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FIREFIGHTERS CARDIORESPIRATORY FITNESS PARAMETERS AFTER 24 WEEKS OF FUNCTIONAL TRAINING WITH AND WITHOUT PERSONAL PROTECTIVE EQUIPMENT

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Abstract
Introduction. Firefighters' (FFs) cardiorespiratory fitness is considered an important capacity for workability. To successfully complete safety standards and rescue protocols, FFs are required to accomplish minimum values of relative VO_{2max}. Physical fitness programs for FFs must take into consideration physiological demands, being essential not only for professional tasks but also as a guarantee of their personal safety. This research aimed to investigate the influence of specific functional training (FT) with and without personal protective equipment (PPE) and self-contained breathing apparatus (SCBA) on the FFs' cardiorespiratory fitness. ***Material and methods.*** Sixty FFs were randomly allocated in three groups (EG1 training with PPE+SCBA; EG2 training with regular fitness equipment and the control group) and enrolled for a 24-week (two sessions/week) FT intervention program. FFs were assessed in anthropometric and 12-minute Cooper test, pre and post-intervention. ***Results.*** Both training groups demonstrated significant improvements from baseline to post intervention EG1 VO_{2max} (39.8 ± 6.5ml.kg^{-1}.min^{-1} and 41.2 ± 5.6ml.kg^{-1}.min^{-1}, $p < 0.001$, +3.5%; EG2 VO_{2max} 41.5 ± 8.3ml.kg^{-1}.min^{-1} and 42.5 ± 7.5ml.kg^{-1}.min^{-1}, $p < 0.05$, +2.4%). ***Conclusions***. The proposed FT intervention, considering the provided equipment in all fire departments, and even without running tasks, seems to be adequate for developing FFs' VO_{2max}. Regular FT with PPE+SCAB must be encouraged to improve adequate VO2max and fitness levels related to firefighting specific tasks.

Key words: physical training, physical fitness, self-contained breathing apparatus

Introduction

To carry out their professional demands, firefighters (FFs) must have excellent physical fitness (PF) levels, as their work capacity includes performing tasks such as pulling a hose, carrying a ladder or rescuing victims [1]. Inadequate fitness levels may reduce FFs' occupational performance [2]. Physiological demands are reflected in metabolic, circulatory, thermoregulatory responses, and hydration status, while psychological tension may be partially reflected in heart rate and endocrine measures [3]. An extra level of physical fitness may be needed when psychic stress and exposure to heat represent an additional burden on the cardiovascular system, leading to reduced efficiency, increased effort and early appearance of fatigue even in younger and well-prepared FFs [4]. In fact, there is an increased risk of cardiovascular disease (CVD), since between 45 and 50% of FFs' deaths occur during strenuous emergency duties compared to those of a non-emergency nature [5].

Firefighters' cardiorespiratory fitness (CF) is thus considered an important capacity for workability [6] with an estimated 27% to 86% of total energy expenditure during firefighting tasks being carried out through this route [7]. Among the different physiological parameters, maximum oxygen consumption (VO_{2max}) is the variable most frequently considered [8].

To successfully complete safety standards and rescue protocols, FFs are required to accomplish minimum values of relative VO_{2max} (> 33 ml.kg^{-1}.min^{-1}; preferably > 45 ml.kg^{-1}min^{-1}) [7, 9]. These values result in oxygen consumption levels between 63% and 97% of VO_{2max} [10] and were observed during the conduct of simulated firefighting tasks.

In general, 90% of the most common activities require average VO_{2max} between 23.4 and 31 ml.kg^{-1}.min^{-1}, and 41.1 and 49.3 ml.kg^{-1}.min^{-1} for more demanding tasks [8]. O'Connell et al., [11] reported that climbing stairs in a simulated fire situation for 5 minutes with protective and respiratory equipment requires average VO_{2max} of 39.0 ml.kg^{-1}.min^{-1}, while Gledhill & Jamnik [8] described values from 23.4 to 25.7 ml.kg^{-1}.min^{-1} for lifting and moving hoses, 30.9 ml.kg^{-1}.min^{-1} in the control of a flexible tube and 36.6 to 44.0 ml.kg^{-1}.min^{-1} for upstairs equipment carrying.

However, in several professional contexts, FFs must use personal protective equipment (PPE) and self-contained breathing apparatuses (SCBAs). Such equipment increases muscle tension, affects users' mobility, decreases range of motion, thus leading to imbalance in gait mechanics and movement patterns and an increase in their task completion time [12]. PPE and SCBAs add loads from 11 and ≥ 25 kg, significantly influencing metabolic, thermal and fatigue efficiency [7].

