 49 men + 54 women |
| Son et al. | 2013 | Japan | questionnaire | 1,282 men |
| Park et al. | 2014 | U.S. | survey + focus group interviews | 48 men + 6 women |
| Boorady et al. | 2013a | U.S. | Semi-strcutured focus group interviews | 22 women |
| Boorady et al. | 2013b | U.S. | Semi-structured focus group interviews | 67 men |
| Lee et al. | 2015 | International* | questionnaire | 1,611 men + 61 women |
| Lee et al. | 2014 | Japan | Experimental tests + interview | 8 men |
| Hsiao et al. | 2014 | U.S. | Direct and indirect** measurement + questionnaire | 863 men + 88 women |
| Moraes et al. | 2019 | Portugal | Questionnaire + semi-structured interviews | 14 men + 2 women |
| An et al. | 2016 | South Korea | Wearer trials + in-depth interviews | 12 (gender not mentioned) |
| Lanham | 2022 | U.S. | experimental tests | 13 men + 1 woman |
| Hsiao et al. | 2015 | U.S. | Self-assessment and indirect** measurement | 863 men + 88 women |

* Australia, Korea, Japan and U.S.
** Using scanning technologies

Sotiriadis and Fletcher (2010) conducted semi-structured interviews with firefighters serving in U.K. fire brigades aiming to understand how PPE affects their performance and decision-making abilities. Son, Lee, and Tochihara (2013) investigated the differences in work environments, physical strain, wearer mobility and satisfaction between different configurations of PPE using a questionnaire which was responded by 1,282 Japanese firefighters.

Park et al. (2014) carried out a survey in combination with focus group interviews with U.S. firefighters aiming to assess the design needs of PPE items other than clothing, such as boots, hood, SCBA, helmet, face mask and gloves. The survey questions related to glove performance aimed to evaluate firefighters' satisfaction with fire/flame protection, water-proofness, thermal comfort, grip, and dexterity. Boorady and colleagues explored the issues firefighters experience when wearing their gear to identify areas needing improvement. The authors conducted semi-structured focus groups interviews with career and volunteer firefighters serving in U.S. fire brigades located in different regions of the country. The authors pointed out the main

[7] Three research papers in Korean and one in Persian languages were excluded.

identified issues by male participant firefighters (Boorady et al. 2013b) and by female participant firefighters (Boorady et al. 2013a). Similarly, aiming to obtain feedback and further suggestions for improving the current PPE as well as to evaluate firefighters' perceptions regarding smart features to be incorporated in the next generation of firefighting PPE, Lee et al. (2015) administered a questionnaire to Australian, Japanese, Korean and U.S. firefighters.

Using mixed methods, Lee et al. (2014) evaluated the thermoregulatory responses and subjective perceptions of 8 Japanese male firefighters using experimental tests followed by interviews. Participants wore different models and styles of firefighting helmets, boots and gloves used in Japan, the U.S. and European countries. Hsiao et al. (2014) collected anthropometric data of 863 male and 88 female firefighters serving in U.S. fire brigades for fire apparatus applications. Among diverse measurements, the authors performed grip strength tests aiming to compare differences between bare and gloved hands.

Focusing specifically on firefighting gloves, Moraes et al. (2019) administered a questionnaire in combination with a semi-structured interview aiming to assess Portuguese firefighters' perceptions and experiences when wearing structural gloves. The questionnaire included questions concerning the participants' level of satisfaction, including fit issues, sizing, level of protection as well as the selecting/purchasing process. Using an experimental approach, An et al. (2016) conducted wearer trials of 18 styles of firefighting gloves from different manufacturers, aiming to examine their wearability. Twelve South Korean firefighters participated in the trials, which involved a standardized set of hand activities (such as turning the thumb, gripping and releasing, pivoting wrist back and forth and side to side) followed by in depth interviews.

