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Effect of brain endurance training on maximal oxygen uptake, time-to-exhaustion, and inhibitory control in runners

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Effect of brain endurance training on maximal oxygen uptake, time-to-exhaustion, and
inhibitory control in runners

Running Head: Brain endurance training and running

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Abstract

We aimed to analyze the effect of brain endurance training on maximum oxygen consumption ($VO_{2\max}$), time-to-exhaustion, and inhibitory control in amateur trained runners. We employed a mixed experimental design, with the group as the between-participant factor and time as the within-participant factor. Forty-five participants attended 36 training sessions over twelve weeks. The cognitive training group (CT) performed the Stroop word-color task [trials of each type (congruent, incongruent, and neutral) were randomly presented during each training session], the endurance training group (ET) participated in a running training program (intensity was 60%Δ of maximal aerobic velocity and performed on a motor-driven treadmill), and the cognitive-endurance training group (CET) made cognitive and endurance training simultaneously over twelve weeks. The total time of each session (i.e., 20 to 40-min) was identical in the experimental groups. $VO_{2\max}$, time-to-exhaustion, and inhibitory control tests were measured before (baseline) and after (post-experiment) the 12-week intervention. A significant effect of interaction (group x time) for $VO_{2\max}$ ($p < 0.05$) was found. A post-hoc test showed an increase in $VO_{2\max}$ from baseline to post-experiment only for ET (Δ% = 2.98) and CET (Δ% = 3.78) groups ($p < 0.05$). Also, the analyses showed a significant interaction (group x time) for time-to-exhaustion ($p < 0.05$), and a post-hoc test revealed an improvement in time-to-exhaustion for ET (Δ% = 8.81) and CET (Δ% = 11.01) ($p < 0.05$). No group x time interaction was found for accuracy and response time in the inhibitory control task ($p > 0.05$). The results conclude that CET was not superior to ET for improving $VO_{2\max}$ and time-to-exhaustion. Also, the findings conclude that CET improved inhibitory control similar to CT.

Keywords: brain, endurance training, neuroscience, aerobic performance, cognitive effort.

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1. Introduction

It has been demonstrated that maximum oxygen consumption (VO_{2max}) is related to cardiovascular function.¹ Previous studies revealed that greater VO_{2max} increases tolerance to physical effort in time-to-exhaustion tests.²⁻⁴ The mean oxygen consumption performing a time-to-exhaustion task with 80% of maximal aerobic velocity represents physiologic demand of approximately 75% of VO_{2max} .⁵ However, endurance performance is also measured during time trials and tests with fixed intensity and duration, and the choice usually depends on the aim of the study. When the aim is to analyze the effect of an experimental intervention on decision-making based-to-effort or pace strategy, usually the test is a time trial.^{2,3,6} However, when the study's rationale is to analyze the effect of experimental manipulation on tolerance to physical effort, the frequently used test is time-to-exhaustion.^{5,7,8} It is important to highlight that considering the ecological validity, the most reliable test to analyze endurance performance could be the time trial.^{6,9} According to the psychobiological model, endurance performance is determined by central mechanisms.^{10,11} It is theoretically hypothesized that the corollary discharge in the motor control areas determines the perception of effort.¹² The perception of effort seems to have a crucial role in endurance performance. Thus, when individuals perceive a high perception of effort, they early disengage from the physical task.

Also, there is another scientific rationale to explain the perception of effort throughout the physical endurance tasks. According to a recent systematic review¹³, oxygenation of the prefrontal cortex (PFC) during prolonged physical tasks might play an important role in endurance performance decisions¹³, which are regulated by the perception of effort.¹² Previous findings revealed that elite Kenyan runners demonstrated higher PFC oxygenation during a 5-km time trial when compared to highly trained runners.¹⁴ So, it seems that high PFC oxygenation during prolonged physical tasks is related to the perception of effort. Also, recent scientific evidence provided a detailed overview of how cerebral oxygenation in the PFC responds to different endurance exercise intensities. For high-intensity or endurance tasks with a constant workload, for example, throughout a time-to-exhaustion physical task, the PFC oxygenation decreases until the total cessation of the physical task.¹³ Consequently, increased cerebral oxygenation in the PFC would improve endurance performance during physical exercise.

The high oxygenation of PFC during endurance physical tasks¹³ can be explained by increased inhibitory control, a cognitive process essential for self-regulation.¹⁵ PFC regulates inhibitory control¹⁶ and reduces the perception of effort during repeated and prolonged physical tasks.¹⁷ The findings of previous studies suggested a superior inhibitory control for subjects

with better whole-body endurance performance.⁶ Moreover, if we consider endurance competitions self-regulated tasks that require inhibiting aversive feelings,^{10,18} the urge to disengage and other negative feelings could be avoided by robust inhibitory control.¹⁹ Previous studies also showed impaired inhibitory control worsened performance throughout endurance tasks.^{20,21} In that sense, finding methods and training strategies to improve inhibitory control and, consequently, endurance performance seems crucial.

A large body of research found improved inhibitory control after endurance training for young adults.²² Also, a systematic review found increased inhibitory control after weeks of computer-based training.²³ Intriguingly, some studies observed that inhibitory control performance is improved during moderate-intensity exercises, which seems to occur in an inverted U shape with decreased performance in low- and high-intensity exercises.^{24,25} Also, inhibitory control performance during rest and exercise is not correlated,²⁶ indicating that inhibitory control training combined with exercise might generate different results than those training separately. The combined cognitive and physical endurance training may improve resilience to the adverse effects of mental fatigue on endurance performance. This statement could be supported by called “self-control training”,²⁷ which suggest that once increased inhibitory control, a people may improve the tolerance to prolonged physical task. Then, the combined training strategy (i.e., brain endurance training) could make the subjects more tolerant to endurance effort.

The combined endurance and computer-based training are called “Brain Endurance Training.” The Brain Endurance Training is based on the rationale that increasing the cognitive load of physical training makes subjects more resilient to mental fatigue and improves their endurance performance.⁷ It is a repeated exposure to the acute negative effects of mental fatigue throughout endurance task¹⁷ or cognitive training combined (simultaneously or separately) with physical endurance training.²⁸ Marcora et al.²⁹ tested the training strategy by comparing an endurance group that completed 12 weeks of cycle training and a brain endurance training group that completed a mentally demanding cognitive task with the cycle training. Both groups exhibited similar increases in VO_{2max} from pre- to post-experiment, presumably due to the same exercise volume. Notably, however, time-to-exhaustion (cycling at 75% of VO_{2max}) increased in the brain endurance training group compared to the control group, coupled with a reduced perceived exertion rating. Another recent scientific investigation also analyzed 6-weeks of brain endurance training.³⁰ Dallaway et al.³⁰ provided evidence supporting the efficacy of brain endurance training to improve endurance performance and work cognitive memory tasks. Barzegarpour et al.⁸ showed that combining the Brain Endurance Training and physical

endurance training instead of only physical endurance training increased performance in healthy volunteers who were physically active. These studies used handgrip tasks for endurance training³⁰ and cycling training⁸ with physically active young adults adopting concurrent Brain Endurance Training. More recently, another study used the same strategy but separately (i.e., endurance and cognitive training performed separately) within the training program. Staiano et al.²⁸ revealed that a combination of standard football training followed by cognitive training throughout four weeks was more effective in improving performance than standard training alone for elite football players.

The study's rationale is based on the psychobiological model of performance, which dictates the importance of the perception of effort for time-to-exhaustion and pacing. Then, considering that inhibitory control (i.e., regulated by PFC) plays a leading role in controlling levels of perception of effort during a physical task, combined training with physical and cognitive demands (i.e., treadmill with Stroop Task) might cause better adaptations.^{17,28,29} Thus, we aimed to analyze the effect of brain endurance training on $VO2_{max}$, time-to-exhaustion, and inhibitory control in amateur trained runners. We hypothesized that brain endurance training improves time-to-exhaustion (without changing $VO2_{max}$) and inhibitory control than cognitive or endurance interventions.

2. Materials and methods

2.1 Participants

We calculated sample size implied power for an analysis of variance (ANOVA) with repeated measures between factors. The sample size was estimated using G*Power software version 3.1.9.2 (Universität Kiel, Kiel, Germany) with power = 0.80, large ES [$\eta^2 = .15$ (Effect size $f = 0.42$)], considering findings of previous study,¹⁷ $\alpha = .05$, number of groups = 3, number of measurements = 2, correlation among repeated measures = 0.5, and nonsphericity correction = 1. Results indicated that forty-five subjects would be necessary for the study. Forty-five endurance-trained young men aged between 18 and 30 years old (age, 23.4 ± 2.9 years; body weight, 74.1 ± 8.0 kg, height, 174.5 ± 5.4 cm; 10 km time trial, 45.6 ± 5.9 min; $VO2_{max}$, 54.6 ± 6.2 ml/kg/min, data expressed in mean \pm SD) were recruited for the study.

