



Acute effect of three different exercise training modalities on executive function in overweight inactive men: A secondary analysis of the BrainFit study



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ABSTRACT

There is currently a consensus about the positive effects of physical exercise on cognition. However, the exercise intensity-dependent effect on executive function remains unclear. Thus, the aim of this study was to compare the acute effects of high-intensity aerobic interval training (HIIT), progressive resistance training (PRT), or combined training (PRT + HIIT) on executive function indicators in overweight inactive adult men (aged 18–30 years old). The participants were screened and excluded for medical conditions known to impact cognitive functioning, which was measured with the Montreal Cognitive Assessment (MoCA) screening cognitive test. A randomised, parallel-group clinical trial was conducted among 36 adults who were randomly assigned to a HIIT (n = 12), PRT (n = 7), PRT + HIIT (n = 7), or control group (n = 10) until the energy expenditure of 400–500 kcal. Cognitive inhibition and attention capacity were examined using the Stroop test and d2 test of attention, respectively, and were obtained pre-exercise for baseline measurement and 1 min post-exercise for each exercise training modality. Cognitive inhibition measured by the Stroop test was improved after the HIIT protocol for the domains of reading by +5.89 ($\eta^2 = 0.33$), colour naming +9.0 ($\eta^2 = 0.60$), interference +10.1 ($\eta^2 = 0.39$), and index interference +6.0 ($\eta^2 = 0.20$). Additionally, the PRT + HIIT group had an increase for the reading condition of +7.1 ($\eta^2 = 0.40$), colour naming +7.5 ($\eta^2 = 0.80$), and interference +5.8 ($\eta^2 = 0.39$). In regard to attentional capacity, the HIIT group elicited small to medium improvements in the concentration level domain of +21.7 ($\eta^2 = 0.44$), total performance domain +56.6 ($\eta^2 = 0.50$), and consistency domain –3.0 ($\eta^2 = 0.27$). These results were similar in the PRT and PRT + HIIT groups in the concentration level and items-processed domains ($P < 0.05$). In conclusion, acute HIIT and PRT + HIIT sessions reported important effect sizes than PRT alone for cognitive inhibition and attention capacity. Taken together, the results suggest that even short-term exercise interventions can enhance overweight adults' executive functions.

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1. Introduction

There is currently a consensus about the positive effects of physical exercise on cognition [1,2]. However, the exercise intensity-dependent

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effect on executive function remains unclear [3]. Epidemiological and prospective studies have suggested that exercise intensity influences the magnitude of cognitive benefits [4], protecting against cognitive decline and dementia [5,6] and improving social, cognitive, and psychological development [7,8]. These cognitive effects are supported by two previous meta-analyses demonstrating that moderate aerobic exercise elicits greater improvements in cognitive performance than exercise at light or high intensity [9,10].

Several epidemiological studies have suggested a dose–response relationship to cognitive outcomes, showing improvements in executive function in individuals with higher levels of aerobic fitness [11,12]. Additionally, low physical activity levels have been closely related to deterioration of hippocampal neuroplasticity, neuronal degenerative diseases, and impairment of executive function [13,14]. Along the same lines, obesity is also known to be linked to reduced executive function [15]. Previous studies on obese mice have identified that exercise plays a protective role against obesity-induced cognitive impairment [16,17].

Interestingly, high-intensity aerobic interval training (HIIT) has been established as an effective method for managing obesity [18] and reducing cardiometabolic risk factors [19,20]. Nevertheless, little is known about the effect of HIIT on executive function in overweight/obese individuals [21]. Barenberg et al. reported that cognitive flexibility improved after two HIIT protocols (> 80% of peak oxygen uptake) compared to a resting condition in healthy university students [22]. Similarly, increased performance in cognitive inhibition tasks was also found in older adults after HIIT [23]. Another study comparing the effect of acute aerobic exercise versus progressive resistance training (PRT) on executive function among young healthy adults found improvement in the processing speed of a working memory task following acute aerobic exercise [24]. With regard to PRT, the prior studies carried out to investigate the effect of PRT on executive function have revealed inconsistent findings [25,26].

Previous research has analysed the potential effects of diverse exercise training modalities including PRT, HIIT, or moderate continuous training on executive function among different populations, including young healthy [24] and older adults [27]. However, the acute effects of different training protocols as well as the combined training on executive function in inactive overweight adults remain unknown.