Carrying heavy equipment and wearing restrictive clothing in extreme heat while performing high-intensity firefighting work causes significant physiological stress that, when combined with deficient PF, can lead to CVD events in the course of action [13]. For these reasons, it is important to emphasize that the maximum performance of FFs, determined from typical

VO_{2max} tests without the use of PPE+SCBAs, may overestimate the real performance capacity in a real situation [14].

Physical fitness programs for FFs must take into consideration physiological demands, being essential not only for professional tasks but also as a guarantee of their personal safety (7). Conventional periodization models improve the performance of FFs in terms of specific physical skills. However, several minutes of rest must be given between sets and repetitions, which does not optimize the stress in the anaerobic and aerobic energy systems, as is the case during real events [15]. In contrast, short-term functional training (FT), which is characterized by short rest periods and relatively high intensity, can place energy production systems in a state of physiological stress that is closer to those that are experienced during real firefighting tasks [16]. FT may be a growing field in intervention to investigate as it attempts to adapt or develop exercises close to a specific task, involving multi-planar, coordinated, and multi-articular movements. As such, little is known about strategies that might make fitness training more effective [16].

Consequently, it is essential to use training methods that effectively address the multilateral development of such component.

Considering the importance of tailoring effective and time-efficient FT, this study aimed to assess the relevance of an innovative FFs specific FT intervention without a running-related task in improving FFs' cardiorespiratory fitness. Furthermore, this study also aimed to examine how the use of PPE+SCBA or its lack influences FFs' cardiorespiratory fitness improvements.

Material and methods

This FT intervention program was carried out for 24 weeks, including a pre (week -1) and post (week 25) assessment. During week -1, FFs were assessed based on anthropometric measures and cardiorespiratory fitness. The subjects wore training clothes and shoes, performing anthropometric tests before the cardiorespiratory fitness test, and were asked to 1) avoid consuming food two hours before the tests, 2) abstain from drinking alcohol and taking stimulants, and 3) abstain from exercising intensely during the 24 hours before the tests. All anthropometric assessment sessions took place at FFs' headquarters facilities. The Cooper test was performed on regular athletics tracks (400 meters per lap). Before the study, all the participants were informed of the objectives, procedures, and protocols, and they all voluntarily signed an informed consent form. The study was carried out following the Helsinki Declaration recommendations for studies in humans and was authorized by the local ethics committee, which gave their ethical clearance (CTC-ESDL-CE002-2019).

Participants

A convenience sample of 60 male Portuguese FFs (30.8 ± 6.5 years; 78.5 ± 13.5 kg; 172.6 ± 6.4 cm) was randomly divided into three groups: training group one (30.9 ± 8.0 years; 79.6 ± 11.6 kg; 172.1 ± 6.3 cm) – EG1 (training with PPE+SCBA), training group two (30.3 ± 6.4 years; 76.4 ± 5.2 kg; 172.8 ± 5.2 cm) – EG2 (training with regular equipment) and control group (31.9 ± 4.6 years; 79.7 ± 16.0 kg; 173.2 ± 8.2 cm). Group EG1 exercised with PPE+SCBA during each session without breathing through (Fig. 1), whereas group EG2 performed the same exercises but without PPE+SCBA.

The inclusion criteria were (i) belonging to the Permanent Intervention Team (PIT), (ii) being over 18 years of age, (iii) showing interest in participating in the study, and (iv) passing the annual medical exam.

Figure 1. Example of firefighter training with personal protective equipment and self-contained breathing apparatus without breathing through

Anthropometric tests

According to the protocol of the International Society for the Advancement of Kinanthropometry [17], each FF was assessed in terms of height to the nearest 0.1 cm with a portable stadiometer (SECA 217, Hamburg, Germany) and weight (SECA 760, Hamburg, Germany) to the nearest 0.5 kg with a scale.

Cardiorespiratory Fitness

Cardiorespiratory fitness was assessed with the Cooper test. This easy and reliable test was used because of its high correlation with maximum oxygen consumption (r = 0.90), [18] economic and safety reasons since it is performed annually as a requirement to be part of FFs' PITs [19].

A 400-meter official athletics track was used to assess the distance covered, and a Geomaute, Onstart 300 stopwatch was used to control the test time. Two trained and experienced researchers supervised the test and assessed the meters covered.

