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Advances in Ergonomics in Design

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Assessment of Portuguese Firefighters' Needs: Preliminary Results of a Pilot Study

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Abstract. Firefighter's job tasks require intensive physical work and involve a range of movements in a wide variety of hazardous environments and thermal conditions. It is thus critical that personal protective equipment allows firefighters to perform their duties with minimal limitations and maximum safety. However, many studies have shown concerns regarding turnout gear fit and comfort. This paper presents preliminary results of an in-progress study, for which the main goal is to develop design solutions to Portuguese firefighters' protective equipment. With the aim of identifying specific needs from this population, a pilot study was conducted in northern Portugal. Data were collected through an online survey and a semi-structured interview, which allowed a deeper understanding of issues encountered. Findings from this pilot study served as a guide to adjust the study and provided insights to recommend an ergonomic redesign of firefighters' gear.

Keywords: Human factors and ergonomics · Fit issues · Turnout ensemble

1 Introduction

Firefighting is necessary, critical, and challenging [1], and is considered one of the most dangerous, arduous [2], and physically demanding occupations [2, 3]. As stated by Coca *et al.* [4], firefighter's job tasks require intensive physical work and involve a range of movements in a wide variety of hazardous environments.

Firefighters' personal protective equipment (PPE) has been designed to provide protection against multiple hazards such as thermal threats (e.g. exposure to flame and excessive heat), toxic gas inhalation, and physical injuries (e.g. cuts, collisions, punctures, slips, falls, etc.) [5]. For this, firefighters are required to wear turnout gear¹ consisting of a protective coat and pants, and other equipment such as a hood, helmet, fire gloves, and bunker boots. Firefighters also carry a self-contained breathing apparatus (SCBA) that

¹ Also called bunker gear or turnout ensembles.

provides an external air supply to protect against toxic gases, hot steam, and debris [5, 6]. It is thus critical that personal protective equipment allows firefighters to perform their duties with minimal limitations and maximum safety [2].

Over the years, the nature of firefighting and the role of firefighters have shifted [6]. Firefighters' PPE has evolved [2, 6], but important trade-offs between protection and comfort remain.

As pointed out by Boorady *et al.* [2] and Park *et al.* [5], higher thermal protection, which combined with advances in material technology during the past decade, has greatly decreased burn injuries. Nonetheless, the efforts in improving thermal protection have inevitably increased the weight and bulkiness of the firefighters' protective gear, hence, significantly compromising firefighters' mobility and comfort [2, 5]. According to Smith *et al.* study, cited by Park and Hahn [6], the bulk and weight of the turnout ensemble increase physical exertion and the risk of heat stress, which, in the worst-case scenario, leads to heat stroke and cardiovascular malfunction.

The Occupational Safety and Health Administration (OSHA) reports that fit and comfort are important features to consider when selecting PPE [7]. Furthermore, Akbar-khanzadeh *et al.* [8] claimed that increased wearability and proper usage of the protective clothing system can be achieved only when human factors and user input are included in the design process. Exploring user input and perceptions of firefighters' protective gear is essential to identify areas for improvement [6].

1.1 Portuguese Firefighters' PPE Study

In Portugal, there are more than 466 fire brigades, comprising about 27,000 firefighters [9]. 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.

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 design solutions to the PPE used by Portuguese firefighters, using 3D body scanning technologies. In order to validate the study methods and tools and to obtain the first insights from firefighters' experiences in wearing their turnout ensembles and other protective equipment, a pilot study was conducted in a Portuguese Fire Brigade. This paper presents the first qualitative results related to their turnout gear, in particular coats and pants.

2 Materials and Methods

The pilot study was conducted in a Fire Brigade located in the northern region of Portugal. After obtaining the permission of the Fire Brigade responsible, firefighters were invited to participate.