The participants were randomly assigned to three parallel groups (see Table 1): cognitive training (CT, $n = 15$), endurance training (ET, $n = 15$), and cognitive and endurance training (CET, $n = 15$). The participants were randomized using a random number table, stratified for maximal oxygen uptake baseline (by a researcher not directly involved in the

recruitment and data collection). No statistical difference was found for age, body weight, height, 10-km time trial performance, and $VO_{2\max}$ between experimental groups at baseline.

As inclusion criteria, participants had to be free from neuromuscular and/or skeletal muscle injuries or disorders on the lower limbs, not use drugs or medications that could affect physical or cognitive performance, and have endurance training experience of at least two years. The average training experience of the participants was 4.7 ± 1.8 years. The study was conducted following the Declaration of Helsinki, and ethical approval was granted by the ethics committee of the local university. The subjects received written instructions describing all the procedures, risks, and benefits related to participation in the study and signed an informed consent form but were not informed about the study's objectives and hypotheses.

Table 1 insert here

2.2 Experimental design

We employed a mixed experimental design, with the group as the between-participant factor and time (baseline and post-experiment) as the within-participant factor. Participants attended 42 sessions over fourteen weeks, consisting of three baselines (week one), 36 training sessions (weeks two to eleven), and three visits post-experiment (week fourteen).

The CT performed the Stroop task, ET participated in a running training program, while CET performed cognitive and endurance simultaneous training over twelve weeks. The total time of each session (i.e., 20-min for training sessions in weeks 1 and 2; 25-min for training sessions in weeks 3 and 4; 30-min for training sessions in weeks 5 and 6; 35-min for training sessions in weeks 7 and 8; 35-min for training sessions in weeks 9 and 10; and 40-min for training sessions in weeks 11 and 12) was identical in all experimental training. Three weekly sessions were performed, separated by 48-h, totaling 36 sessions over twelve weeks.

Maximal oxygen uptake ($VO_{2\max}$), time-to-exhaustion (at 80% of maximal aerobic velocity), inhibitory control (i.e., Stroop task), and cognitive effort (i.e., diameter pupil) throughout time-to-exhaustion were measured before (baseline) and after (post-experiment) the 12-week intervention. An interval of 24-48 h was adopted between each test in both baseline and post-experiment measurements.

All experimental procedures are illustrated in Figure 1. The participants were asked to avoid any physical exercise, vigorous activity, and alcohol ingestion 24-h before experimental visits during the whole 14-week experiment and refrain from consuming caffeine at least 3-h before each training session. In addition, instructions were given to the participants to restrain performing other physical exercise programs and daily sleep at least 7 hours throughout the whole 14-week experiment. It was used checklists for all experimental visits on arrival at the lab.

Figure 1 insert here

2.3 Interventions

2.3.1 Cognitive training

The Stroop task was used for cognitive training. This task requires interference control. The Stroop task was chosen to facilitate comparison because it is the leading cognitive task used in previous studies to induce prolonged cognitive effort and causes mental fatigue in amateur endurance athletes.^{6,16} Each trial commenced with a 500 ms presentation of a fixation cross, followed by a blank screen that was presented for 1000 ms. Subsequently, one of four possible target stimuli was presented for maximally 2,000 ms or until the participant made a response, which ever came first. The target stimulus consisted of congruent, incongruent, or neutral stimuli. Congruent stimuli were either a word representing the same color and meaning (e.g., the word representing the color green printed in green). Incongruent stimuli consisted of the word representing a different color (e.g., red printed in green and green printed in red). Neutral stimuli consisted of the symbols ‘###,’ which were either printed in red or green. The participant had to indicate the color where the word or symbol string was printed as fast and accurately as possible by pressing F for green and J for red. A blank screen was presented after the target stimulus for a random duration between 600–1,200 ms, and the next trial started immediately after that. Each training session used 500 (~20-min) to 1,000 (~40-min) trials for the Stroop task. Trials of each type (congruent, incongruent, and neutral) were randomly presented during each training session. Every two weeks over 12-week intervention training increased 125 trials (~5-min) for each training session. The cognitive load was increased in order to maintain activities as a constant challenge. Previous studies revealed higher cognitive load when the time for cognitive interference control tasks was increased.^{31,32} During cognitive training, the participants received feedback on whether their performance was correct or not throughout all cognitive training sessions.

2.3.2 Endurance training

The endurance-training program was laboratory-based. Exercise intensity was 60%Δ of maximal aerobic velocity (V_{\max}) found at maximal incremental test during baseline visits and performed running on a motor-driven treadmill (model ATL, Inbramed, São Paulo, Brazil). All endurance training sessions were monitored with a heart rate monitor and a rating of perceived exertion each minute. Once there was a 10% reduction of HR and RPE throughout three consecutive training sessions, the velocity was increased by 2 to 5% for maintaining the intensity (60%Δ of $VO_{2\max}$) proposal. Each endurance training session lasted between 20-min to and ~40-min. Over 12-week intervention training was increased 5-min for each endurance training session every two weeks. The physical training load was increased to maintain the same time duration for the CT group.

2.3.3 Cognitive and endurance combined training

The CET group performed cognitive and endurance training simultaneously. The participants simultaneously performed the endurance training on a motor-driven treadmill (model ATL, Inbramed, São Paulo, Brazil) and Stroop word-color task. The same procedures utilized for CT and ET groups also were used for CET. The subjects should keep running intensity at the same workload throughout the Stroop word-color task. Two buttons were available for the stimulus's response on the 21 inches screen.

2.4 Measurements

2.4.1 Maximal oxygen uptake

The participants performed a maximal running incremental test on a motor-driven treadmill (model ATL, Inbramed, São Paulo, Brazil). Participants were also given standard instructions for the overall rating of perceived exertion (RPE) using the 10-point Borg scale.³³ Each participant was subsequently asked to rate their perceived effort at each minute during the test. After a 3-min warm-up at 9 km/h, the speed was increased by 1 km/h every 3 min until exhaustion. The participants received strong verbal encouragement to ensure the attainment of maximal values. Gas exchange was measured breath-by-breath using a gas analyzer (Cortex Metalyzer 3B, Cortex Biophysik, Leipzig, Germany) and subsequently averaged over 10-s intervals throughout the test. Before each test, the gas analyzer was calibrated according to the manufacturer's recommendations. $VO_{2\max}$ was determined when at least two criteria were met:

a respiratory exchange ratio greater than 1.1, a higher value of 9 at a 10-point Borg Scale, and a ± 10 bpm of the predicted maximal heart rate (i.e., $220 - \text{age}$).

The highest velocity achieved during the test was recorded as the maximal aerobic velocity (V_{max}). When the participants could not complete the entire last stage (<3 min), the V_{max} was calculated using fractional time supported in the last stage multiplied by the increment rate.

2.4.2 Time-to-exhaustion

Participants were positioned on the same treadmill used for the incremental exercise test. The constant velocity time-to-exhaustion test consisted of a 3-min warm-up at 50% of V_{max} followed by a rectangular workload corresponding to $80\% \Delta V_{\text{max}}$. Time to exhaustion was measured from the start of the rectangular workload until the point of volitional exhaustion (i.e., unable to sustain the exercise intensity). RPE was taken during the last 15-s of every minute throughout all time-to-exhaustion tests. Pupil diameter was recorded continually throughout the time-to-exhaustion test with a portable Eye Tracking-XG (Applied Science Laboratories, USA) equipment with a sampling frequency of 60 Hz.

2.4.3 Inhibitory control

The incongruent Stroop task was used to evaluate inhibitory control (PsychoPy v1.85.6, University of Nottingham, United Kingdom). We employed the Stroop task adopting 300 incongruent trials (one trial every 2,500 milliseconds). The task was performed in a silent and illuminated room, with the participants sitting comfortably on a chair in front of a 21 inches monitor wearing an earphone damper auditive to avoid noise distractions. In this task, four words (blue, yellow, red, and green) were presented in Arial font 60, once at a time, in random order, at the center of a computer screen (21 inches). The words were inked with the color blue, yellow, red, or green in an incongruent manner (e.g., word blue painted with red ink). Subjects were instructed to press a colored button on the computer keyboard corresponding to the correct response as quickly and accurately as possible. The word's ink determined the correct response. If the ink was blue, green, or yellow, subjects should press the button corresponding to the ink color (e.g., if the word "green" appeared inked in yellow, the button yellow should be pressed). If the ink color was red, the button that should be pressed was the button corresponding to the word's meaning, not the ink color (e.g., if the word "blue" appeared inked in red, the button blue should be pressed). Each word stayed on the screen until 2,500 ms or until subjects pressed any answer button. The test was paced with an interval of 1,000 ms between the response and

a new stimulus. The behavioral performance was measured as accuracy (%) and response time (ms) answers. Two sessions with at least 72-hours intervals were required to identify the Stroop task reliability values for all participants. The values found for accuracy and response time, respectively, were intraclass coefficient correlation (ICC) = 0.97 (CI_{95%} = 0.94 to 0.99) and ICC = 0.92 (CI_{95%} = 0.89 to 0.99).

