

Article

Effects of a 6-Month Minimal-Equipment Exercise Program on the Physical Fitness Profile of Portuguese Firefighter Recruits

José Augusto Rodrigues dos Santos ¹, Domingos José Lopes da Silva ² and Andreia Nogueira Pizarro ^{3,*}

¹ Centre of Research, Education, Innovation and Intervention in Sport (CIFID2D), Faculty of Sport (FADEUP), University of Porto, 4200-450 Porto, Portugal; jaugusto@fade.up.pt

² Research Centre in Mathematics and Applications, University of Évora, 7000-671 Évora, Portugal

³ Research Centre in Physical Activity, Health and Leisure (CIAFEL), Faculty of Sports (FADEUP), University of Porto, Portugal and Laboratory for Integrative and Translational Research in Population Health (ITR), 4200-450 Porto, Portugal

* Correspondence: anpizarro@fade.up.pt

Abstract

Firefighting requires high and multidimensional fitness to ensure operational readiness and public safety. In Portugal, there is limited data regarding firefighters' fitness and exercise programs to improve readiness are lacking. This study evaluated the effects of a 6-month minimal-equipment exercise program on the physical fitness of firefighter recruits. Thirty-five male subjects (23.0 ± 2.72 years) were assessed at baseline, 3 and 6 months for body composition, handgrip strength, running speed, cardiovascular endurance, anaerobic power, and upper- and lower-body strength. The intervention entailed daily sessions with 15 min of continuous running (50–65% HRmax) and active stretching, followed by alternating routines, including endurance running, free weights, interval sprints, calisthenics, and drills. A repeated-measures ANOVA and Bonferroni adjusted post hoc comparisons identified time-based changes. Significant improvements occurred across all fitness variables. Body fat fell by 8.4% and VO_2max increased ($p < 0.001$), surpassing occupational thresholds required for extended suppression tasks. Bench press and sit-up performance improved by 88% and 81%, respectively, while countermovement jump showed double-digit gains (13%), all of which can translate directly to hose advancement, victim rescue, and forcible entry. These results highlight that resource-constrained departments can implement effective, low-cost exercise programs for enhancing pivotal fitness components, supporting policy initiatives to include structured training throughout firefighters' careers.

Keywords: physical fitness; conditioning program; occupational performance; occupational health



Academic Editor: Robin M. Verble

Received: 6 December 2025

Revised: 4 January 2026

Accepted: 22 January 2026

Published: 27 January 2026

Copyright: © 2026 by the authors.

Licensee MDPI, Basel, Switzerland.

This article is an open access article distributed under the terms and

conditions of the [Creative Commons Attribution \(CC BY\)](https://creativecommons.org/licenses/by/4.0/) license.

1. Introduction

Firefighting is a highly demanding occupation characterized by significant physical, psychological, and environmental stressors. Despite extensive research, most studies have focused on North American populations, and data on the fitness characteristics or training responses of Portuguese firefighters are scarce. In Portugal, there were 26,123 firefighters in 2021, mostly operating as volunteers; however, no recent data on their physical fitness profile are available. In 2013, a report from the Ministry of Health showed the only available evidence indicating high rates of overweight and obesity among volunteers [1], factors that may contribute to an increased risk of musculoskeletal injuries and cardiovascular disease [2]. Moreover, fitness programs are neither

mandatory nor common, and many firefighters lead sedentary lives [3]. Nevertheless, the demands of the duty require a good physical condition, as firefighters perform numerous demanding tasks, such as ladder raises, carrying heavy equipment, pulling hoses, dragging, or crawling [4] in harsh environments such as high temperatures and the presence of chemicals or physical hazards. Previous research has demonstrated that strength, power and aerobic capacity are significant predictors of performance on simulated fireground tasks and composite firefighter ability tests, supporting their relevance for occupational readiness [5,6]. Exercise programs targeting these components induce well-documented physiological adaptations, including neuromuscular efficiency, increased strength and power, and enhanced aerobic capacity, contributing to greater work efficiency and reduced physiological strain during high-intensity occupational tasks [7,8]. However, most available evidence derives from North American firefighter cohorts operating within structured and well-resourced training systems. Consequently, the extent to which similar adaptations occur in resource-constrained European contexts, such as Portuguese firefighter academies characterized by minimal equipment and mixed professional–volunteer structures, remains unclear.

Given that physical preparedness is critical for occupational safety and performance, there is a clear need to investigate effective training interventions targeting this population. This study aimed to explore the effects of a 6-month exercise program on the physical fitness of future career firefighters.

2. Materials and Methods

2.1. Study Design

This is an observational longitudinal study with data obtained from mandatory routine physical assessments conducted during an official firefighter recruitment and training program. Under Portuguese Decree Law No. 21/2014 and Decree Law No. 80/2018, institutional ethics committee review is required only for clinical research that intervenes in health care; therefore, routine operational assessments fall outside the scope of mandatory review. Nevertheless, treatment of data was approved by the fire department Brigade Command of Bombeiros Sapadores do Porto. Prior to publication, participants received information explaining the purpose and scope of the secondary research use of their anonymized data and the right to withdrawal their data without repercussions, and their consent was obtained by lead author. Data were pseudonymized at source and stored on an encrypted university server accessible only to the research team. Procedures conformed to the Declaration of Helsinki (2013) and current ethical guidelines for sport and exercise science research [9].

2.2. Participants

Participants were firefighter recruits enrolled in the same official firefighter training academy. Approximately 200 candidates applied to the recruitment process, and selection was performed by the fire service based on physical performance and psychometric tests. The final sample comprised the 35 highest-ranked recruits, selected according to institutional criteria and with no research team involvement. During the training period (internal regimen), recruits were exposed to a mandatory professional skills program and an exercise intervention for 6 months (Table 1). Participants were assessed for speed, endurance, and strength, as well as body composition, at three time points: in the first week of the training program (M_1), at the third month (M_2), and at the end of the 6-month training period (M_3), prior to graduation.

Table 1. Weekly training schedule and prescribed training variables (frequency, intensity, duration, volume, and rest intervals) of the 6-month minimal-equipment exercise program implemented during mandatory firefighter candidate training.

