

Effects of Acute Physical Exercise on Executive Functions: A Comparison Between Aerobic and Strength Exercise

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The aim of this study was to compare the effects of acute aerobic and strength exercises on selected executive functions. A counterbalanced, crossover, randomized trial was performed. Forty-two healthy women were randomly submitted to three different conditions: (1) aerobic exercise, (2) strength exercise, and (3) control condition. Before and after each condition, executive functions were measured by the Stroop Test and the Trail Making Test. Following the aerobic and strength sessions, the time to complete the Stroop “non-color word” and “color word” condition was lower when compared with that of the control session. The performance in the Trail Making Test was unchanged. In conclusion, both acute aerobic and strength exercises improve the executive functions. Nevertheless, this positive effect seems to be task and executive function dependent.

Keywords: cognition, training, middle-aged adults

The term *executive function* generally refers to “higher-level” cognition, embracing a large variety of cognitive functions, such as working memory, planning, inhibition, and mental flexibility, as well as the initiation and monitoring of action (Chan, Shum, Touloupoulou, & Chen, 2008; Alvarez & Emory, 2006; Burgess, Veitch, de Lacy Costello, & Shallice, 2000). Interestingly, there is a consistent body of literature showing that an acute moderate-intensity exercise bout may improve specific executive functions (e.g., working memory and selective attention) as well as nonexecutive (e.g., processing speed) (McMorris, Sproule, Turner, & Hale, 2011; Yanagisawa et al., 2010; Pontifex, Hillman, Fernhall, Thompson, & Valentini, 2009; Lambourne & Tomporowski, 2010; Tomporowski, 2003; Brisswalter, Collardeau, & René, 2002).

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For instance, Yanagisawa et al. (2010) compared the cortical activation pattern during the Stroop Test (i.e., an executive function test of selective attention and conflict resolution) before and after an acute bout of moderate aerobic exercise (50% of $\text{VO}_{2\text{peak}}$) in healthy subjects aged 21 ± 5 years. As a consequence of the intervention, the authors observed an improvement in the Stroop Test performance, which was paralleled by an increased the dorsolateral prefrontal activation, as assessed by functional near-infrared spectroscopy. There is similar evidence suggesting that an acute bout of strength exercise may improve executive function. In this regard, Chang and Etnier (2009) found a significant improvement in the Stroop Test after an acute moderate-intensity strength exercise (10 sets of 10 repetitions for six exercises) session in healthy middle-aged (49 ± 9 years) adults. Altogether, these findings reveal the potential of both aerobic and strength exercise alone in improving executive functions. However, it is currently unknown whether one is more effective to this end.

In this respect, Pontifex et al. (2009) compared the influence of acute aerobic exercise *versus* acute strength exercise on executive control of working memory in healthy adults aged 20 years on average. The authors found a shorter response time latency during a working memory task after the acute aerobic exercise, whereas no effects were observed after the acute strength exercise. However, this study did not evaluate other important executive functions, such as selective attention and inhibitory control. Furthermore, the sample investigated was only comprised by young adults; this limits the generalizability of these findings to middle age and older adulthood. Therefore, a thorough comparison of aerobic and strength exercise effects remains precluded due to (1) the paucity of studies involving acute strength exercise; (2) the differences in executive functions investigated; and (3) the age differences of the participants, with very few studies involving middle-aged and late middle-aged adults.

Currently, strength exercises have been considered complementary to aerobic exercises in well-designed training programs aimed to improve strength, coordination, body composition, metabolic and cardiovascular parameters, self-esteem, and quality of life (Garber et al., 2011). However, little is known regarding the possible distinct effects of aerobic and strength exercises on executive functions. To gather knowledge on this topic, we compared the effects of acute moderate-intensity aerobic and strength exercises on selected executive functions in middle-aged adults (52 ± 7 years).

Methods

Subjects

To select a homogenous sample, subjects were recruited from a community-supervised physical fitness program comprised of twice-a-week, 90 min per session, combined aerobic and strength exercises. Participants had been engaged in this program from 3 to 9 months before entering in this study.