2.4.4 Pupil diameter

Pupil diameter was recorded continually throughout time-to-exhaustion and Stroop color test with a portable Eye Tracking-XG (Applied Science Laboratories, USA) equipment with a sampling frequency of 60 Hz. The gaze position was calibrated before the initial task using a 3-point calibration. The raw data of each participant was extracted using the SMI BeGaze 3.2 software system (SMI, Berlin, Germany) to be further processed in RStudio software. A low-pass Butterworth filter (4 Hz) was applied to create a reliable signal profile. Then, the eye-tracker detected blinks, saccades events, artifacts, and outliers' values (mean \pm 2*SD) that were removed using a linear interpolation algorithm. We used pupil diameter to measure cognitive effort.³⁴ Pupils react to workload, which dilates when the mental workload increases.³⁴ We averaged the pupil diameter in the 500 ms before stimulus onset to measure resting pupil diameter. During this period, the participants saw a fixation cross with the same level of luminosity as the letters (i.e., Stroop color task) or screen in front of a treadmill (i.e., time-to-exhaustion), so there was no interference from eye reflexes to the environmental lighting. The stimulus-evoked pupil data was analyzed in RStudio software as we did with the resting pupil diameter. Resting pupil diameter and the mean pupil diameter peak activity for each time-on-task interval (i.e., mean each 30-seconds and 2-minutes during Stroop color task and time-to-exhaustion, respectively) were exported for further analysis. For time-to-exhaustion, the pupil diameter measures were used as a percentage of the overall time from the task.

2.4.5 Rating of perceived exertion (RPE)

It was monitored RPE throughout time-to-exhaustion using a CR-10 scale.³³ Specifically, the participants were instructed to provide their RPE every minute. Once we found within-and between-subjects differences for time-to-exhaustion, the RPE means were compared in an iso-work (i.e., the percentage for time-to-exhaustion). So, we compared RPE for 25, 50, 75, and 100% for time-to-exhaustion in baseline and post-experiment.

2.4.6 Internal training load

The session rating of perceived exertion (RPE-session) quantified the internal training load.³³ After 30 min of each training session, the participants answered the following question: “How was your training?”. The participant was asked to demonstrate the intensity perception of the session from the 10-point Borg scale (0 = rest to 10 = maximum effort), according to the method previously developed.³³ The product of the values demonstrated by the RPE scale and the total time in minutes of the training session was calculated, thus expressing the training session’s internal load in arbitrary units (A.U.). The weekly internal training load was obtained from daily internal training loads. The total internal training load of twelve weeks was calculated from the weekly internal training loads. Noteworthy, the participants were familiarized with the RPE-session method before the beginning of the investigation.

2.4.7 Mental demand

The mental demand subscale of the NASA-TLX scale quantified the mental demand of each session.³⁵ Immediately after each training session, the participants answered the mental demand subscale. The participant was asked to demonstrate the mental demand perception of the session from a 10-point scale (0 = rest to 10 = maximum mental demand).³⁵ The weekly mental demand was obtained from the sum of daily mental demand values. The mental demand of twelve weeks was calculated from the sum of mental demand. Noteworthy, the participants were familiarized with the mental demand subscale before the beginning of the investigation.

2.5 Statistical analysis

Data normality and variance equality were assessed through the Shapiro–Wilk and Levene tests, respectively. Data are presented as mean (SD). A two-way ANOVA with repeated measures was used to analyze a group (CT vs. ET vs. CET) x time (baseline vs. post-experiment) interaction for VO2_{máx}, time-to-exhaustion (performance, diameter pupil, and RPE), and inhibitory control (accuracy, response time, and diameter pupil), adopting group as between-factor, time as within-factor, and subjects as factor random. The post-hoc Bonferroni test was utilized to identify the localization of statistical differences. Partial eta squared (η^2) was used to determine the effect size (ES) and was interpreted using the following cutoff’s:³⁶ small effect, $\eta^2 < 0.03$; moderate effect, $0.03 \leq \eta^2 < 0.10$; large effect, $.10 \leq \eta^2 < 0.20$; very large effect, $\eta^2 \geq 0.20$. The Mauchly test assessed the sphericity assumption, and Greenhouse-Geiser correction was used when needed. Percentage change ($\Delta\%$) within-group for VO2_{máx}, time-to-exhaustion, and inhibitory control from baseline-to post-experiment was calculated as

follows: $\Delta\% = ([\text{post-pre}]/\text{pre}) * 100$. A mixed-model repeated-measures analysis was used to analyze a group (CT vs. ET vs. CET) x time (weeks 1-2 vs. weeks 3-4 vs. weeks 5-6 vs. weeks 7-8 vs. weeks 9-10 vs. weeks 11-12) interaction for internal training load and mental demand adopting group as between-factor, time as within-factor, and subjects as factor random. Also, the mixed-model repeated-measures analysis was used to analyze a group (CT vs. CET) x time (weeks 1-2 vs. weeks 3-4 vs. weeks 5-6 vs. weeks 7-8 vs. weeks 9-10 vs. weeks 11-12) interaction for response time [incongruent stimulus and stroop effect (mean for congruent stimulus minus mean for congruent stimulus)] of cognitive training, adopting group as between-factor, time as within-factor, and subjects as factor random. Similarly, a mixed-model repeated-measures analysis was used to analyze a group (ET vs. CET) x time (weeks 1-2 vs. weeks 3-4 vs. weeks 5-6 vs. weeks 7-8 vs. weeks 9-10 vs. weeks 11-12) interaction for mean velocity (km/h) and total distance performed (km) at endurance training, adopting group as a between-factor, time as a within-factor, and subjects as a random factor. The Tukey post-hoc test identified the statistical differences. Data were processed in the Statistical Package for Social Sciences Version 21.0 (IBM Corp., Armonk, NY, USA) and GraphPad Prism 9 (San Diego, CA, USA). A significance level of 5% was adopted.

3. Results

3.1 $VO2_{\text{máx}}$

There was a significant main effect of time for $VO2_{\text{máx}}$ [Figure 2; $F_{(1, 42)} = 25.49$; $p = 0.001$ ($CI_{95\%} = 0.001$ to 0.004); $\eta p^2 = 0.07$ ($CI_{95\%} = 0.05$ to 0.09); ES = moderate]. No main effect was found for group on $VO2_{\text{máx}}$ [$F_{(2, 42)} = 0.17$; $p = 0.84$ ($CI_{95\%} = 0.72$ to 0.93); $\eta p^2 = 0.01$ ($CI_{95\%} = 0.003$ to 0.02); ES = small]. There was a significant group x time interaction for $VO2_{\text{máx}}$ [$F_{(2, 42)} = 4.87$; $p = 0.01$ ($CI_{95\%} = 0.002$ to 0.03); $\eta p^2 = 0.09$ ($CI_{95\%} = 0.06$ to 0.17); ES = moderate]. Post-hoc test showed an increase in $VO2_{\text{máx}}$ from baseline (CT = 53.59 ± 4.33 ml/kg/min⁻¹; ET = 53.58 ± 5.07 ml/kg/min⁻¹; CET = 53.61 ± 4.26 ml/kg/min⁻¹) for post-experiment (CT = 53.78 ± 4.44 ml/kg/min⁻¹, $\Delta\% = 0.3$; ET = 55.18 ± 5.11 ml/kg/min⁻¹, $\Delta\% = 2.98$; CET = 55.64 ± 4.48 ml/kg/min⁻¹, $\Delta\% = 3.78$) only for ET and CET groups ($p < 0.05$).

3.2 Time-to-exhaustion

There was a significant main effect of time for time-to-exhaustion [Figure 2; $F_{(1, 42)} = 45.28$; $p = 0.001$ ($CI_{95\%} = 0.001$ to 0.004); $\eta p^2 = 0.15$ ($CI_{95\%} = 0.11$ to 0.22); ES = large]. There was found no main effect of group for time-to-exhaustion [$F_{(2, 42)} = 0.97$; $p = 0.38$ ($CI_{95\%} = 0.32$ to 0.53); $\eta p^2 = 0.01$ ($CI_{95\%} = 0.004$ to 0.02); ES = small]. There was a significant group x

time interaction for time-to-exhaustion [$F_{(2, 42)} = 19.08$; $p = 0.001$ ($CI_{95\%} = 0.001$ to 0.01); $\eta p^2 = 0.11$ ($CI_{95\%} = 0.08$ to 0.19); ES = large]. Post-hoc test showed an increase in time-to-exhaustion from baseline (CT = 45.66 ± 8.30 min; ET = 45.93 ± 8.89 min; CET = 47.20 ± 9.54 min) for post-experiment (CT = 45.20 ± 8.46 , $\Delta\% = 1.00$; ET = 49.80 ± 8.81 , $\Delta\% = 8.42$; CET = 52.40 ± 8.87 min, $\Delta\% = 11.01$) only for ET and CET groups ($p < 0.05$).

