

Portuguese firefighters' boots: obtaining user input for an ergonomic redesign

Abstract

Firefighters are the first responders to a wide variety of situations which require them to perform an array of movements. Firefighters' personal protective equipment is designed to protect against hazardous conditions and must allow the accomplishment of firefighting job tasks with maximum safety and minimal limitations. Fire boots are made to protect firefighters' feet, ankles, and lower legs from high heat, slippery surfaces, standing water, punctures, cuts, abrasions, and so on. However, literature shows the impacts of fire boots on firefighters' performance. This paper presents preliminary results of an ongoing study which main goal is to propose solutions for an Ergonomic redesign of personal protective equipment used by Portuguese firefighters. In order to obtain first insights, identifying firefighters' perceptions and specific needs, a pilot study was conducted in a fire brigade located in the North of Portugal. For qualitative data collection, both an online survey and an in-person semi-structured interview were administered. The responses and specific considerations about the structural fire boots obtained from 49 firefighters who participated in the pilot study are described and discussed. Findings from this study allowed a better understanding of the main issues encountered by Portuguese firefighters in wearing their fire boots and provided valuable inputs for developing the next phases of the study.

Keywords: fit, comfort, personal protective equipment, user's input, firefighting boots

Volume 6 Issue 1 - 2020

ASP Moraes,¹ RS Boldt,¹ MA Carvalho,¹ FN Ferreira,¹ SP Ashdown,² L Griffin³

¹Department of Textile Engineering, University of Minho, Portugal

²Department of Textiles and Apparel, Cornell University, USA

³Department of Design, Housing, and Apparel, University of Minnesota, USA

Correspondence: ASP Moraes, University of Minho, Department of Textile Engineering, Azurém Campus, Guimarães, Braga, Portugal, Tel +351 915 295 292, Email sophiapiaceza@gmail.com

Received: October 31, 2019 | **Published:** January 17, 2020

Abbreviations: PPE, personal protective equipment; SCBA, self-contained breathing apparatus; USA, United States of America; 3D, tridimensional

Introduction

In Portugal, there are more than 466 fire brigades, comprising about 27,000 firefighters.¹ As in many other countries, Portuguese firefighters "are the first ones called to a variety of situations",² responsible for responding to many different circumstances and emergencies like structural fires, wildfires, chemical spills, extrication from vehicles, medical emergencies, and so on.

While performing their job tasks, firefighters encounter a wide variety of hazards conditions and perform an array of movements² adopting different postures, such as crawling, crouching, bending, and "duck walking", and locomotions, such as ladder and stair climbing, entering/exiting emergency vehicles, or dragging a charged hose line on the fire ground.³

Firefighters are required to wear personal protective equipment (PPE) composed of a turnout gear,¹ and other equipment such as a hood, face mask, helmet, fire gloves, and fire boots². Firefighters also carry a self-contained breathing apparatus (SCBA) that provides an external air supply to protect against toxic gases, hot steam, and debris.^{4,5}

Considering that the PPE is the main protection for firefighters, wearing properly fitting PPE is critical not only to firefighters' safety but also to their occupational performance⁵ and should provide minimal limitations² and allow easy locomotion.³

¹Protective coat and pants.

²Also called bunker boots or turnout boots.

However, the literature identifies negative effects of the PPE on a firefighter's work efficiency, due to ergonomic aspects that limit mobility⁶ and hinder performance,⁷ impairing body balance and causing musculoskeletal injuries.^{3,4} In fact, significant progress has been made regarding chemical and flame protective functions of firefighting PPE, while the lack of attention around comfort issues in clothing design remains a challenge.⁸ Furthermore, the Occupational Safety and Health Administration reports that fit and comfort are important features to consider when selecting PPE.⁹ In this sense, Ergonomics, or Human Factors, the scientific discipline concerned with the understanding of interactions among humans and other elements of a system¹⁰ can assist in the development of improved PPE for firefighters.

