

Female Firefighters' Body Weight and Stature: a Comparison between two Portuguese Fire Brigades

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Abstract. Anthropometric data are essential for applying ergonomic principles to the design of a wide range of products and are paramount when developing personal protective equipment. In the case of occupations that deal with extreme circumstances, as is the case of firefighting, a proper fit and sizing of personal protective equipment is related not only with work performance and comfort but also with protection level. The increase in the number of female firefighters have raised the discussion about the barriers and challenges faced by women in firefighting. Issues with the fit of personal protective equipment commonly appear among physical and psychological stressors encountered by female firefighters. The need to provide gender-specific protective equipment for such professionals is highlighted by many studies. Furthermore, significant anthropometric differences among specialized occupational groups have also been found. However, anthropometric databases on firefighters are still very limited. Aiming to fulfill this shortcoming as well as to understand if Portuguese firefighters' protective equipment is adjusted to their anthropometrics, a study designated as *Size FF Portugal – Anthropometric Study of Portuguese Firefighters* is currently underway. This paper presents a preliminary comparison of anthropometric data of female firefighters from two different fire brigades located in the North of Portugal. Stature and body weight measurements of 30 participants were analyzed using both descriptive and inferential statistics. Results show that there were not statistically significant differences on the average stature nor on the average body weight of female firefighters from both brigades. Moreover, significant differences were not found when comparing their types of commitment for both considered measurements. However, the comparison of stature data of female firefighters with two available anthropometric databases of the Portuguese population presented statistically significant differences. These results corroborate similar research and highlight the relevance of the on-going study. A discussion regarding the results is presented, taking into consideration the current stage of the study and its limitations.

Introduction

Firefighting is considered one of the most challenging, dangerous, arduous, and physically demanding occupations [1–4]. The nature of firefighting and the role of firefighters has evolved over the past decades [5,6]. Among the many differences identified there is a demographic change.

Although considered a traditionally male dominated occupation in which the number of women is still underrepresented [1,7,8], it is possible to observe an increase in the number of female firefighters. Recent data from the U.S. National Fire Protection Association [9] reported a total of 93,700 female firefighters, comprising 8% of the total of firefighters in the U.S. Among career firefighters, 15,200 (4% of total career firefighters) were women. In the case of volunteers, female firefighters summed 78,500, corresponding to 11% of the total of volunteer firefighters. In Portugal, the number of women joining the fire service is also on the rise. The most updated data from the

Statistics Portugal [10] reported a total of 5,102 female firefighters in Portugal, corresponding to 18.93% of the total firefighters. Considering types of commitment, the majority were volunteer firefighters: 3,474 women, corresponding to 68.09% of the total of female firefighters. The number of female career firefighters summed 1,628, corresponding to 31.91% of the total of female firefighters. Data of other countries [11,12] indicate that the increase in the number of female firefighters may be a worldwide trend.

Barriers and Challenges for Female firefighters. Despite the increase in the number of female firefighters, physical and psychological barriers are still faced by women serving in the fire service. Almost 85% of the female participants in the study conducted by Hulett et al. [1] reported having experienced different treatment because of their gender. Workplace harassments are commonly experienced by such professionals [8]. Furthermore, Liao et al. [13], in examining workplace injuries suffered by U.S. firefighters over a 12-year period, found that female firefighters experienced more injuries than their male counterparts.

Such challenges have been encouraging studies that specifically address the difficulties and needs of female firefighters. McQuerry, Kwon, and Johnson [14] advocate that barriers faced by female firefighters are often caused by or exacerbated by the protective clothing and equipment they wear, which demonstrates the relevance of further exploring the issues encountered.

Issues of Personal Protective Equipment for Female Firefighters. The lack of personal protective equipment (PPE) adjusted to the female body sizes and shapes appears as a common topic reported in the literature. Many authors [6,14] advocate that satisfaction of female firefighters with their PPE can be attributed to the use of turnout ensembles designed for the male body.

Encountering problems with ill-fitting equipment was positively answered by almost 80% of female participants of the study conducted by Hulett et al. [1], nearly four times the 20.9% reported by men. Among the participants of the study conducted by H. Park and Hahn [6], female firefighters showed significantly lower satisfaction with the fit and functionality of the turnout ensemble in multiple areas compared to their male colleagues.