The FFs were allocated in groups of 8 elements, carrying a distinctive color mark. Ten minutes before starting the test, a standard warm-up was carried out by the researchers. The warm-up comprised 6 minutes of running at a self-selected pace followed by two sets of ten repetitions of walking lunges, front leg swings, side leg swings, iron cross and "groiners".

The test began under the command voice "Attention! Start!". At that moment, the chronometer was started and the FFs began running. During the test, the FFs were informed individually about the remaining time after each lap, and the countdown began in the last 10 seconds. The end of the 12 minutes was announced with the sound of a whistle. The subjects were encouraged to cover the longest distance possible; they were allowed to walk if necessary but they were asked to avoid this behaviour. After the end of the test, the subject left a mark on the spot and continued walking for 3 to 5 minutes to facilitate recovery. In the end, the total number of meters covered was recorded on an individual form for further analysis. For assessing VO_{2max} ($ml.kg^{-1}.min^{-1}$), the equation of Heyward & Gibson [18] was used, based on the maximum distance covered in the 12 minutes (VO_{2max} ($ml.kg^{-1}.min^{-1}$) = 0.0268 x (distance covered in meters) - 11.3).

Intervention program

The FT intervention program was carried out for a period of 24 weeks, two sessions per week, divided into 4 phases. Phase 1 (mesocycle adaptation) lasted 4 weeks; phase 2 (mesocycle

Gain 1) took 8 weeks; phase 3 (mesocycle Gain 2) took 4 weeks; phase 4 (mesocycle improvement) lasted 8 weeks (Tab. 1).

The training program included 12 functional fitness exercises for FFs. The exercise program included a general warm-up followed by the workout which, depending on the mesocycle, was organized as stations or in circuit. In each exercise, station/circuit-specific information was provided to identify the exercises to be performed and the order in which they should be performed. All exercises were demonstrated under specific progressive challenges and by a proficient subject, to ensure their correct execution. Weekly meetings provided education on proper movements and progressions used in the FT program.

The training load was increased according to training principles (i.e., by increasing the load, frequency, volume, complexity or instability). Training intensity was individually normalized through the % of reserve Heart Rate (HR) [(220 - age) - (resting HR) x% intensity) + resting HR] (20), and controlled in the immediate period after effort.

The FT program combined aerobic, body weight and weight-lifting exercises designed to use the available equipment in a fire station (e.g., weight racks, benches) or on the fire ground (e.g., carrying equipment, dragging a dummy) (Fig. 2).

Table 1. Example of the Functional Training intervention macrocycle plan

PHASE I – Mesocycle Adaptation (4 weeks/2x week)		
Objective low/moderate General fatigue **Intensity** 50-65% da MaxHR	**Station training** 1 set per exercise x2 **Exercises sequence** S1 (1-2-3, 1-2-3); S2 (4-5-6, 4-5-6); S3 (7-8-9, 7-8-9); S4 (10-11-12, 10-11-12)	**Workout time** 30" Exercise 20" Rest **Total Timing** 24:30
PHASE II – Mesocycle Gain 1 (8 weeks/2x week)		
Goal moderate/intense Local fatigue **Intensity** 65-75% da MaxHR	**Station training** 2 sets per exercise x2 **Exercises sequence** S1 (1-1-2-2-3-3); S2 (4-4-5-5-6-6); S3 (7-7-8-8-9-9); S4 (10-10-11-11-12-12)	**Workout** 45" Exercise 20" Rest **Total Timing** 29:00
PHASE III – Mesocycle Gain 2 (4 weeks/2x week)		
Goal moderate/intense General fatigue **Intensity** 65-75% da MaxHR	**Station training** 3 sets per exercise x3 **Exercises sequence** S1 (1-2-3, 1-2-3, 1-2-3); S2 (4-5-6, 4-5-6, 4-5-6); S3 (7-8-9, 7-8-9, 7-8-9); S4 (10-11-12, 10-11-12)	**Workout** 60" Exercise 20" Rest **Total Timing** 51:00
PHASE IV – Mesocycle Improvement (8 weeks/2x week)		
Goal very intense General fatigue **Intensity** 80-90% da MaxHR	**Circuit training** 1 set per exercise x2C **Exercises sequence** C1 (1-2-3-4 ... 10,11,12); C2 (1-2-3-4… 10,11,12)	**Workout** 60" Exercise 15" Rest **Total Timing** 31:30

S – Station; **C** – Circuit; **MaxHR** – Maximum heart rate; " – seconds.