3.2.1 Pupil diameter

There was a significant main effect of time for diameter pupil throughout time-to-exhaustion [Figure 2; $F_{(1, 42)} = 4.83$; $p = 0.03$ ($CI_{95\%} = 0.01$ to 0.05); $\eta p^2 = 0.06$ ($CI_{95\%} = 0.03$ to 0.12); ES = moderate]. Follow-up tests showed difference in diameter pupil throughout time-to-exhaustion from baseline (CT = 0.80 ± 0.13 mm ; ET = 0.84 ± 0.08 mm; CET = 0.90 ± 0.12 mm) for post-experiment (CT = 0.88 ± 0.15 mm , $\Delta\% = 10.01$; ET = 0.91 ± 0.10 mm, $\Delta\% = 8.33$; CET = 0.94 ± 0.14 mm , $\Delta\% = 4.44$). There was no found a main effect of group for diameter pupil throughout time-to-exhaustion [$F_{(2, 42)} = 2.75$; $p = 0.08$ ($CI_{95\%} = 0.04$ to 0.13); $\eta p^2 = 0.02$ ($CI_{95\%} = 0.01$ to 0.05); ES = small]. Also, there was no found an group x time interaction for diameter pupil throughout time-to-exhaustion [$F_{(2, 42)} = 0.22$; $p = 0.80$ ($CI_{95\%} = 0.68$ to 0.87); $\eta p^2 = 0.01$ ($CI_{95\%} = 0.003$ to 0.02); ES = small].

Figure 2 insert here

3.3 Inhibitory control

3.3.1 Accuracy

There was a significant main effect of time for accuracy [Figure 3; $F_{(1, 42)} = 30.70$; $p = 0.001$ ($CI_{95\%} = 0.001$ to 0.02); $\eta p^2 = 0.09$ ($CI_{95\%} = 0.06$ to 0.18); ES = large]. Follow-up tests showed a difference in accuracy from baseline (CT = 94.93 ± 3.55 %; ET = 94.66 ± 3.61 %; CET = 93.86 ± 3.85 %) for post-experiment (CT = 96.80 ± 3.23 %, $\Delta\% = 1.96$; ET = 97.26 ± 3.17 %, $\Delta\% = 2.74$; CET = 97.73 ± 2.65 %, $\Delta\% = 4.12$) ($p < 0.05$). There was no found main effect of group for accuracy [$F_{(2, 42)} = 0.01$; $p = 0.98$ ($CI_{95\%} = 0.94$ to 0.99); $\eta p^2 = 0.004$ ($CI_{95\%} = 0.002$ to 0.01); ES = small]. Also, there was no found an group x time interaction for accuracy [$F_{(2, 42)} = 1.35$; $p = 0.26$ ($CI_{95\%} = 0.18$ to 0.39); $\eta p^2 = 0.004$ ($CI_{95\%} = 0.003$ to 0.02); ES = small].

3.3.2 Response time

There was a significant main effect of time for response time [Figure 3; $F_{(1, 42)} = 50.22$; $p = 0.001$ ($CI_{95\%} = 0.001$ to 0.02); $\eta p^2 = 0.12$ ($CI_{95\%} = 0.08$ to 0.19); ES = moderate]. Follow-up tests showed an difference in response time from baseline (CT = 588.80 ± 110.15 ms; ET = 580.88 ± 120.19 ms; CET = 604.46 ± 137.65 ms) for post-experiment (CT = 568.50 ± 104.45 ms, $\Delta\% = 3.44$; ET = 573.66 ± 116.17 ms, $\Delta\% = 1.24$; CET = 573.06 ± 140.29 ms, $\Delta\% = 5.19$) ($p < 0.05$). There was no found a main effect of group for response time [$F_{(2, 42)} = 0.02$; $p = 0.97$ ($CI_{95\%} = 0.87$ to 0.99); $\eta p^2 = 0.01$ ($CI_{95\%} = 0.003$ to 0.02); ES = small]. Also, there was no found an group x time interaction for response time [$F_{(2, 42)} = 1.63$; $p = 0.20$ ($CI_{95\%} = 0.13$ to 0.34); $\eta p^2 = 0.01$ ($CI_{95\%} = 0.003$ to 0.03); ES = small].

3.3.3 Pupil diameter

There was no found a main effect of time [Figure 3; $F_{(1, 42)} = 0.020$; $p = 0.88$ ($CI_{95\%} = 0.71$ to 0.95); $\eta p^2 = 0.003$ ($CI_{95\%} = 0.001$ to 0.01); ES = small], group [Figure 3; $F_{(1, 42)} = 0.89$; $p = 0.41$ ($CI_{95\%} = 0.27$ to 0.55); $\eta p^2 = 0.004$ ($CI_{95\%} = 0.003$ to 0.01); ES = small], neither a group x time interaction [Figure 3; $F_{(1, 42)} = 0.09$; $p = 0.91$ ($CI_{95\%} = 0.76$ to 0.96); $\eta p^2 = 0.003$ ($CI_{95\%} = 0.001$ to 0.004); ES = small] for pupil diameter throughout stroop color task. The values were similar from baseline (CT = 0.78 ± 0.14 mm; ET = 0.73 ± 0.18 mm; CET = 0.80 ± 0.16 mm) for post-experiment (CT = 0.79 ± 0.13 mm, $\Delta\% = 1.28$; ET = 0.73 ± 0.13 mm, $\Delta\% = 0.3$; CET = 0.79 ± 0.14 mm, $\Delta\% = 0.9$) for all experimental groups.

Figure 3 insert here

3.4 RPE

There was a significant main effect of time for RPE throughout time-to-exhaustion [Figure 4; $F_{(2.716, 114)} = 694.10$; $p = 0.001$ ($CI_{95\%} = 0.001$ to 0.002); $\eta p^2 = 0.54$ ($CI_{95\%} = 0.41$ to 0.62); ES = very large]. There was found a main effect of group for RPE throughout time-to-exhaustion [$F_{(2, 42)} = 29.71$; $p = 0.001$ ($CI_{95\%} = 0.001$ to 0.01); $\eta p^2 = 0.12$ ($CI_{95\%} = 0.07$ to 0.20); ES = large]. There was a significant group x time interaction for RPE throughout time-to-exhaustion [$F_{(6, 126)} = 4.25$; $p = 0.002$ ($CI_{95\%} = 0.001$ to 0.004); $\eta p^2 = 0.08$ ($CI_{95\%} = 0.04$ to 0.14); ES = moderate]. Follow-up tests showed an increase in RPE from 25% (Baseline: CT = 5.86 ± 0.63 a.u.; ET = 5.93 ± 0.59 a.u.; CET = 5.73 ± 0.59 ; Post-experiment: CT = 5.86 ± 0.51 a.u.; ET = 5.80 ± 0.56 a.u.; CET = 5.33 ± 0.49 a.u.) for 50% (Baseline: CT = 7.20 ± 0.56 a.u.; ET = 6.93 ± 0.45 a.u.; CET = 6.93 ± 0.47 a.u.; Post-experiment: CT = 7.40 ± 0.53 a.u.; ET = 7.06 ± 0.45 a.u.; CET = 6.06 ± 0.59 a.u.), from 50% for 75% (Baseline: CT = 8.73 ± 0.59 a.u.;

ET = 8.60 ± 0.51 a.u.; CET = 8.46 ± 0.52 a.u.; Post-experiment: CT = 8.93 ± 0.25 a.u. ; ET = 8.40 ± 0.63 a.u.; CET = 7.60 ± 0.51 a.u.), and from 75% for 100% time-exhaustion (Baseline: CT = 10.00 ± 0.0 a.u.; ET $10.0 = 0.0$ a.u. \pm ; CET = 9.88 ± 0.21 a.u.; Post-experiment: CT = 9.87 ± 0.35 a.u.; ET = 9.80 ± 0.41 a.u.; CET = 9.33 ± 0.48 a.u.) for all experimental groups ($p<0.05$). A post-hoc analysis revealed lower RPE for CET than other experimental groups during time-to-exhaustion in post-experiment ($p<0.05$).