Similar results were found in the J. Park and Langseth-Schmidt [15,16] study, as female firefighters showed a significantly lower survey rating on overall satisfaction, perceived comfort, and performance of the turnout pants when compared to men. According to the authors [15] such results may be attributed to the use of uniforms designed for the male body shape.

Moreover, Nawaz and Troynikov [17] demonstrated how differences in the female body shape influence the air gaps of the turnout coats, impacting the level of safety. The authors [17] advised that the body geometry should be considered when designing a protective jacket for female firefighters, particularly under the chest/bust, through the stomach, and around the back and hips.

Sinden et al. [18] pointed out that although equipment designed for women is commercially available, it is not always provided locally. However, McQuerry, Kwon, and Johnson [14] highlighted that although some PPE manufactures have attempted to address these issues by offering “female-sized” turnout gear, they are a simple “downscaling” of the male proportioned gear and do not consider physical anthropometric differences between the male and female human forms.

Furthermore, issues of PPE for female firefighters may not be solved simply applying changes according to standard sizing systems for the male and female body. Despite providing information on the differences between genders, there are aspects to be considered in the case of PPE.

Firefighters’ Anthropometrics. In the last decades, studies have been finding significant anthropometric differences among specialized occupational groups. Hsiao, Long, and Snyder [19], for example, compared data from a U.S. anthropometric database and identified that both men and women serving in protective service occupations, including firefighting and fire prevention occupations, police, detectives, and guards, have different body dimensions and configurations. Later, another study specifically focused on firefighters [20] provided more detailed information concerning the anthropometrics of this occupational group in the U.S.: the male firefighters were heavier than

males in the general population and the female firefighters were taller than the females in the general population.

However, regardless of recent studies, anthropometric databases on firefighters are still very limited. To the best of our knowledge, the only available data of Portuguese firefighters' anthropometrics were presented on the report of the study Power Textiles XXI [21] as well as in the study conducted by Veiga [22]. However, as data are based on self-reported measurements, the accuracy of such data is questionable. According to the Hsiao, Weaver, et al. [23] study, even in physically active professional groups in which there is presumably knowledge of body dimensions, such as firefighters, measured and self-reported anthropometric information may present discrepancies.

Such differences justify the need for a better understanding of the anthropometrics of specific occupational groups, plus the consideration of the recognized differences between genders.

Anthropometric data and the fit of Personal Protective Equipment. Anthropometric data are essential for applying ergonomic principles to the design of a wide range of products and are paramount when developing PPE.

A proper fit of PPE depends on appropriate sizing systems. This, in turn, depends on the methods used for developing the sizing system and the validity of the data from which it was constructed. As stated by Zakaria and Gupta [24], an accurate sizing system must be built based on actual anthropometric data as the understanding of body sizes and shapes is the only way to cater to the needs of consumers.

In the case of occupations that deal with extreme circumstances, as is the case of firefighting, a proper fit and sizing of PPE is related not only with work performance and comfort but also with protection level.

The study Size FF Portugal. Since 2018, the study *Size FF Portugal – Anthropometric Study of Portuguese Firefighters* is being developed by 2C2T – Centre for Textile Science and Technology at the University of Minho. The study was brought to Portugal in cooperation with a consortium comprising 12 U.S. universities responsible for the development of a project focused on Personal Protective Technologies for Current and Emerging Occupational Hazards [25].

The main goal of the study is to provide an anthropometric database of Portuguese firefighters, contributing to fulfill the lack of information on this specific occupational group. Furthermore, the study aims to evaluate if the PPE available to Portuguese firefighters is adjusted to their anthropometrics, identify specific needs and areas needing improvement, as well as to present redesign proposals to the current equipment.

This paper presents a preliminary comparison of anthropometric data – body weight and stature, of female firefighters from 2 fire brigades located in the North of Portugal.

Materials and Methods

In order to obtain authorization to conduct data collection in their departments, formal requests were sent to the fire brigades' chiefs-in-command. All firefighters from both fire brigades were invited to contribute to the study. Once willing to participate, subjects were fully informed about the study protocols and requested to sign a consent form. A unique identifying number was assigned to each participant to maintain confidentiality.

