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Effects of an intensive firefighter training program on a simulated fire-escape staircase climb

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Abstract

To evaluate the effects of a four-week intensive training program on weighted stair-climb performance, 18 participants (17 men, 1 woman) completed 16 training sessions combining strength, power, and endurance work. Pre- and post-intervention assessments included a loaded fire-escape staircase climb test, incremental VO_2max test, 30-s Wingate test, submaximal squat test, anthropometric measures, and the ANTI-Vea attentional task. Linear mixed models were used to assess intervention effects; effect sizes were expressed as Cohen's *d*. Stair-climb time decreased significantly after training (EMC: −1.26 s; $d = -0.88$). Post-intervention performance was predicted by a composite Strength Score (βstd = − 0.65) and Wingate Score (βstd = − 0.35; model $R^2 = 0.86$). High-load squat velocity and power, estimated 1RM, and Wingate mean power improved significantly (all $d > 0.67$), whereas VO_2max, ventilatory thresholds, and body mass remained unchanged. ANT-I mean reaction time improved ($dz = -0.59$), with a shift from a linear to a quadratic vigilance decrement pattern. In conclusion, four weeks of intensive firefighter training improved stair-climb performance primarily through neuromuscular and anaerobic adaptations. Training programs targeting this task should prioritize explosive strength at task-relevant loads and anaerobic endurance, while dedicated cognitive training may be required to improve higher-order vigilance components.

INTRODUCTION

Access to the Spanish fire department requires passing public service examinations comprising physical, psychological, and theoretical tests, so optimizing physical-test preparation is fundamental for securing a position. One of the most demanding tests requires ascending 18 vertical meters on a fire-escape staircase loaded with 25 kg of simulated equipment in less than 45 seconds. Performance depends on strength, power, glycolytic metabolism, maximum aerobic power (VO_2max), and specific strength — the force applied during the technical gesture characteristic of the test [1,2].

Strength is strongly related to performance in high-intensity, short-duration tasks. Increases in squat strength explained approximately 60% of the variance in sprint performance improvements [3], and in firefighters a 1 cm²/kg increase in quadriceps cross-sectional area has been associated with reductions of approximately 40 seconds in a weighted step test [1]. However, the relationship of other physiological qualities with weighted-ladder performance remains unstudied. Numerous studies [4] have examined firefighter training programs targeting strength and power, VO_2max, jump, sprint, or body composition [5–7].

Nevertheless, to our knowledge, there are no specific data about the effects of a training program on a fire-escape staircase test. Furthermore, limited research has been published analyzing the effects of short training program durations (lower than 10 weeks). However, these data are of special interest for firefighters preparing for public service exams.

Although firefighter selection emphasizes physical fitness, occupational performance also depends on attentional and cognitive capacities — sustained attention, decision-making, and situational awareness under demanding conditions [8,9]. Sleep deprivation and heat, common with shift work and fire exposure, produce significant declines in sustained attention and increased errors in repetitive tasks, compromising critical operations [10,11]. However, Teixeira et al. [12] found that Stroop, Paced Auditory Serial Addition, and Trail Making performance was largely maintained after a firefighting simulation — with improved Stroop inhibitory control — suggesting acute exposure does not consistently degrade cognition in this population. Extreme heat nonetheless impairs working memory and visual processing when core temperature exceeds 38.5°C, particularly combined with high exertion [13,14]. Conversely, physical conditioning in healthy populations improves attentional resilience and executive functioning, with aerobic interventions benefiting complex attentional tasks and inhibitory control [15] and dual-task training improving reaction times [16] — pointing to a need for structured interventions to mitigate cognitive decline in firefighters under extreme conditions.

Therefore, the aim of this research is to analyze the changes in fitness (including strength, power, and endurance) and performance of firefighters preparing for public service exams after 4 weeks of intensive training for an 18 metres fire-escape staircase climb test. Based on these considerations, three primary hypotheses were formulated. First, four weeks of intensive training would significantly reduce stair-climb time (H1). Second, given the short duration and predominantly glycolytic nature of the task (~ 30–45 s), post-intervention stair-climb performance would be primarily explained by neuromuscular and anaerobic variables — specifically squat-derived strength and power metrics and Wingate-derived anaerobic capacity — rather than aerobic capacity (H2). Third, the intervention would improve global attentional processing speed without impairing accuracy, shifting the vigilance decrement from linear decline to a quadratic trajectory; higher-order executive and arousal vigilance components would remain unchanged (H3).

METHODS

Study design

A quasi-experimental, single-group, pre–post study was conducted to evaluate the effects of a four-week intensive training program on weighted stair-climb performance, its physiological and neuromuscular determinants, and attentional function in firefighters preparing for public service examinations. All participants completed the same experimental intervention (see Fig. 1). The study was approved by the ethics committee of the Catholic University of Valencia "San Vicente Mártir" (UCV/2020–2021/090) and conducted in accordance with the Declaration of Helsinki 2024. All participants provided written informed consent prior to enrollment. Physiological and physical performance assessment was conducted at the exercise physiology laboratory, while training intervention took place at private and public facilities between September and December of 2022.

Figure 1. **Schematic representation of the study design and testing protocol.**

Participants

18 firefighters (men, *n = 17;* women, *n* = 1; age = 37.41 ± 6.37 years; VO_2max = 40.11 ± 3.42 ml·kg^{-1}·min^{-1}) who were either active members of the Spanish fire department or candidates actively preparing for public service firefighter examinations were recruited through convenience sampling from a training center specializing in firefighter exam preparation (Valencia, Spain). Of the 21 volunteers initially recruited, two were withdrawn from the analyses during the training program because of injury; 19 completed the intervention and 18 were included in the final analyses. One participant was excluded from VO_2 analysis due to problems during the register process, making it impossible to include gas exchange data; and one subject was excluded from attentional analyses due to incomplete post-intervention assessment. Sample size was calculated a priori for the training effect on staircase climb with a dz = 0.8, α = .05 and $1\text{-}\beta$ = 0.95.

Inclusion criteria were: (a) age between 18 and 45 years; (b) active involvement in a structured training program for firefighter public service examinations or current employment as a firefighter; (c) no musculoskeletal injury or medical condition contraindicating maximal physical testing at the time of enrollment; and (d) willingness to attend all scheduled training and testing sessions. Exclusion criteria were: (a) inability to complete both pre- and post-intervention testing sessions; (b) attendance below 100% of the prescribed training sessions; and (c) presence of any acute illness or injury during the intervention period that prevented full participation.

Training intervention

The training intervention was a four-week, intensive, multicomponent program designed to improve loaded stair-climb performance through concurrent development of maximal strength, neuromuscular power, anaerobic capacity, and task-specific conditioning. The program was grounded on the principle that weighted staircase climbing demands the integration of high-force production at moderate-to-heavy loads, rapid force development, and sustained glycolytic capacity over approximately 30–45 seconds of maximal effort. Accordingly, the training combined heavy resistance exercises targeting lower-body maximal strength (squat, deadlift, lunge), explosive movements for power transfer (high pulls, jump squats, kettlebell swings, box step-ups), high-intensity running for anaerobic and glycolytic conditioning, and task-specific loaded drills simulating the demands of the staircase climb (box climbs and circuits performed with a weighted vest).

The intervention consisted of 16 sessions distributed across four weeks at a frequency of four sessions per week. The workload was organized through a non-linear, micro-periodized structure in which training emphasis alternated between strength-dominant, power-dominant, and conditioning-dominant sessions within each week (Table 1) [17]. Within this framework, relative intensity progressed across weeks: during weeks 1 and 2, resistance exercises were prescribed at 75–80% of each participant's estimated one-repetition maximum (RM), whereas during weeks 3 and 4, loads increased to 80–85% RM for primary exercises, with the introduction of supramaximal half-squat work (100–120% RM) in week 3. Running-based conditioning progressed from fartlek and moderate-distance intervals (200–400 m at 75–80% of maximal heart rate) in weeks 1 and 2 to shorter, higher-intensity sprints (68–150 m at 80–85% of maximal heart rate) with added external load (weighted vest) in weeks 3 and 4. Rest intervals ranged from 30 seconds for metabolic circuit elements to 3–5 minutes for heavy compound lifts, consistent with established recommendations for maximal strength and power development [18].