Fire boot characteristics

Fire boots are made to protect firefighters' feet, ankles, and lower legs from high heat, slippery surfaces, standing water, punctures, cuts, abrasions and more. In addition, must provide a proper fit, traction, and the capacity for ease of movement and agility. Specific types of fire boots are required for different firefighting missions. In Portuguese fire brigades appropriate boots for both structural/proximity firefighting and wildland firefighting must be available.

According to the NFPA 1977: Standard on Protective Clothing and Equipment for Wildland Fire Fighting, wildland firefighting footwear must comply with at least 11 performance standards: heat resistance, corrosion resistance, cut resistance, slip resistance, attachment strength, flame resistance, label legibility and durability, and sewing thread heat resistance. Furthermore, the NFPA 1971¹¹: Standard on Protective Ensembles for Structural Fire Fighting and Proximity Fire Fighting cover the standards required for wildland footwear and also a

set of additional requirements: liquid penetration resistance, pathogen resistance, puncture resistance, electricity resistance, bending resistance, water resistance, and flex cracking resistance.

Firefighter boots are made of either rubber, leather, and/or synthetic leather materials. They shall have a sole with a heel, an upper, a puncture resistant device, an insole, a ladder shank or whole sole equivalent, and an impact and compression-resistant toe cap. The primary insulation is provided by linings, with different thickness and placement¹² that also protect against punctures.

Structural fire boots are designed to slip-on over the foot and lower leg with the use of handles, and typically do not have laces.¹³ Turnout pants are worn over the boots, which must fit inside of the pants' legs.^{3,13} Structural fire boots can weigh up to 4.4 kg, and are typically anywhere between 11" to 14" high.³

Fire boot issues

Studies that addressed the impact of bunker boots on firefighter performance have found specific issues concerning the weight, material, and fit.

The weight of fire boots directly impacts the firefighters' work performance, significantly increasing physiological stress.³ This is because items of the PPE that are worn farthest from the body's center of gravity impose the greatest potential stress in terms of weight and burden.¹² According to Taylor et al.,¹⁴ fire boots have a greater impact on firefighter exertion than other equipment, such as SCBA and turnout ensembles, which may be heavier overall but are worn on the torso and therefore are closer to the center of gravity.

Considering the materials, rubber boots provide greater protection from chemical hazards, whereas leather boots provide greater tactile sensitivity.¹⁵ Participants of the Park et al.⁴ study showed a strong preference for leather boots as opposed to rubber boots, as they were considered to afford a snugger fit, lighter weight, better flexibility, ankle support, tactile sensation on the ground, more comfortable foot motion, and easier size choice.⁴ Although participants reported a greater change in walking pattern with rubber boots than with leather boots, results of another study showed that leather boots with high flex resistance lead to greater negative impacts on gait.³ Another study¹⁵ reported that firefighters wearing rubber boots may be more effective at resisting fatigue and exhibit increased productivity compared to those wearing leather boots.

Furthermore, the fit of fire boots frequently appears among firefighters' complaints. According to Park et al.⁴ study the "poor fit is a major reason for changes in firefighters' walking patterns, which negatively impacts on their safety on the fire ground". Blisters on the calves, around the boot collar and plantar foot caused by ill-fitting bulky rubber fire boots were also pointed out by the study.⁴ Likewise, participants of the Boorady et al.² study (2013) reported issues with the boot length, describing a difficulty in bending the legs because the top of the boots hit high. Variations in pant length and boot heights to avoid such common issues are suggested by the authors.²

Portuguese firefighter PPE study

To understand if the Portuguese firefighters' protective personal equipment is adjusted to their anthropometrics and identify specific needs, a study designated as SizeFF Portugal – Anthropometric Study of Firefighters is being developed by 2C2T–Centre for Textile Science and Technology, in the Department of Textile Engineering at University of Minho, in partnership with an USA study, involving twelve Universities.

The study's main goal is to assess and present Ergonomic redesign solutions to the PPE used by Portuguese firefighters. To reach this goal both qualitative and quantitative data will be collected among firefighters of different fire brigades located in Portugal. Table 1 summarizes the type of data and data collection methods of the study.