Anthropometric data were collected through both direct and indirect techniques. Indirect measurements were obtained using a 3D handheld body scanner. Additionally, participants' body weight, stature, crotch height, calf circumference, and calf height measurements were directly manually-collected. Measurements were acquired with participants barefoot and wearing underwear. Furthermore, all measurements were collected by the same researcher to avoid intermeasurer differences. Data acquisition followed standardized protocols [26] as described below.

Stature. Stature was measured using a portable stadiometer. Subjects were asked to stand on the floor plate, place feet on premarked footprints, and keep heels together while touching the vertical board. The head was positioned in the Frankfort Horizontal Plane and the movable headpiece was brought down to the most superior point on the head with sufficient pressure to compress the hair. Participants were requested to maintain a fully erect position, deeply inhale, and hold their breath while being measured. Values were recorded to the nearest 1 mm.

Body Weight. Body weight was measured using a digital scale. Subjects were asked to stand still and upright over the center of the scale, with weight equally distributed on both feet. Values were recorded to the nearest 0.1 kg.

Subsequently data were treated and analyzed. Descriptive statistics analysis was performed for the arithmetic mean, standard deviation, minimum, maximum, as well as median for each measurement. Coefficients of variation were calculated for each measurement. A screening was made to verify the presence of outliers as suggested in the EN-ISO 15535:2012 Standard [27]. Later, statistical hypothesis tests were performed aiming to verify differences between measurements of firefighters from both brigades. For the application of hypothesis tests, normality of data was assessed using the Shapiro-Wilk test. In the cases in which normality of data was verified, F-test was applied to verify the equality of variances and determine the appropriate T-test to be applied. In the cases in which normality of data was not verified, the non-parametric Mann-Whitney U test was applied.

Results and Discussion

As aforementioned, data were collected in 2 Portuguese fire brigades located in the North of Portugal. The results are presented as follows: firstly, a brief characterization of the fire brigades and sociodemographic information of participants. Secondly, results of stature and body weight measurements using basic descriptive statistics. And third, an inferential analysis of considered measurements, aiming to verify if there are statistically differences between participants from both brigades, as well as considering their type of commitment. An additional analysis compared data of female firefighters with an anthropometric database data of Portuguese female workers [28,29] as well as with an anthropometric database of the Portuguese female population [30].

Fire Brigades Characterization. From the 2 fire brigades in which data were collected, one brigade, hereafter referred to as FB.01, serves a medium municipality of about 157,000 inhabitants with a population density of 651 people per square km. The other brigade, hereafter referred to as FB.02, serves a municipality of about 194,000 inhabitants with a population density of 1,054.2 people per square km. The FB.02 shares the protection of the municipality with another fire brigade.

Types of missions performed by firefighters from both brigades are very similar and include fighting fires in rural and urban areas, controlling hazardous materials accidents and incidents, extrication from vehicles, emergency medical services, as well as other health care services.

According to the Decree-Law no. 247/2007 [31], both brigades are considered to be mixed brigades. As described in the same Decree-Law [31] mixed fire brigades depend on a municipality of an association of firefighters and have both career firefighters and volunteer firefighters.

In both brigades, career firefighters work on a professional basis, in 8-hour daily shifts. Additionally, career firefighters from both brigades should offer their services on a voluntary basis. Volunteer firefighters are part-time firefighters who voluntarily offer their services in firefighting, serving during night and weekend shifts.

Socio-demographic Information. A total of 30 female firefighters agreed to participate in the study: 12 firefighters from the FB.01 and 18 firefighters from the FB.02. Considering the type of commitment, from the 30 participants, 10 were career-volunteer firefighters (05 from the FB.01 and 05 from the FB.02) and 18 participants were volunteer firefighters (05 from the FB.01 and 13 from the FB.02). Two participants from the FB.01 were trainees.

Concerning the average age as well as years of experience in firefighting, participants from the FB.01 were on average 29.33 years-old while participants from the FB.02 were on average 33.06 years-old. Participants from the FB.02 had on average more years of experience in firefighting when compared to participants from the FB.01. The number of participants, their type of commitment, as well as other sociodemographic information such as average age and years of experience in firefighting are summarized in Table 1.

Table 1 – Socio-demographic information of participants.

