Acute Effect of Three Different Exercise Training Modalities on Executive Function in Overweight Inactive Men: The BrainFit Study

By

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A thesis submitted to the School of Medicine and Health Science of Universidad del Rosario
in partial fulfillment of the requirements for the degree of Master of Physical Activity and Health

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2017

Article type: Original Article

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Runner title: Exercise Training and Executive Function in Overweight Men

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Conflicts of Interest: All authors declared no potential conflict of interest.

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), resistance training (RT), or combined training (RT+ HIIT) on executive function indicators in overweight inactive men adults (age 18–30 years old). The participants were screened and excluded for medical conditions known to impact cognitive functioning, and that was measured with Moca test screening cognitive. Randomized, parallel-group clinical trial among 36 adults were randomly assigned to a HIIT, RT, RT+HIIT, and a control group (n=10) until the energy expenditure of 400-500 kcal. Cognitive inhibition and attention capacity were examined using Stroop Test and d2 Test of Attention respectively, were obtained pre-exercise for baseline measurement and immediately 1-min post-exercise for each exercise training modalities. Cognitive inhibition measured as Stroop test was improved after HIIT protocol for the reading +5.89(η^2=0.33), colors naming +9.0(η^2=0.60), interference +10.1 (η^2=0.39) and index interference domain +6.0(η^2=0.20). Additionally, the RT+HIIT group had an increase +7.1(η^2=0.40) for the reading condition, colors naming +7.5(η^2=0.80), and interference +5.8(η^2=0.39). In regard to attentional capacity, the HIIT group elicit moderate to large improvements the concentration levels domain +21.7(η^2=0.44), item processed domain +56.6 (η^2=0.50), and % errors -3.0(η^2=0.27). These results were similar in RT and RT+HIIT group on concentration levels and item processed domain(P<0.05). In conclusion, acute HIIT and RT+HIIT session reported moderate to large effect sizes than RT alone for cognitive inhibition and attention capacity. Taken together, the results suggest that even short-term exercise interventions can enhance overweight adults' executive functions.

KEYWORDS: Cognitive function; Attention capacity; Inhibition; Obesity; Inactivity; Physical exercise.

TRIAL REGISTRATION: ClinicalTrials.gov NCT02915913 (Date: September 22, 2016, https://clinicaltrials.gov/ct2/show/NCT02915913).

BACKGROUND

There is currently a consensus about the positive effects of physical exercise on cognition (Y. K. Chang, Labban, Gapin, & Etnier, 2012; Verburgh, Königs, Scherder, & Oosterlaan, 2014). However, the exercise intensity-dependent effect on executive function remains unclear (Lambourne & Tomporowski, 2010). Epidemiological and prospective studies have suggested that exercise intensity influences the magnitude of cognitive benefits (Kamijo, Nishihira, Higashiura, & Kuroiwa, 2007; Peruyero, Zapata, Pastor, & Cervelló, 2017), protecting against cognitive decline and dementia (van der Wardt et al., 2017; Vidoni et al., 2015) and improving social, cognitive, and psychological development (TSUKAMOTO et al., 2017; Weng, Pierce, Darling, & Voss, 2015). These cognitive effects are supported by two previous meta-analysis demonstrating that moderate aerobic exercise elicits greater improvements in cognitive performance than exercise at light or high intensity (Ludyga, Gerber, Brand, Holsboer-Trachsler, & Pühse, 2016; McMorris & Hale, 2012).

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 (Curlik, Shors, & Shors, 2013; Etnier, Nowell, Landers, & Sibley, 2006). Additionally, low physical activity levels has been closely related to deterioration of hippocampal neuroplasticity, neuronal degenerative diseases, and impairment of executive function (Itoh et al., 2011; Liu, Zhao, Cai, Zhao, & Shi, 2011). Along the same lines, obesity is also known to be linked to reduced executive function (Gunstad, Paul, Cohen, Tate, & Gordon, 2006). Previous studies in obese mice have identified that exercise exerts a protective role against obesity-induced cognitive impairment (Kim, Choi, & Chung, 2016; Woo, Shin, Park, Jang, & Kang, 2013).