Thus, the aim of this study was to compare the acute effects of HIIT, PRT, or combined training (PRT+ HIIT) on executive function indicators (i.e., cognitive inhibition and attention capacity) in overweight inactive adult men (aged 18–30 years old).

2. Methods

2.1. Participants

The present study is a secondary randomised-controlled trial (ClinicalTrials.gov ID: NCT02915913; ‘BrainFit Study’). The study received ethical approval from the Medical Research Ethics Committee of the Universidad Nacional de Colombia (code no. 018-223-16). Random allocation to treatment was performed at the individual level. Details of background and design methods (i.e., characteristics of participants, sample calculation, randomisation, outcomes, and analysis plan) of the BrainFit Study have been previously published elsewhere [28,29]; nevertheless, the most relevant information is briefly described below.

Cognitive excluded criteria were established by screening the Montreal Cognitive Assessment (MoCA) test < 24 points, which indicates possible cognitive impairment. Likewise, the Goldberg anxiety and depression scale was applied [30]. Individuals with a maximum score (9 points) or visible affect disorder in assessment preview were excluded, due to a negative influence on cognitive performance. In addition, individuals with a history of a medical condition identified by the American Heart Association (AHA) as an absolute contraindication to exercise testing were excluded from this study [31].

2.2. Intervention

Each of the volunteers participated in four randomised trials (HIIT, PRT, combined, and control [no exercise]), and the starting trial was randomised. All the interventions were performed in the same facilities.

2.2.1. HIIT group

All HIIT sessions were preceded by a 5-min warm-up and ended with a 4-min cool down at 65% maximum heart rate (HRmax) until the subject expended between 400 and 500 kcal of the exercise in total. The HIIT protocol consisted of four bouts of 4-min intervals at 85–95% HRmax interspersed with 4 min of active recovery at 75–85% HRmax. Participants were instructed to reach their target HR for each interval within the first 2 min of the 4-min interval. We calculated the training energy expenditure with the consensus public health recommendations from the WHO [32] and the US Department of Health and Human Services [33]. HR monitors (A3, Polar Elector OY, Finland) were used to adjust workload to achieve the target HR. In addition, a rating of perceived exertion was also measured during each exercise session (15–17 during high intensity and 11–13 during recovery).

2.2.2. PRT group

The PRT session was initiated with ~12–15 repetitions per set of six exercises that targeted all the major muscle groups at high intensity. A 60-s recovery was permitted as many times as needed according to the subject's weight until the subject expended between 400 and 500 kcal at 50–70% of one-repetition maximum (1RM).

2.2.3. Combined training (PRT + HIIT) group

The PRT + HIIT group performed the 50% aerobic training programme plus the 50% RT programme during each session. The energy expenditure associated with the physical training prescribed for the PRT + HIIT group was therefore ~400–500 kcal/session [34].

2.2.4. Control group

No exercise.

2.3. Calculation of the caloric expenditure during the training session

The caloric expenditure of the exercises that compose each part of sessions A (5-min warm-up and ended with a 4-min cool down) and B (HIIT, RT, combined protocols) was estimated by indirect calorimetry using a Cosmed K5 portable metabolic system (Rome, Italy), assuming a non-protein respiratory exchange ratio.

2.4. Maximum rate of O₂ uptake

$\dot{V}O_{2max}$ was determined 48 h before acute intervention using a maximum treadmill exercise test (Precor TRM 885, Italy) in inactive individuals. Subjects completed an incremental maximal oxygen uptake test on a treadmill ergometer. A metabolic cart with an on-line gas collection system (Cosmed K5 portable metabolic system, Rome, Italy) was used to acquire $\dot{V}O_{2max}$ and carbon dioxide production data, and HR was monitored continuously with an HR monitor (Polar A3, Lake Success, NY).

2.5. Muscular strength

Muscular strength was assessed 48 h before acute intervention using the 1RM test, implemented according to similar procedures [35]. The 1RM was performed in six resistance exercises (bicep screw curl, triceps extension, dumbbell side lateral, military press, dumbbell squat, and dumbbell front lunge) carried out in the morning between 9 and 11 h, and the highest loads of three attempts were reported per exercise. Total muscle strength was calculated as the sum of the six exercises. Fifty to 70% of 1RM was used to determine the workload during the

single sessions for the experimental group.