Training loads for resistance exercises were individualized based on each participant's estimated RM, assessed during familiarization and adjusted by the supervising coach when a participant consistently exceeded the prescribed repetition target at a given load. Running intensities were prescribed relative to individual maximal heart rate. Weighted exercises and loaded drills were performed using vests of 25 kg for men and 20 kg for women, matching the load specifications of the firefighter selection examination. All strength and power training sessions were conducted at a fully equipped training center dedicated to the preparation of candidates for public service

firefighter examinations. Running and cardiovascular sessions were held at a public athletics track. Sessions were delivered face-to-face under the direct supervision of a certified strength and conditioning coach with experience in firefighter physical preparation, maintaining a strict one-to-one or small-group (maximum three participants) coach-to-participant ratio throughout all sessions. This ratio permitted immediate verbal and tactile feedback on exercise execution and pacing strategy.

Session intensity was monitored by the supervising coach through heart rate responses during running bouts and mean propulsive velocity during resistance exercises. Training program adherence was monitored through session attendance records maintained by the supervising coach. All participants who completed the study attended 100% of the prescribed sessions (16 of 16 sessions).

Table 1
Structure of the four-week training program.

Week	Session 1	Session 2	Session 3	Session 4
1	**Running** **30′ Fartlek with pace changes @ 75% max HR**	**Squat** **6 x 6 reps @ 75% RM / Rest: 3 min** **Deadlift** **6 x 6 reps @ 75% RM / Rest: 3 min** **Kettlebell Swing + Burpees** **Box Jump (55–60 cm) + Dumbbell Power Clean** **21-15-9 reps @ bodyweight as fast as possible / Rest: 5 min**	**Running** **3 x 400 m @ 80% max HR** **3 x 300 m @ 80% max HR**	**Squat** **7 x 5 @ 75% RM / Rest: 3 min** **Bench Press** **7 x 5 @ 75% RM / Rest: 3 min** **Pull-ups** **5 x 6 reps + 12 jumping lunges @ bodyweight as fast as possible / Rest: 5 min** **Jump Squat + Push-ups** **5 x 12 reps @ bodyweight as fast as possible / Rest: 5 min**
2	**Squat** **8 x 4 reps @ 80% RM / Rest: 3 min** **High Pull from the Floor (Barbell)** **5 x 5 @ 80% RM / Rest: 3 min** **Thrusters** **4 x 30 sec with vest (25/20 kg) / Rest: 30 sec** **Deadlift + Bar Jump Burpees** **4 x 12 reps @ 50/35 kg / as fast as possible**	**Running** **10 x 60–80 m uphill @ 85% max HR / Rest: 3 min**	**Lunge** **8 x 4 (bodyweight) + 6 horizontal jumps without weight / Rest: 3 min** **Box Step-ups** **6 x 6 (bodyweight) / Rest: 3 min** **Kettlebell Swing** **15-12-9 reps @ bodyweight + 4 kg as fast as possible / Rest: 5 min** **Medicine Ball Throw** **5 x 30 sec vertical throws (squat + push) / Rest: 30 sec**	**Running** **8 x 200 m @ 80% HRmax / Rest: 3 min** **Jumping Lunges** **5 x 30 sec @ with added weight (20–25 kg) / Rest: 30 sec** **Push-ups + Rope Climb** **5 x 10 push-ups + 1 rope climb in 30 sec / Rest: 30 sec**
3	**Split** 2 x (10 reps + 10 reps) / Rest: 3 min **Squat** 3 x 3 reps @ 85% RM / Rest: 3 min **Half Squat** 2 x 5 reps @ 100% RM 2 x 3 reps @ 110% RM 2 x 2 reps @ 120% RM / Rest: 3 min **Thrusters** 4 x 30 sec with vest (25/20 kg) / Rest: 30 sec **Deadlift + Bar Jump Burpees**	**Running** 4 x 100 m @ 80–85% HRmax / Rest: 3 min 3 x 120 m @ 80–85% HRmax / Rest: 3 min 3 x 150 m @ 80–85% HRmax / Rest: 3 min	**Quarter Squat with Jump** 3 x 8 @ 30–40% RM / Rest: 3 min **Half Squat** 3 x 3 reps @ 85% RM / Rest: 3 min **High Pull from the Floor (Barbell)** 6 x 3 @ 85% RM / Rest: 3 min **Box Climb** 4 x 30 sec with added weight (25/20 kg) / Rest: 4 min **Pull-ups** To failure + 10 jumps with knees to chest / Rest: 3 min	**Bench Press** 4 x 4 @ 80% RM / Rest: 3 min **Shoulder Press** 4 x 4 @ 80% RM / Rest: 3 min **Dumbbell Row Pulls** 4 x 4 @ 80% RM / Rest: 3 min **Running** 6 x 60–80 m @ 80–85% max HR uphill with vest (25/20 kg) / Rest: 4 min

Note. 1RM = one-repetition maximum; HR = heart rate; max HR = maximal heart rate.

	4 x 12 reps @ 50/35 kg / as fast as possible			
4	**Squat** 4 x 3 @ 85% RM / Rest: 3 min **Half Squat** 4 x 3 reps @ 85% RM / Rest: 3 min **High Pull from the Floor (Barbell)** 4 x 3 @ 85% RM / Rest: 3 min **Box Step-ups** 5 x 6 reps with vest (25/20 kg) + Kettlebell (12–20 kg) / Rest: 30 sec **Front Plank** 5 x 30 sec (bodyweight) / Rest: 30 sec **Circuit** 6 x (5 squats + 10 lunges + 10 push-ups + 30 m sprint) with weighted vest (20/25 kg) / Rest: 30 sec	**Running** 3 x 60–80 m @ 85% HRmax / Rest: 3 min + **Farmer's Walk 60–80 m holding 12–20 kg** 3 x uphill 60–80 m @ 85% HRmax without weight / Rest: 3 min 3 x 200 m @ 85% HRmax without weight / Rest: 3 min	**Squat** 4 x 30 sec with vest (25/20 kg) / Rest: 30 sec **Burpees with Vest + Pull-ups** 3 x 12 burpees + 6 x pull-ups with added weight (20–25 kg) as fast as possible Kettlebell Swing + Jumps 3 x 12 kettlebell swings @ 80–85% RM + 12 x bodyweight jumps as fast as possible	**Bench Press** 4 x 4 @ 80% RM / Rest: 3 min **Shoulder Press** 4 x 4 @ 80% RM / Rest: 3 min **Dumbbell Row Pulls** 4 x 4 @ 80% RM / Rest: 3 min **Running** Fartlek 20 min with 25–30 m pace change @ 75% HRmax every 100 m

Note. 1RM = one-repetition maximum; HR = heart rate; max HR = maximal heart rate.

Anthropometric measures

Body mass (kg) was recorded with participants wearing light clothing and without shoes using a calibrated mechanical scale [Seca, Viva 762]. Thigh skinfold thickness (mm) and thigh perimeter (cm) were measured on the dominant leg following the International Society for the Advancement of Kinanthropometry (ISAK) standardized protocols by a certified ISAK Level 1 anthropometrist. All anthropometric measurements were taken in duplicate, and the mean value was used for analysis.

Fire-escape staircase climb test

As the primary outcome, climbing time (s) was measured on a 20 m high, left-turning, fire-escape staircase located at the testing facility. The staircase was equipped with handrails on both sides. Participants performed the test while wearing a weighted vest (25 kg for men; 20 kg for women), replicating the load specifications of a firefighter public service examination. Within 30 seconds of being fitted with the vest, participants assumed a standing start position at the base of the staircase. Timing began when the participant crossed the first photocell gate and ended upon crossing the gate positioned at the top of the staircase. Climbing time was recorded using photocell gates (Velleman PEM10D; Boscosystem, Barcelona, Spain) connected to a Chronopic timing device and processed through Chronojump software (Boscosystem, Barcelona, Spain). Each participant completed a single maximal-effort trial.