Interestingly, intensity aerobic interval training (HIIT) has been established as an effective method for managing obesity (Boutcher, 2011) and reducing cardiometabolic risk factors

(Batacan, Duncan, Dalbo, Tucker, & Fenning, 2017; Keating, Johnson, Mielke, & Coombes, 2017). Nevertheless, little is known about the effect of HIIT on executive function in overweight/obese individuals (COSTIGAN, EATHER, PLOTNIKOFF, HILLMAN, & LUBANS, 2016). 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 (Barenberg, Berse, & Dutke, 2015). Similarly, increased performance on cognitive inhibition tasks was also found in older adults after HIIT (Alves et al., 2014). Likewise, the effects of acute maximal-intensity exercise in children and adolescents suggest improvements in attention (Samuel, Zavdy, Levav, Reuveny, Katz, Dubnov-Raz, 2017). Another study comparing the effect of acute aerobic exercise versus resistance training (RT) on executive function among young healthy adults found an improvement in the processing speed of a working memory task following acute aerobic exercise (Pontifex, Hillman, Fernhall, Thompson, & Valentini, 2009). With regard to RT, the prior studies carried out to investigate the effect of RT on executive function have revealed inconsistent findings (Y.-K. Chang, Tsai, Huang, Wang, & Chu, 2014; Dunsky et al., 2017).

Previous research has analyzed the potential effects of diverse exercise training modalities including RT, HIIT or moderate continuous training on executive function among different populations including overweight children (Davis et al., 2011), adolescents (Peruyero et al., 2017), young healthy (Pontifex et al., 2009) and even older adults (Coetsee & Terblanche, 2017). 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, RT, or combined training (RT+ HIIT) on executive function indicators (i.e., cognitive inhibition and attention capacity) in overweight inactive men adults (age 18–30 years old).

METHODS

Participants

Males aged 18–30, physically inactive individuals (i.e. <150 min of moderate-intensity exercise per week for greater than 6 months), with waist circumference ≥ 90 cm or excess weight, body mass index (BMI) ≥ 25 and ≤ 30 kg/m^2, and identified as being willing and having almost immediate availability were initially recruited and randomly assigned to HIIT, RT, RT+HIIT and control group. Excluded criteria included systemic infections, weight loss or gain of >10% of body weight in the past 6 months for any reason, currently taking medication that suppresses or stimulates appetite, uncontrolled hypertension, gastrointestinal disease, including self-reported chronic hepatitis or cirrhosis, any episode of alcoholic hepatitis or alcoholic pancreatitis within past year, inflammatory bowel disease requiring treatment in the past year, recent or abdominal surgery (e.g., gastrostomy), asthma, diagnosed diabetes (type 1 or 2), fasting impaired glucose tolerance (blood glucose 118 mg/dL) or use of any anti-diabetic medications, currently taking antidepressant, steroid, or thyroid medication, unless dosage instable (no change for 6 months), and any other conditions which, in opinion of the investigators, would adversely affect the conduct of the trial. Cognitive excluded criteria was established by screening Montreal Cognitive Assessment (Moca) test <24 points, this score show possible cognitive impairment. Likewise, depression and anxiety scale was applied (Goldberg, Bridges, Duncan-Jones,Grayson, 1988), individuals with score maximum (9 points) or visible affect disorder in assessment preview was excluded, due to 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 (Lauer, Froelicher, Williams, Kligfield, & American Heart Association Council on Clinical Cardiology, Subcommittee on Exercise, Cardiac Rehabilitation, and Prevention, 2005).

Subjects who were interested in participating were approached with further information: (*i*) initially screened for pre-participation in exercise using a cardiovascular and musculoskeletal checklist (i.e., the patient's medical history, disease history, physical fitness and more); (*ii*) baseline testing; (*iii*) a single iso-caloric acute training protocol; and (*iv*) post-training testing. Written informed consent was obtained from all participants. This study was conducted according to the guidelines laid down in the Declaration of Helsinki and was approved by the regional Ethics Committee for Medical Research Ethics Committee of The University National of Colombia (Code N° 018-223-16).

Blinding and randomisation methods

Randomization into the four study arms was performed by Centre of Studies in Physical Activity Measurements (CEMA) at the University of Rosario, Bogotá (Colombia), using block randomization with a block size of four. Eligible participants were randomly assigned after completing the baseline measurements to HIIT, RT, RT+HIIT and control [no exercise]. The principal investigator was coordinating the allocation sequence, and randomization was computer generated. Investigators and statisticians were blinded to treatment allocation throughout the trial protocol. Access to the allocation code was restricted to one study statistician who did not perform the final study analyses. Randomization was conducted independently using sealed opaque envelopes. The importance of maintaining the blinding and allocation concealment were reinforced by regularly scheduled conference calls at the sites and daily meetings with the field investigators.