2.6. Familiarisation session

Before the exercise protocol started, participants provided their sociodemographic data and performed a Stroop test and d2 test training session. In accordance with the test manual and normative data d2, the execution time was shortened from 20 s to 15 s in order to prevent the learning effect in the posterior application.

2.7. Anthropometric and performance measures

Anthropometric measurements were used to assess participants' weight, height, and body mass index (BMI). Weight and height were measured using a scale and a stadiometer to the nearest 0.5 kg and 0.1 cm, respectively. BMI was calculated as weight in kg divided by the square of height in metres [32].

2.8. Cognitive inhibition

The present study utilised a Spanish adaptation of Golden's Stroop test [36], which has three different conditions. Each condition included 100 stimuli (20 items per line) printed on a 21.5 × 28 cm sheet of paper (Supplemental Fig. FS1). This test measures the correct responses in 45 s, and there is no limit to the number of possible responses (three conditions). In the first condition (reading), the participant had to read the words printed in black (i.e., red, green, and blue). In the second condition (naming), the participant needed to name the colour of the 'x' line (e.g., an xxxx line in blue ink is naming as 'blue'). In the third condition (interference), the participant had to name the colour of the ink in which the words are written while the reading word is different of the ink. The meaning of each word had to be ignored, since it was incongruent with the colour to name (e.g., the word 'green' written in red ink). Correct responses at times and the number of errors (uncorrected reading, naming, and fail to interference) were the main variables of interest. In addition, the index Stroop interference was calculated for each participant as a difference between a correct answer in the third condition minus the estimated interference score (appropriate reaction time on interference condition).

A previous study of the reliability and validity of the instrument shows it is a good tool to measure cognitive inhibition, showing a high intra-class correlation index for different temporal measures (> 0.90) [37].

2.9. Attention capacity

Spanish adaptation by Seisedos Cubero of Brickenkamp's selective attention and concentration test was used [38] (Supplemental Fig. FS2). The d2 test is a simple paper-and-pencil test consisting of 14 rows, each containing 47 randomly mixed letters ('p' and 'd') from measures of selective attention and cognitive inhibition, and its reliability and validity have been tested previously in adults [38]. In brief, the letters 'p' and 'd' appear with one or two dashes above or below each letter. Participants were instructed to mark all 'ds' that appeared with two dashes (i.e., relevant elements) at a rate of 15 s/row. The remaining combinations of characters were considered as irrelevant elements. There are three variables measured within the d2 test to assess attention capacity (consistency performance, concentration performance, total performance). Each variable was normalised into a ratio according to the total number of d2s within the test. The consistency performance measures stability of execution in individuals throughout the test. Dependent variables were the overall learning success (number of correctly marked items minus wrongly marked items and omissions of correct items), concentration performance (number of correctly marked target signs minus wrongly marked items), and consistency (difference in the major and minor performances throughout the test). Internal

stability indices were very high, > 0.90. For all conditions, participants had to respond as quickly as possible while making the least amount of errors and omissions.

2.10. Statistical analysis

Descriptive statistics were produced for baseline characteristics for this study sample of participants. Prior to the planned statistical analyses, a preliminary analysis was conducted (Shapiro–Wilk test) to confirm data distribution normality. To attain the efficiency of the trial design, all participants who received the aerobic intervention (HIIT and combined protocol) were compared with all those who did not (RT and control exercise group); a similar approach was used for the RT group. Analysis of covariance (ANCOVA) was used to adjust for the baseline cognitive score and the other intervention (main effect term). To correct for multiple comparisons in the combined exercise group, the Bonferroni correction ($p < 0.025$) was used. Cohen's d for effect size was also calculated to determine the magnitude of the group differences. Effect sizes (η^2) were classified as small, medium, and medium-to-large effects (< 0.20, 0.2–0.6, and 0.6–1.2, respectively), and partial η^2 was considered small if $\eta^2 < 0.04$, and large if $\eta^2 > 0.36$. Parametric datasets are summarised in the text as mean (SD) and figures' mean difference between groups as mean (SEM). All statistical analyses were performed using Statistical Analysis Statistical analysis IBM SPSS Statistics version 24.0 (Chicago, IL, USA).