Aiming to quantify the impact of glove use and occupational tasks on hand performance, Lanham (2022) assessed the isometric handgrip strength of 14 U.S. firefighters, including 1 female firefighter. A hand dynamometer was used for the evaluation conducted in different simulated fireground tests. The study conducted by Hsiao et al. (2015) requested participants to self-assess the fit of their gloves (fit well or fit poorly) considering tasks performed in regular firefighting operations. Furthermore, the study obtained 14 hand dimensions of firefighters serving in U.S. fire brigades, using a bi-dimensional scanner. Data were further used for developing a new sizing scheme for structural firefighting gloves.

## 3.2 Performance Issues – Dexterity, Grip, Donning/Doffing and Protection

Limited dexterity and lack of grip are considered common disadvantages of current gloves, appearing as major concerns of participant firefighters in many studies (Boorady et al. 2013b; Lee et al. 2015; Moraes et al. 2019; Park et al. 2014; Sotiriadis and Fletcher 2010). Dexterity and grip are directly related to the ability to perform essential movements with hands and especially when handling tools such as radios, walkie-talkies, hoses and axes. From all the evaluated criteria in the study conducted by Park et al. (2014) dexterity had the lowest satisfaction level among participants. Lack of grip was identified especially on the palm region of gloves (Park et al. 2014). Moreover, Lanham (2022) and Hsiao et al. (2014) demonstrated the impact of wearing gloves on lowering handgrip strength.

Studies recognized that donning and doffing difficulties may influence the tendency of firefighters to avoid wearing their gloves in diverse situations (Boorady et al. 2013b; Park et al. 2014), or in contrary, to not remove their gloves (Lee et al. 2015), which also increase their exposure to many risks. Lee et al. (2014) highlighted the relevance of an easiness glove donning and doffing for cooling the hands between duties, attenuating the onset of hyperthermia and increase the work capacity.

The level of protection was considered satisfactory by participants of the Moraes et al. (2019) and the Sotiriadis and Fletcher (2010) studies. However, participants expressed a reduced level of protection when gloves become wet, increasing the risk of burn injury due to the quicker heat transfer compared to dry gloves, mentioned in the Park et al. (2014) and in the Moraes et al. (2019) studies. Wet gloves were also considered to cause a decrease in firefighters' mobility (Son et al. 2013).

## 3.3 Design Issues – Fit, Sizing, Materials, Construction and Interface

Sizing and fit are considered critical issues of firefighting gloves (Hsiao et al. 2015; Lee et al. 2015; Moraes et al. 2019). Limited mobility and dexterity are directly related to ill-fitting and wrongly-sized gloves (Park et al. 2014). A glove that is too tight may constrict the wearer's hand, affect circulation in the fingers and restrict movements, especially those related to grabbing. On the other hand, bulky and loose-fitting gloves may impact movements due to a decreased dexterity and grip capability and also lessen protection, being more susceptible to penetration of water and contamination particles. As mentioned by Griffin et al. (2019), glove fit influences hand safety, function, comfort, and ultimately, the decision to wear gloves. Similarly, Park et al. (2014) advocate that a poor fit affects firefighters' work efficiency and safety. Proper fit and sizing seem to be especially defying for female firefighters, who have smaller hands (Boorady et al. 2013a; Lee et al. 2015; Park et al. 2014). Hsiao et al. (2015) mentioned that 30% of male participants of the study experienced problems with the fitting or bulkiness of their gloves, while among women, these issues were reported by 62% of participants.

Park et al. (2014) pointed out the oversized design and the multi-layered structure of firefighting gloves. Excessive glove finger length appears to be a commonly reported issue and was mentioned by participants of the study. Current

firefighting gloves are considered stiff (Lee et al. 2014, 2015; Park et al. 2014), bulky and thick (Boorady et al. 2013b) impairing mobility and hand function. According to the results of the study conducted by An et al. (2016), most evaluated gloves have too much protective materials which makes glove thick, especially in fingers. The excess of materials on fingertips impacts tactility making it not easy to handle small objects. Difficulty in operating radio buttons with gloved hands was mentioned by Boorady et al. (2013b).