2.1 Data Collection

For data collection, an online survey was administered. Participants were requested to answer the questions based on their perceptions and experience of wearing their current equipment. Although the survey was administered online, a researcher was available throughout the process to clarify any issues or answer any questions participants may have. While administering the survey, researchers also conducted semi-structured interviews, allowing a deep understanding of issues encountered and better exploring their needs.

Survey. The online survey was comprised of 83 questions, divided into five parts, including questions about: sociodemographic information, turnout coat, turnout pants, fire boots, and fire gloves. Figures indicating specific areas of the turnout ensemble, gloves, and boots were presented to the participants, followed by questions containing common fit issues related to the respective body areas.

Interview. The interview questions were initially formulated based on results from similar studies [2, 6]. Throughout the pilot study, additional questions were included in the interview, as the participants mentioned some other specific items, not previously included in the survey. In addition, while applying the survey, researchers followed up with additional questions when responses required further information or clarification, assuring a more natural and relaxed conversation.

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

2.2 Data Analysis

Data obtained in the interviews were coded and analyzed using an interpretive thematic analysis method, while responses from the online survey were statistically analyzed. Data were organized by classifying the most common problems and areas needing improvement identified by the participants.

3 Results

3.1 Demographic Information

The Fire Brigade is comprised of 38 firefighters, including both career and volunteer personnel² and only volunteer personnel. The Brigade serves a medium size municipality³ (about 160,000 inhabitants), including urban and suburban populations, as well as the wildland environment surrounding the city.

² In Portugal, career firefighters usually volunteer in their Brigade and/or other brigades.

³ The Fire Brigade shares the territory protection with another smaller Fire Brigade.

Sixteen firefighters participated in the pilot study, including firefighters that are only volunteer (25%, $n = 4$) and both career and volunteer (75.00%, $n = 12$). 12.5% of the participants were female ($n = 2$) and 87.5% ($n = 14$) were male. The average age of the respondents was 37 years (ranging from 21 to 61 years; $SD = 11$). The average years of experience in firefighting was 17 for male participants (ranging from 4 to 33 years; $SD = 10$), and 0.75 year for female respondents.

3.2 Turnout Gear Selection

For many years, the Fire Brigade has been investing in specifically tailored turnout gear. For this, a manufacturer assists firefighters in selecting their turnout coat and pants, providing a sample set of sizes and making adjustments to tailor items to individual measurements. However, at the beginning of a new purchasing process, not all firefighters have their turnout gear replaced⁴.

The main adjustments made by the manufacturer were in sleeve length (5 participants had their coat sleeve shortened) and in the pants leg length (3 participants had their pants legs shortened). Even with the assistance of the manufacturer, 2 participants (12.5%) affirmed having difficulties in selecting the turnout coat size and 2 participants (12.5%) affirmed the same for the pants. 2 participants described their experience when they had their gear substituted:

“it was difficult to select the size... there was a size M, which is the size I usually wear, on normal clothes, but I saw, in terms of comfort, tasks, all this, it was not the most appropriate... [So, you have chosen the L size?] Yes, you have more comfort and maneuverability” (male/career and volunteer).

“My previous coat was an L size... I asked for an XL, but they still gave me an L... when it is a bit loose we always can move better, but sometimes, to pass like, through a window, if it is a bit tighter, it is easier” (male/career and volunteer).

3.3 Turnout Gear Protection Level

Concerning the protection level, 75% ($n = 12$) of the participants affirmed feeling very protected by their turnout coat, and 25% ($n = 4$) affirmed feeling somewhat protected. One participant who affirmed feeling somewhat protected mentioned that his coat is too worn out. Another participant affirmed that he does not feel very protected by his coat, and cited that:

“not so much... the velcro does not stick anymore” (male/volunteer).

The firefighters' perceptions regarding the pants were slightly better, as 81.25% ($n = 13$) of the respondents affirmed feeling very protected and 18.75% ($n = 3$) affirmed feeling somewhat protected. One participant mentioned that he has sewed the suspenders on the pants, as the fastening had broken.