Incremental ramp test

Maximal oxygen uptake (VO_2max) was assessed via an incremental ramp protocol performed on a motorized treadmill (HP Cosmos, Traunstein, Germany) set at a fixed 1% gradient to better replicate the energetic cost of outdoor running, as previously recommended [19]. The protocol commenced at 4 km·h⁻¹ and increased by 1 km·h⁻¹ every minute until volitional exhaustion. Ventilatory variables — oxygen uptake (VO_2), carbon dioxide output (VCO_2), and minute ventilation ($\dot{V}E$) — were recorded breath-by-breath using a portable metabolic analyzer (Oxycon Mobile; CareFusion, San Diego, CA, USA), calibrated before each test according to the manufacturer's specifications. VO_2max was defined as the highest 30-second rolling average of VO_2 recorded during the test. Achievement of a true maximal effort was confirmed when a VO_2 plateau was observed, defined as an increase in treadmill speed without a concomitant rise in VO_2 exceeding 2.1 ml·kg⁻¹·min⁻¹ [20]. VO_2max was expressed in both absolute (ml·min⁻¹) and relative (ml·kg⁻¹·min⁻¹) terms. First and second ventilatory

thresholds (VT1 and VT2) were determined from the gas exchange data by the ventilatory equivalents method and expressed in absolute ($ml \cdot min^{-1}$) and relative (% of VO_2max) terms.

Squat test

Lower-body neuromuscular performance was assessed using a submaximal, two-load, incremental 90° back squat protocol performed on a guided Smith machine equipped with a 13 kg bar. A linear position transducer (T-Force System; Ergotech, Murcia, Spain) attached to the barbell recorded displacement–time data during the concentric phase of each repetition at a sampling rate of 1000 Hz [21,22]. Participants first performed four repetitions at 25 kg and, after a two-minute rest period, performed four additional repetitions at 75 kg (45 kg for women). All repetitions were executed with maximal intended concentric velocity. Trained sport scientists visually inspected each repetition to ensure correct squat depth (thighs parallel to the floor) and proper execution.

Three primary outcomes were derived from the propulsive phase of the best repetition at each load: mean propulsive velocity (MPV_{25} and MPV_{75}; $m \cdot s^{-1}$), mean propulsive power (MPP_{25} and MPP_{75}; W), and estimated one-repetition maximum (Estimated RM; kg), calculated from the load–velocity relationship using the T-Force system's built-in algorithm [21–23]. This two-load protocol was designed to characterize neuromuscular performance across the force-velocity continuum, capturing both high-load strength capacity and velocity-dependent mechanical qualities that are functionally relevant to loaded stair-climbing performance [21,22,24].

Wingate test

Anaerobic power and capacity were assessed using a 30-second Wingate protocol performed on a friction-loaded cycle ergometer (Cardgirus, W3). The test was preceded by a five-minute warm-up at a self-selected cadence against zero resistance. Following the warm-up, participants stopped pedaling for a 10-second countdown, after which they pedaled maximally for 30 seconds against a resistance equivalent to 7.5% of their body mass [25]. Standardized verbal encouragement was provided throughout the test. The protocol concluded with five minutes of unloaded pedaling for active recovery. Four outcomes were derived from the Cardgirus software: peak power (W), defined as the highest power output sustained over any three-second period; mean power (W), defined as the average power output across the full 30-second effort; minimum power (W), defined as the lowest power output recorded at the end of the test; and fatigue index (%), calculated as the percentage decline in power from the peak to the minimum value [25].

ANTI-VEA

Attentional performance was assessed using a computerized version of the ANTI-Vea task [26,27], which measures the efficiency of the three core attentional networks — alerting, orienting, and executive control — as defined by the Attentional Network Test for Interactions (ANT-I), together with two vigilance components: executive vigilance and arousal vigilance. Each participant completed the task autonomously at home before each assessment period (pre- and post-intervention), using an online version of the task run on a computer screen [26]. They were instructed to complete the task while wearing a weighted vest (25 kg for men; 20 kg for women), at approximately 60 cm from the monitor, where all stimuli was presented at eye level and in a dimly lit room, following previous ANT studies [28]. The task comprised 480 trials distributed across six blocks, with short rest periods between blocks. Each trial presented a sequence of auditory (tone/no tone) and spatial (valid/invalid/no cue) cues followed by a target flanker display (congruent/incongruent) [26]. Participants were instructed to respond as quickly and accurately as possible to the direction of the central arrow while ignoring flanking distractors. Embedded within the ANT-I trials, infrequent target stimuli were presented to assess executive vigilance (signal detection under conditions of low target probability) and arousal vigilance (maintenance of response speed across the task duration). Reaction time (ms) and accuracy (proportion correct) were recorded for each trial. A familiarization block was completed before each assessment, to reduce learning effect.

PROCEDURE

Each participant visited the exercise physiology laboratory of the Faculty of Sport Sciences at the Catholic University of Valencia “San Vicente Mártir” on two occasions, separated by the four-week training intervention. Both testing sessions (pre- and post-intervention) followed an identical protocol to ensure comparability of assessments. Written informed consent and data protection documentation were signed prior to any testing.

Following the anthropometric measurements, participants completed a standardized warm-up consisting of five progressive exercises: (a) single-leg isometric stand (30 s per leg); (b) single-leg airplane squat with hip thrust (20 repetitions per leg); (c) single-leg airplane squat with trunk rotation (20 repetitions per leg); (d) single-leg airplane squat with kettlebell and trunk rotation (10 repetitions per leg, self-selected load); and (e) monster walk with ankle resistance band (TheraBand), performed in the forward, backward, and lateral directions over 3 m each, followed by one minute of rest.

Tests were administered in a fixed order designed to minimize the influence of accumulated fatigue on subsequent assessments: (1) anthropometric measurements; (2) squat test; (3) Wingate anaerobic test; (4) fire-escape staircase climb test; and (5) incremental ramp test to exhaustion. A 10-min rest was provided between the squat and Wingate tests and between the Wingate and staircase-climb tests, and participants received specific instructions regarding the aims and execution of each assessment prior to its administration. The ANTI-Vea attentional task was completed autonomously at home by each participant before each assessment period (pre- and post-intervention). The post-intervention session was conducted two days after the final training session and replicated the pre-intervention protocol identically.

DATA PROCESSING & STATISTICAL ANALYSIS

All analyses were performed using RStudio (version 2025.09.2 + 418; Posit, Boston, MA, USA). Statistical significance was set at $p < .05$, and 95% confidence intervals (*CI*) are reported for all estimates.

A complete-case approach by variable was adopted, with effective sample sizes corresponding to the number of valid paired observations available for each outcome. For the primary outcome (stair-climb time), a linear mixed-effects model (LMM) with time (pre vs. post) as a fixed effect and participant as a random intercept was fitted using restricted maximum likelihood estimation (REML). The significance of the fixed effect was evaluated using the Satterthwaite approximation for degrees of freedom. The estimated mean change (EMC) from pre to post, its 95% CI, and the corresponding *t* statistic and *p*-value are reported. LMM assumptions (normality and homoscedasticity of residuals) were verified visually and with Shapiro-Wilk tests; no violations were detected.

For secondary outcomes — including anthropometric (body mass, thigh skinfold, thigh perimeter), neuromuscular (MPV_{25}, MPV_{75}, MPP_{25}, MPP_{75}, Estimated RM), anaerobic (Wingate peak power, mean power, minimum power, fatigue index), and cardiorespiratory (VO_2max, relative VO_2max, VT1, relative VT1, VT2, relative VT2) variables — the same LMM specification was applied independently to each outcome. To control for multiple testing across physical and physiological secondary outcomes, *p*-values were adjusted using the Benjamini–Hochberg false discovery rate (FDR) procedure. Paired Cohen's *d*_z effect sizes (standardized mean difference divided by the standard deviation of differences) were computed with 95% CIs based on the noncentral *t* distribution. Effect size magnitudes were interpreted as trivial (< 0.20), small (0.20–0.59), moderate (0.60–1.19), and large (≥ 1.20).

To identify the physiological and neuromuscular determinants of stair-climb performance, analyses were conducted at the post-intervention time point using cross-sectional regression. First, a series of univariable linear regression models were fitted with post-intervention stair-climb time as the dependent variable and each of seven prespecified candidate predictors as individual explanatory variables: body mass, relative VO_2max, Estimated RM, MPV_{25}, MPP_{25}, Wingate peak power, and Wingate fatigue index. For each model, unstandardized and standardized regression coefficients (β_std), 95% CIs, p-values, and explained variance (R^2) are reported. P-values were adjusted for multiple testing using the Benjamini–Hochberg FDR procedure.