Figure 4 insert here

3.5 Training program

3.5.1 Internal training load

A significant condition x time interaction effect was found for internal training load [Figure 5; $F_{(10, 210)} = 9.97, p = 0.001$]. The Tukey post-hoc test indicated an increase in internal training load from “weeks 1-2” until “weeks 7-8” ($p<0.05$). Also, the Tukey post-hoc test revealed an increase in internal training load from “weeks 7-8” for “weeks 11-12” ($p<0.05$). Moreover, a higher internal training load was found for CET and ET than the CT group ($p<0.05$). In addition, a higher internal training load was found for CET than ET group ($p<0.05$).

3.5.2 Mental demand

A significant condition x time interaction effect was found for mental demand [Figure 5; $F_{(10, 210)} = 10.88, p = 0.001$]. The Tukey post-hoc test indicated an increase at mental demand from “weeks 1-2” until “weeks 7-8” ($p<0.05$). Also, the Tukey post-hoc test revealed an increase in mental demand from “weeks 7-8” for “weeks 11-12” ($p<0.05$). Moreover, higher mental demand was found for CET and CT than the ET group ($p<0.05$). Still, higher mental demand was found for CET than CT group ($p<0.05$).

Figure 5 insert here

3.5.3 Cognitive training

A significant condition x time interaction effect was found for the response time of incongruent stimuli [Table 2; $F_{(5, 140)} = 2.36, p = 0.04$]. The Tukey post-hoc test indicated a decrease in response time of incongruent stimuli from “weeks 1-2” until “weeks 7-8” ($p<0.05$). Also, the Tukey post-hoc test revealed a decrease in response time of incongruent stimuli from

“weeks 7-8” for “weeks 11-12” ($p<0.05$). Moreover, a higher response time of incongruent stimuli was found for CET than the CT group ($p<0.05$).

A significant condition x time interaction effect was found for the Stroop effect [Table 2; $F_{(5, 140)} = 3.71, p = 0.02$]. The Tukey post-hoc test indicated a decrease in the Stroop effect from “weeks 1-2” until “weeks 5-6” ($p<0.05$). Also, the Tukey post-hoc test revealed a decrease in the Stroop effect from “weeks 7-8” for “weeks 11-12” ($p<0.05$). Still, a lower Stroop effect was found for CET when compared to the CT group ($p<0.05$).

3.5.4 Endurance training

There was found a significant main effect of time for mean velocity [Table 2; $F_{(6, 168)} = 241.8, p = 0.001$]. The Tukey post-hoc test indicated an increase in mean velocity from “weeks 1-2” until “weeks 11-12” ($p<0.05$). However, no main effect of the group was found for mean velocity [$F_{(1, 28)} = 0.70, p = 0.82$]. Also, no group x time interaction was found for mean velocity [$F_{(5, 140)} = 0.84, p = 0.37$].

There was found a significant main effect of time for total distance performed [Table 1; $F_{(6, 168)} = 371.62, p = 0.001$]. The Tukey post-hoc test indicated an increase in total distance performed from “weeks 1-2” until “weeks 11-12” ($p<0.05$). However, no main effect of group was found for total distance performed [$F_{(1, 28)} = 0.03, p = 0.97$]. Also, no group x time interaction was found for total distance performed [$F_{(5, 140)} = 0.55, p = 0.73$].

Table 2 insert here

4. Discussion

The objective of this study was to analyze the effect of brain endurance training on $VO_{2\max}$, time-to-exhaustion, and inhibitory control in amateur trained runners. The main findings indicated an improvement of $VO_{2\max}$ and time-to-exhaustion only for ET and CET groups, while the inhibitory control was improved in the three groups after the twelve-week investigation. These results partially corroborate the initial hypothesis.

The improvement in $VO_{2\max}$ for ET and CET groups after the twelve-week corroborates previous studies that found changes in $VO_{2\max}$ after whole-body endurance training.^{37,38} The $VO_{2\max}$ may be improved by adopting a progressive workload in an endurance training program. In the present study, the workload was increased every two weeks (i.e., more 5-min of training), which explains the improvement in $VO_{2\max}$ in ET and CET groups. However, the $VO_{2\max}$ remained similar for the CT group following the intervention. It seems that interference

with cognitive training does not affect aerobic fitness,³⁹ and it is dependent only on endurance training.

The findings demonstrated an increase only for ET and CET experimental groups about time-to-exhaustion. Both experimental groups performed the same external endurance training load [i.e., velocity (60% Vmax) and total distance performed (volume)] throughout the twelve-week training program. However, the ET improved 8.8 %, while CET increased 11.0 % for time-to-exhaustion. Although there was no difference in time-to-exhaustion between ET and CET, it is essential to highlight that the improvement magnitude was higher for the CET than for the ET group. Previous studies also found higher tolerance to prolonged endurance tasks for the brain endurance training group than the control (i.e., only ET) group in physically active subjects^{29,30} or professional athletes.²⁸ There are differences in methods of brain endurance training utilized between the previous studies and the present research, which could explain the lack of statistical difference between ET and CET experimental groups. Previous studies applied between four and six weeks^{17,28,40} to analyze the effects of Brain Endurance Training on endurance performance while the present study applied twelve weeks. Thus, Brain Endurance Training could have a ceiling effect on endurance performance after a few weeks. However, a seminal study about brain endurance training also applied twelve weeks to analyze the effects of Brain Endurance Training on endurance performance. Marcora et al.⁴¹ found better time-to-exhaustion for brain endurance training than the control group. Although it is different finding from the present study, Marcora et al.⁴¹ used only one cognitive task throughout the brain endurance training program. It is currently unknown how effective additional cognitive load during endurance training will be beneficial. The divergent results on time-to-exhaustion between the present investigation and Marcora et al.'s²⁹ study could be explained by the whole-body endurance task or the participant's characteristics. In Marcora et al.'s study, healthy male volunteers performed cycling combined with a cognitive task (AX-CPT during 60-min) while trained amateur runners were participants in the present study. The previous scientific literature suggests that the less trained, the greater the improvement for endurance performance^{42,43}, which could explain the positive results from the Marcora et al.²⁹ study. In addition, the previous scientific investigations used a varied and progressive cognitive training load, while the present study adopted only a progressive cognitive training load (i.e., 20 to 40-min with only a Stroop word-color task). For example, Staiano et al.²⁸ submitted to a cognitive task male professional football players for 20 to 30-min immediately following the last daily physical training session throughout 4-weeks using three different inhibitory control tasks (i.e., flanker task, go/no-go task, and AX-continuous performance test). Dallaway et al.,¹⁷

submitted healthy college students to two different cognitive tasks throughout six weeks for approximately 10-min in each session (i.e., Stroop word-color task and 2-back memory task) simultaneously to endurance task with handgrip. Dallaway et al.⁴⁰ submitted healthy undergraduate students to two different computer-based cognitive tasks (2-back and stroop task) prior to physical training sessions per five weeks. Dallaway et al.⁴⁰ also suggested increasing the difficulty of the cognitive tasks used within brain endurance training as each week progressed in addition to using a variety of tasks that could require different executive processes. So, considering the differences in methods of brain endurance training for previous studies, it is possible that the cognitive training program for CET in the present investigation was not challenging enough and could present potential learning and adaptation effects of the Stroop task.

Despite the methodological differences between previous studies and the present investigation, it is reasonable to say that repeated brain endurance training causes higher mental demand and internal training load than alone endurance training, as found in the present study. It is important to note that the internal training load might also increase when there is a high cognitive load during physical training.^{16,44} So, perhaps the high mental demand from repeated Brain Endurance Training could make the recreational or amateur endurance athlete more tolerant of prolonged physical effort.

The time-to-exhaustion or tolerance-to-exertion involves cognitive effort because of cognitive resources to perform the physical task. Thus, an increase in cognitive effort during a physical task can improve physical performance. It was found that all experimental groups increased pupil diameter during the time-to-exhaustion task (i.e., an indicator for cognitive effort) after a twelve-week investigation. However, the increased cognitive effort exerted improved for time-to-exhaustion only for ET and CET groups. An explanation about findings of time-to-exhaustion for CT could be the mental demand found throughout the twelve-week training program. The cognitive training utilizing inhibitory control in computer-task (i.e., Stroop word-color task) seems to recruit the frontal brain areas, especially the anterior cingulate cortex (ACC) and prefrontal cortex (PFC).³² The ACC and PFC are considered brain areas with important roles throughout endurance task⁴² because they control decision-making based-to-effort and perceptual responses as RPE.^{13,40} High mental demand for training sessions in the CT group would increase the cognitive effort for an endurance task performed. The present study revealed higher mental demand for CT than ET group, which would explain the maintenance of time-to-exhaustion performance for CT after twelve-week.