Monday	Tuesday	Wednesday	Thursday	Friday
WARM-UP ROUTINE: Continuous running at HRmax 50–65%: 15 min Active Stretching: 7 min				
Continuous running	Free weights training All body	12 × 200 m running	Calisthenics for upper limbs and core in the vertical rope, bar and espalier: 3 × 3 min	Technical running skills (e.g., steps, hops, multi-jumps, ...)
HRmax 60–75% 60 min	~10–15 reps 3 to 4 series	maximum speed rest: 1 min	40–50 min	Sprint: 10 × 40 m maximum speed rest: 2 min
COOL DOWN AND PASSIVE STRETCHING: 7–10 min				

All participants were male (100%), healthy, as confirmed by initial medical screening, without musculoskeletal, visual, or hearing impairments and who successfully passed the required physical condition tests. Participants were aged 18–30 years (mean ± SD: 23.03 ± 2.72 years), with a mean body mass of 67.8 ± 6.58 kg and height of 173.4 ± 4.43 cm. No dropouts or training-related injuries were reported during the study period.

Dietary intake was assessed with a 3-day diary (on 2 weekdays and 1 weekend day) recorded at two times: in the first week of recruitment (M₁) and three months later (M₂). As nutritional intake was similar between all firefighter recruits, as they had the same meals during the training process (intern regimen), we did not include these data in the analysis.

2.3. Physical Fitness

Physical fitness assessments were conducted following a standardized sequence designed to minimize the impact of fatigue and to progress from low- to high-intensity efforts. First, anthropometric measurements were obtained, after which participants performed jump-based tests in the following order: squat jump, counter-movement jump, and standing long jump. Subsequently, upper-limb and trunk strength/endurance were assessed through handgrip dynamometry, pull-ups, and sit-ups, followed by linear sprint performance over 50 m, an anaerobic cycling effort using the Wingate Test, and finally the Cooper 12 min run.

Body mass measurement, in kilos (kg), was assessed with participants wearing only underwear with a Seca Alpha Model 770 (Seca, Hamburg, Germany).

Subcutaneous fat was measured using skinfold thickness in millimeters (mm) with a Holten Calliper (Holtain Tanner/Whitehouse callipers, Holtain Ltd., Pembrokeshire, UK). Seven skinfold thicknesses were measured according to standardized procedures in the following body sites: bicipital, tricipital, subscapular, suprailiac, abdominal, thigh, and calf [10].

Anaerobic power, reported in watts (W), was assessed using a 30 s Wingate cycling test on a mechanically braked cycle ergometer (Monark 828E Ergomedic, Monark Exercise AB, Vansbro, Sweden) to determine peak power, mean power, minimum power, and fatigue index [11]. The breaking force was individually determined according to the standard Wingate protocol and set at 7.5% of each participant’s body mass (resistance = body mass × 0.075). Before the test, participants did a warm-up, cycling at 60 revolutions per minute (RPM) for 4 min against a resistance of 90 Watts, including three sprints. Participants pedaled

lightly for three minutes to recover. The participant then began to pedal as fast as possible with minimal resistance (10 w). Within 3 s, the selected resistance was applied and the participant continued to pedal all out for 30 s. Verbal encouragement was provided throughout the test. Once the test was over, the participant recovered cycling for 1–2 min at 60–80 RPM without any resistance [11]. Fatigue index percentage was calculated using the formula $\text{Fatigue index} = (\text{peak power} - \text{minimum power}) / (\text{peak power}) \times 100$, a standard approach described in the Wingate test literature [11] that reflects the rate at which power declines across the test and is operationally relevant because firefighting often requires repeated high-intensity efforts separated by limited recovery. A lower value indicates superior resistance to anaerobic fatigue.

Cardiovascular endurance was assessed with the Cooper Test [12] in which participants ran as far as possible within 12 min. The test was carried out on tartan athletics track and reported in meters (m).

Handgrip strength was measured with a mechanical Smedley Hand Dynamometer (Stoelting, Wood Dale, UK) adjustable to the width of the hand. Participants were placed standing with arms out-stretched parallel to the trunk and applied maximum strength with each hand without support. The measurement was repeated three times alternately separated by 1 min to avoid neuromuscular fatigue. The maximum value for each hand was recorded in kg, following previously described procedures for adult populations [13].

Running speed was evaluated by 50 m sprint time (standing start) [14]. The front foot was placed 5 cm before the first timing gate. Time was recorded with photoelectric cells placed 50 m apart (Microgate WITTY Wireless Training Timer Double Photocell Kit). The 50 m sprint was performed 2 times, separated by at least 3 min of passive recovery. The best performance, in seconds (sec), was recorded.

Upper-body endurance strength was tested using a flat barbell bench press with 50 kg. Starting with full arm extension, the participant lowers the bar to their chest and then presses it back up to the starting position. The number (n) of self-paced repetitions completed to voluntary fatigue was recorded [4].

The total number (n) of strict pull-ups completed (until chin clears the top of the bar) before failure was used to measure endurance [15].

Squat jumps (SJs) and countermovement jumps (CMJs) were performed on a jump mat (Globus Ergo Tester) after 5 min of free warm-up. Testing was performed with feet shoulder-distance apart, the toes pointing slightly outward, and hands on hips. For SJs, the starting position was achieved after flexing the knees to an angle of 90 degrees; then, participants jumped to a maximum height registered in centimeters (cm). For CMJs, the starting position was standing; then, participants actively flexed the knees to an angle of 90 degrees and jumped to a maximum height. Three maximal jumps were performed for each test, with 1 min of rest. The maximum jump height was recorded in cm [16].

The elastic index, calculated as the relative difference between countermovement jump and squat jump height, represents the contribution of the stretch-shortening cycle to lower-limb power production, with larger differences reflecting greater elastic energy utilization during dynamic movements, as discussed in the literature on vertical jump mechanics [17].

For standing long jump (SLJ) assessment, participants stood behind a line with feet shoulder-width apart. Then, an arm swing and knee flexion preceded a jump forward, taking off and landing with both feet together. The horizontal distance from the take-off line to the rearmost heel was registered in m. The best of 2 attempts was recorded [18].