Intervention

1. HIIT group: The HIIT protocol was completed with fast walking or running on a treadmill with the deck inclined to reach the desired intensity. All HIIT sessions were preceded with a 4-min warm-up and ended with a 4-min cool-down at 65% heart rate (HR) maximal until the expenditure of 400 to 500 kcal. The HIIT protocol consisted of four bouts of 4-min intervals at 85–95% HR maximal, interspersed by 4-min of active recovery at 75–85% HR reserve. Participants in the HIIT groups were instructed to reach the target HR for each interval within the first 2 min of the 4-min interval. We calculated the training energy expenditure for participants' age ranges associated with meeting the consensus public health recommendations from the World Health Organization (WHO) ("WHO | Physical Activity and Adults," 2015) and the US Department of Health and Human Services ("Physical Activity Guidelines Advisory Committee report, 2008. To the Secretary of Health and Human Services. Part A: executive summary.," 2009). During the supervised intervention, we recorded HR using an HR monitor (Polar Pacer, USA) to ensure compliance with the exercise stimulus at the predetermined target HR zone. In addition, rating of perceived exertion was also measured in each exercise session (15-17 in high intensity and 11-13 to recovery).

2. RT group: The RT session started with ≈25 to 30 repetitions per set of six exercises targeting all the major muscle groups at high intensity, 60 s recovery as many times as needed according to subject weight until the expenditure of 400 to 500 kcal at 50-70% one repetition maximum (1RM). The 1RM was measured for six different exercises 48 h before the beginning of the training period: bicep screw curl, triceps extension, dumbbell side lateral raise, military press, dumbbell squat and dumbbell front lunge. Single session was preceded and followed by a gradual warm-up and cool-down period (both of 10-min duration and consisting of walking and light, static stretching (avoiding muscle pain) in most muscle groups). The cool-down period also included relaxation and stretching exercises. Each participant's workloads were prescribed on an individual basis using their 1RM results during the initial orientation.

3. Combined training (RT+HIIT) group: This group received both RT and HIIT protocols as described above. Therefore, the energy expenditure associated with the physical training prescribed for this group was ≈ 400 to 500 kcal/session.

4. Control group: no exercise.

Intensity, duration and energy expenditure control

In terms of exercise intensity, the actual values of intensity were the mean of HR measured in HIIT or combined groups, and the average value of workload and repetitions determined in acute session in RT group, respectively. Using the heart rate and oxygen consumption data obtained from the baseline maximal oxygen intake ($\dot{V}O_2max$) test, the heart rate associated with an oxygen consumption of approximately 85–95% (load) and approximately 75–85% (recovery) were prescribed for HIIT or Combined group. At these exercise intensities, the energy expenditure targets (exercise amount) were ≈ 400 to 500 kcal/session. Energy expenditure was estimated during exercise via indirect calorimetry using a Cosmed K5 portable metabolic system (Rome, Italy) assuming a non-protein respiratory exchange ratio (Graf et al., 2013). The gradual increase in total energy expenditure in expected to minimize fatigue, soreness, injuries and attrition. Energy expenditure targets for the all group (matched for intensity) was designed such that this energy would be expended in approximately 60 minutes to conform to physical activity guidelines [31,33]. Prescribing dose based on energy expenditure rather than time was done to reduce inter-individual variability in exercise capacity [33]. The exercise training was 100% supervised for graduated student. Attendance at supervised sessions includes compliance with target HR and energy expenditure and were monitored and recorded by research staff.

Familiarization Session

Before exercise protocol started, participants completed their sociodemographic data and performed a Stroop test and d2-test training session. In accordance with the test manual and normative data d-2, execution time was shortened from 20 seconds to 15 seconds in order to prevent the learning effect in the posterior apply. Into each sheet of Stroop stimuli was order modified for have enough material to repeat the test and to avoid ceiling effects.

Anthropometric and performance measures

Anthropometric measurements were used to assess participants weight, height and 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 meters [32].

$\dot{V}O_2max$ was determined 48h 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 a HR monitor (Polar A3, Lake Success, NY).

Muscular strength was assessed 48h before acute intervention using the 1RM test, implemented according to similar procedures (Ramírez-Vélez et al., 2016). 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. 50 to 70% of 1RM was used to determine the workload during the single sessions for the experimental group.

Cognitive Inhibition

The present study utilized a Spanish adaptation of Golden's Stroop Test (Golden, 1994) that has three different conditions. Each condition included 100 stimuli (20 items per line) printed on a 21.5 x 28 cm sheet of paper. This test measures the correct responses in 45 seconds, 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 color of the "x" line (e.g. a xxxx line in blue ink is naming as "blue"). In the third condition (interference), the participant had to name the color 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 color 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 correct answer in third condition minus 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) (Carlota Rodríguez Barreto, Del Carmen Pulido, & Alejandro Pineda Roa, 2016).