The time-to-exhaustion performance also involves tolerance to physical effort.⁵ The effort-based decision is made when the perception of effort is maximal, and the continuation of the endurance task seems impossible.⁷ The increase of tolerance to physical effort shows reduced RPE throughout the physical task for the same constant workload.²⁹ The present investigation found lower RPE throughout time-to-exhaustion in post-experiment only for the CET group. So, the time-to-exhaustion task was performed with lower perceived effort for CET than other experimental groups. A possible explanation for this finding is the increased inhibitory control found for the CET group after twelve weeks of training. The higher inhibitory control has a relationship with lower RPE throughout prolonged endurance tasks.⁶ Another explanation for the lower perceived effort for CET than other experimental groups could be the internal training load throughout the training program. The findings demonstrated a higher internal training load for CET than other experimental groups. So, the internal training load throughout twelve weeks perhaps has allowed the participants of the CET group to become more tolerant to the physical effort, although it was not found a statistical difference in time-to-exhaustion performance utilizing 80% Vmax. It is essential to highlight that the time-to-exhaustion task was performed using an intensity higher (i.e., 80% Vmax) than the intensity trained (i.e., 60% Vmax) throughout the twelve-week experiment. It was decided to use a higher intensity in the time-to-exhaustion task than the intensity used during training because the task's duration, adopting an intensity of 60% Vmax, could be too long. However, a different result could have been revealed if time-to-exhaustion had been performed with 60% Vmax. It is recommended that future researchers investigate this.

The results showed improvement for all experimental groups without difference between them regarding inhibitory control. A recent meta-analysis found improved inhibitory control after at least four-week computerized cognitive training interventions.^{23,45} More specifically, a meta-analysis also showed a small-to-moderate effect of computer-based cognitive training on inhibitory control in young subjects.²³ So, it is reasonable to assume that computer-based cognitive training utilizing interference cognitive control tasks for at least four weeks can improve inhibitory control in healthy adults. The CT and CET experimental groups performed the same cognitive training (i.e., interference control training) for twelve weeks, explaining these findings for both groups. However, the response time for incongruent stimuli was slower for CET when compared to the CT group throughout cognitive training. These findings can be explained by dual-task performance (i.e., endurance and cognitive training) for the CET group. Previous studies also revealed slower response time for executive function computer-task when participants performed dual-task,^{46,47} corroborating the results of the

present study. Another difference between CT and CET groups throughout cognitive training was the Stroop effect. The findings indicated a higher Stroop effect for CT than the CET group. It seems that endurance exercise with moderate intensity (i.e., 60% Vmax) could increase brain catecholamines release,⁴⁸ which would improve the cognitive performance of runners. Then, the lower Stroop effect for CET than the CT group throughout the twelve-week training program could be explained by mechanisms behind endurance exercise.

Regarding inhibitory control for ET, the findings also showed an improvement after the twelve-week experiment. Previous findings also found improved inhibitory control after an endurance exercise program.²² One possible neurobiological mechanism underlying the positive effects of endurance training is the increased synthesis and release of neurotransmitters and neurotrophins, resulting in neurogenesis, angiogenesis, and neuroplasticity.⁴⁹

The improvement of inhibitory control for all experimental groups was not explained by cognitive effort (i.e., pupil diameter) because the pupil diameter remained similar from baseline-to post-experiment in the Stroop task. It was found improved inhibitory control without changes in the number of cognitive resources for performing Stroop tasks in all experimental groups. Regardless of the brain mechanisms, it is important to improve inhibitory control, especially in young adults, because this executive function is utilized for daily activities. Inhibition is a key part of the executive function and is related to successful task performance.¹⁵ It enables individuals to control their attention, behavior, thoughts, and emotions.¹⁵

Although the present study presents important findings, some limitations should be mentioned. It was not analyzed cardiorespiratory measures in the time-to-exhaustion task. Only one constant workload was used for time-to-exhaustion (i.e., 80% Vmax). In the Stroop task, the inhibitory control task did not utilize oxygenation measure over the PFC. Also, only male-trained runners participated in this study, making the generalization impossible for female or untrained subjects. In addition, there was no measured motivation throughout training sessions for this investigation, which could be considered a major limitation of the present study. A control group could not be added to the study, which might be considered another limitation. Finally, another limitation of the present study could be the lack of variation for cognitive tasks within the cognitive training program, in which the participants would have to exert additional self-control if the Stroop learning effects have occurred. The participants of the present study did the Stroop task for 12 weeks, so they could easily have adapted to the task's demands, reversing the inhibition effect and resulting in a lack of 'brain endurance training' stimulus. Then, the results should be interpreted with caution.

5. Perspective

The results conclude that concurrent brain endurance training was not superior to ET just for improvement VO_{2max} and time-to-exhaustion but showed reduced RPE throughout time-to-exhaustion tasks. Also, the findings enable concluding that concurrent brain endurance training improved inhibitory control similar to CT just. From the practical standpoint, the findings from the present study demonstrate that repeated concurrent brain endurance training is a training approach that can make an endurance task have lower perceived effort. However, it does not improve the tolerance to prolonged physical effort compared to endurance training alone in amateur runners. Also, from a practical standpoint, repeated concurrent Brain Endurance Training could be considered time-efficient because it takes less time in each training session to improve inhibitory control and endurance performance compared to endurance and cognitive training separately.

Athletic coaches can prescribe repeated concurrent brain endurance training utilizing only 30-min per session instead 30-min for each type of training (e.g., 30-min for endurance and 30-min for cognitive training) once the present study revealed high mental demand and internal training load for the CET group throughout twelve-weeks training. However, it is suggested that coaches apply different cognitive tasks within the brain endurance training program to avoid potential learning and adaptation effects.

6. References

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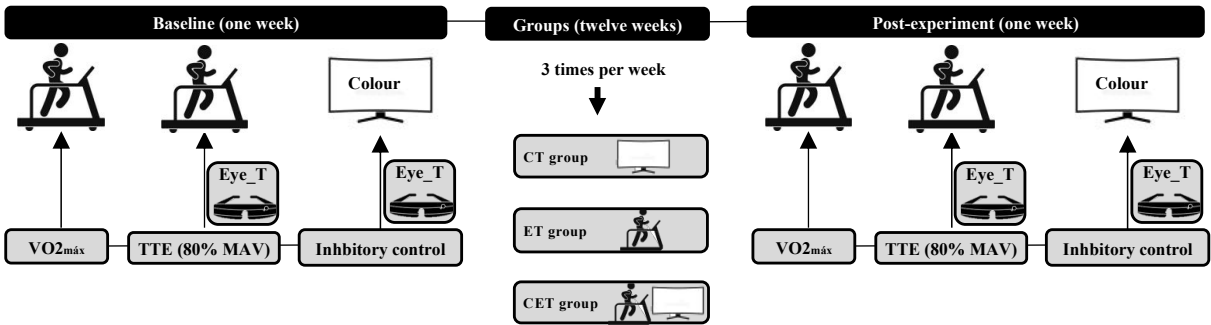


Figure 1. Experimental design of study.
Note. VO_{2max} = Maximal oxygen uptake; TTE = time-to-exhaustion; MAV = maximal aerobic velocity; Eye_T = Eye-tracker (cognitive effort); CT = cognitive training; ET = Endurance training; CET = cognitive endurance training.