To measure abdominal strength and endurance, the total number (n) of valid cross sit-ups completed in 2 min was registered as described by Portuguese civil protection department (Despacho n° 446/2025, de 13 de maio). The participant started lying supine, legs bent at 90° and naturally apart, hands at the back of the neck with fingers interlocked, feet fixed on the backrest (or ankles held by a helper on their knees at their side). Then, lift, bend, and twist the torso, touching the right elbow to the left knee before returning to the starting position. Alternating the movement of the elbows/knees in each repetition.

All assessments were conducted by the same trained research team (same investigator in a particular test at different time points) using standardized protocols and identical equipment at each testing moment (M_1 , M_2 , and M_3), minimizing inter-rater variability. All tests have demonstrated good-to-excellent test-retest reliability, with intraclass correlation coefficients (ICCs) typically >0.85 and low standard error of measurement (SEM). Specifically, skinfold measurements, handgrip strength, sprint running, jump tests, aerobic field tests, resistance exercise tests, and Wingate-based anaerobic measures have been shown to provide reliable and reproducible outcomes when administered under standardized conditions [4,10–12,14,16]. Given the longitudinal repeated-measures design, these established reliability properties support the interpretation of observed changes over time.

2.4. Exercise Protocol

During the 6-months of recruiting, the weekly standard physical training curriculum implemented was applied uniformly to all recruits and consisted of the following (Table 1):

The 6-month program was conducted five days per week (Monday–Friday), with standardized warm-up, main training, and cool-down phases. Rest days were institutionally scheduled on Saturdays and Sundays. Training intensity and volume were controlled using predefined heart rate zones for aerobic work, while speed and power components were controlled through fixed running distances and sprint repetitions with standardized recovery. Resistance and calisthenics sessions were prescribed using standardized sets, repetitions, and timed work intervals, as detailed in Table 1.

In addition to the structured physical training sessions, recruits engaged in approximately 30 min of military drills and 90 min of technical firefighting training during weekdays. These activities included hose handling, ladder drills, equipment carries, victim rescue simulations, and task-specific movements, performed with and without fire protective clothing.

Although external loading progression was constrained by limited equipment availability, training progression was implemented through structured adjustments in training volume, exercise intensity (e.g., predefined heart rate zones and sprint efforts), and task complexity across the training period. Progression occurred within the institutional training framework and was guided by participants' readiness, with running pace and overall workload increasing as training adaptations developed. All training sessions were conducted at the fire department under the supervision of qualified exercise professionals, ensuring uniform implementation across participants.

The physical training program was designed by a member of the research team based on the material conditions available at the training location. The program was implemented institutionally as part of standard academy procedures and applied uniformly to all recruits. No modifications to the training program were made for research purposes, and the research team did not influence training delivery during the study period.

2.5. Statistical Analysis

Mean ($\bar{x}$) and standard deviation (SD) were presented as descriptive statistics. The normality of the distributions was assessed using the Shapiro–Wilk test at each assessment time point. No violations were detected that required data transformation or non-parametric alternatives. The one-way repeated-measures ANOVA was used to compare the mean of three repeated measures of the anthropometric and motor variables. The circularity of the covariances matrix in endogenous variables was verified by Mauchly’s test [19]. We used the sphericity assumed if the Mauchly test gives a p -value > 0.05 . However, in the case of sphericity violation, we used a correctional adjustment (ϵ) of the degree of freedom: if $\epsilon < 0.75$, we used the Greenhouse–Geisser correction [20,21], or if $0.75 < \epsilon \leq 1$, we used the Huynh–Feldt correction [21,22]. In the presence of statistically significant differences among the means of time points (i.e., among the three assessment times), we realized multiple pairwise comparisons by Bonferroni post hoc test to analyze the differences between each anthropometric and physical variables at moment 1 (M_1), moment 2 (M_2), and moment 3 (M_3). The partial Eta squared (η_p^2) test was used to quantify the percentage of the variance of the dependent variable that can be explained by the independent variable (effect size) and, according to Lakens [23], is interpreted as follows: $\eta_p^2 < 0.01$: trivial effect; $0.01 \leq \eta_p^2 < 0.06$: small effect; $0.06 \leq \eta_p^2 < 0.14$: moderate effect; and $\eta_p^2 \geq 0.14$: large effect. The statistics observed power was used to find a statistical difference from zero if there is a true difference to be found. Statistical significance was set at $\alpha = 0.05$. Data were recorded and analyzed using SPSS version 28 (SPSS Inc., Chicago, IL, USA).

3. Results

Table 2 presents the descriptive statistics (mean and standard deviation) in all dependent variables at the three time points, i.e., moment 1, moment 2, and moment 3, of a sample of $n = 35$ professional Portuguese firefighters with a mean age of $23.0 (\pm 2.72)$; $\min = 18$, $\max = 30$) years old. Table 2 shows significant differences across time points. The correctional adjustments are shown. It also presents the F-value and its associated significance level. Here, we can see that, with the exception of body weight, calf skinfold, and fatigue index, all variables presented an overall statistically significant difference among the means of the time points ($p < 0.05$). So, anthropometric and fitness variables have a significant impact over time. Post hoc comparisons identified where differences occurred. Additionally, a generally large effect size ($\eta_p^2 > 0.14$) was found, except for body weight and calf skinfold, which had a moderate effect size ($0.06 \leq \eta_p^2 < 0.14$), and fatigue index, which had a small effect size ($\eta_p^2 < 0.06$).

Table 2. Data variation (time effect, one-way repeated-measures ANOVA) and changes in anthropometric and motor fitness variables of professional Portuguese firefighters over the three moments.