Attention capacity

Spanish adaptation by Seisdedos Cubero of the of Brickenkamp's selective attention and concentration test was used (Brickenkamp, 2012). The d2-test is a simple paper-and-pencil test that consisting of fourteen different rows, each containing forty-seven randomly mixed letters ('p' and 'd') from measures selective attention and cognitive inhibition, and its reliability and validity have been tested previously in adults (Brickenkamp, 2012). In brief, the letters ‘p’ and ‘d’ appear with one or two dashes above or below each letter. Participants were instructed to mark all ‘d’ 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. The d2 test has been shown to be valid, and reliable in measuring some components of attention cognition function, such as sustained and selective attention (Budde et al., 2012). There are three variables measured within the d2 test to assess attention capacity (consistency performance, concentration performance, total performance). Each variable was normalized into a ratio according to the total number of d2’s within the test. The consistency performance measures stability execution in individual along the test. Dependent variables were the overall learning success (number of correctly market items minus wrong market items and omissions of correct items), concentration performance (number of correctly marked target signs minus wrong market items) and consistency (difference into the major and minor performance along the test). Internal stability indices are very high, greater than 0.90. For all conditions, participants had to respond as quickly as possible, while making the least amount of errors and omissions.

Statistical analysis

Descriptive statistics were produced for baseline characteristics for this study sample of participants. Prior to the planned statistical analyses, preliminary analysis was conducted (Shapiro–Wilk test) to confirm data distribution normality. A two-way mixed analysis of covariance (ANCOVA) with repeated measures was used to test the main effect (i.e., group effect) and the interaction effect (time and group interaction) with the baseline value as covariate on the outcome variables (cognitive responses). Cohen’s d for effect size were also calculated to determine the magnitude of the group differences. Effect size 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 η^2<0.04, and large if η^2 >0.36. Parametric datasets are summarized in text as mean (SD) and figures mean difference between groups as mean (SEM). All statistical analysis was performed using Statistical Analysis Statistical analysis IBM SPSS Statistics version 24.0 (Chicago, IL, USA).

RESULTS

The present study is a randomized controlled trial (ClinicalTrials.gov ID: NCT02915913). The BrainFit Study is a single blind, randomized controlled 2×2 factorial trial. Recruitment began September 1, 2016, and closed June 30, 2017. The final follow-up visit was in July 2017. Figure 1 shows the BrainFit Trial Flow Diagram. Of 45 participants who entered the run-in phase, 36 (80%) were randomized. Reasons for pre-randomization withdrawal included BMI >30 kg/m^2, refuse to participate, or a medical condition. Nine participants (1 from control group, 4 from the RT group, and 4 from the combined group) were excluded because cognitive function was technically inadequate.

*****Figure 1 here*****

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 four groups began the trial under similar conditions.

*****Table 1 here*****

Cognitive inhibition measured as Stroop test was improved after HIIT protocol for the reading +5.89 (95% CI: 2.1 to 9.5; P=0.004, η^2=0.33), colors naming +9.0 (95% CI: 5.6 to 12.3; P=0.001, η^2=0.60), interference +10.1 (95% CI: 4.4 to 15.8; P=0.001, η^2=0.39) and index interference +6.0 (95% CI: 1.7 to 11.3; P=0.028, η^2=0.20). The RT+HIIT group had a +7.1 (95%

CI: 1.3 to 12.9; P=0.020, η^2=0.40) for the reading condition, colors naming +7.5 (95% CI: 5.1 to 10.2; P=0.001, η^2=0.80), and interference +5.8 (95% CI: 1.8 to 10.8; P=0.026, η^2=0.39). Additionally, the RT group enhanced interference +5.4 (95% CI: 1.6 to 9.6; P=0.009, η^2=0.48), and index interference 6.0 (95% CI: 1.7 to 11.3; P=0.028, η^2=0.20) in the RT group (see Figure 1S. Index interference, supplemental file).

*****Figure 2 here*****

An ANCOVA analyses revealed a significant between HIIT vs control group on interference domain (group-workout interaction effect F=3.60, P=0.024, η^2=0.25), mean difference 11.7, (95% CI: 1.6 to 21.8; P=0.015) and colors naming (Group-workout interaction effect F=5.06, P=0.006, η^2=0.32), mean difference 7.7, (95% CI: 1.8 to 13.5; P=0.005).