	TOTAL	FB.01			FB.02			
		Total	Career-volunt.	Volunt.	Trainee	Total	Career-volunt.	Volunt.
# Participants	30	12	5	5	2	18	5	13
Age [yrs.]								
<i>Mean</i>	31.57	29.33	33.8	26.60	25.00	33.06	38.80	30.85
<i>Stand. Dev.</i>	9.45	7.20	6.69	6.80	5.66	10.62	14.91	8.16
<i>Minimum</i>	20	20	26	20	21	23	26	23
<i>Maximum</i>	63	43	43	36	29	63	63	46
Experience in firefighting [yrs.]								
<i>Mean</i>	8.46	6.57	8.80	6.83	0.34	9.72	12.70	8.58
<i>Stand. Dev.</i>	7.09	6.31	7.05	5.85	0.23	7.47	10.15	6.29
<i>Minimum</i>	0.17	0.17	1	1.17	0.17	2	5	2
<i>Maximum</i>	29.5	16	16	14	0.5	29.5	29.5	22

Descriptive Analysis. As aforementioned, descriptive statistics analysis on the participants' stature and body weight were performed for the arithmetic mean, standard deviation, minimum, maximum, as well as median for each measurement.

The mean stature of all participants was 1614.4 mm (SD = 56.47), ranging from 1501 mm to 1760 mm. A difference of 32.5 mm was observed when comparing stature of the total participants from each fire brigade. Participants' stature was on average 1633.9 mm in the case of FB.01 and 1601.4 mm in the case of FB.02. Furthermore, participants from the FB.02 presented a wider stature range, varying from 1501 mm to 1710 mm. For participants from the FB.01, stature ranged from 1557 mm to 1760 mm.

Considering the type of commitment, career-volunteer participants from the FB.01 were on average 30.4 mm taller than participants from the FB.02 of the same type of commitment. Career-volunteer firefighters from FB.01 were 1600.2 mm tall while career-volunteer firefighters from the FB.02 were 1569.8 mm tall. Similarly, volunteer firefighters from the FB.01 were taller than volunteer firefighters from the FB.02, with an average stature of 1639.2 mm and 1613.6 mm, respectively. However, career-volunteer firefighters from the FB.02 presented a wider stature range, varying from 1501 mm to 1704 mm. The trainees from the FB.01 were on average 1705.0 mm tall.

In a further analysis, participants were divided only according to their type of commitment. Career-volunteer firefighters from both brigades were, on average, 35.7 mm shorter than volunteer firefighters. Stature varied from 1501 mm to 1704 mm in the case of career-volunteer firefighters, and the average stature was 1585.0 mm (SD = 55.00). In the case of volunteer firefighters, stature varied from 1541 mm to 1710 mm and was on average 1620.7 mm (SD = 44.33).

The average body weight of the total of participants was 68.05 kg. Participants from the FB.01 were heavier than participants from the FB.02, presenting an average body weight of 71.7 kg when compared to 65.61 kg of participants from the FB.02. The body weight ranged from 46.4 kg to 141.3 kg, presenting a coefficient of variation of 26.69%.

When taking both the brigade and the type of commitment into account, career-volunteer firefighters from the FB.01 had an average body weight of 64.8 kg while career-volunteer firefighters from the FB.02 had an average body weight of 61.26 kg. In the case of volunteer firefighters, the average body weight was 81.9 kg for participants from the FB.01 and 67.3 kg for participants from the FB.02. The average body weight of trainees from the FB.01 was 63.6 kg.

Furthermore, considering only the type of commitment, volunteer firefighters were, on average, heavier than career-volunteer firefighters: 71.3 kg (SD = 22.07) and 63.0 kg (SD = 9.41), respectively. Body weight varied from 48.8 kg to 83.7 kg in the case of career-volunteer firefighters and from 46.4 kg to 141.3 kg in the case of volunteer firefighters.

In data screening, none of participants presented stature and body weight measurements out of the range proposed by the EN ISO 15535:2012 Standard [27].

Considering all participants, the coefficient of variation of stature was 3.5%, which is in the characteristic value range proposed by Pheasant and Haslegrave [32] (3-4%). However, in the case of body weight, the coefficient of variation of 26.69% exceeded the value range proposed (10-21%) by the same authors [32].

Table 2 presents the descriptive statistics for both stature and weight of participants considering their type of commitment.