In order to obtain initial insights from firefighters' experiences in wearing their PPE and to adjust and validate the study methods, a pilot study was conducted in a fire brigade located in the North of Portugal. Preliminary results regarding the fire gloves and the turnout coat and pants are presented elsewhere.^{16,17} This paper presents the first qualitative results related to their structural fire boots, obtained from the survey and the interview.

Table 1 Type of data and data collection method

Type of data	Data collection method
Sociodemographic information (age, race, ethnicity, years of experience, type of commitment, etc.)	Online survey
General perceptions of their PPE	Semi-structured interview
Personal experience when wearing their PPE	Online survey
	Semi-structured interview
PPE in use (including donning and doffing)	Direct Observation
Weight and height	Manual measuring
Head circumference measurement	Manual measuring
Hand measurements	3D body scanning
Foot measurements	3D body scanning
Body measurements	3D body scanning

Material and methods

After obtaining permission from the fire brigade's chief in command, all firefighters were invited to participate. For data collection, both an online survey and an in-person semi-structured interview were administered. Participants were requested to answer the questions based on their perceptions and experience of wearing their current equipment. A researcher was available throughout data collection to assist in filling out the survey, to administer additional questions as well as to clarify any issues or answer any questions participants may have had.

Survey

The online survey comprised 87 questions, divided into five parts. The first part included 11 sociodemographic questions including gender, age, race and ethnicity, firefighting status (type of commitment, years of experience, types of firefighting missions), and protected municipality identification questions (city and state, number of inhabitants, type of environment protected by the fire brigade). The second part included 20 specific questions about the turnout coat, the third part included 20 questions about the turnout pants, and the fourth part included 20 questions about the fire gloves.

The fifth part included 16 questions focused on fire boots, divided into 4 topics: brand, style, and size identification (3 questions); purchasing and selection process (4 questions); modifications made during use (1 question); fit issues related to specific regions of the boots (8 questions). The survey questions concerning fire boots are summarized in Table 2.

Table 2 Online survey questions

Question topic	Survey question (with provided answer selection)	Question number
Brand style and size	What brand of fire/bunker boots do you wear? (Fal, Haix, Holik, Jolly, Lavoro, Tigar, Other, I don't know)	FB.Q01
	What style of fire/bunker boots do you wear? *	FB.Q02
	What gender/size of fire/bunker boots do you wear? (Women's, Men's, Unisex, I don't know)	FB.Q03
	Where these fire/bunker boots purchased specifically for you? (Yes, No)	FB.Q04
Purchasing/Selection	Did you select the size of your fire/bunker boots yourself? (Yes, No)	FB.Q05
	How did you select the size of your fire/bunker boots? (Similar to size worn before, I was measured and then compared to chart or sizing system, Tried on various sizes brought into the station by the manufacturer, Tried on various sizes available in the station, Other – please explain)	FB.Q06
	Have you experienced any difficulties in finding the appropriate fire/bunker boot size? (No, Yes – please explain)	FB.Q07
Modifications	Have you ever modified your fire/bunker boots? (No, Yes – please explain how and why)	FB.Q08
	Please explain your fit issues with the straps of your fire/bunker boots.**	FB.Q09
	Please explain your fit issues in the top edge region/opening of your fire/bunker boots.**	FB.Q10
Fit Issues	Please explain your fit issues at the shin/calf region of your fire/bunker boots.**	FB.Q11
	Please explain your fit issues with the toe cap region of your fire/bunker boots.**	FB.Q12
	Please explain your fit issues at the top of forefoot region of your fire/bunker boots.**	FB.Q13
	Please explain your fit issues in the arch region of your fire/bunker boots.**	FB.Q14
	Please explain your fit issues in the ball/bottom of your fire/bunker boots.**	FB.Q15
	Please explain your fit issues in the heel region of your fire/bunker boots.**	FB.Q16

* provided answers according to the answer in FB.Q01.

** provided answers are shown in Table 3.

For assisting participants' responses on questions related to fit issues in specific regions of their fire boots, the drawing shown in Figure 1 was included in the online survey.