S – Station; C – Circuit.

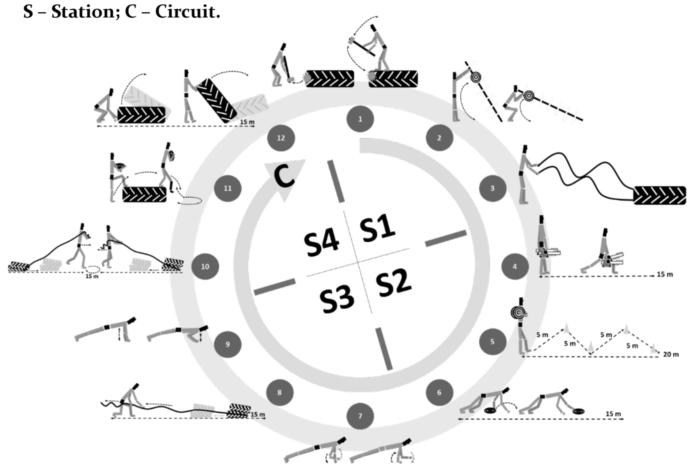

Figure 2. Functional training intervention exercise plan

Statistical analyses

Descriptive statistics were calculated to provide a profile for each measured factor. According to the variable's normal distribution, the paired and independent sample t-tests were performed. Furthermore, Bonferroni post hoc analyses were employed when appropriate to determine between-group, as well as pre, post, and pre-to-post intervention differences. Additionally, the effect sizes (ES) were assessed according to Cohen's d using the pooled standard deviation of the random effects, considering that d = 0.2 small effect size, 0.5 represents a 'medium' effect size and 0.8 a large effect size [21]. All statistics were performed using SPSS software (version 24 for Windows, IBM, USA) with a confidence level of 95%.

Results

The descriptive data of FFs' physical fitness conditions, both before and after the FT intervention, are presented in Table 2.

Significant changes were found from baseline to post-intervention in the CF, according to the Cooper test. Both training groups demonstrated significant improvements from baseline

Table 2. Cardiorespiratory fitness of the firefighters, pre and post intervention

Cooper test	EG1 (n = 22) Mean ± SD	p value	% dif	ES	EG2 (n = 21) Mean ± SD	p value	% dif	ES	CG (n = 17) Mean ± SD	p value	% dif	ES
Estimated VO_{2max} at baseline	39.8 ± 6.5	0.000	+3.5	0.230	41.5 ± 8.3	0.031	+2.4	0.126	37.0 ± 4.9	0.651	-0.5	0.041
Estimated VO_{2max} post intervention	41.2 ± 5.6				42.5 ± 7.5				36.8 ± 4.8			
Meters covered at baseline	2288.2 ± 247.0*	0.000	+2.5	0.232	2365.4 ± 372.0*#	0.040	+1.7	0.113	2159.1 ± 218.5	0.873	-0.1	0.009
Meters covered post intervention	2346.2 ± 252.4*				2405.7 ± 338.3*#				2156.9 ± 215.8			

VO_{2max} – maximum oxygen consumption (expressed in ml/kg/min); EG1 – experimental group 1; EG2 – Experimental group 2; CG – Control Group; % dif. – percentage of difference; ES – Effect size; * – significant differences between baseline and post intervention; # – + significant differences between CG and EG2 (p < 0.05).

to post-intervention in meters covered (EG1 meters covered from 2288.2 ± 247.0 m to 2346.2 ± 252.4, $p < 0.05$, +2.5%; EG2 meters covered from 2365.4 ± 372.0 m to 2405.7 ± 338.3 m, $p < 0.05$, +1.7%), and in estimated VO_{2max} (EG1 VO_{2max} from 39.8 ± 6.5 $ml.kg^{-1}.min^{-1}$ to 41.2 ± 5.6, $ml.kg^{-1}.min^{-1}$, $p < 0.001$, +3.5%; EG2 VO_{2max} from 41.5 ± 8.3 $ml.kg^{-1}.min^{-1}$ to 42.5 ± 7.5 $ml.kg^{-1}.min^{-1}$, $p < 0.05$, +2.4%).