Second, to evaluate the combined explanatory power of conceptually grouped sets of predictors, a hierarchical block regression approach was employed. Predictors were organized into four cumulative blocks entered sequentially: Block 0 (body composition: body mass), Block 1 (+ cardiorespiratory fitness: relative VO_{2max}), Block 2 (+ neuromuscular strength: Strength Score), and Block 3 (+ anaerobic power: Wingate Score). The Strength Score was computed as the mean of the z-standardized values of Estimated RM, MPV_{25}, and MPP_{25}; the Wingate Score was computed as the mean of the z-standardized values of Wingate peak power and Wingate fatigue index. This composite score approach was adopted to reduce multicollinearity among highly correlated predictors within the same physiological domain while preserving their shared variance. Model comparison was based on leave-one-out cross-validation root mean square error (LOOCV-RMSE), with the model yielding the lowest LOOCV-RMSE considered to demonstrate the best predictive performance. For the selected model, regression coefficients (unstandardized and standardized), 95% CIs, R^2, adjusted R^2, and variance inflation factors (VIF) are reported. Multicollinearity was considered acceptable when all VIF values were below 5.

For the ANTI-Vea task, complete data were available for 16 participants (one participant did not complete the post-intervention session). Data processing followed the procedures described by Sanchis et al. 29. For the ANT-I and executive vigilance components, trials with incorrect responses or reaction times shorter than 200 ms or longer than 1500 ms were excluded from reaction-time analyses. ANT-I

network scores were computed using the standard subtraction method: phasic alertness (no tone minus tone within the no-cue condition), orienting (invalid minus valid cue), and executive control (incongruent minus congruent flankers). For executive vigilance, block-wise hit rate, false-alarm rate, perceptual sensitivity (A'), response bias (B"), mean reaction time for hits, and reaction-time variability were computed. For arousal vigilance, block-wise mean reaction time, reaction-time variability, and lapse rate (responses ≥ 600 ms) were calculated. To examine the temporal evolution of attentional performance, separate repeated-measures analyses of variance (RM-ANOVAs) were conducted for each ANTI-Vea outcome using two within-subject factors: Time (pre, post) and Block (1 to 6). Main effects of Time and Block, and the Time × Block interaction, were evaluated. Sphericity was assessed using Mauchly's test, and Greenhouse–Geisser-corrected degrees of freedom and p-values are reported when the sphericity assumption was violated. Effect sizes are expressed as partial eta-squared (η^2p). When effects involving Block were significant or of theoretical interest, polynomial decomposition of the Block factor was used to evaluate linear and quadratic temporal trends across the six blocks within each time point (pre, post). Post-hoc pairwise comparisons were conducted with Holm adjustment for multiplicity.

The datasets generated and analyzed during the current study are available in the OSF repository https://osf.io/tva8w/overview?view_only=83336222e030496e8d231fe3f7f88e2e

RESULTS

Stair-climb time

For the primary outcome, the linear mixed-effects model with time (pre vs. post) as a fixed effect and participant as a random intercept revealed a significant reduction in stair-climb time following the intervention (*EMC* = − 1.26 s; 95% CI [− 2.00, − 0.52]; t(16.06) = − 3.62; *p* = .002; *d_z* = − 0.88; 95% CI [− 1.45, − 0.29]), corresponding to a 3.8% improvement (Fig. 3).

Physical and physiological variables

Results of the LMMs for all secondary outcomes, with FDR-adjusted *p*-values and paired Cohen's *d_z* effect sizes, are presented in Table 2. Among neuromuscular variables, significant improvements were observed in mean propulsive velocity at 75 kg, mean propulsive power at 75 kg, and estimated one-repetition maximum. In contrast, velocity and power at the lighter load (MPV_{25} and MPP_{25}) did not change significantly after the intervention. Regarding anaerobic performance, Wingate mean power and fatigue index improved significantly, reflecting enhanced sustained anaerobic output. Wingate peak power showed a trend toward improvement that did not survive FDR correction, whereas minimum power did not change. Markers of aerobic capacity and ventilatory thresholds — VO_2max, relative VO_2max, VT1, VT2, and their relative expressions — did not show significant improvements following the four-week intervention. For anthropometric variables, thigh perimeter decreased significantly and thigh skinfold increased significantly. Body mass remained unchanged.

Table 2
Estimated mean change in secondary outcomes from pre- to post-intervention.

Outcome	EMC [CI]	*df*	*t*	*pFDR*	*d*
MPV_{75}	0.05 [0.02, 0.09]	16.26	3.17	.026*	0.78
MPP_{75}	56.95 [24.13, 89.77]	16.19	3.67	.026*	0.90
Wingate Mean Power	18.57 [7.19, 29.94]	16.04	3.46	.026*	0.83
Wingate Fatigue Index	6.91 [2.37, 11.46]	16.49	3.22	.026*	0.80
Thigh Perimeter	-0.93 [-1.60, -0.27]	16.06	-2.98	.032*	-0.73
Estimated RM	3.67 [0.85, 6.49]	16.10	2.76	.042*	0.67
Thigh Skinfold	1.52 [0.29, 2.75]	16.09	2.63	.047*	0.63
Wingate Peak Power	33.50 [1.31, 65.68]	16.15	2.20	.095	0.53
Wingate Minimum Power	-33.09 [-67.57, 1.39]	16.30	-2.03	.118	-0.50
VT1	-246.17 [-590.71, 98.37]	17.00	-1.51	.270	-0.36
VO_2max	90.40 [-53.53, 234.32]	15.26	1.34	.329	0.34
VT2	-233.17 [-668.73, 202.38]	17.00	-1.13	.380	-0.27
MPV25	0.02 [-0.02, 0.06]	16.18	0.97	.413	0.25
MPP25	-1.77 [-23.95, 20.40]	16.30	-0.17	.868	-0.03
Relative VT1	-2.66 [-8.17, 2.85]	15.33	-1.03	.412	-0.24
Relative VO_2max	1.22 [-0.83, 3.28]	15.74	1.26	.337	0.31
Relative VT2	-1.05 [-5.33, 3.23]	15.13	-0.52	.685	-0.13
Body Weight	0.14 [-0.83, 1.12]	16.02	0.31	.802	0.07

*Note. EMC = Estimated Mean Change from pre- to post-intervention via linear mixed model; MPV = mean propulsive velocity; MPP = mean propulsive power; CI = confidence interval; df = degrees of freedom; pFDR = p-value adjusted by the Benjamini–Hochberg false discovery rate; d_z = paired Cohen's d (standardized by SD of differences) with 95% CI. * = statistically significant after FDR adjustment (p < .05).*

Determinants of stair-climb performance after training

Univariable linear regressions with post-intervention stair-climb time as the dependent variable revealed significant associations for five of the seven prespecified predictors (Table 3). Estimated RM demonstrated the strongest association (*β_std* = − 0.88, 95% CI [− 1.14, − 0.62], *p_FDR* < 0.001, R^2 = 0.78), followed by MPV (β_std = − 0.81, 95% CI [− 1.16, − 0.46], *p_FDR* < 0.001, R^2 = 0.66), MPP_{25} (*β_std* = − 0.77, 95% CI [− 1.14, − 0.40], *p_FDR* < 0.001, R^2 = 0.60), Wingate Peak Power (*β_std* = − 0.69, 95% CI [− 1.10, − 0.28], *p_FDR* = 0.004, R^2 = 0.47), and Wingate Fatigue Index (*β_std* = − 0.56, 95% CI [− 0.97, − 0.15], *p_FDR* = 0.029, R^2 = 0.31). No association was found for other secondary outcomes (all *p* > .05). The hierarchical block regression analysis comparing four progressively complex models showed that the full model incorporating body mass, relative VO_2max, Strength Score, and Wingate Score provided the best predictive performance. In the selected model, the Strength Score emerged as the dominant predictor (*β_std* = − 0.65; 95% CI [− 0.95, − 0.34]; *p* = .001), followed by the Wingate Score (*β_std* = − 0.37; 95% CI [− 0.69, − 0.04]; *p* = .031). Body mass (β_std = − 0.09; *p* = .523) and relative VO_2max (β_std = 0.06; *p* = .659) did not contribute significantly to the model after accounting for neuromuscular and anaerobic variables. All variance inflation factors were below 2.0, indicating no multicollinearity concerns.