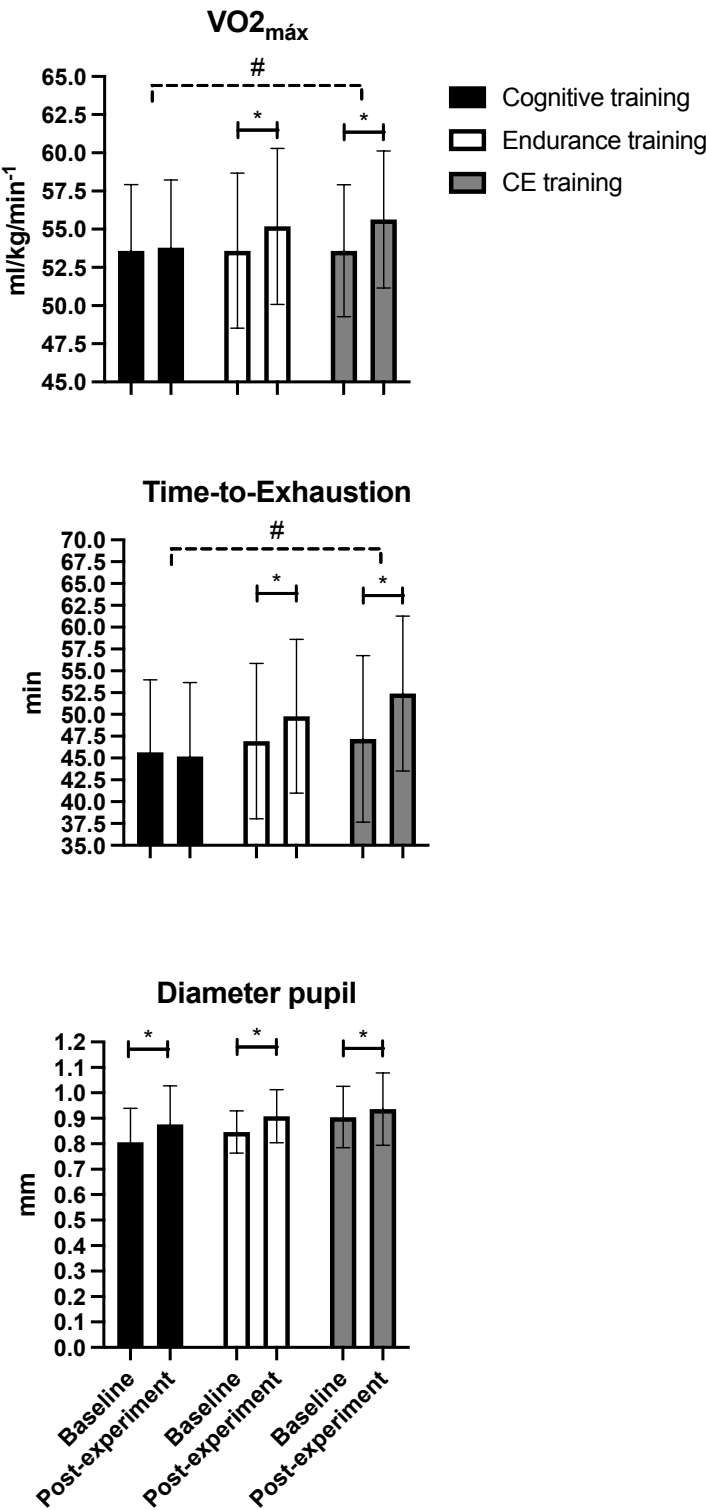


Figure 2. Maximal oxygen uptake, time-to-exhaustion, and pupil diameter according to group (CT, ET, and CET) and time (baseline and post-experiment).
Note. VO2_{máx} = maximal oxygen uptake; **p*<0.05 difference baseline-vs. post-experiment within-group; #*p*<0.05 a significant time x group interaction effect.

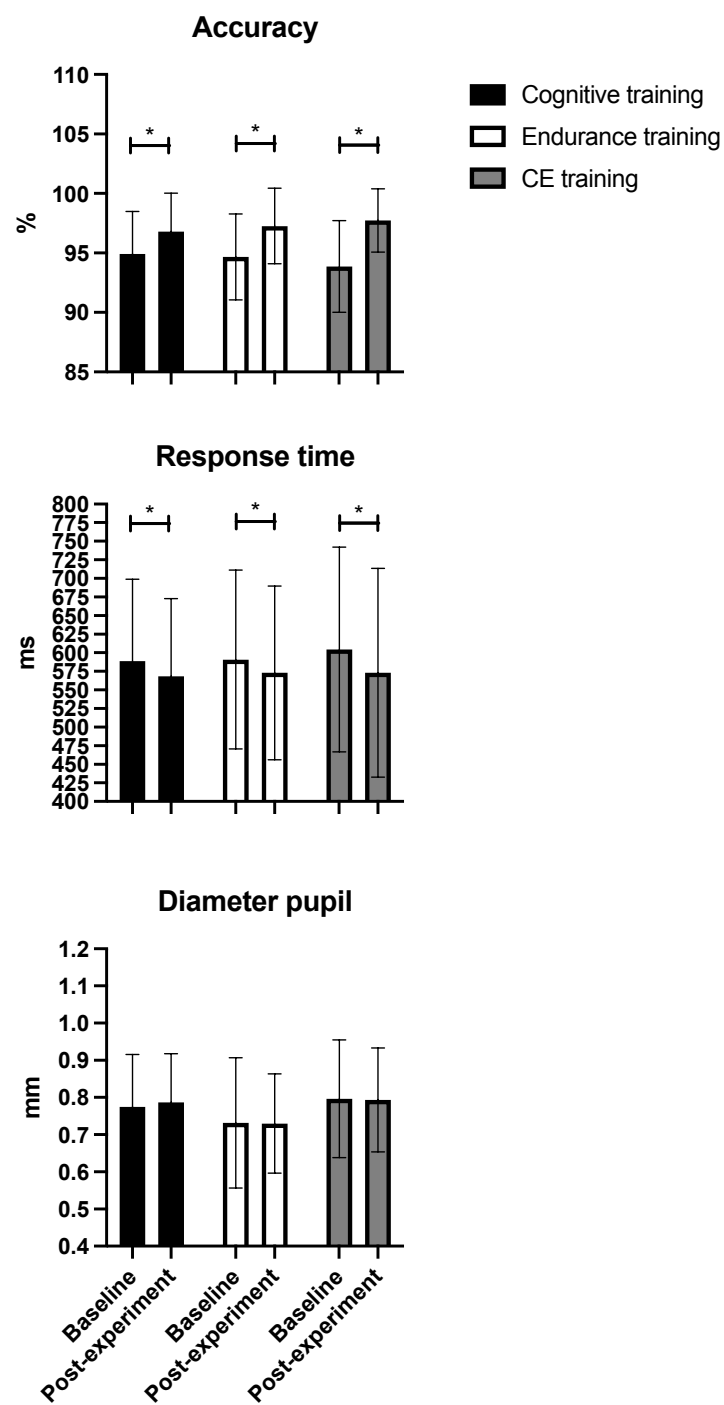


Figure 3. Stroop task (accuracy and response time) and diameter pupil according to group (CT, ET, and CET) and time (baseline and post-experiment).
Note. * $p < 0.05$ difference baseline-vs. post-experiment within-group.

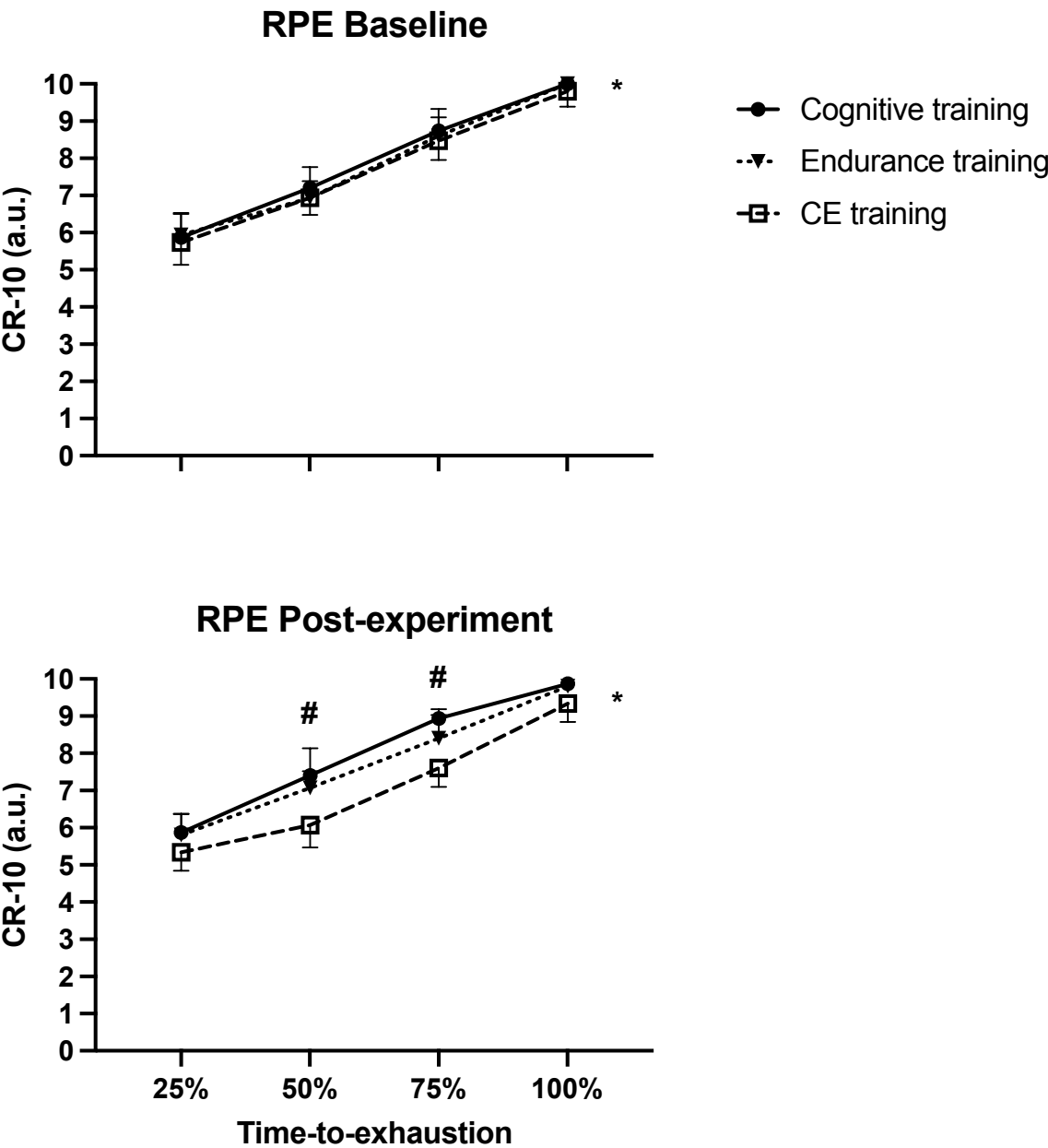


Figure 4. Rating perceived exertion and time-to-exhaustion according to group (CT, ET, and CET) and time (baseline and post-experiment).
Note. RPE = rated perceived exertion; * $p<0.05$ a main time effect; # $p<0.05$ a significant difference between-groups.