Table 2 – Descriptive statistics of stature and body weight of participants

	TOTAL	FB.01			FB.02			
		Total	Career-volunt.	Volunt.	Trainee	Total	Career-volunt.	Volunt.
# Participants	30	12	5	5	2	18	5	13
Stature [mm]								
<i>Mean</i>	1614.4	1633.9	1600.2	1639.2	1705.0	1601.4	1569.8	1613.6
<i>Stand. Dev.</i>	56.47	53.67	11.43	47.90	77.78	55.94	78.09	42.69
<i>Minimum</i>	1501	1557	1590	1557	1650	1501	1501	1541
<i>Maximum</i>	1760	1760	1615	1670	1760	1710	1704	1710
<i>Median</i>	1612.5	1626	1593	1662	1705	1605	1544	1620
<i>Coef. Var.</i>	3.5	3.28	0.71	2.92	4.56	3.49	4.97	2.65
Body Weight [kg]								
<i>Mean</i>	68.05	71.70	64.8	81.9	63.6	65.61	61.26	67.3
<i>Stand. Dev.</i>	18.16	25.56	11.92	37.82	0.21	11.15	7.05	12.19
<i>Minimum</i>	46.4	46.4	51.0	46.4	63.4	48.3	48.8	48.3
<i>Maximum</i>	141.3	141.3	83.7	141.3	63.7	90.0	66.2	90.0
<i>Median</i>	63.8	63.6	62.0	65.0	63.6	63.9	63.9	65.1
<i>Coef.Var.</i>	26.69	35.64	18.41	46.17	0.33	16.99	11.51	18.12

Inferential Analysis. In order to verify if differences of stature and body weight of participants from each fire brigade as well as from different types of commitment are statistically significant, hypothesis tests were applied. All tests were performed at a 0.05 significance level. Data of the 2 trainees from the FB.01 were not considered in the analysis.

Initially, due to the small sample sizes, Shapiro-Wilk tests were applied to verify the normality of data. Results indicated that stature data of participants from each brigade were normally distributed. A *p-value* of 0.322640 was found in the case of FB.01 and a *p-value* of 0.740950 in the case of FB.02. No outlier was identified for both brigades.

Concerning body weight, data were not normally distributed only for the FB.01 brigade. For the FB.01, the *p-value* of the Shapiro-Wilk test was 0.00256402 and 2 outliers were identified (96.1 and 141.3). In the case of FB.02, body weight data were normally distributed, and the *p-value* was

0.230949. The test identified 3 outliers (48.3, 84.2, and 90.0) in the case of body weight of participants from the FB.02.

From the results of the normality test, the F-test was applied for stature data in order to verify the equality of variances between both samples. The results of the F-test showed that the difference between the sample standard deviation of FB.01 and FB.02 data on stature was not big enough to be statistically significant, and the *p-value* equals 0.9133. Further, the appropriate T-test for independent samples (unpaired test, unequal sample sizes, similar variances) was applied. Results showed that the average stature of female firefighter population from the FB.01 was considered to be equal to the average stature of female firefighter population from the FB.02. The *p-value* equals 0.124748 and the T-statistic equals 1.582583.

Regarding the body weight, as data from the FB.01 were not normally distributed, the non-parametric Mann-Whitney U test was applied. It is important to highlight that Mann-Whitney U test is robust to the presence of outliers. The null hypothesis was accepted, meaning that the difference between body weight of participants from both brigades was not big enough to be statistically significant. The *p-value* equals 0.9157 (Z-statistic = -0.1059, U = 105).

Moreover, a second inferential analysis was performed, and participants were grouped considering their types of commitment. The Shapiro-Wilk test showed that stature data of career-volunteer firefighters were normally distributed (*p-value* = 0.516368) as well as the stature of data of volunteer firefighters (*p-value* = 0.959478). Regarding the body weight, Shapiro-Wilk test presented a normal distribution (*p-value* = 0.0880895) and 3 outliers (48.8, 51.0, 83.7) for career-volunteer participants. In the case of volunteer participants, body weight data were not normally distributed (*p-value* = 0.00262241) and 01 outlier was identified (141.3 kg).

Once again, mean tests were applied for verifying if there were significant differences considering the type of commitment. For stature, results of the F-test showed that standard deviation of both types of commitment were considered to be equal (*p-value* = 0.4243). Afterward, the T-test was applied, showing that the difference between the average stature of career-volunteer firefighter population and volunteer firefighter population was not statistically significant.