Table 3
Hierarchical block regression models predicting post-intervention stair-climb time.

Predictors	R^2	adj_ R^2	RMSE
body weight + relative_vo2max + strength_score + wingate_score	.86	.81	2.11
body weight + relative_vo2max + strength_score	.78	.72	2.21
body weight	.21	.16	3.78
body weight + relative_vo2max	.20	.08	4.05

Note. R² = coefficient of determination; adj R² = adjusted R²; RMSE = leave-one-out cross-validation root mean square error. Predictors were entered as cumulative blocks; the Strength Score and Wingate Score are composites of z-standardized variables.

Accordingly, the predictive equation for post-intervention stair-climb time was:

$$\text{Stair-Climb Time}' = 32.352 - 0.310 \cdot z(\text{BW}) + 0.204 \cdot z(\text{VO}_{2max\text{relative}}) - 2.354 \cdot z(\text{Strength Score}) - 1.334 \cdot z(\text{Wingate Score})$$

Where $z(x) = \left(x - \bar{x}\right) / SD(x)$ denotes z-score standardization (using the training sample mean and SD). Strength Score was computed as $[(\text{Estimated RM}) + z(\text{MPV25}) + z(\text{MPP25})] / 3$, and Wingate Score as $[z(\text{Wingate Peak Power}) + z(\text{Wingate Fatigue Index})] / 2$.

ANTI-Vea

Global indices. ANT-I mean reaction time (RT) was significantly lower after the intervention than before it (PRE: 674.56 ± 102.57 ms; POST: 639.51 ± 111.65 ms; mean difference = − 35.05 ms, 95% CI [− 66.76, − 3.34], p = .032, dz = − 0.59). No other global ANT-I, executive vigilance, or arousal vigilance summary outcome reached statistical significance. Specifically, ANT-I error rate, phasic alertness, orienting, executive control, hit rate, false-alarm rate, A', B", and RT variability were not significantly different between PRE and POST (all $p \geq .140$). Executive vigilance mean RT (p = .056), arousal vigilance mean RT (p = .052), and lapse rate (p = .084) showed non-significant reductions after the intervention.

ANT-I mean RT. The main effect of Time was significant, $F(1,15) = 5.61$, p = .032, ηp^2 = .272, as was the main effect of Block, $F(3.20, 47.97) = 3.14$, p = .031, ηp^2 = .173. The Time × Block interaction did not reach significance, $F(3.78, 56.63) = 2.55$, p = .052, ηp^2 = .145. Planned polynomial contrasts across Blocks 1–6 for ANT-I mean RT showed a significant linear component in the PRE condition (estimate = − 190.86, SE = 74.00, t = − 2.58, p_adj = .021), whereas in the POST condition the significant component was quadratic (estimate = − 248.18, SE = 90.09, t = − 2.75, p_adj = .013). In addition, the PRE–POST difference in the quadratic Block component for ANT-I mean RT was statistically significant (estimate = − 341.58, SE = 121.19, t = − 2.82, p_adj = .011), whereas the PRE–POST difference in the linear component was not (p_adj = .489).

ANT-I error rate. The main effects of Time, $F(1,15) = 0.87$, p = .367, ηp^2 = .055, and Block, $F(3.08, 46.16) = 1.35$, p = .271, ηp^2 = .082, were not significant, and neither was the Time × Block interaction, $F(3.36, 50.47) = 0.94$, p = .435, ηp^2 = .059.

Executive vigilance (EV). EV mean RT showed a main effect of Time, $F(1,15) = 4.53$, p = .050, ηp^2 = .232, while the effects of Block, $F(1.71, 25.59) = 1.24$, p = .301, ηp^2 = .076, and Time × Block, $F(1.71, 25.61) = 0.43$, p = .622, ηp^2 = .028, were not significant. For hit rate, false-alarm rate, A', B", and RT variability, no significant effects of Time, Block, or Time × Block were observed (all $p \geq .297$). Planned trend contrasts for EV mean RT showed no significant linear (p = .261) nor quadratic (p = .145) block trend. However, Holm-adjusted pairwise comparisons indicated significantly lower RTs at POST in Block 1 (estimate = 45.34 ms, SE = 20.43, t = 2.22, p = .0423) and Block 2 (estimate = 49.55 ms, SE = 16.56, t = 2.99, p = .009), with no significant differences in Blocks 3–6 (all $p > .05$). No additional significant linear or quadratic block trends were detected in the remaining outcomes (all $p > .05$).

Arousal vigilance (AV). AV mean RT showed a significant main effect of Block, $F(3.20, 47.99) = 2.74$, p = .050, ηp^2 = .155, whereas the main effect of Time, $F(1,15) = 1.69$, p = .214, ηp^2 = .101, and the Time × Block interaction, $F(3.40, 50.99) = 0.71$, p = .569, ηp^2 = .045, were not significant. AV RT variability was not affected by Time, Block, or their interaction (all $p \geq 0.410$). Lapse Rate showed no significant effects of Time, $F(1,15) = 3.42$, p = .084, ηp^2 = .186, Block, $F(2.45, 36.77) = 2.38$, p = .096, ηp^2 = 0.137, or Time × Block, $F(1.99, 29.91) = 0.34$, p = .711, ηp^2 = .022. Planned contrasts for arousal vigilance mean RT, revealed a significant quadratic component in both PRE (estimate = 100.90, SE = 28.83, t = 3.50, p = .003) and POST (estimate = 67.89, SE = 30.73, t = 2.21, p = .043). Nevertheless, no PRE-POST differences were detected on the quadratic trend after adjustment (p = .861).

Polynomial decomposition of the Block factor within each condition confirmed a significant linear trend for ANT-I mean RT pre-intervention (estimate = − 178.27, SE = 39.65, t = − 4.50, $p < .001$) and a significant quadratic trend post-intervention (estimate = − 128.65, SE = 58.84, t = − 2.19, $p = .045$), indicating a shift from a monotonic decline to a U-shaped trajectory.

DISCUSSION

The aim of this study was to assess changes induced by a specific training program on physical, physiological and attentional variables. Stair-climb time improved 3.8% (1.26 s) after the four-week intervention and, with post-intervention performance predominantly explained by neuromuscular strength/power and sustained anaerobic capacity. High-load mechanical performance and Wingate mean power improved, but lighter-load velocity-dependent metrics did not. Additionally, ANT-I mean reaction time improved, with a shift from a linear to a quadratic vigilance decrement pattern; executive and arousal vigilance remained unchanged.

Our results are consistent with previous research. Sheaff et al.[2] demonstrated that aerobic capacity, anaerobic power, and muscular strength are key determinants of simulated firefighter tasks in the Candidate Physical Ability Test (CPAT). Improvements in lower-limb function may partly explain our findings, as quadriceps size and quality influence stair-climb performance in career firefighters [1]. Cardiorespiratory fitness also contributes, with fitter firefighters completing simulated high-rise climbs more efficiently and with lower perceived exertion [30].

Although the improvement may appear modest, it must be read against the strict thresholds of firefighter selection tests, where small gains can determine success or failure. The modest effect may also reflect the multifactorial demands of the task under heavy external load. Latosinski et al.[31] found equipment weight to be the strongest predictor of stair ascent speed, with loads near 30% of body mass decreasing ascent speed by 24.8%, underscoring the mechanical and metabolic cost of external loading. Because of this complexity, gains in isolated qualities do not translate proportionally into task performance, and participants' pre-existing training background may have further limited the improvement ceiling.

Our results revealed that post-intervention stair-climb time was most strongly associated with Estimated RM, MPV_{25}, MPP_{25}, Wingate Peak Power, and Wingate Fatigue Index, whereas aerobic capacity (VO_2max), ventilatory thresholds, and body weight showed no association. Moreover, the model composed of the Strength Score (composite of Estimated RM, MPV_{25}, and MPP_{25}), Wingate Score (composite of Wingate Peak Power and Fatigue Index), body weight, and relative VO_2max demonstrated the best predictive performance of the stair-climb test. However, within this model, only the Strength Score and Wingate Score were predictors of stair-climb time, confirming our hypothesis that post-intervention performance would be primarily explained by neuromuscular and anaerobic variables rather than aerobic capacity.