⁴ According to a participant, career firefighters have priority over volunteers, as they use their equipment more frequently. All the participants that are volunteers wear available turnout ensemble from former firefighters.

None of the participants affirmed having had any injuries caused by the fit of the turnout coat and pants.

3.4 Turnout Coat Fit Issues

Figure 1 shows the participants' responses to fit issues in specific parts of the turnout coat.

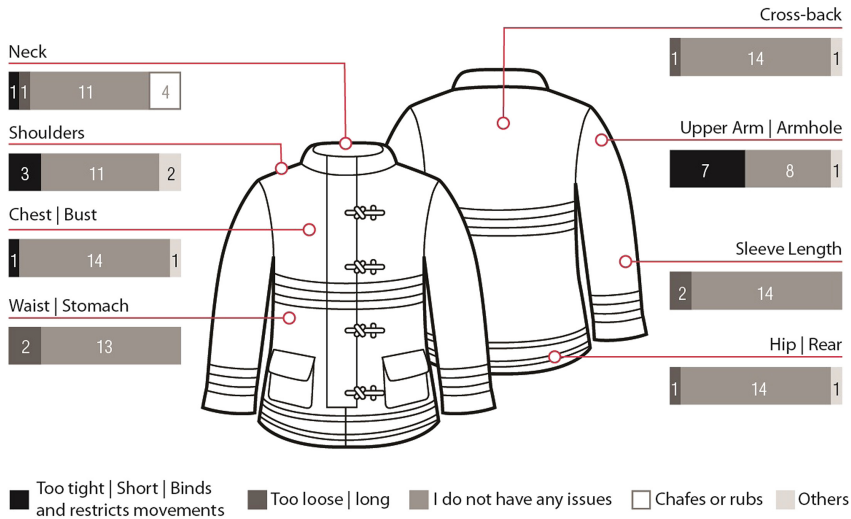


Fig. 1. Turnout coat fit issues.

The upper arm/armhole area was the most cited area by firefighters. For 43.75% (n = 7) of the participants, it binds and restricts movements or is too tight. The main impact in the use is related to movements in an upper head level, as described by 2 participants:

“it is difficult to make maneuvers above the head” (male/career and volunteer).

“the armhole region restricts movements a bit, even being specifically selected [for me]” (male/career and volunteer).

Still, it was cited that the most impacted activity is the extrication, when tools are used to cut the vehicles metal sheets. According to another participant, the armhole is just a bit tight (6.25%). Other participants also pointed out the impact of the fabric in this specific region:

“yes, it is a bit... donning it is a bit hard, because the coat is not very flexible, and also, we put the SBCA⁵ on, which also hampers the maneuvers” (male/career and volunteer).

“I think it is a bit tough... there is a small discomfort” (male/career and volunteer).

⁵ Self Containing Breathing Apparatus.

The other 50% (n = 8) of the participants affirmed to not having any issues about the upper arm/armhole area. In the same way, the turnout coat shoulders appeared as the second area with more fit issues, with 18.75% (n = 3) of the responses for binds and restrict movements. A participant clarified:

“the coat interferes with moving... the shoulders bind and restrict movements... after being fully equipped, you can’t move your arms” (male/career and volunteer).

For 2 participants (12.5%) the turnout coat is not flexible because it was recently purchased, explaining that after some cleaning, it tends to become softer:

“the shoulders restrict movement, in this area [shoulder region] is a bit tight... but I think that’s because it is still new... after washing, it will have a better fit” (male/career and volunteer).

“you know, at this moment, it still has the fabric starch as it is new... and this is a bit restricting...” (male/career and volunteer).

Still, 68.75% (n = 11) of the participants affirmed not experiencing any fit issues relating to the shoulders area.