Variables	Time Effect				Moment 1 (M ₁)		Moment 2 (M ₂)			Moment 3 (M ₃)			
	<i>F</i>	<i>p</i>	η^2_p	Power	$\bar{x}$	<i>s</i>	$\bar{x}$	<i>s</i>	$\Delta^{(1)} (\%)$	$\bar{x}$	<i>s</i>	$\Delta^{(2)} (\%)$	$\Delta^{(3)} (\%)$
Body weight (kg)	2.763 $\perp$	0.086	0.075	0.456	67.8	6.58	68.1	6.07	0.44	68.4	6.16	0.44	0.9
Biceps SKF (mm)	5.656 $\sharp$	0.013 *	0.143	0.734	3.3	0.77	3.2	0.74	−3.03	3.2	0.73	0.00	−3.0
Triceps SKF (mm)	9.095 $\bullet$	<0.001 *	0.211	0.97	6.9	2.14	6.5	2.12	−5.80	6.4	2	−1.54	−7.2
Subscapular SKF (mm)	11.907 $\sharp$	<0.001 *	0.259	0.966	8.6	2.39	8.1	1.99	−5.81	8.1	1.9	0.00	−5.8
Suprailiac SKF (mm)	19.241	<0.001 *	0.361	0.999	8.6	3.18	6.7	2.2	−22.09	7.2	2.19	7.46	−16.3
Abdominal SKF (mm)	7.875 $\sharp$	0.003 *	0.188	0.872	10.7	4.11	9.8	3.67	−8.41	9.3	3.15	−5.10	−13.1
Thigh SKF (mm)	6.607 $\perp$	0.004 *	0.163	0.863	9.9	3.31	9.1	3.04	−8.08	9.2	2.83	1.10	−7.1
Calf SKF (mm)	2.417 $\perp$	0.110	0.066	0.417	6.5	2.79	6.7	2.71	3.08	6.1	2.23	−8.96	−6.2
Body density (kg/m ³)	22.5 $\perp$	<0.001 *	0.398	1.000	1.073	0.007	1.076	0.062	0.28	1.075	0.006	−0.05	0.2
Body fat (%)	22.386 $\perp$	<0.001 *	0.397	1.000	11.3	3.01	10	2.67	−11.50	10.3	2.62	3.00	−8.9
Body fat (kg)	16.663 $\perp$	<0.001 *	0.329	0.997	7.8	2.51	6.9	2.15	−11.54	7.1	2.15	2.90	−9.0
Fat-free mass (kg)	27.339 $\perp$	<0.001 *	0.446	1.000	60.1	5.14	61.2	5.13	1.83	61.3	5.07	0.16	2.0
Squat jump (cm)	27.016 $\perp$	<0.001 *	0.443	1.000	33.64	4.7	37.07	4.46	10.20	38.2	4.18	3.05	13.6
CMJ (cm)	7.783 $\bullet$	0.001 *	0.186	0.942	37.93	4.74	39.52	4.91	4.19	40.48	5.17	2.43	6.7
Elastic index (%)	4.267 $\perp$	0.030 *	0.112	0.641	4.29	3.13	2.45	4.36	−42.89	2.28	3.26	−6.94	−46.9
50 m speed run (sec)	9.319 $\perp$	0.001 *	0.215	0.952	6.99	0.22	7.05	0.24	0.86	6.93	0.24	−1.70	−0.9
Cooper test (m)	54.763 $\perp$	<0.001 *	0.617	1.000	2805	207.4	3054	161	8.88	3043	230	−0.36	8.5
Bench press (kg)	123.721 $\perp$	<0.001 *	0.784	1.000	9.8	7.3	14.43	7.95	47.24	18.46	8.05	27.93	88.4
Pull-ups (n)	37.087 $\bullet$	<0.001 *	0.522	1.000	13.83	4.6	16.63	4.17	20.25	17.86	4.37	7.40	29.1
Sit-ups (n)	84.508 $\sharp$	<0.001 *	0.713	1.000	19.23	6.98	25.57	8.12	32.97	34.77	12.8	35.98	80.8
SLJ (m)	24.72 $\perp$	<0.001 *	0.428	1.000	2.29	0.16	2.23	0.19	−2.62	2.43	0.16	8.97	6.1
Right handgrip (kg)	4.803 $\perp$	0.016 *	0.124	0.726	51.5	4.82	52.7	4.65	2.33	50.9	5.65	−3.42	−1.2
Left handgrip (kg)	9.132 $\bullet$	<0.001 *	0.212	0.971	52.7	5.28	53.1	5.53	0.76	50.9	5.52	−4.14	−3.4
Maximal power (W)	15.969 $\bullet$	<0.001 *	0.32	0.999	10.18	0.82	10.69	0.64	5.01	10.83	0.65	1.31	6.4
Average power (W)	27.709 $\bullet$	<0.001 *	0.449	1.000	7.62	0.51	7.98	0.47	4.72	8.17	0.44	2.38	7.2
Minimal power W	8.395 $\bullet$	0.001 *	0.198	0.957	5.61	0.58	5.79	0.54	3.21	6.01	0.6	3.80	7.1
Fatigue index (%)	0.964 $\perp$	0.368	0.028	0.191	44.69	7.96	45.86	5.87	2.62	44.09	6.46	−3.86	−1.3
VO ₂ max (mL·kg ^{−1} ·min ^{−1})					51.42		56.99			56.75			

Note: * Significant time Effect ($p < 0.05$), $\bullet$ Sphericity assumed, $\sharp$ Greenhouse–Geisser correction, $\perp$ Huynh–Feldt correction. $\Delta^{(k)} = [(\bar{x} (M_j) \times 100) / \bar{x} (M_i)] - 100, k = 1, 2 \rightarrow \Delta^{(1)} (\%), \bar{x} (Moment 1) \text{ vs. } \bar{x} (Moment 2) \text{ and } \Delta^{(2)} (\%), \bar{x} (Moment 2) \text{ vs. } \bar{x} (Moment 3), \Delta^{(3)} (\%), [\bar{x} (Moment 3) \times 100] / \bar{x} (Moment 1) - 100$. SKF—skinfold. CMJ—Countermovement jump. SLJ—Standing long jump. SKF—Skinfold.

3.1. Anthropometric Changes

In the anthropometric variables, statistically significant differences ($p < 0.05$) were observed in all skinfolds (biceps, triceps, subscapular, suprailiac, abdominal, thigh, and calf), as well as in the body density, fat mass (%), fat mass (kg), and fat-free mass (kg). The effect size varied between 0.066 (moderate) and 0.446 (large). The observed power (or post hoc power) varied between 0.417 and 1.000.

3.2. Fitness Changes

In the physical fitness variables, statistically significant differences ($p < 0.05$) were observed in all motor variables, including jump performance (squat jump, countermovement jump, standing long jump), running speed (50 m sprint), aerobic capacity (Cooper test), muscular strength and endurance (bench press, pull-ups, sit-ups), and power output (maximal, average, and minimal power), with the exception of fatigue index ($p > 0.05$) and handgrip strength that slightly decreased. The effect size varied between 0.028 (small) and 0.784 (large). The observed power varied between 0.191 and 1.000.