These findings are consistent with the body of evidence indicating that anaerobic capacity and neuromuscular performance are the primary determinants of short-duration firefighter tasks. For example, Sheaff et al. [2] reported that absolute VO_2max and Wingate anaerobic fatigue resistance combined to explain 81.7% of the variance in CPAT time, with Wingate mean power being significantly higher in CPAT's successful firefighters. Likewise, Ryan et al. [32] identified peak power and torque as the strongest neuromuscular predictors of stair-climb performance in career firefighters, increasing that correlation when age and body fat were included. In the same line, Beitia et al [33] reported that anaerobic fitness parameters explained 78% of variance in firefighter physical ability test scores, with handgrip strength and vertical jump significantly correlated with performance. Finally, in a firefighter cohort study, Cho et al. [34] also found that Wingate mean power showed a stronger correlation with circuit test time than peak power, which aligns with our finding that sustained anaerobic output is more relevant than instantaneous peak power for tasks lasting approximately 30 seconds. This observation is further supported by the energy systems literature: for maximal efforts of this duration, the glycolytic system is the dominant anaerobic pathway, and total anaerobic work capacity (reflected by Wingate mean power) is more representative of performance than phosphagen-dependent peak power [35].

The dominance of the Strength Score reflects its integrative nature, combining maximal strength (Estimated RM) with velocity and power at a submaximal load (MPV_{25} and MPP_{25}) — the ability to generate force rapidly under moderate resistance, mechanistically relevant to loaded stair climbing. A dissociation emerged between predictors and intervention effects: the strongest predictors of stair-climb time (Estimated RM, MPV_{25}, MPP_{25}, Wingate Peak Power) did not all improve, since MPV_{25}, MPP_{25}, and Wingate Peak Power remained unchanged while gains concentrated in high-load performance (MPV_{75}; MPP_{75}; Estimated RM) and Wingate mean power. This may partly explain the modest stair-climb improvement (3.8%) and suggests that further gains require targeting lighter, velocity-dependent loads and peak anaerobic power.

Our intervention clearly improved high-load mechanical performance: mean propulsive velocity (MPV75) and power (MPP75) both increased significantly, accompanied by greater estimated maximal strength. In contrast, lighter-load metrics (MPV25 and MPP25) did not improve, only partially confirming our hypothesis: high-load performance and anaerobic mean power improved as anticipated, but the lighter-load and peak-power variables most predictive of stair-climb time remained unchanged. This divergence suggests that the training stimulus — emphasizing heavy resistance exercises (squats, deadlifts, high pulls at 75–85% RM) — improved performance under higher loads but did not transfer to lighter, more velocity-dependent conditions, potentially suboptimal for the stair-climb test. Such load-specific adaptation aligns with the principle of velocity and load specificity in resistance training [36].

Among the Wingate-derived measures, mean power and fatigue index improved. The mean-power gain reflects enhanced capacity to sustain high-intensity output over 30 seconds, matching the time domain of weighted stair-climb tests, whereas peak and minimum power were unchanged — indicating improved maintenance of high output rather than maximal instantaneous power. For short-duration occupational tasks, Sheaff et al. [2] showed that sustained anaerobic capacity, indexed by Wingate mean power and fatigue resistance, ranked among the strongest correlates of CPAT performance alongside absolute VO_2max, more so than peak power alone.

Markers of aerobic capacity and ventilatory thresholds (VT1, VT2, VO_2max, and their relative expressions) did not improve after the intervention. Although contrary to our expectations, this is consistent with literature showing that meaningful VO_2max and threshold changes require longer duration, greater aerobic-specific volume, or both. Bacon et al. [5], in a meta-analysis, found that programs shorter than seven weeks showed the smallest VO_2max gains, with duration a significant moderator. Similarly, Hickson et al. [37] demonstrated that VO_2max rises during the first three weeks of high-intensity training but then plateaus without progressive overload, suggesting four weeks may be insufficient. In addition, Londeree [38] reported that already-conditioned individuals show much smaller threshold improvements than sedentary subjects, indicating the participants' high baseline fitness may have limited aerobic gains within four weeks. Our program prioritized resistance and explosive-power training, with only two weekly running sessions at moderate intensity (75–85% maximal heart rate) — likely insufficient in volume and specificity for meaningful aerobic adaptation, consistent with evidence that aerobic gains in firefighters generally require well beyond four weeks [6].

Contrary to our hypothesis that part of the training effect would be conditioned by anthropometric change, body mass remained unchanged across the intervention, indicating that performance and physiological improvements were not driven by reductions in body weight. At the same time, thigh perimeter decreased and thigh skinfold increased modestly. However, interpreting these anthropometric changes requires caution. Skinfold measurements have limited precision, with measurement error often exceeding the magnitude of changes expected over a four-week period [39], and small shifts in circumference and skinfolds can be influenced by hydration status, measurement variability, or local tissue changes rather than true changes in muscle or adipose tissue. Additionally, given the short duration of the intervention (four weeks, 16 sessions), the strength and power improvements are most parsimoniously explained by neural adaptations rather than morphological changes. This interpretation is supported by a substantial body of evidence demonstrating that the initial phase of strength training (first 2–4 weeks) is dominated by neural mechanisms, including increased motor unit recruitment, enhanced discharge rate, improved intermuscular coordination, and reduced antagonist co-activation [40].

ANT-I global mean reaction time was faster after the intervention without changes in error rate, confirming improved global processing speed without loss of accuracy — consistent with evidence linking physical fitness to faster cognitive processing [41–43]. This improvement occurred without significant change in aerobic capacity (VO_2max), consistent with evidence that cognitive benefits may be mediated not by cardiovascular adaptations but by neuromodulatory pathways mechanistically distinct from and temporally faster than aerobic structural changes [44]. Both resistance and aerobic exercise upregulate brain-derived neurotrophic factor (BDNF) and norepinephrine (NE) within days to weeks, promoting synaptic efficiency in frontoparietal circuits independently of cardiac output or oxygen-carrying capacity [41,44]. This timeline aligns with the concurrent strength gains, which over four weeks are predominantly neural — increased motor unit recruitment and synchronization rather than hypertrophy [42] — suggesting a shared neuroadaptive substrate. Moreover, the global RT reduction across all ANTI-Vea conditions, rather than a selective reduction in executive conflict cost, points to enhanced tonic alerting modulated by the NE–locus coeruleus axis, which responds to exercise at the neural level [45]. Short-duration mixed-training programs may thus produce cognitive benefits through neural pathways before aerobic adaptations become detectable, with practical relevance for occupational contexts prioritizing rapid cognitive improvement.

The temporal pattern of attentional performance also changed after training. Polynomial decomposition of the Block factor revealed that, in the PRE condition, ANT-I mean RT followed a significant linear trend, reflecting a progressive decline in reaction times from Block 1 to Block 6 that is consistent with the classical vigilance decrement, in which sustained attention deteriorates monotonically over time depending on physical effort duration and intensity [29,41,45–48]. In contrast, in the POST condition, the significant component was

quadratic, suggesting that instead of a constant decline, participants displayed initial improvement followed by partial recovery or stabilization at later blocks. Critically, the PRE–POST difference in the quadratic component was statistically significant.

A purely linear decline suggests progressive resource depletion without compensatory mechanisms, whereas a quadratic pattern with a late recovery component may reflect the engagement of compensatory attentional strategies or enhanced cognitive reserve that allows participants to partially counteract the decline in sustained attention.

No significant changes occurred in executive or arousal vigilance, consistent with our hypothesis that four weeks of predominantly physical training would leave these higher-order components unchanged. Sanchis et al. [29] showed that acute cycling and caffeine modulate executive and arousal vigilance through dissociable mechanisms, with moderate-intensity exercise improving only executive vigilance mean RT. The absence of vigilance changes here may reflect the different task condition — our static loaded condition (simulating firefighting equipment, no movement) versus cycling — which complicates direct comparison.

These findings carry several practical implications for preparing firefighter candidates and designing programs for fire-escape staircase tests. First, maximal strength and velocity-dependent power at submaximal loads are the strongest predictors of stair-climb performance, followed by sustained anaerobic power; practitioners should therefore prioritize maximal and explosive strength at task-relevant loads (approximating combined body mass and equipment weight), complemented by anaerobic endurance. Second, four weeks of heavy resistance training developed high-load strength and power but did not sufficiently target the lighter-load, velocity-dependent qualities most predictive of stair-climb time; future programs should incorporate ballistic and plyometric exercises at lighter loads to develop rate of force development and power at velocities matching the climbing pattern. Third, the improvement in processing speed and the shift in vigilance pattern suggest that intensive physical training may confer attentional benefits relevant to operational readiness, where sustained attention and rapid decision-making are critical.