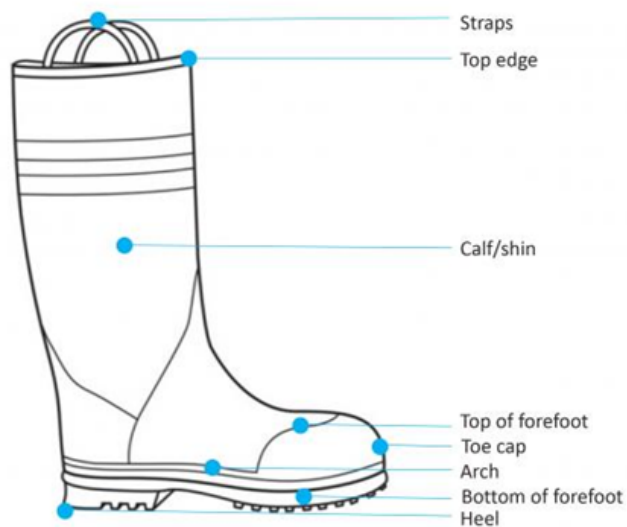


Figure 1 Specific regions of the boots as presented in the online survey.

Interview

The semi-structured interview questions were initially formulated based on results from similar studies.^{2,5} Throughout the pilot study, additional questions were included in the interview, as the participants shared their perceptions and mentioned some other items not previously considered. Specifically for fire boots, these questions were mainly related to the fire boot weight, the use of socks, and the addition of extra insoles. During interviews, researchers followed up with additional questions when responses required further information and clarification, assuring a more natural and relaxed conversation.

After obtaining the participants' consent, interviews were audio recorded to ensure that all comments were captured. Further, each interview recording was transcribed for the sake of data analysis accuracy. Data was collected in December 2018 and January 2019, and each interview/survey took approximately 40 minutes.

Data was organized by classifying the most common problems and areas needing improvement identified by participants.

Results and discussion

In general, participants of the pilot study expressed satisfaction with their structural fire boots. In comparison to other PPE items

included in this study, boots were more positively evaluated by participants. The online survey presented few negative responses and, during the interview, many positive comments were spontaneously expressed by participants. The main survey/interview results of the pilot study are following presented and discussed.

Demographic information

The fire brigade comprises about 140 firefighters, including about 40 firefighters that are both career/volunteer personnel³ and about 100 only volunteer personnel. The brigade serves a medium size municipality,⁴ including urban and suburban populations, as well as the wildland environment surrounding the city.

Forty-nine firefighters participated in the pilot study, including: only volunteer firefighters (30.61%, n=15), both career and volunteer firefighters (63.27%, n=31), and trainees (4.08%, n=2). The assistant chief responsible for the brigade also participated in the study (2.04%, n=1).

Most participants were male, corresponding to 73.47% (n=36) and 26.53% (n=13) of participants were female. The average age of the respondents was 36.49 years (ranging from 20 to 61 years; SD=10.23), whereas the average years of firefighting experience was 16.64 years (ranging from 4 months to 36 years; SD=10.82).

Fire boot identification

All participants wore the same brand and style of fire boots, provided by the fire station. These boots are specifically used for structural firefighting, as other boots are provided for wildland firefighting.

Unlike the responses regarding other PPE included in the study (turnout coat, turnout pants, and fire gloves), in which brands were not identified by most respondents, the brand of boots (FB.Q01) worn was reported by more than half of participants (57.14%, n=28). This is probably related to the fact that their boots are from a local brand, manufactured in the same city where the fire brigade is located. However, none of the participants was able to identify the style of their fire boots (FB.Q02).

When asked which size and gender their fire boots are for (FB.Q03), 15 participants (30.61%) responded that they wear Men's style and 33 participants (67.35%) responded that their boots are Unisex.