3.3. Relative Changes

In the anthropometric variables, the major relative changes (i.e., reduction) occurred in the suprailiac, abdominal, triceps, thigh, calf, subscapular, and biceps skinfolds. The body density had a slight increase (about 0.23%), as did the fat-free mass (about 2%). On the other hand, the fat mass had a reduction of more than 8%. On average, considering the seven skinfolds, we observed a reduction of 7.6% from M₁ to M₂, 1% from M₂ to M₃, and 8.4% from M₁ to M₃.

In the fitness variables, the major changes were observed in the bench press (+88.4%), sit-ups (+80.8%), elastic index (−46.9%), pull-ups (+29.1%), and squat jump (+13.6%).

3.4. Post Hoc Comparisons

Table 3 shows the pairwise comparisons as statistically significant. A post hoc test using Bonferroni correction reveals that

Table 3. Bonferroni adjustment for multiple comparisons.

Variables	(1) vs. (2)	(1) vs. (3)	(2) vs. (3)
Body weight	0.610	0.214	0.416
Body density	<0.001 *	<0.001 *	0.439
Body fat (%)	<0.001 *	<0.001 *	0.447
Body fat (kg)	<0.001 *	0.004 *	0.355
Fat-free mass	<0.001 *	<0.001 *	1.000
Squat jump	<0.001 *	<0.001 *	0.094
Countermovement jump	0.079	0.003 *	0.285
Elastic index	0.177	0.036 *	1.000
Speed run 50 m	0.048 *	0.201	<0.001 *
Cooper test	<0.001 *	<0.001 *	<0.001 *
Bench press	<0.001 *	<0.001 *	<0.001 *
Pull-ups	<0.001 *	<0.001 *	0.025 *
Sit-ups	<0.001 *	<0.001 *	<0.001 *
Standing long jump	0.330	<0.001 *	<0.001 *
Right handgrip	0.087	0.001 *	<0.001 *
Left handgrip	1.000	<0.001 *	0.010 *
Maximal power	0.002 *	<0.001 *	0.598
Average power	<0.001 *	<0.001 *	0.026 *
Minimal power	0.305	0.001 *	0.048 *
Fatigue index	1.000	1.000	0.193

Note: * the mean difference is significant at the $\alpha = 0.05$ level. 1 (Moment 1—baseline); 2 (Moment 2—at 3 months); 3 (Moment 3—at 6 months).

- In anthropometric variables there is a statistically significant difference between the first and the second time points, as well between the first and the third time points of assessment, except in the body weight. The mean of body density and fat-free mass increases from the first to the third time point, while the mean of body fat (%) and body fat (kg) decreases from the first to the third time point.
- In fitness variables, with the exception of the 50 m speed run, all the observed statistically significant differences between the first and the second time points are due to the best mean performance of the second time point. Between the first and time points, with the exception of the elastic index and right and left handgrip, the statistically significant differences are due to the best mean performance of the third time point. Between the second and third time points, the Cooper test, bench press, pull-ups, sit-ups, and handgrip revealed a higher and statistically significant mean on the second time point, while for the 50 m speed run, standing long jump, average power, and minimal power, the third time point had the best mean performance.

4. Discussion

This six-month minimal-equipment program substantially enhanced the multifaceted fitness profile that underpins safe and efficient firefighting, producing significant improvements in body composition, muscular strength and power, aerobic capacity, and anaerobic power in male Portuguese firefighter recruits. These adaptations are known to improve core tasks such as ladder raises, hose advancement, equipment carries, and victim rescue [5,24], thereby increasing operational readiness while potentially reducing injury [24] and cardiovascular event risk [25]. Moreover, these gains were achieved without specialized facilities, underscoring the feasibility of implementing structured fitness curricula in resource-limited fire departments.

To cope with the intensive physical work in a wide variety of extreme environments and thermal conditions that expose firefighters to a high level of physical exertion [26], well-structured exercise training programs should be mandatory, aiming at an excellent overall level of readiness and fitness. Nevertheless, in Portugal, it is not common for firefighters to engage in specific exercise programs [3], as most fire departments do not have a regular fitness program for their professionals, nor provide sufficient support or motivation. In the US, fire departments are also reported not to adhere to health and fitness recommendations set by governing associations and lack structured fitness monitoring and improvement programs for personnel [27]. The reasons for this might be linked to department leaders' lack of knowledge of the benefits to firefighters and of how to successfully apply interventions [28]. Therefore, dissemination strategies should be promoted by stakeholders.

Although our results did not show significant changes in body weight between the time points, there was a significant improvement in body composition, as percentage body fat fell by 8.4% and fat-free mass rose by ~2% at the end of intervention, reflecting the desirable phenotype reported in other tactical cohorts [29]. Besides health impacts including lowering the risk of chronic diseases and sudden cardiac events [30] typically associated with excess weight, a leaner profile can impact firefighters by reducing their risk of musculoskeletal injuries, enhancing their heat tolerance [31], and attenuating the hemodynamic strain that predisposes firefighters to duty-related cardiac events—the leading cause of line-of-duty deaths worldwide [25]. Excess body fat can hinder mobility and agility, making it more difficult to perform critical tasks during rescues [32]. A number of studies have explored body composition in firefighters and suggested worse body compositions are significantly related to poor firefighting task performance [5,24]. Despite the fact that our

exercise intervention led to decreases in % body fat, in line with other research, an adequate diet is known to improve body composition [33].

Aerobic capacity has also been reported as an important predictor of health and job performance in firefighting [2]. Even though our participants baseline mean VO_2max was above the recommended values for firefighters (42 mL/kg/min) [34], they were still able to make improvements (VO_2max $M_1 = 51.42 (\pm 4.64)$; $M_2 = 56.99 (\pm 3.59)$; $M_3 = 56.74 (\pm 5.15)$ mL/kg/min), emphasizing the importance of a regular exercise program throughout the career span to maintain job effectiveness, particularly as this capacity tends to decrease with age [7]. Aerobic capacity is essential to cope with tasks such as fire suppression [35], given the intense submaximal workload for numerous minutes at a time [36], and to prevent overexertion and increase cardiovascular strain [35]. Importantly, our gains were achieved without treadmills or cycle ergometers, demonstrating that field-based interval running and circuit modalities can elicit clinically meaningful aerobic adaptations in resource-constrained brigades.