Several methodological limitations should be acknowledged when interpreting the present findings. First, the single-group pre-post design without a control group precludes causal attribution of the observed changes exclusively to the training intervention. Second, the four-week intervention period, while ecologically relevant for firefighter exam preparation, limits the capacity to observe aerobic adaptations and morphological changes that typically require longer training durations. Third, participants' physical activity, dietary habits, sleep patterns, and other lifestyle factors outside the training program were not systematically monitored or controlled, introducing potential confounding variables.

Future research should address the limitations of the present study by employing randomized controlled designs with larger and more diverse samples, including female firefighters and individuals with varying levels of prior training experience.

CONCLUSIONS

Four weeks of intensive firefighter training produced a significant improvement in weighted stair-climb performance, alongside gains in high-load lower-body strength and power and sustained anaerobic capacity. Post-intervention stair-climb performance was predominantly explained by neuromuscular strength/power and anaerobic capacity. Attentional performance improved, with faster global reaction times and a shift in the vigilance decrement pattern from monotonic decline to a quadratic trajectory, suggesting enhanced attentional resilience.

Declarations

FUNDING DECLARATION

This research received no external funding.

Author Contribution

Conceptualization, C.S.; Methodology, C.S.; Formal analysis, C.S.; Investigation (data collection), C.S., J.M.M., J.B.M., D.N.M. and J.Z.; Writing – original draft, C.S.; Writing – review & editing, C.S., C.M., J.M.M., J.B.M., D.N.M. and J.Z.; Project administration and correspondence, C.M. All authors have read and agreed to the published version of the manuscript.

Data Availability

We have added a data availability statement at the end of the Data Analysis section, indicating that the datasets generated and analysed during the current study are available in an open-access repository. The datasets generated and analyzed during the current study are available in the OSF repository https://osf.io/tva8w/overview?view_only=83336222e030496e8d231fe3f7f88e2e

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49. ADDITIONAL INFORMATION
50. The authors declare no conflict of interest.

Figures

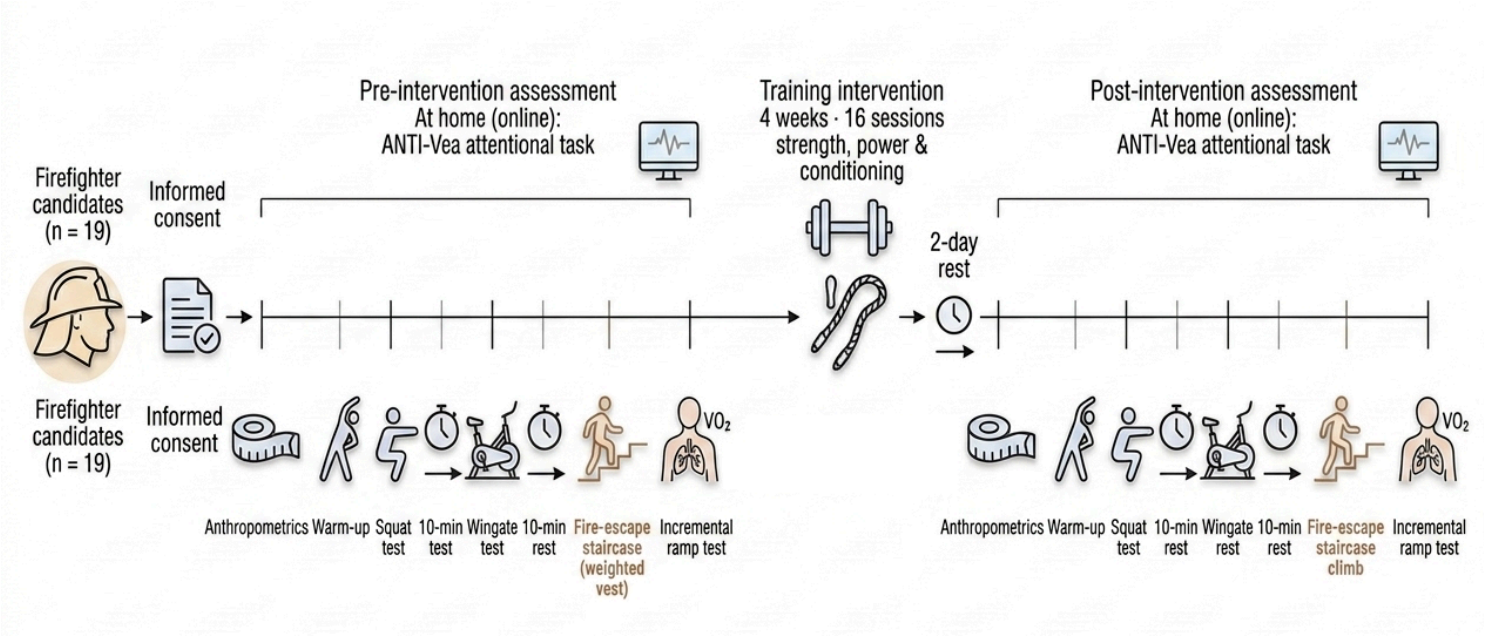


Figure 1

Study design and testing protocol. Schematic representation of the quasi-experimental, single-group, pre–post design, showing the sequence of baseline (pre) and follow-up (post) testing sessions relative to the four-week intensive firefighter training intervention.