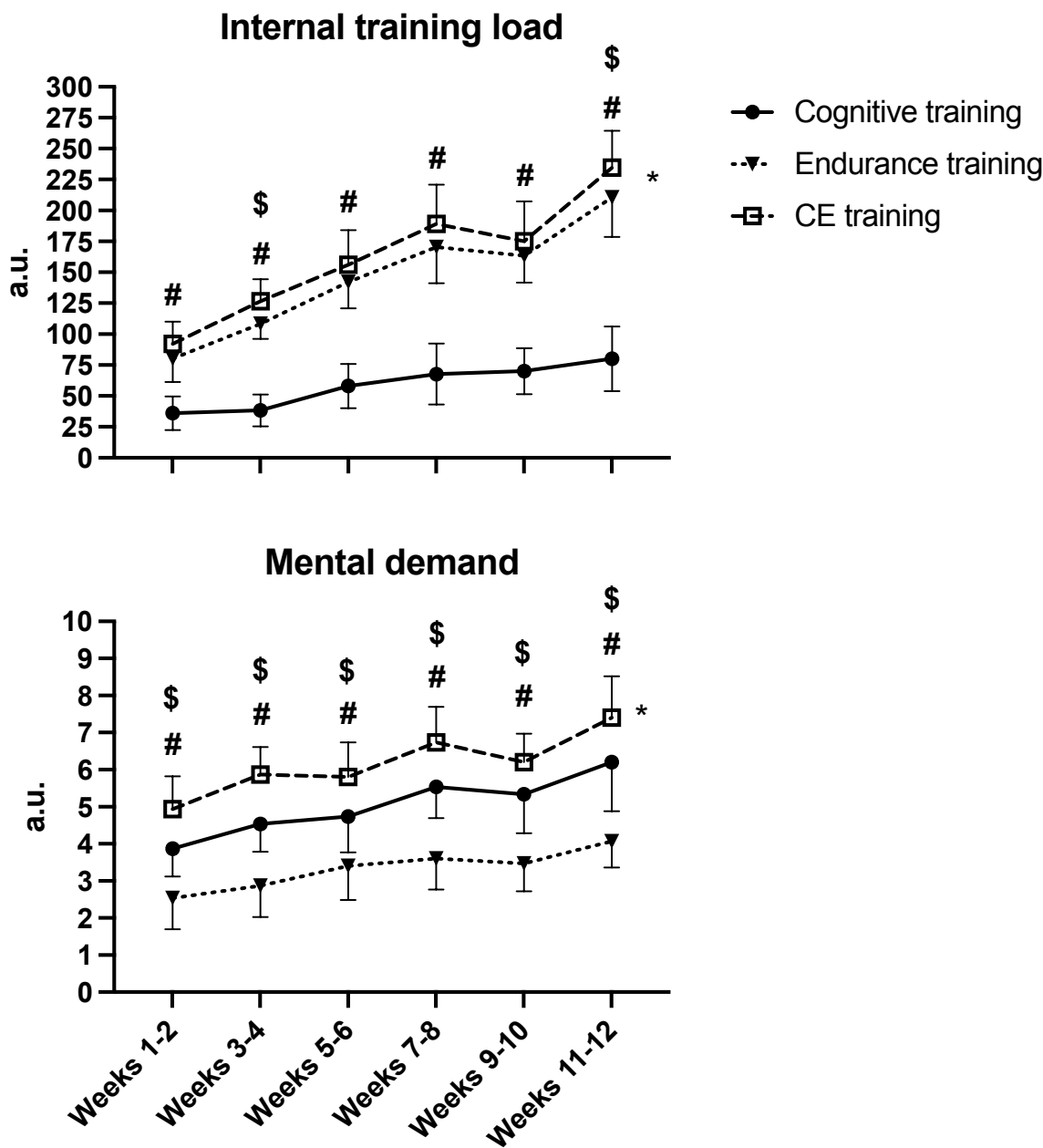


Figure 5. Internal training load and mental demand according to group (CT, ET, and CET) and time (weeks).
Note. a.u. = arbitrary units; CE = Cognitive and Endurance; * $p<0.05$ a main time effect; # $p<0.05$ a significant difference of Endurance Training group and CET group for Cognitive Training Group; $p<0.05$ a significant difference between Endurance Training group and Cognitive and Endurance Training group.

Table 1. Demographic data according to parallel groups.

Group	CT	ET	CET
Number of participants	15	15	15
Age (years)	23.2 ± 2.7	23.7 ± 2.5	23.2 ± 2.9
Body weight (kg)	73.8 ± 7.7	74.4 ± 8.2	74.0 ± 8.3
Height (cm)	173.8 ± 5.9	174.6 ± 5.5	174.9 ± 5.8
10-km time trial (min)	45.1 ± 6.3	45.7 ± 6.6	45.3 ± 6.2
VO ₂ _{máx} (ml/kg/min)	54.5 ± 6.4	54.7 ± 6.0	54.3 ± 6.3

Note. CT = Cognitive training group; ET = Endurance training group; CET = Cognitive and Endurance training group; VO₂_{máx} = maximum oxygen uptake.

Table 2. Cognitive (response time of incongruent stimulus and stroop effect) and endurance training (mean velocity and total distance) according to experimental group and weeks.

Group	CT	ET	CET
Cognitive training			
<i>Response time incongruent stimulus (ms)</i>			
Weeks 1-2 [#]	729.8 ± 106.2	-	758.5 ± 111.8
Weeks 3-4 [#]	723.2 ± 104.8*	-	748.9 ± 110.6*
Weeks 5-6	718.0 ± 107.3*	-	734.2 ± 108.2**
Weeks 7-8 [#]	717.8 ± 102.6***	-	738.2 ± 99.1*
Weeks 9-10	715.1 ± 105.7**	-	733.1 ± 107.4**
Weeks 11-12	715.6 ± 105.3**	-	733.6 ± 110.9**
<i>Stroop effect (%)</i>			
Weeks 1-2 [#]	37.0 ± 7.4	-	30.3 ± 7.3
Weeks 3-4 [#]	37.0 ± 7.9	-	29.5 ± 7.9*
Weeks 5-6 [#]	36.1 ± 7.8**	-	26.7 ± 7.2**
Weeks 7-8 [#]	36.4 ± 6.4*	-	27.7 ± 7.3**
Weeks 9-10 [#]	36.4 ± 7.2	-	26.8 ± 7.2**
Weeks 11-12 [#]	36.9 ± 7.6	-	26.7 ± 7.8**
Endurance training			
<i>Mean velocity (km/h)</i>			
Weeks 1-2	-	10.3 ± 1.2	10.3 ± 1.0
Weeks 3-4	-	10.5 ± 1.2	10.4 ± 1.0
Weeks 5-6	-	10.6 ± 1.2*	10.6 ± 1.0*
Weeks 7-8	-	10.7 ± 1.2**	10.7 ± 0.9**
Weeks 9-10	-	10.8 ± 1.3**	10.8 ± 1.0**
Weeks 11-12	-	10.9 ± 1.2***	11.0 ± 0.9****
<i>Total distance performed (km)</i>			
Weeks 1-2	-	18.6 ± 2.3	18.5 ± 1.9
Weeks 3-4	-	26.2 ± 3.1*	26.0 ± 2.5*
Weeks 5-6	-	31.8 ± 3.7**	31.8 ± 3.0**
Weeks 7-8	-	37.4 ± 4.3***	37.5 ± 3.3***
Weeks 9-10	-	37.7 ± 4.5***	37.8 ± 3.4***
Weeks 11-12	-	43.4 ± 5.0****	43.8 ± 3.7****

Note. CT = Cognitive training group; ET = Endurance training group; CET = Cognitive and Endurance training group; **p*<0.05 a significant difference for Weeks 1-2 for within-group; ***p*<0.05 a significant difference for Weeks 3-4 for within-group; ****p*<0.05 a significant difference for Weeks 5-6 for within-group; *****p*<0.05 a significant difference for Weeks 7-8 for within-group; [#]*p*<0.05 a significant difference between experimental groups.