Other crucial abilities for firefighters include strength and power, and exercises for improving these abilities should be incorporated in the training programs, as the unique duties of firefighters include rapid bursts of energy like pushing or pulling, forceful entries, lifting objects, carrying equipment, and climbing stairs [6]. Our intervention showed overall improvements in power and strength were present over the 6-month period, which could allow firefighters to sustain high-intensity efforts more effectively and with less energy expenditure. Handgrip strength values increased at mid-intervention and decreased modestly at the final assessment, likely reflecting the specificity of training stimuli and cumulative manual task demands. Bench-press and sit-up scores improved by 88% and 81%, respectively, while vertical and horizontal jump tests showed double-digit gains. This could translate to faster high-step climbing and hose pulls and might directly support forcible entry and casualty drags, as suggested in previous research [5]. These findings corroborate task simulation studies showing that upper- and lower-body power predict the completion time for composite fire-ground scenarios [37]. Other studies have shown correlations between superior job performance and faster times on timed firefighting tasks [5], with, for example, upper-body strength (significantly correlated with time for hose pull, hose pack stair climb, victim drag, and equipment hoist) and lower-body power (significantly correlated to fireground tasks) [38]. All aspects of anaerobic performance and specifically anaerobic fitness parameters (i.e., anaerobic power, peak anaerobic power, anaerobic capacity, and fatigue index) would be related to optimal performance in the firefighter's physical ability test [37].

One interesting finding was that fatigue index did not change significantly over time, with recruits, overall, experiencing moderate fatigue despite an increase in maximum power. These stable values might suggest that our recruits already possessed adequate anaerobic fatigue resistance. In fact, this is supported by baseline scores comparable to elite tactical athletes. The fatigue index values found in our research are lower than the ones found in firefighters (mean age 40; fatigue index = 49.7%) [36] and for male power athletes following intensive anaerobic training regimens in NCAA Division IA (49.1%) [39]. On the other hand, in younger ages, Naharudin and Yusof [40] found a fatigue index of 40.9% in collegiate cyclist athletes (mean age = 22), while Maud and Shultz [41] reported a 35% fatigue index for male college student athletes. Although the fatigue index is closely related to the energy systems involved in various activities, it does not fully capture the specific muscle activation patterns required in real-world firefighting tasks, meaning that improving endurance and fatigue resistance in firefighters its essential targeted work training that might not be captured in a cycling test.

When compared with recruit academy cohorts reported in the U.S., the pattern of our adaptations is broadly consistent with the expected training-induced improvements across academy training. For example, Wohlgemuth et al. [33] reported meaningful gains in health and fitness across a U.S. fire academy, with improvements in cardiorespiratory fitness and muscular performance occurring over the training timeline and coinciding with improvements in simulated occupational performance. Similarly, academy-based high-intensity functional training studies in U.S. recruits have shown significant improvements in fitness and firefighter ability following relatively short academies (e.g., 7 weeks), supporting that structured recruit training elicits rapid adaptations in operationally relevant capacities [4]. In the present study, the longer training duration (6 months), competitive selection of recruits, and minimal-equipment approach may partly explain the magnitude and profile of change (e.g., substantial upper-body endurance gains) relative to shorter academy reports, highlighting that meaningful fitness adaptations can be achieved even in resource-limited settings.

Although minimal detectable change (MDC) or minimally clinically important difference (MCID) values are not available for all assessed measures in firefighter populations, established thresholds exist for some outcomes. In particular, published MDC estimates derived from measurement error and reliability data for vertical jump performance (~2–3 cm) indicate that our improvements in squat and countermovement jump height exceeded typical measurement error, supporting their practical relevance [16,17]. For other outcomes, including upper-body strength, muscular endurance, and aerobic capacity, practical significance was interpreted using effect sizes and percentage changes, which demonstrated moderate-to-large magnitudes of change across the training period.

This is one of the first studies involving firefighters in Portugal in a time where climate changes are increasing the number of calls to action. We selected several fitness components governed largely by the practicalities of the duty capturing the major job needs (cardiovascular endurance, anaerobic endurance, muscular endurance, strength, and power), which is a strength of our study.

An important limitation of our work is that the sample included only male recruits, restraining generalizability to mixed-gender brigades. Second, the absence of a control group precludes causal inference, and findings should be interpreted as within-group changes associated with program participation, rather than definitive causal effects. Also, better control of the training variables and planned progressions are essential for a long-term exercise regimen, given that fitness equipment in fire departments is scarce, limiting the ability to add the additional external load necessary to increase stimuli. Finally, the study focuses on physical fitness outcomes and did not assess psychological factors such as stress or resilience, which are also relevant to firefighter performance. Although the training program was designed by a member of the research team, it was implemented as a mandatory institutional curriculum and not modified specifically for research purposes. An additional limitation is the lack of detailed information regarding participants' pre-academy physical activity and training history, which may have influenced individual responses to the training program.

Future studies should incorporate periodized loading, include female recruits, integrate psychological and occupational stress measures, and examine on-shift performance outcomes.

5. Conclusions

Even with minimal equipment, a structured training regimen can substantially enhance the multifaceted fitness profile required for modern firefighting.

Regular inclusion of such programs in firefighter recruit training and throughout a firefighter's career may enhance occupational readiness and long-term health, while minimizing financial barriers for smaller departments.

Author Contributions: Conceptualization, J.A.R.d.S. and A.N.P.; program design, J.A.R.d.S.; methodology, J.A.R.d.S. and D.J.L.d.S.; formal analysis, D.J.L.d.S.; data curation, D.J.L.d.S.; writing—original draft preparation, J.A.R.d.S.; writing—review and editing, A.N.P. and D.J.L.d.S.; supervision, J.A.R.d.S. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Ethical review and approval were waived for this study as this is an observational study with data obtained from mandatory routine physical assessments conducted during an official firefighter recruitment and training program. Under Portuguese Decree Law No. 21/2014 and Decree Law No. 80/2018, institutional ethics committee review is required only for clinical research that intervenes in health care; therefore, routine operational assessments fall outside the scope of mandatory review. Nevertheless, treatment of data was approved by the fire department Brigade Command of Bombeiros Sapadores do Porto.