Fire boot sizing and purchasing

Concerning the fire boot select and purchasing process (FB.Q04), 34 participants (69.39%) responded that their boots were not specifically bought for them, while 15 participants (30.61%) responded that they wore specifically purchased boots. It was possible to note that this question was differently interpreted by participants, as some of them considered it as specifically designed and manufactured for them and other considered the fact that the brigade had ordered their specific size to the manufacturer as they were not available in the brigade.

Most participants (95.92%, n=47) responded to have selected the size of the fire boots by themselves (FB.Q05), and only 2 participants (4.08%) responded negatively, further explaining:

³In Portugal, career firefighters offer their services on a volunteer basis to their fire brigade in the hours that they are not regularly paid.

⁴About 160,000 inhabitants.

"those [boots] were assigned to me" (male/career-volunteer).

"I've got the available size at the station" (male/ volunteer).

When asked how the boot size was selected (FB.Q06), 29 participants (59.18%) responded that they had tried on various sizes available at the station, 11 participants (22.45%) responded that it was similar to the size worn before, and 3 participants (6.12%) responded that they have tried on various sizes brought into the station by the manufacturer. None of the participants responded « I was measured and then compared to chart or sizing system ». Six other participants (12.24%, n=6) responded as « Other », further explaining that their shoe size was asked, or they have asked for specific size, or they received the available size at the station.

Difficulties in selecting the fire boot size

When asked about difficulties experienced in finding the appropriate fire boot size (FB.Q07), 87.76% (n=43) of the participants replied that they had not had any difficulty, while 12.24% (n=6) replied having experienced difficulties. Two respondents mentioned the availability of sizes in the fire brigade:

"I should wear a size 39, but as there were no size 39 available... so, I got a [size] 40" (female/ volunteer).

"I got the smaller size available, as there was not my size number" (female/ volunteer).

For another participant, the difficulty in selecting the fire boot size was directly related to fit:

"the only issue was the calf of the boot...as I have slim legs... I have to wear an extra pair of socks for a better fit... that's the only thing... but this is because I am slim" (male/career-volunteer).

Many participants expressed strategies to overcome such difficulties, as wearing two pairs of socks, longer soccer socks, and thicker socks.

Sizing system

Sizing system issues were mentioned by some of the participants of the pilot study, which are also pointed out by other studies found in the literature. Stull & Stull¹⁸ suggest that fire boots must come in a full range of men's and women's full and half sizes and in three widths. One participant expressed his opinion when asked about difficulties in selecting his fire boot:

"they are size 40, but it is a bit big...I think they [manufacturers] should make some adjustments to this.. the size 39 doesn't fit... well, they fit, but my fingers... you know, it is hard to make shoes for everyone" (male/career-volunteer).

Another participant, despite having answered not having any difficult when selecting the boot size, further elaborated during the interview:

"As they are a bit big, I wear two pairs of socks in order to avoid bruising the skin... the smaller size is too tight... they should have some sizes in between" (male/career-volunteer).

Fire boot modifications

When asked if they had ever modified their turnout boots (FB.Q08), most of participants (97.96%, n=48) responded negatively.

Only one participant (2.04%, n=1) indicated having inserting an after-market insole for comfort:

"I added an extra insole, for more comfort" (male/career-volunteer).

Boot weight

Despite not being included in the survey, the weight of fire boots are described as an issue in the literature.^{3,12,14} During the pilot study it was spontaneously cited by one female participant, and after that it was included in the semi-structured interview script.

Most participants stated that their structural fire boots are not heavy when compared to their wildfire boots. Lighter boots are

especially desirable in the case of wildfires, as usually these type of firefighting require longer intervention times. In general, participants expressed being more satisfied with the weight of their structural boots than with the weight of their wildfire boots. It is possible to assume that the comparison to the heavier wildfire boots may have affected participant's perceptions.

Fire boot fit issues

The straps and top of forefoot were the fire boot regions with fewer fit issues according to the participants of the pilot study, while the top edge/opening and the shin/calf were the regions where most fit issues were identified. Table 3 shows the participants' responses to fit issues in specific areas of their fire boots as presented in the online survey.