According to 18.75% (n = 3) of the participants, the turnout coat waist/stomach area is too loose, while 81.25% (n = 13) affirmed not having any fit issue related to this area. One male participant noted the flexibility of the fabrics impact in this region:

“it is a bit difficult to bend... you know, after a while even the fabric starts losing its rigidity, and maybe it can get better... but when it is still new, it is not very flexible” (male/career and volunteer).

The turnout coat neck main fit issues are related to causing chafing and rubbing, cited by 18.75% (n = 3) of the participants as being too tight. However, one participant (6.25%) considered the coat neck too loose. For 68.75% (n = 11) of the participants, the turnout coat neck did not present any fit issues.

The sleeve length was cited as too long by 12.50% (n = 2) of the participants.

Concerning the turnout coat cross-back area, 6.25% (n = 1) of the participants affirmed it to be too loose, 6.25% (n = 1) of the participants affirmed it to be a bit loose, and 87.5% (n = 14) of the participants expressed no fit issue.

Regarding the hip/rear area, 6.25% (n = 1) affirmed it to be too loose, while 87.50% (n = 14) of the participants affirmed not having any fit issue. A female participant stated that her coat was a bit short in the hip area and that this was important when she selected her coat size:

“the coat is unisex, but it is a bit short, if I had chosen a smaller size it would have been really short... it needs to be longer for when we are bending over” (female/volunteer).

Still, another participant clarified that when wearing the SBCA inside the fire truck or ambulance, the rear tends to become exposed:

“when we are on the way to a fire, we put on the SBCA inside the vehicle, and the back hip area tends to rise... we always take a look at each other to check...” (male/career and volunteer).

The chest/bust area was cited as too loose by 1 participant (6.25%), a bit tight by 1 participant (6.25%), while most of the participants (87.5%, n = 14) affirmed not having any fit issue regarding this area.

3.5 Turnout Pants Fit Issues

Participants' perceptions with regard to specific areas of the turnout pants are shown in Fig. 2.

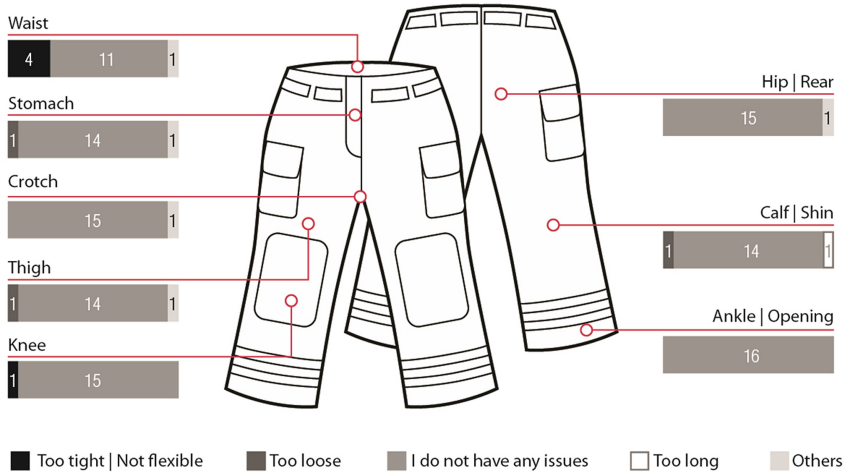


Fig. 2. Turnout pants fit issues.

The waist region appeared as the most problematic. 25.00% (n = 4) of the participants affirmed that the waist is too loose. One female participant even affirmed tying up the region with an elastic band. On the other hand, for a male participant, the waist is too tight, as well as the stomach and hip region, which makes it difficult to bend over or to climb a small fence.

For other 6.25% of the participants, the stomach region of the turnout pants is too loose, while 87.5% (n = 14) of the participants this region did not present any fit issue.

Regarding the hip/rear region, most of the participants (93.75%, n = 15) stated to not having any fit issue.

93.75% (n = 15) affirmed not having any fit issue with the turnout pant crotch. Only one participant (6.25%) mentioned the crotch as a problematic area, and described that

“climbing stairs restricts [movements] a little bit” (male/career and volunteer).