Informed Consent Statement: Verbal informed consent was obtained from the participants. The rationale for utilizing verbal consent is because data collection was conducted within the context of a mandatory firefighter recruitment and training program, in which all physical fitness assessments were routinely performed as part of institutional training and operational requirements. No additional experimental procedures, clinical interventions, or deviations from standard training practices were introduced for research purposes. In accordance with Portuguese regulations governing non-clinical, operational, and training-related assessments, written informed consent is not required when data are collected as part of routine institutional procedures and subsequently used for secondary research analysis. Therefore, verbal informed consent was deemed appropriate and proportionate to the study context. Verbal consent procedure: Prior to the inclusion of their data for research purposes, all participants received a standardized verbal explanation from a member of the research team. This explanation covered the purpose of the study, namely the analysis of changes in physical fitness during recruitment training, based on assessments already conducted at the training academy. It was further explained that the research aimed to contribute to a better understanding of firefighter training practices. Participants were informed that all data would be anonymized, securely stored, used exclusively for research purposes, and reported only in aggregated form. They were also made aware that the use of their data for research was entirely voluntary and had no influence on their training evaluation or professional advancement. Participants were explicitly informed of their right to request the removal of their personal data at any time prior to publication, without any negative consequences. Finally, they were given the opportunity to ask questions or to decline participation in the research use of their data. No participants declined participation or requested data withdrawal.

Data Availability Statement: Our data were obtained as part of an official firefighter training program and derived from routine assessments conducted during this process. As such, the data are not publicly available due to institutional confidentiality policies and the nature of their collection during mandatory procedures. Although consent was obtained from participants and data handling was approved by the fire department, the data cannot be shared to protect participant privacy and comply with institutional regulations.

Acknowledgments: We would like to thank the recruits and command of Bombeiros Sapadores do Porto for allowing us to complete this project. AP is supported by Fundação para a Ciência e Tecnologia [FCT UID/00617/2025 and LA/P/0064].

Conflicts of Interest: The authors declare no conflicts of interest. One author was professionally involved in the design of the firefighter training program as part of his institutional role within the fire department; however, the program was implemented as a standard, mandatory curriculum and was not modified for research purposes. No financial or personal benefits were derived from this role.

Abbreviations

The following abbreviations are used in this manuscript:

RPM	Revolutions per minute
CMJ	Countermovement jump
NCAA	National Collegiate Athletic Association
MDC	Minimal detectable change
MCID	Minimally clinically important difference

References

1. Direção-Geral da Saúde (DGS). *Promoção de um Estilo de Vida Saudável nos Bombeiros Portugueses*; Direção-Geral da Saúde (DGS): Lisbon, Portugal, 2018.
2. Ras, J.; Kengne, A.; Smith, D.; Soteriades, E.; November, R.; Leach, L. Effects of Cardiovascular Disease Risk Factors, Musculoskeletal Health, and Physical Fitness on Occupational Performance in Firefighters-A Systematic Review and Meta-Analysis. *Int. J. Environ. Res. Public Health* **2022**, *19*, 11946. [CrossRef]
3. Carvalho, C.; Maia, A. Exposição adversa, psicopatologia e queixas de saúde em bombeiros portugueses. In Proceedings of the I Congresso Luso-Brasileiro de Psicologia da Saúde, Experiências e Intervenções, Faro, Portugal, 5–7 February 2009; pp. 1047–1067.
4. Chizewski, A.; Box, A.; Kesler, R.; Petruzzello, S. Fitness Fights Fires: Exploring the Relationship between Physical Fitness and Firefighter Ability. *Int. J. Environ. Res. Public Health* **2021**, *18*, 11733. [CrossRef]
5. Rhea, M.; Alvar, B.; Gray, R. Physical fitness and job performance of firefighters. *J. Strength Cond. Res.* **2004**, *18*, 348–352.
6. Michaelides, M.; Parpa, K.; Thompson, J.; Brown, B. Predicting performance on a firefighter's ability test from fitness parameters. *Res. Q. Exerc. Sport* **2008**, *79*, 468–475. [CrossRef] [PubMed]
7. American College of Sports Medicine. *ACSM's Guidelines for Exercise Testing and Prescription*, 10th ed.; Lippincott Williams & Wilkins: Philadelphia, PA, USA, 2018.
8. Chizewski, A.; Petruzzello, S.J. Personality Fuels the Fire: Predicting Firefighter Physical Readiness. *Fire* **2024**, *7*, 465. [CrossRef]
9. Harriss, D.; Jones, C.; MacSween, A. Ethical Standards in Sport and Exercise Science Research: 2022 Update. *Int. J. Sports Med.* **2022**, *43*, 1065–1070. [CrossRef]
10. Lohman, T.; Roche, A.; Martorell, R. *Anthropometric Standardization Reference Manual*; Human Kinetics Books: Champaign, IL, USA, 1988.
11. Castañeda-Babarro, A. The Wingate Anaerobic Test, a Narrative Review of the Protocol Variables That Affect the Results Obtained. *Appl. Sci.* **2021**, *11*, 7417. [CrossRef]
12. Cooper, K. A means of assessing maximal oxygen intake. Correlation between field and treadmill testing. *JAMA* **1968**, *203*, 201–204. [CrossRef]
13. U.S. Department of Health and Human Services; Centers for Disease Control and Prevention. *Muscle Strength Procedures Manual*; CDC: Atlanta, GA, USA, 2013. Available online: https://wwwn.cdc.gov/nchs/data/nhanes/public/2013/manuals/Muscle_Strength_2013.pdf (accessed on 15 December 2025).
14. Zagatto, A.M.; Beck, W.R.; Gobatto, C.A. Validity of the Running Anaerobic Sprint Test for Assessing Anaerobic Power and Predicting Short-Distance Performances. *J. Strength Cond. Res.* **2009**, *23*, 1820–1827. [CrossRef]
15. Department of the Navy. *MCO 6100.13A CH-1; Marine Corps Physical Fitness and Combat Fitness Tests*; Headquarters, U.S. Marine Corps: Washington, DC, USA, 2019.
16. Markovic, G.; Dizdar, D.; Jukic, I.; Cardinale, M. Reliability and Factorial Validity of Squat and Countermovement Jump Tests. *J. Strength Cond. Res.* **2004**, *18*, 551–555.
17. Van Hooren, B.; Zolotarjova, J. The Difference Between Countermovement and Squat Jump Performances: A Review of Underlying Mechanisms with Practical Application. *J. Strength Cond. Res.* **2017**, *31*, 2011–2020. [CrossRef] [PubMed]
18. Adam, C.; Klissouras, V.; Ravazzolo, M.; Renson, R.; Tuxworth, W. EUROFIT: European test of physical fitness. In *Handbook for the EUROFIT Tests of Physical Fitness*; Committee for the Development of Sport: Rome, Italy, 1988.
19. Mauchly, J. Significance test for sphericity of a normal-variate distribution. *Ann. Math. Stat.* **1940**, *11*, 204–209. [CrossRef]
20. Greenhouse, S.; Geisser, S. On methods in the analysis of profile data. *Psychometrika* **1959**, *24*, 95–112. [CrossRef]
21. Girden, E. *ANOVA: Repeated Measures*; SAGE: Newbury Park, CA, USA, 1992.
22. Huynh, H.; Feldt, L. Estimation of the Box correction for degrees of freedom from sample data in randomised block and split-plot designs. *J. Educ. Stat.* **1976**, *1*, 69–82. [CrossRef]
23. Lakens, D. Calculating and reporting effect sizes to facilitate cumulative science: A practical primer for *t*-tests and ANOVAs. *Front. Psychol.* **2013**, *4*, 863. [CrossRef]
24. Michaelides, M.; Parpa, K.; Henry, L.J.; Thompson, G.; Brown, B. Assessment of physical fitness aspects and their relationship to firefighters' job abilities. *J. Strength Cond. Res.* **2011**, *25*, 956–965. [CrossRef]