*****Figure 3 here*****

Intent-to-treat analysis for d2 test performance at baseline and changes after acute effect are presented in Figure 4. The HIIT group elicit moderate to large improvements the concentration levels domain +21.7 (95% CI: 10.6 to 32.8; P=0.001, η^2=0.44), total performance domain +56.6 (95% CI: 29.0 to 76.2; P=0.001, η^2=0.50), and consistency domain -3.0 (95% CI: -5.3 to -0.8; P=0.010, η^2=0.27). These results were similar in RT and RT+HIIT group on concentration levels and total performance domain ($P<0.05$).

*****Figure 4 here*****

An ANCOVA analyses revealed a significant between HIIT vs control group on total performance (mean difference 44.8, 95% CI: 6.2 to 83.5; P=0.016) and RT vs control group (mean difference 43.4, 95% CI: 1.2 to 83.0; P=0.050), group-workout interaction effect (F=4.21, P=0.013, η^2=0.28), Figure 5.

*****Figure 5 here*****

DISCUSSION

To the best of our knowledge, this study is the first to investigate the acute effects of HIIT, RT and RT+HIIT modalities on executive function (cognitive inhibition and attention capacity*)* in inactive overweight men adults. The main findings were that HIIT and RT+HIIT training session reported moderate to large effect sizes than RT alone for cognitive inhibition and attention capacity. Between groups, results revealed that HIIT intervention led in change of Index Stroop interference (group-workout interaction effect F=3.60, P=0.024, η^2=0.25), and colors naming (group-workout interaction effect F=5.06, P=0.006, η^2=0.32) in comparison with the control group, while RT and HIIT group led to higher effect size in item processed domain (F=4.21, P=0.013, η^2 =0.28).

Existing evidence suggests that executive function can be temporarily altered by physical training (Barella, Etnier, & Chang, 2010; Dunsky et al., 2017; Hillman et al., 2009; Ludyga et al., 2016; Weng et al., 2015). 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 (Diamond, 2009; Miller, Barnes, & Beaver, 2011; Taylor Tavares et al., 2007). Among the different components of executive function (Diamond, 2013), the present study was focused on cognitive inhibition and attention capacity. Currently, several hypotheses may explain how exercise intervention may augment cognitive control functions: (1) regulation of neurotrophins (such as growth factors, brain-derived neurotrophic factor, neurotrophin-3, and neurotrophin-4/5); (2) increase in oxygen saturation due to increased blood flow and circulatory angiogenesis; and (3) increase in brain neurotransmitters (e.g., norepinephrine and serotonin) facilitating information processing [8,45]. 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 on several cognitive task categories including attention, information processing, and memory (Ludyga et al., 2016). Thus, aerobic exercise has been suggested to create a nutritive environment by facilitating cortical activity, hemodynamics, and metabolism (Ludyga et al., 2016). 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 (Barella et al., 2010; Hillman et al., 2009; Joyce, Graydon, McMorris, & Davranche, 2009). Consequently, acute benefits of exercise may be useful to prepare for situations demanding high executive function (Ludyga et al., 2016).

The magnitude of possible acute cognitive benefits has been reported to be exercise intensity dependent (Lambourne & Tomporowski, 2010; Wohlwend, Olsen, Håberg, & Palmer, 2017). In fact, a recent meta-analysis showed that the greatest benefits on executive function was identified during moderate aerobic exercise (McMorris & Hale, 2012). Similarly, Kamijo et al. found that more attentional resources were allocated to an executive function task after 20 min of moderate intensity exercise (Kamijo et al., 2007). 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 (Kamijo et al., 2009). Interestingly, our results revealed that HIIT displayed improvements on performance on Stroop tasks (reading, colors 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 (Alves et al., 2014). 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 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 combined training (RT+HIIT), RT and HIIT protocols, elicit large improvements in concentration performance ($p<0.05$). Some evidence support that RT ameliorates the performance of cognitive functions (Teresa Liu-Ambrose et al., 2010). Also, a previous meta-analysis identified that the greatest benefits on cognitive function were observed when aerobic exercise was paired with RT (Colcombe & Kramer, 2003). Thus, it has been suggested that there are mechanisms by which RT or HIIT could improve cognitive process (T Liu-Ambrose & Donaldson, 2009). 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 (Hill et al., 2008). Additionally, increases in catecholamine levels during HIIT can lead a preferential activation of the limbic system at the expense of the prefrontal lobes, causing a breakdown of performance on executive control tasks (Labelle, Bosquet, Mekary, & Bherer, 2013; McMorris et al., 2009). Pontifex et al. reported improvements in cognitive function following acute aerobic exercise but not RT in a population of young adults (20 years old) (Pontifex et al., 2009). It should also be emphasized that in this study the exercise intensity ranged from 60%–70% of VO_2max, whereas in our study 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 (Labelle et al., 2013). Further studies are needed to clarify the effect of different HIIT protocols as well as combined training including RT.