Another aspect commonly cited is the difficulty of donning wet gloves once they had been taken off. Participants of many studies (Boorady et al. 2013b; Lee et al. 2015; Moraes et al. 2019; Park et al. 2014) mentioned that the glove lining tends to come out when hands are wet and/or sweaty and reported their difficulties in placing the lining back inside the glove. This is considered a ´classical´ problem (Stull and Stull 2007) in the design of structural firefighting gloves due to the multi-layered feature and the way gloves are constructed.

Moreover, current glove sizing systems may not be the most appropriate as some relevant dimensions of hands may be disregarded or size ranges and variations of shape underrepresented (Hsiao et al. 2015). Another pertinent aspect pointed out was the inconsistency in glove sizes by different manufacturers (Park et al. 2014), resulting in difficulties when choosing gloves.

Furthermore, a proper interface is critical for the integrity of the overall protection provided by the turnout protective ensemble. However, issues regarding the interface between gloves and turnout coat sleeves were also mentioned as problematic for participant firefighters of some studies (Boorady et al. 2013b; Lee et al. 2015; Moraes et al. 2019).

### 3.4 Recommendations, Suggestions and Recent Developments

The aforementioned performance and design issues demonstrate the need for evaluating the interaction and compatibility of firefighters and the current gloves offered in the market. Aiming to overcome some of these issues, efforts in improving sizing systems, incorporating wearable technologies as well as developing new methods for evaluating size and fit have been identified in this literature review.

The relevance of revisiting anthropometric data to re-evaluate the sizing systems of PPE is pointed out (Park et al. 2014). In this direction, the research conducted by the National Institute for Occupational Safety and Health (NIOSH) and published by Hsiao et al. (2015) is remarkable, as an improved glove sizing scheme that better accommodates the U.S. firefighters' hands was proposed. The results of the study prompted a recent review of the NFPA 1971 Standard.

Regarding the inclusion of wearable technologies to fire gloves, it is possible to highlight the Carton and Dunne (2013) study, which focused on the development of a vibrotactile glove for assisting firefighters of the size and location of objects in low vision search contexts.

Furthermore, some studies focused on dynamic anthropometrics. Interested in this subject, Griffin et al. (2019) developed a method for evaluating measurement changes of hands in dynamic positions. Moreover, the use of three-dimensional (3D) scanners ensures a better assessment of hands size, shapes as well as volumes and seems to be a recent trend in studies interested in hand anthropometrics.

## 4. Final Considerations

Ergonomics (or Human Factors) is defined by the International Ergonomics Association as the scientific discipline concerned with the understanding of interactions among humans and other elements of a system to design in order to optimize human well-being and overall system performance (IEA 2022). From this, it is possible to conclude that issues faced by firefighters when wearing protective gloves would be of interest to ergonomics researchers and practitioners.

The literature evidence, in the past decade, a growing recognition of the difficulties experienced by firefighters as well as a rising interest on investigating opportunities for improving firefighting gloves. Researchers are increasingly aware of the relevance of gathering users' input and how their experiences and insights may be useful in the design process and, in the end, facilitate the acceptance and use of protective gloves. However, there are still shortcomings that must be addressed.

It is possible to notice that although research has been focusing on aspects related to the use and interaction of firefighters with their gloves, few authors relate such aspects to the Ergonomics discipline, as evinced by the reduced number of papers resulting from the conducted searches in two relevant scientific databases. Another relevant aspect found in this literature review was the fact that types of gloves are not always identified by authors. As firefighters wear different types of gloves varying to types of missions, it is important to identify specifically not only the risks but also the context in which the gloves are going to be worn, including the environment, main tools used and tasks to be performed.

The development of new methods and the availability of relevant data would facilitate the application of ergonomic principles in the design of protective gloves. This involves the understanding that although many disciplines may contribute with specific knowledge, a multi-disciplinary and user-centered approach is paramount to overcome some of the identified issues. In conclusion, ergonomics research can contribute to a better balance of the trade-offs between protection and comfort of firefighting gloves. In the end, it aims to contribute to optimize the operational performance of firefighters.

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