3. Results

The baseline participant characteristics by group training are shown in Table 1. The ANCOVA test indicated no statistically significant differences in baseline characteristics between the exercise training protocols ($P > 0.05$), confirming that participants in the four groups began the trial under similar conditions.

Cognitive inhibition measured by the Stroop test was improved after the HIIT protocol for the reading +5.89 (95% CI: 2.1–9.5; $P = 0.004$, $\eta^2 = 0.33$), colour naming +9.0 (95% CI: 5.6–12.3; $P = 0.001$, $\eta^2 = 0.60$), interference +10.1 (95% CI: 4.4–15.8; $P = 0.001$, $\eta^2 = 0.39$), and index interference +6.0 (95% CI: 1.7–11.3; $P = 0.028$, $\eta^2 = 0.20$). The PRT + HIIT group for the reading condition was +7.1 (95% CI: 1.3–12.9; $P = 0.020$, $\eta^2 = 0.40$), colour naming +7.5 (95% CI: 5.1–10.2; $P = 0.001$, $\eta^2 = 0.80$), and interference +5.8 (95% CI: 1.8–10.8; $P = 0.026$, $\eta^2 = 0.39$). Additionally, the RT group had enhanced interference of +5.4 (95% CI: 1.6–9.6; $P = 0.009$, $\eta^2 = 0.48$), and index interference was 6.0 (95% CI: 1.7–11.3; $P = 0.028$, $\eta^2 = 0.20$) in the PRT group (Supplemental Fig. FS3, Supplemental Fig. FS4).

Table 1
Baseline participant characteristics by training group.

Characteristics	Control (n = 10)	RT (n = 7)	HIIT (n = 12)	HIIT + RT (n = 7)
Age, y	24.7 (3.4)	22.8 (3.1)	24.5 (3.7)	22.2 (3.4)
BMI, kg/m ²	28.7 (2.0)	27.8 (1.3)	27.4 (1.7)	28.1 (1.2)
EE during exercise, Kcal	–	462.6 (74.9)	460.9 (86.7)	461.7 (59.1)
Heart rate in exercise, bpm	–	Pre: 71 (10) During: 155 (32)	Pre: 62 (12) During: 175 (22)	Pre: 68 (9) During: 177 (29)
Total muscle strength, kg; total of six exercises	142.7 (43.7)	136.5 (34.6)	156.3 (53.4)	147.2 (38.5)

Data shown as mean (standard deviation).

Abbreviations: HIIT, high-intensity interval training; RT, resistant training; BMI, body mass index; EE, energy expenditure; $\dot{V}O_{2max}$, cardiorespiratory fitness; 1RM, one repetition maximal; NA, not applicable.