To date, most longitudinal studies have been focused on the effect of a single exercise training modality on cognitive function, mainly aerobic or resistance exercise. There is relatively little data regarding the combined effects of HIIT and RT on executive function (Coetsee & Terblanche, 2017). In the present study, acute HIIT session reported larger effect sizes (η^2=0.112) than RT (η^2=0.004) and combined intervention (η^2=0.018) for Index Stroop Interference. Along the same lines, HIIT and RT induced the largest gain in information processing speed (η^2=0.181) such as HIIT proved the greatest benefits for performance on the same domain (Stroop tasks naming (η^2=0.276)), and additionally in interference index (η^2=0.276) (Coetsee & Terblanche, 2017). 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 (Schmolesky, Webb, & Hansen, 2013) while RT or combined intervention produces increased levels of IGF-1 (Borst et al., 2001), both related with 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 (Bischof & Park, 2015). Although the mechanisms underlying the pathogenesis of obesity-induce cognitive decline are still unclear, brain atrophy, disruption in cerebrovascular function or systemic and central inflammation have been proposed as potential mediators (Nguyen, Killcross, & Jenkins, 2014). 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 4-month HIIT in obese adults improved cognitive function (Drigny et al., 2014). Nevertheless, since this study was focused on the chronic effect induced by HIIT and the aim of our study was to analyze 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 obesity and overweight populations.

Study strengths and limitations

Our study has both limitations and strengths. First, since the effects of exercise training on executive function are known to be affected by age, 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 generalizable to other populations with different characteristics. Another limitation could be the non-availability of data on other relevant factors such as timing of testing or task complexity. The main strength of our study is that, to our knowledge, this is the first randomized clinical trial to examine the acute impact of exercise training modalities on inactive overweight individual's executive function. In addition, this study was carried out in a well-characterized cohort and specific aspects of executive function including cognitive inhibition and attention capacity were investigated.

CONCLUSION

In summary, the novel findings of this study were that acute HIIT and RT+HIIT session reported moderate to large effect sizes than RT 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.

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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 training, Kcal	N.A	460.9 (86.7)	462.6 (74.9)	461.7 (59.1)
Bicep screw curl (1RM), kg	25.6 (11.6)	21.9 (10.3)	23.4 (7.9)	20.9 (6.9)
Triceps extension (1RM), kg	16.1 (5.7)	17.1 (4.9)	16.1 (5.3)	17.9 (4.0)
Dumbbell side lateral (1RM), kg	9.0 (1.9)	8.9 (1.9)	10.8 (3.6)	10.2 (3.3)
Military press (1RM), kg	25.8 (9.4)	22.8 (13.5)	23.0 (8.3)	19.0 (5.1)
Dumbbell squat (1RM), kg	47.8 (23.0)	53.3 (14.1)	55.0 (34.4)	52.8 (23.5)
Dumbbell front lunge (1RM), kg	28.4 (7. 7)	22.7 (6.6)	28.0 (16.2)	26.3 (10.7)
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; $\dot{V}O_2$max, cardiorespiratory fitness; 1RM, one repetition maximal; NA, not applicable.

FIGURE CAPTION

Figure 1. The BrainFit Trial Flow Diagram.

Figure 2. Pre and post training values between exercise interventions and control group (mean ± standard deviation) in reading, colors naming, interference condition and Index Stroop Interference at acute effect.

Figure 3. Mean difference values between exercise interventions and control group (mean ± standard deviation) in reading, colors naming, interference condition and Index Stroop Interference at acute effect.

Figure 4. Pre and post training values between exercise interventions and control group (mean ± standard deviation) in concentration levels, item process (performance), and % errors domain at acute effect.

Figure 5. Mean difference values between exercise interventions and control group (mean ± standard deviation) in concentration levels, item process (performance), and % errors domain at acute effect.

Supplemental file (Figure 1S)

Figure 1S. Pre and post training values between exercise interventions and control group (mean ± standard deviation) in Index interference at acute effect.