Comparing the body weight of the 2 types of commitment, similar results were found. Results of the Mann-Whitney U test indicated that the differences between body weight of firefighters considering their type of commitment is not big enough to be statistically significant (*p-value* = 0.472, Z-statistic = -0.7193).

Comparison with Portuguese Anthropometric Databases. In a previous publication [33], data of participants from the FB.01 were presented and compared to the anthropometric database of Portuguese workers [28,29]. Analysis of data showed that it was not enough evidence to assume that the stature and body weight of female firefighters were different from Portuguese female workers.

However, using data of participants from both fire brigades, new analyses were conducted and found contrasting results. The anthropometric data available for Portuguese female workers [28,29] and the Portuguese female population [30] provided in Table 3 were used to perform such analyses.

Table 3 – Anthropometric data of Portuguese female workers and the Portuguese female population

	Portuguese workers Barroso et al. [28,29]		Portuguese population Póinhos et al. [30]	
	Stature [mm]	Body weight [kg]	Stature [mm]	Body weight [kg]
Sample size	399	399	1842	1842
Mean	1565	64	1640	70
Stand. Deviat.	66	10	65.6	10.5

The comparison between stature of female firefighters from both fire brigades and Portuguese workers found statistically significant differences between the average stature of the Portuguese female firefighters and the Portuguese female workers (p -value = 0.0000776979, T-statistic = -3.990161). Similarly, stature data of female firefighters was compared to stature data of the Portuguese population [30]. Again, statistically significant differences were found (p -value = 0.0464737, T-statistic = 1.992388).

In the case of body weight, as data of female firefighters were not normally distributed, a parametric hypothesis test could not be applied.

Discussion

Although participant firefighters from the FB.01 presented higher values of mean stature and mean body weight when compared to the participants from the FB.02, the results of the inferential analysis showed that such differences were not statistically significant in the population of female firefighters from both brigades. Furthermore, volunteer participants from both brigades presented higher values of mean stature and mean body weight when compared to the career-volunteer participants. Similarly, the results of the inferential analysis did not indicate that such differences were not significant in the population of firefighters from each type of commitment.

However, significant differences were found when comparing stature data of participants and the two available anthropometric databases of the Portuguese women. Such results corroborate with similar studies focused on firefighting populations [19,20,23].

It is important to highlight the fact that the presented data were collected in fire brigades located in the same region of Portugal, and that factors such as ethnicity or even environmental effects may not be well-represented in the sample.

Additionally, it is worth mentioning that the reduced sample size may have affected the results. The evaluation of the coefficients of variation showed that results were impacted by outliers. Furthermore, some of the hypothesis tests applied presented low power values, meaning that a larger sample size would ensure the validity of the results. Still, larger sample sizes could allow the application of parametric tests in the case of body weight, as normality of data was not verified in the current sample.

A further analysis of the correlation between age of participants and their stature and body weight data could also contribute to identifying secular trends in anthropometric characteristics of the Portuguese population.

Conclusions

Anthropometric databases are paramount for the development of PPE. In the case of professions that deal with extreme circumstances, as is the case of firefighting, anthropometric databases can advance the improvement of fit and sizing of PPE. The increase of women serving in fire services seems to be a worldwide trend. However, barriers and challenges are commonly faced by female firefighters. Ill-fitting PPE is a relevant issue for these professionals. The need to provide gender-specific equipment to female firefighters is highlighted by many studies.

In this paper, anthropometric data of female firefighters from 2 Portuguese fire brigades were presented. Inferential analysis showed that differences between stature and body weight of both brigades were not statistically significant. Similarly, significant differences concerning types of commitment were not found. However, comparisons of stature data of Portuguese female firefighters with anthropometric databases of the Portuguese female workers as well as the Portuguese female population presented statistically significant differences.

The results presented demonstrate that special attention must be given to the characteristics of Portuguese firefighters' anthropometrics and highlight the relevance of the on-going study. The continuation of the study in other Portuguese fire brigades will allow the development of a more

comprehensive, reliable, and detailed anthropometric database of Portuguese female firefighters and contribute to the improvement of personal protective equipment for a professional group on the rise.

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