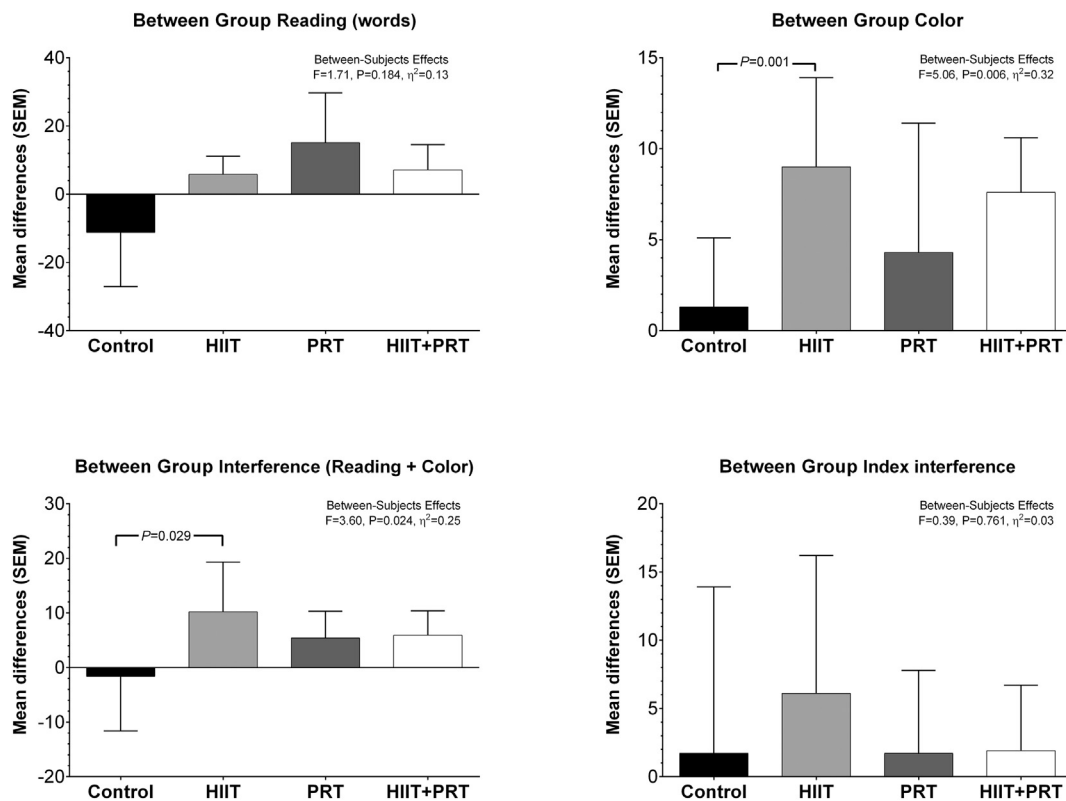


Fig. 1. Mean difference values between exercise interventions and control group (mean \pm standard deviation) in reading, colour naming, interference condition, and Stroop interference index at acute effect.

The ANCOVA test revealed a significant difference between HIIT vs control group in the interference domain (group-workout interaction effect $F = 3.60$, $P = 0.024$, $\eta^2 = 0.25$), with a mean difference of 11.7, (95% CI: 1.6–21.8; $P = 0.015$), and colour naming (group-workout interaction effect $F = 5.06$, $P = 0.006$, $\eta^2 = 0.32$), with a mean difference of 7.7, (95% CI: 1.8–13.5; $P = 0.005$) (Fig. 1). (See Fig. 2.)

Intent-to-treat analysis for d2 test performance at baseline and changes after acute effect are presented in Supplemental Fig. FS5. The HIIT group elicited small to medium improvements in the concentration level domain of +21.7 (95% CI: 10.6–32.8; $P = 0.001$, $\eta^2 = 0.44$), total performance domain (items processed) +56.6 (95% CI: 29.0–76.2; $P = 0.001$, $\eta^2 = 0.50$), and consistency domain -3.0 (95% CI: -5.3 – -0.8 ; $P = 0.001$, $\eta^2 = 0.27$). These results were similar in the PRT and PRT + HIIT groups in the concentration level and total performance domains ($P < 0.05$).

Lastly, we found a significant effect between HIIT vs control group in total performance (items processed, mean difference 44.8, 95% CI: 6.2–83.5; $P = 0.016$) and PRT vs control group (mean difference 43.4, 95% CI: 1.2–83.0; $P = 0.050$) in group-workout interaction effect ($F = 4.21$, $P = 0.013$, $\eta^2 = 0.28$) (Fig. 2).

4. Discussion

To the best of our knowledge, this study is the first to investigate the acute effects of the HIIT, PRT, and PRT + HIIT modalities on executive function (cognitive inhibition and attention capacity) in inactive overweight adult men. The main findings were that the HIIT and PRT + HIIT training sessions reported important effect sizes compared to PRT alone for cognitive inhibition and attention capacity. Between groups, results revealed that the HIIT intervention led to changes in the Stroop interference index (group-workout interaction effect $F = 3.60$, $P = 0.024$, $\eta^2 = 0.25$) and colour naming (group-workout interaction effect $F = 5.06$, $P = 0.006$, $\eta^2 = 0.32$) in comparison with the control group, while the PRT and HIIT groups had higher effect sizes in the

items-processed domain ($F = 4.21$, $P = 0.013$, $\eta^2 = 0.28$).

Existing evidence suggests that executive function can be temporarily altered by physical training [7,10,26,39,40]. Executive function has been widely investigated, since it is a key domain of many aspects of life, including mental and physical health, as well as social, cognitive, and psychological development [41–43]. Among the different components of executive function [44], the present study was focused on cognitive inhibition and attention capacity. Currently, several hypotheses may explain how exercise intervention may augment cognitive control functions: i) regulation of neurotrophins; ii) increase in oxygen saturation due to increased blood flow and circulatory angiogenesis; and iii) increase in brain neurotransmitters facilitating information processing [29]. This would likely explain the link with exercise training and the association with higher executive function.