Discussion

The complexity and nature of FFs' duties and heavy PPE require excellent CF. The findings of this study indicate that the implemented specific FT program was relevant in the improvement of FFs' CF independent of training modality (with or without PPE+SCBA). However, despite the similarity of the two interventions, EG1 (PPE+SCBA) had the greatest increase, observed as % of difference and effect size, when compared to EG2 (no PPE+SCBA) and CG. Exercising under the conditions PPE+SCBA might generate more beneficial outcomes in the long term because of a more accurate simulation of the actions carried out by FFs on daily interventions and promoted an extra overload during the intervention program. Our results also indicate that the Cooper test and the estimation of VO_{2max} from the total distance covered with the equation from Heyward & Gibson [18] are useful and may provide substantial predictive validity on assessments in FFs' performance.

Several studies associate low VO_{2max} values in FFs with specific factors such as modifiable factors, task factors and equipment factors. As a task factor, we can identify the use of PPE and SCBA by decreasing aerobic capacity at a rate of 12% and 17%, respectively [22, 23]; the type of tactics chosen for the execution of tasks [24]; types of warm environments and contaminated atmospheres [4, 25]. The equipment factors rely on technical and thermoregulation properties of textiles used in protective equipment, with an important impact on the thermal physiological responses. The VO_{2max} values (predicted) presented by our FFs are in accordance with the literature for the most common tasks of this population and physical evaluation tests. Our intervention registered significant improvements in VO_{2max} values in EG1 (VO_{2max} 41.2 ± 5.6 $ml.kg^{-1}.min^{-1}$, $p < 0.001$), and EG2 (VO_{2max} 42.5 ± 7.5 $ml.kg^{-1}.min^{-1}$, $p < 0.05$). However, there are values below 43 $ml.kg^{-1}.min^{-1}$, which have been associated with an injury incidence of 2.2 times higher compared to those who demonstrate aerobic capacity greater than 48 $ml.kg^{-1}.min^{-1}$ [26]. Therefore, and even with notable improvements, these PIT FFs must continue to increase aerobic capacities to guarantee that FFs' tasks require less effort and thus provide a higher safety margin in daily tasks (27). Comparing the results with similar studies, which used a running test to determine VO_{2max}, our findings show similar capacity scores to Italian [28], American [29], Australian (6) and Spanish [30] FFs. Lower values were found in Brazilian [31], Swedish [32], Norwegian [9], American [26, 33], Spanish [34], Canadian [10] and Italian [7, 35] FFs. These differences may be probably mediated by cultural background and because in Portugal PITs are a new concept relaying in the reconversion of volunteer FFs that must pass the Cooper test annually to be part of PITs [19]. This evidence may be observed in baseline results, where EG1 present inferior values that EG2, but also strengthening the evidence of the benefits of the FT intervention with PPE + SCBA [36]. The scores on VO_{2max} and meters covered in EG1 and EG2 improved significantly post intervention, demonstrating the effectiveness of this FT intervention. This effect guarantees that for FFs' cardiovascular training, running may be a secondary task, as the goal was to improve CF assessed by running tests. Another important indicator was that these achievements contribute significantly to improving our participants' operational capacity, resilience to FFs' mission, injuries and reducing CVD risk factors.

This study has some limitations. The sample size was limited to a convenience sample and did not include females, making it impossible to conduct a similar analysis. Additionally, the participants may not have been representative of all firefighters across Portugal, the habitual physical activity was not controlled, and the participants may have been in different work rotations, which may have impacted their physical state. However, this department was like most fire departments across Portugal and other countries that have no formal wellness or fitness program leading to an excellent opportunity to improve FFs' capability. Regular training with PPE+SCAB must be encouraged but under appropriate supervision and in a normally hydrated state and low ambient temperatures, so as not to induce heat illness, because thermoregulatory cooling mechanisms are rendered ineffective due to the thermal barrier produced by the PPE [37].

If heat stress is a concern, alternative methods such as increasing load carriage, with a weighted vest or just wearing the SCBA without turnout gear, may be considered. This kind of training helps FFs maintain a healthy general physical condition and develop fitness attributes that are associated with occupational performance [16].

Conclusions

A modern functional training, based on FFs' professional functions, and even without running-specific tasks, enhances FFs' cardiorespiratory fitness.

Regular functional training with PPE+SCAB must be encouraged to improve adequate physical fitness and VO_{2max}, developing a healthy general physical condition and optimum fitness levels related to firefighting-specific tasks.

The proposed functional training intervention, considering the provided equipment in all fire departments, seems to be adequate for developing FFs' VO_{2max} and running capacity.

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