In the thigh region, one participant (6.25%) considered it too loose, and another participant (6.25%) mentioned that the thermal liner of his pants is already too damaged in this area, as well as the crotch region, which ends up bruising the skin due to the contact with the moisture barrier.

In respect of the knee region of the turnout pants, only one participant (6.25%) cited having a fit issue:

“it is not flexible, and doesn’t bend easily” (male/career and volunteer).

The other 93.75% (n = 15) affirmed not having any fit issue in the knee region.

Concerning the shin/calf area, 6.25% (n = 1) of the participants mentioned it as being too long, 6.25% (n = 1) affirmed it as being too loose, and 87.5% (n = 14) affirmed not experiencing any fit issue. None of the participants mentioned having any fit issue in the ankle region.

4 Discussion

In general, participants of the pilot study revealed being satisfied with their personal protective gear, and many positive comments were obtained during data collection. However, some fit issues expressed by participants are also described in similar studies, which corroborates with their perceptions.

4.1 Turnout Ensemble Sizing

As stated by Torvi and Hadjisophocleous [10], correct sizing is particularly important in protective clothing, as the performance of the clothing depends on the correct fit. In the pilot study, it was possible to note the effort of the Fire Brigade to improve the fit of the turnout gear, as assisted by a manufacturer, by purchasing specifically tailored gear.

However, the adjustments were restricted to the sleeve length and pants leg length. Despite the fact that sleeves and pant legs must be of the correct length to provide protection for the wrists and ankles [10], they can be limited in dealing with issues such as the interface with other protective clothing items, for example boots and gloves, and the adjustment of fit to women’s anatomy.

4.2 Turnout Ensemble Fit

Coat Length. The turnout coat length is of paramount relevance in protecting fire-fighters, as a short coat left them vulnerable to the risk of burn injuries because their back was likely to be exposed to external heat and steam during active body movements such as bending, crawling, and reaching overhead [6]. On the other hand, a coat that is too long increases the risk that the hem can be caught by a ladder while ascending or descending, which becomes a safety issue [6]. In the pilot study, this aspect was cited by many participants. They also pointed out a strategy among peers of ensuring that their back does not become exposed when donning the SBCA inside the fire truck or ambulance. Some participants also mentioned a new style turnout coat that has been introduced with a longer hem in the rear, which is better than the previous style.

Suspenders. The suspenders place most of the weight of the pants on shoulders, where the SBCA also rests, and can lead to fatigue when firefighters are in their gear for long periods of time [2]. Many participants of the pilot study expressed concerns regarding the suspenders. Participants revealed a desire for a different system for supporting the weight of the pants and stated having trouble adjusting the suspenders. Despite the fact that suspenders were not included in the survey questions, some participants mentioned their problems with them. One of the first participants discussed them as follows:

“the only thing missing [in the survey] are the suspenders... ok, it is part of the protection system, it is, and also they stand for the pants, but sometimes, when we are donning, the suspenders can get twisted... and these new ones are even better than the previous, [as the straps are] in an “X” shape, and the old ones were in “H” shape... and the new ones are cushioned... they are getting a bit better, but when donning, of course, we are doing this in a rush, [straps] can twist...” (male/career and volunteer).

One participant cited that the only thing she would like to change in the gear would be the suspenders, and mentioned that wearing the SCBA hurts her clavicle bones:

“I would like to remove the suspenders, but I know they are necessary, otherwise the pants would fall... in my case it ends up being uncomfortable, someone puts it on, but it never goes straight, folds... in this area, over these bones, it hurts me, I have prominent bones in this area...but this is in my case” (female/career and volunteer).

Another male participant mentioned that the suspenders need to be tightened up, and after putting the SCBA, it ends up having two straps on shoulders. Other participants mentioned that they do not like the suspenders, and even questioned their utility:

“the pants can be adjusted by the belt” (male/career and volunteer).
“it disturbs me... mine is always loose” (male/volunteer).