In agreement with our results, a single bout of aerobic exercise has been reported to improve performance in several cognitive task categories, including attention, information processing, and memory [10]. Thus, aerobic exercise has been suggested to create a nutritive environment by facilitating cortical activity, hemodynamics, and metabolism [10]. Interestingly, findings from experimental studies investigating executive function 20 to 60 min post-exercise have suggested that benefits are maintained at least temporarily after the cessation of aerobic exercise [39,40,45]. Consequently, acute benefits of exercise may be useful to prepare for situations demanding high executive function [10].

The magnitude of possible acute cognitive benefits has been reported to be exercise intensity dependent [3,46]. In fact, a recent meta-analysis showed that the greatest benefits in executive function were identified during moderate aerobic exercise [9]. Similarly, Kamijo et al. found that more attentional resources were allocated to an executive function task after 20 min of moderate-intensity exercise [4]. In another study, a greater improvement of cognitive inhibition was found after moderate- compared to low-intensity aerobic exercise in both young and older adults [47]. Interestingly, our results revealed that HIIT

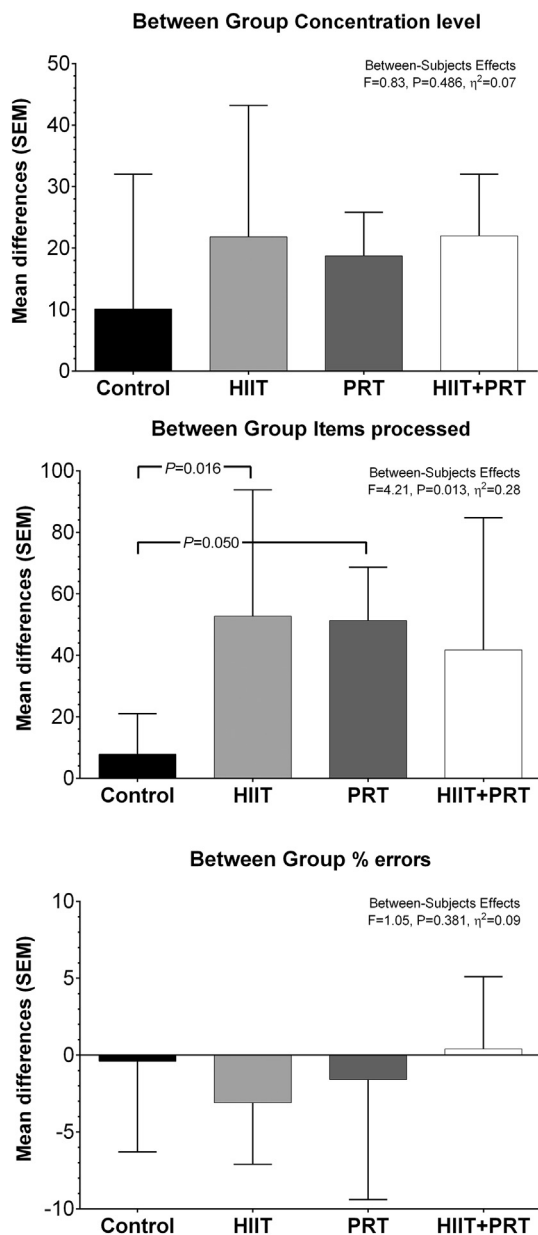


Fig. 2. Mean difference values between exercise interventions and control group (mean ± standard deviation) in concentration levels, items processed (performance), and % errors domain at acute effect.

displayed improvements in performance in Stroop tasks (reading, colour naming, interference, and interference index), supporting the benefits of these exercise training modalities on cognitive inhibition. Similarly, Alves et al. reported an increased performance in inhibitory control tasks after HIIT in older adults [23]. However, in this study the performances in other subtasks of the Stroop test were not significantly greater after a HIIT protocol consisted of 10 1-min intervals. It is important to highlight that in our study the HIIT session consisted of four bouts of 4-min intervals at 85–95% HR reserve, interspersed by 4 min of active recovery at 75–85% HR reserve. Thus, the differences in time intervals and the age of the sample might explain the differences between studies.