25. Kales, S.N.; Soteriades, E.S.; Christophi, C.A.; Christiani, D.C. Emergency duties and deaths from heart disease among firefighters in the United States. *N. Engl. J. Med.* **2007**, *356*, 1207–1215. [[CrossRef](#)]
26. Nazari, G.; Lu, S.; MacDermid, J. Quantifying physiological responses during simulated tasks among Canadian firefighters: A systematic review and meta-analysis. *J. Mil. Veteran Fam. Health* **2021**, *7*, 55–75. [[CrossRef](#)]
27. National Fire Protection Association (NFPA). *Fifth Needs Assessment of the U.S. Fire Service*; National Fire Protection Association (NFPA): Quincy, MA, USA, 2020.
28. Andrews, K.; Gallagher, S.; Herring, M. The effects of exercise interventions on health and fitness of firefighters: A meta-analysis. *Scand. J. Med. Sci. Sports* **2019**, *29*, 780–790. [[CrossRef](#)]
29. Nelson, R.; Cheatham, J.; Gallagher, D.; Bigelman, K.; Thomas, D.M. Revisiting the United States Army body composition standards: A receiver operating characteristic analysis. *Int. J. Obes.* **2019**, *43*, 1508–1515. [[CrossRef](#)]
30. Bode, E.; Mathias, K.; Stewart, D.; Moffatt, S.; Jack, K.; Smith, D. Cardiovascular Disease Risk Factors by BMI and Age in United States Firefighters. *Obesity* **2021**, *29*, 1186–1194. [[CrossRef](#)]
31. Cramer, M.; Jay, O. Explained variance in the thermoregulatory responses to exercise: The independent roles of biophysical and fitness/fatness-related factors. *J. Appl. Physiol.* **2015**, *119*, 982–989. [[CrossRef](#)] [[PubMed](#)]
32. Sergi, T.; Bode, K.; Hildebrand, D.; Dawes, J.; Joyce, J. Relationship between Body Mass Index and Health and Occupational Performance among Law Enforcement Officers, Firefighters, and Military Personnel: A Systematic Review. *Curr. Dev. Nutr.* **2023**, *7*, 100020. [[CrossRef](#)]
33. Wohlgemuth, K.J.; Conner, M.; Tinsley, G.; Palmer, T.; Mota, J. Strategies for Improving Firefighter Health On-Shift: A Review. *J. Funct. Morphol. Kinesiol.* **2024**, *9*, 105. [[CrossRef](#)]
34. Mier, C.; Gibson, A. Evaluation of a treadmill test for predicting the aerobic capacity of firefighters. *Occup. Med.* **2004**, *54*, 373–378. [[CrossRef](#)]
35. Storer, T.; Dolezal, B.; Abrazado, M.; Smith, D.; Batalin, M.; Tseng, C.; Cooper, C. Firefighter health and fitness assessment: A call to action. *J. Strength Cond. Res.* **2014**, *28*, 661–671. [[CrossRef](#)]
36. Antolini, M.; Weston, Z.; Tiidus, P. Physical fitness characteristics of a front-line firefighter population. *Acta Kinesiol. Univ. Tartu.* **2015**, *21*, 61–74. [[CrossRef](#)]
37. Beitia, P.; Stamatis, A.; Amasay, T.; Papadakis, Z. Predicting Firefighters' Physical Ability Test Scores from Anaerobic Fitness Parameters & Mental Toughness Levels. *Int. J. Environ. Res. Public Health* **2022**, *19*, 15253. [[CrossRef](#)]
38. Lindberg, A.; Oksa, J.; Antti, H.; Malm, C. Multivariate statistical assessment of predictors of firefighters' muscular and aerobic work capacity. *PLoS ONE* **2015**, *10*, e0118945. [[CrossRef](#)]
39. Coppin, E.; Heath, E.; Bressel, E.; Wagner, D. Wingate anaerobic test reference values for male power athletes. *Int. J. Sports Physiol. Perform.* **2012**, *7*, 232–236. [[CrossRef](#)] [[PubMed](#)]
40. Naharudin, M.; Yusof, A. Fatigue index and fatigue rate during an anaerobic performance under hypohydrations. *PLoS ONE* **2013**, *8*, e77290. [[CrossRef](#)] [[PubMed](#)]
41. Maud, P.J.; Shultz, B. Norms for the Wingate anaerobic test with comparison to another similar test. *Res. Q. Exerc. Sport.* **1989**, *60*, 144–151. [[CrossRef](#)] [[PubMed](#)]

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.