Pockets. Some studies [2, 6] have cited the lower satisfaction of participants with their gear pockets. However in this pilot study, pockets were not cited as an issue by any of the participants.

4.3 Gear Fabrics

Firefighting turnout coat and pants are made with three functional layers for enhanced thermal protection: an outer shell, a moisture barrier, and a thermal liner. Fabrics of firefighting gear appear as a problematic issue in many studies [2, 6], mainly related to flexibility. Participants of Boorady *et al.* [2] study expressed a reduced sensation for touch, and tears in the gear.

This aspect was also cited by the participants of the pilot study who discussed a feeling of reduced mobility. However, many participants felt that the fabric's rigidity was due to the fact that the gear is still new, and tends to become softer after several cleanings.

4.4 Turnout Gear Maintenance

It is very difficult to estimate the useful lifetime of turnout gear for firefighters: while some obvious incidences of degradation are easy to detect, such as rips in the outer

shell, degradation due to repeated laundering, or exposure to high heat fluxes or to certain types of radiation may not be apparent [10]. In addition, simply stating that a garment can be used for a certain number of years of service is not sufficient, since fire departments may have different levels of usage and exposure to ultraviolet radiation, various approaches to firefighting, and different cleaning frequencies. Even gear belonging to different firefighters in the same department will be exposed to different conditions over the garment's lifetime.

As previously mentioned, in the past 2 years, most career firefighters of the Fire Brigade had their turnout gear replaced. However, as described by some participants, the average length of service from the past turnout gear varied from 8 to 12 years. Some participants expressed concerns regarding their equipment maintenance, which were directly connected to their protection level perceptions.

4.5 Personal Hygiene

Commonly, firefighters wear their turnout ensemble over the station uniform or their own normal everyday clothing [11]. In the pilot study, most participants confirmed that they wore the turnout coat over the station t-shirt, and the turnout pants over cotton pants. However, this is a personal choice, for a better personal hygiene and comfort. As stated by the participants, some firefighters prefer to not wear any pants under the turnout ensemble, or wear a one-piece jumpsuit underneath.

One participant suggested development of a removable liner for more frequent cleaning:

"maybe the liner, I believe would be an advantage to be removable for better personal hygiene... sometimes we are in a fire, and it [the turnout ensemble] doesn't get really dirty outside, but only the fact of wearing the gear, we start sweating, and they will not clean the gear only because we sweat... the fabrics also start to loose quality... the liner should be removable for laundering" (male/career and volunteer).

4.6 Study Limitations

This pilot study investigated Portuguese firefighters' perceptions regarding the ensemble they are currently wearing. Despite the valuable contributions and insights provided by the participants, it is not possible to make generalizations from this pilot study. However, it has revealed the priorities that need to be considered in the next study phase, around the country.

Another limitation is related to the fact that participants wear different styles of turnout gear, as some of them had their equipment replaced recently, and others have a variety of other styles of equipment (individually purchased or offered by private companies). In addition, specific equipment for different missions (e.g., wildfires) were not included in the study.

5 Final Considerations

Firefighting is considered one of the most dangerous, arduous and physically demanding occupations. Due to elevated and diverse threats, firefighters' personal protective equipment has evolved. However, issues concerning fit, sizing, comfort, protection and health remain as relevant in firefighters' PPE.

This pilot study investigated Portuguese firefighters' perceptions and experiences when wearing their turnout ensemble. In general, the participants of the study reported that they feel very satisfied with their gear. The main issues identified by the participants were the turnout coat shoulders and armhole, and the pants waist region. Additional insights concerning maintenance, personal hygiene, fabrics, and the suspenders were cited as areas needing improvement.

Findings from this pilot study serve as a guide for adjusting the current study in future and provide qualitative insights to recommend ergonomic improvements of the Portuguese firefighters' gear.

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