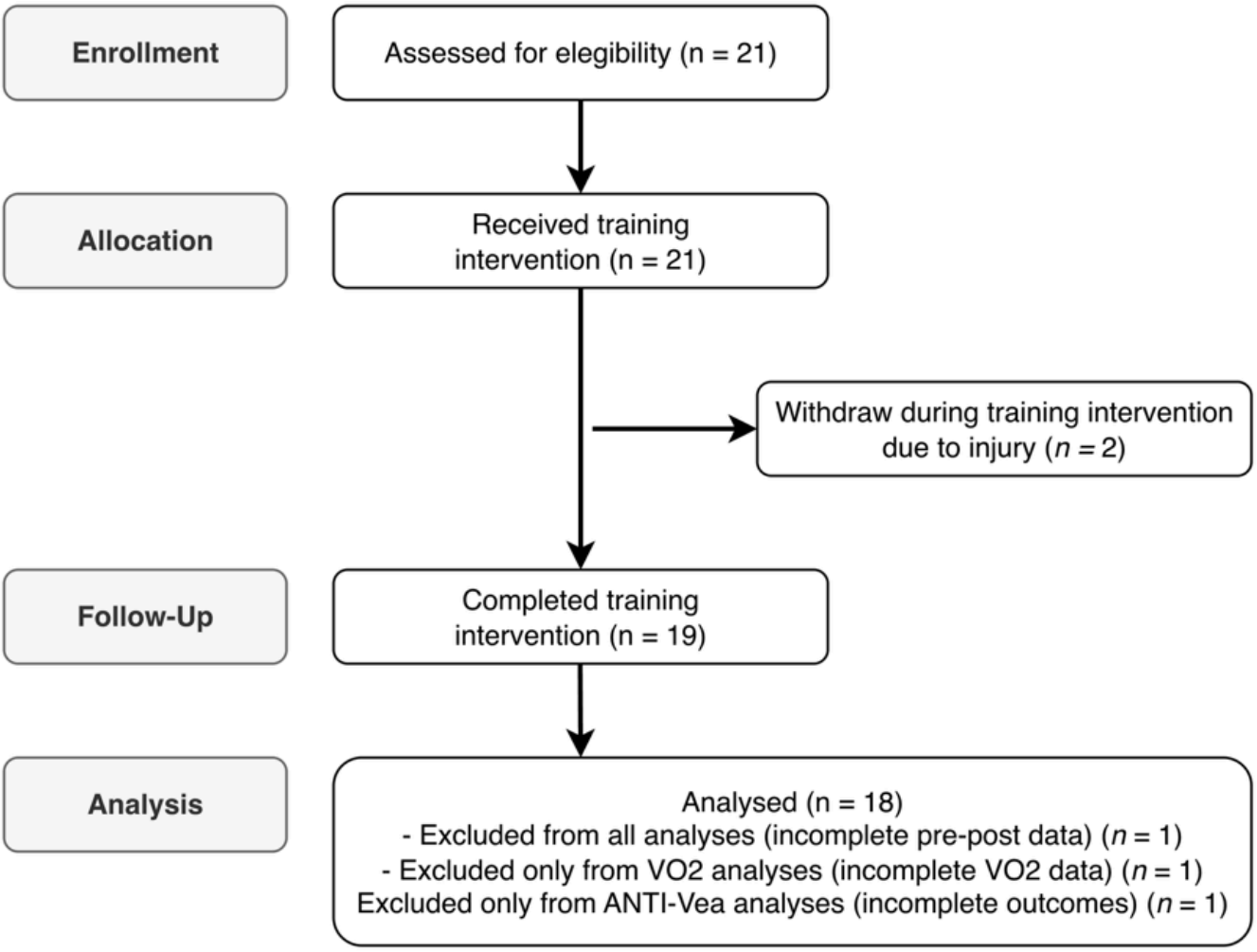


Figure 2

Participant flow through the study. CONSORT-style flow diagram showing the number of individuals assessed for eligibility, enrolled, allocated to the training intervention, and included in the final analysis, with reasons for exclusion or attrition indicated at each stage.

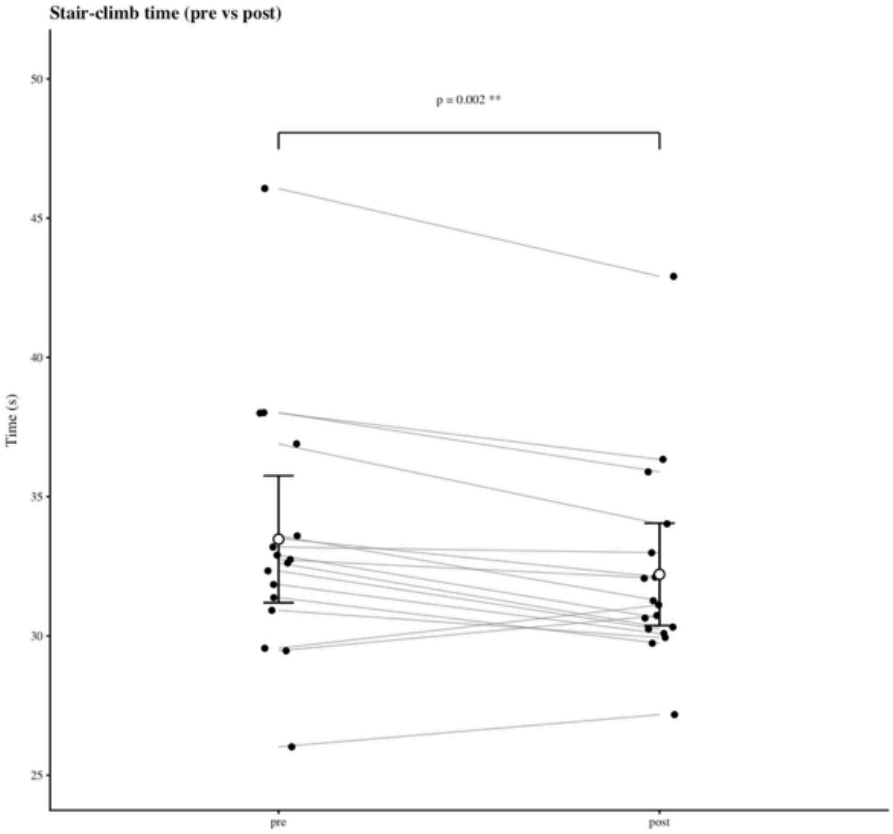


Figure 3

Effect of the training intervention on stair-climb performance. Individual stair-climb completion time before (pre) and after (post) the four-week training intervention. Thin grey lines connect data from the same participant across the two time points; open circles denote the group mean ± SD at each time point; the bracket and associated p-value indicate the significant time effect from the linear mixed-effects model.

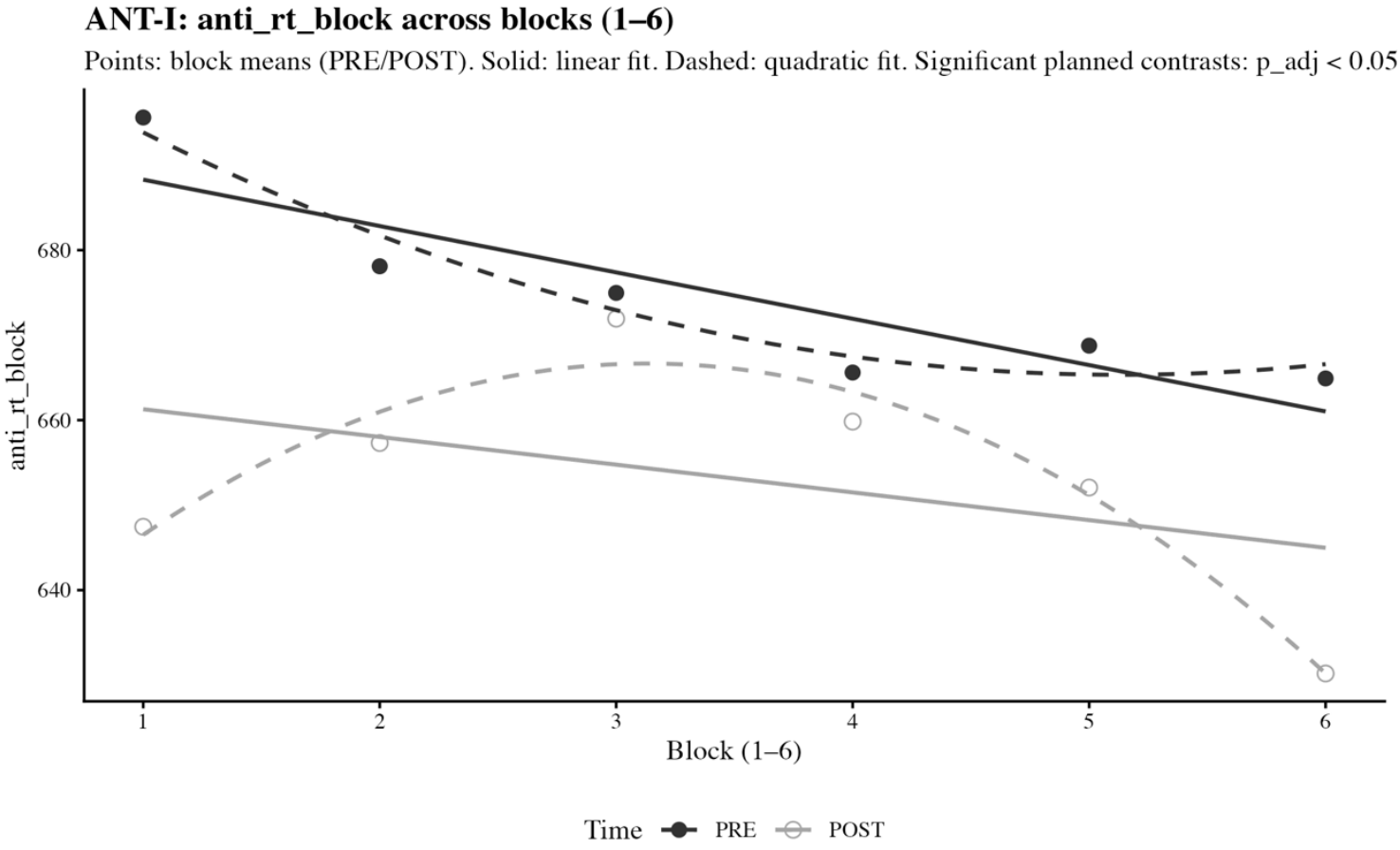


Figure 4

Effect of the training intervention on attentional reaction time. Reaction time on the ANT-I task across six consecutive task blocks, before (pre) and after (post) the intervention. X-axis, block number; y-axis, reaction time (ms). Brackets denote the significant linear and quadratic polynomial contrasts identified pre- and post-intervention.