Regarding attention capacity, our findings support that the combined training (PRT + HIIT), PRT, and HIIT protocols elicit large improvements in concentration performance ($p < 0.05$). Some evidence supports that RT ameliorates the performance of cognitive functions [48]. Also, a previous meta-analysis identified that the greatest benefits

in cognitive function were observed when aerobic exercise was paired with PRT [49]. Thus, it has been suggested that there are mechanisms by which PRT or HIIT could improve the cognitive process [50]. The prefrontal cortex, closely linked with executive functions and movement coordination, could be the last region of the brain to mature, and therefore, each dimension of executive functions could benefit from coordinative training.

In this context, although the mechanisms by which HIIT or combined training can influence attention capacity are unclear, it has been proposed that HIIT may provoke increases in circulating cortisol levels and therefore increase arousal, which might lead to impaired cognitive performance [51]. Additionally, increases in catecholamine levels during HIIT can lead to preferential activation of the limbic system at the expense of the prefrontal lobes, causing a breakdown of performance in executive control tasks [52,53]. Pontifex et al. reported improvements in cognitive function following acute aerobic exercise but not PRT in a population of young adults (20 years old) [24]. It should also be emphasised that in this study the exercise intensity ranged from 60% to 70% of VO_{2max} , whereas in our study the HIIT sessions included intervals at 85–95% HR reserve. Furthermore, the differences in training level between this study population (healthy adults) and our study cohort (overweight adults) might explain the inconsistent findings. As previously noted, the contradictory data reported regarding the acute effects of bouts of exercise on cognitive performances may be due to methodological differences, such as exercise intensity or level of aerobic fitness [52]. Further studies are needed to clarify the effect of different HIIT protocols as well as combined training including PRT.

To date, most longitudinal studies have focused on the effect of a single exercise training modality on cognitive function, mainly aerobic or resistance exercise. There are relatively little data regarding the combined effects of HIIT and PRT on executive function [27]. In the present study, an acute HIIT session reported trivial effect sizes ($\eta^2 = 0.20$) than PRT ($\eta^2 = 0.004$) and combined intervention ($\eta^2 = 0.01$) for the Stroop interference index. Along the same lines, HIIT and RT induced the medium gain in information processing speed (d2 items processed, $\eta^2 = 0.50$), such as HIIT proved the greatest benefits for performance in the similar domain (Stroop task naming [$\eta^2 = 0.33$]) and in the Stroop colour naming ($\eta^2 = 0.60$) [27]. The differential effects of both exercise training modalities on cognitive function may be explained by the fact that aerobic training is linked to elevated levels of BDNF [54], while PRT or combined intervention produces increased levels of IGF-1 [55], both related to executive function in different ways.

There is a growing body of evidence supporting that obesity is a predictor of global cognitive impairment that may affect attention capacity, executive function, speed of processing, and verbal memory, among others [56]. Although the mechanisms underlying the pathogenesis of obesity-induced cognitive decline are still unclear, brain atrophy, disruption in cerebrovascular function, or systemic and central inflammation have been proposed as potential mediators [57]. To our knowledge, no study has been conducted to evaluate the effects of different exercise training modalities on cognitive function in a population of overweight adults. A recent study indicated that a four-month HIIT in obese adults improved cognitive function [58]. Nevertheless, since this study was focused on the chronic effect induced by HIIT and the aim of our study was to analyse the acute effect, it is difficult to compare these findings. Therefore, future research is required in order to clarify the acute effect of different exercise training modalities on cognitive function in obese and overweight populations.

Our study has both limitations and strengths. First, since the effects of exercise training on executive function are known to be affected by age and nutritional and training status, and taking into account that our study sample was limited to inactive and overweight middle-aged males, these findings may not be generalisable to other populations with different characteristics [28,29]. The main strength of our study is that, to our knowledge, this is the preliminary randomised clinical trial

to examine the acute impact of exercise training modalities on inactive overweight individuals' executive function. In addition, this study was carried out in a well-characterised cohort, and specific aspects of executive function, including cognitive inhibition and attention capacity, were investigated.

In conclusion, the novel findings of this study were that acute HIIT and PRT + HIIT sessions reported important effect sizes compared to PRT alone for cognitive inhibition and attention capacity in inactive overweight men. Taken together, the results suggest that even short-term exercise interventions can enhance executive functions. Future research is needed to investigate the link between different exercise protocols and their effects in people with body composition alterations.

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.physbeh.2018.09.010>.

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