Table 3 Fit issues answers

Fire boot region	Fit issues						Does not work well with pants	Not enough support (roomy)	Too much support (tight)	Too hard	Too soft	I don't have any issues	Other (please explain)
	Too long	Too short	Too wide	Too narrow	Too tight	Too loose							
Straps	0	1	0	1								46	1
Top edge/opening			2		3		0					35	9
Shin/calf	1	0			2	2						37	7
Toe cap	0	0	3	0								43	3
Top of forefoot			1	0	0	2						46	0
Arch								7	1			40	1
Ball/bottom of forefoot			2	0						4	1	38	4
Heel					0	6						41	2

Fit issues for the shin/calf region of the boot (FB.Q11) were cited by 12 participants. For 2 participants (4.08%) the region was too loose, for other 2 participants (4.08%) the region was too tight. One female participant who responded as being too tight, further recounted:

"As I have fat calves, they [the boots] get really tight...and I can't don them completely up to the top as they should be. I put them on, but they don't go all the way up... but it is nothing that hampers the performance" (female/volunteer).

Still regarding the shin/calf region, 1 participant (2.04%) responded that this region was too long, whereas 37 participants (75.51%) responded not having any fit issue in this region. Seven participants (14.29%, n=7) responded as « Other ». For 5 of them, the shin/calf region is just a bit loose, and for 2 of them the boot material is so damaged that the boots collapse in the calf area.

The top edge region (FB.Q10) was considered too wide by 2 participants (4.08%) and too tight by other 3 participants (6.12%). For 35 participants (71.43%) the top edge region does not present any fit issue. Nine participants responded as «Other»: 4 participants affirmed that the region is just a bit wide, 1 participant affirmed that the region is a bit tight, and 4 participants responded that this region tends to bruise the skin. According to one participant:

"If you don't wear long socks, when you start sweating, the skin gets red, starts to rub, and the skin gets inflamed if you don't wear socks... there is a sponge inside [the edge]...but mine is damaged... I am waiting for new boots... I have already asked for them" (male/career-volunteer).

Regarding the ball/bottom of the region of the forefoot (FB.Q15), 8.16% of participants (n=4) responded as being too hard and one participant (2.04%, n=1) responded as being too soft. For 2 participants (4.08%) the arch region is too wide, while for 77.55% of participants (n=38) this region does not present any fit issue. Four other participants (8.16%, n=4) responded as « Other ». Two of them described the bottom region of the forefoot as a bit wide. Another participant expressed the same opinion and further explained:

"the boots are a bit wide there... I wear two pairs of socks... then gets great" (male/career-volunteer).

The fourth participant who have responded as « Other » suggested that their boots should have insoles made with breathable materials.

According to 7 participants (14.29%), the arch region (FB.Q14) does not provide enough support (roomy), and one of them mentioned having included an extra insole for better support. According to another

respondent (2.04%, n=1), the arch region is too tight, providing too much support. For most participants (81.63%, n=40), the arch region does not present any fit issue. One participant (2.04%, n=1) responded as « Other » and further explained:

“the arch region doesn't fit the curvature of the foot” (male/career-volunteer).

Most of participants (83.67%, n=41) did not expressed any fit issue in the heel region (FB.Q16). However, six participants (12.24%, n=6) considered the heel region as being too loose, and 2 participants (4.08%, n=2) responded as « Other ». For both of them, the fit issue in this region is related to bruising the skin, and further explained:

“I get blisters [on the heels] after using [the boots] for a long period of time... but it is just a question of using the boots longer... because they are still new” (male/career-volunteer).

“If I wear thin socks, they rub [the heel]” (male/career-volunteer).

The toe cap region (FB.Q12) was considered problematic by a total of 6 participants. Three participants (6.12%, n=3) responded as too wide while 3 other participants (6.12%, n=3) responded the question with « Other ». One female participant described her experience in the following manner:

“they don't hurt, as my toes don't get over there... if I wear two pairs of socks, it is great” (female/volunteer).

For another male participant who have responded as «Other» the fit issue with the toe cap region is related to his boot size, which too big for him, and for another participant it is only a bit wide. The other 43 participants (87.76%) responded not having any issues in the toe cap region of their boots.

Regarding the top of the forefoot region (FB.Q13), 2 participants (4.08%, n=2) responded as being too loose and 1 (2.04%, n=1) participant responded as being too wide. According to 46 participants (93.88%), the forefoot region does not present any fit issue.

Considering the fit issues with the straps (FB.Q09), responses were very similar as most of participants (93.88%, n=46) indicated not having any fit issue. For those that have expressed having fit issues, 1 participant (2.04%) responded that they were too short, 1 participant (2.04%) responded that they were too narrow, and illustrated his difficulty as described here:

“The previous boot style had these type of straps [as in the picture shown in the survey]... but the one we wear now, they don't have... this is faulty... there is only a small strap... as we have the pant legs together with the boots, it is hard to put them in.. it was much easier before... I don't know why they took this out in this style” (male/career-volunteer).

The interface between different PPE items is also crucial for the firefighters' protection and a proper layering between the pants and boots are crucial to ensure protection when performing tasks. During data collection, many participants mentioned the strategy of setting the pants and boots up together⁵. However, some other participants, despite having responded not having any fit issue, reported the difficulty in finding and reaching the boot straps because of the bulkiness of the pants, especially when they are folded and inserted in the boots.

⁵The boots are inserted through the bottom of the turnout pants to put on both items in unison and allow a faster donning when called to duty.

Conclusion

Firefighters' PPE is the only protection against multiple hazards while performing varied and highly demanding job tasks. Thus, wearing a poorly fitting turnout ensemble can greatly impact a firefighter's work efficiency.

This study explored the issues that Portuguese firefighters experience when wearing their fire boots in order to identify areas needing improvement. In general, participants of the pilot study expressed satisfaction with their structural fire boots, in comparison to other PPE items included in this study. Few negative responses were obtained from the survey and during the interview many positive comments were expressed by firefighters who have participated in the pilot study.

However, issues regarding the unavailability of sizes in the brigade, the sizing system, and fit and comfort were cited by some participants throughout the pilot study. The top edge/opening region and the shin/calf region were considered as the most problematic by participants. To overcome some of these problems strategies adopted, like adding extra insoles, wearing two pairs of socks, long soccer socks or thicker socks, were mentioned. These strategies were mainly cited for avoiding bruises and blisters, and also for a better adjust in terms of size. They evidence the need for improving the fire boots' comfort and fit. Quantitative data obtained from the 3D scanners of participants' feet will help to better understand such issues in subsequent phases of the study.

Despite the small sample size, the input obtained from participants support similar findings in the literature, allowed the validation of the preliminary results of this pilot study. However, generalizing these findings for all Portuguese firefighters requires some caution. Also, it is possible to mention the fact that PPE items may vary in different fire brigades, and other firefighters may have different perceptions of their fire boots. In spite of its limitations, the findings of this pilot study served as a guide for adjusting the study methods and insights provided by participants were crucial for understanding their specific needs and to further define ergonomic recommendations for redesigning Portuguese firefighters' PPE.

Acknowledgments

We would like to acknowledge 2C2T-Science Center for Textile Technology from University of Minho. This work is financed by FEDER funds through the Competitive Factors Operational Program (COMPETE) POCI-01-0145-FEDER-007136 and by national funds through FCT-Portuguese Foundation for Science and Technology, under the project UID/CTM/000264 and by *Fundo de Apoio às Vítimas dos Incêndios de Pedrógão*. We would also like to acknowledge the United States North Central Multistate Research Project titled NC-170 for assistance developing the questionnaire.

Funding

FEDER funds through the Competitive Factors Operational Program (COMPETE) POCI-01-0145-FEDER-007136 and by national funds through FCT-Portuguese Foundation for Science and Technology, under the project UID/CTM/000264.

Conflicts of interest

The authors certify that they have no affiliations with or involvement in any organization or entity with any financial interest

or non-financial interest in the subject matter or materials discussed in this manuscript.

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