Forty-two women (among whom 36 were postmenopausal) took part in this study (descriptive characteristics are showed in Table 1). The participants were nonsmokers and none of them had depression or neuromuscular, cerebral, cardiovascular, respiratory, and color vision dysfunction at medical examination.

Table 1 Descriptive Characteristics of Subjects

Age (years)	52.0 ± 7.3
Body weight (kg)	66.3 ± 11.2
Height (cm)	158.7 ± 7.7
Body Mass Index	26.2 ± 3.8

Note. Data are expressed as mean ± standard deviation.

In addition, none of them were taking any drugs. All the participants were engaged in the community physical fitness program for at least 3 months.

The volunteers signed an informed consent form after they had received a verbal explanation about the procedures of the tests. The procedures were approved by the local ethics committee.

Study Design

This is a counterbalanced crossover randomized trial. All volunteers were required to perform one familiarization session on the cognitive tests and exercise protocols. Seven days after the familiarization session, the subjects randomly performed three experimental sessions separated by seven days each. All sessions were performed between 2 and 6 p.m. The interventions were (1) aerobic exercise, (2) strength exercise, and (3) control. Executive functions were measured by the Victoria version of Stroop Test (Spreen & Strauss, 1998) and the Trail Making Test (TMT) (Soukup, Ingram, Grady & Schiess, 1998). Each complete session of cognitive function tasks lasted about 5 min.

Executive Function Tasks

The Victoria version of Stroop Test is a short version of the Stroop Test that uses three conditions that consist in naming the color of dots (i.e., “color”), of neutral words (i.e., “non-color word”), and of color words printed in incongruent colors (i.e., “color word”), with each condition containing 24 items. This is a paper-based task with four different possible colors. In the Stroop “non-color word” and mainly in the Stroop “color word,” the normal tendency to read the word, rather than the color of the ink in which the words are printed, elicits a significant slowing in reaction time called the *interference effect*. Consequently, the Stroop Test is considered as a valid measure to assess selective attention (i.e., the prioritization of information for further processing) and the susceptibility to interference from conflicting stimuli (Bayard, Erkes, & Moroni, 2011; Sibley, Etnier, & Le Masurier, 2006; Alvarez & Emory, 2006; Spreen & Strauss, 1998; Stroop, 1935).

The Trail Making Test is one of the most commonly used tests in the assessment of inhibition function (i.e., the ability to suppress irrelevant or interfering stimuli or impulses). This test includes two conditions (i.e., “A” and “B”), where “A” condition reflects motor and visual control and “B” condition reflects the additional executive control needed to switch between number and letter sequences (Chang & Etnier, 2009; Arbuthnott & Frank, 2000). In the “A” condition, subjects are instructed to involve drawing a line to connect consecutively numbered dots from 1 to 25 in

a random pattern on a piece of paper. In the “B” condition, subjects are required to connect numbers and letters in a given sequence (e.g., 1—A—2—B—3—C). Subjects are considered unable to complete the test if they perform ≥ 7 errors in either “A” or “B” conditions.

Performance in both tests is assessed based on the time (seconds) to complete each condition and the number of errors. To provide further insight into the effects of the exercise interventions upon the executive functions, the following ratios are calculated: TMT “B”/“A”, Stroop “non-color” word/“color,” and Stroop “color word”/“color” (Arbuthnott & Frank, 2000; Spreen & Strauss, 1998).

Exercise Protocols and Control Condition

All test sessions were monitored by a trained fitness professional and conducted in the same locale. Heart rate (HR) was monitored during all exercise protocols and registered before and immediately after each cognitive testing session by HR monitors (Polar). The acute aerobic exercise was composed of 30 min of walking and the intensity was set at the corresponding HR between 50–60% of the HR reserve. The maximal HR used to calculate the reserve HR was determined according to Tanaka, Monahan, & Seals (2001). The acute strength exercise consisted of two sets of 15 maximal repetitions for six exercises (i.e., chest press, leg press, lat pull-down, leg extension, squat, and sit-ups). A 1-min interval was allowed between sets. The rating of perceived exertion (RPE) was measured using a validated scale (Robertson et al., 2003). The strength exercise session lasted 30 min. The control session (designed to be an active-comparator session) comprised 15 min of instructions about the benefits of regular exercise training on overall health (e.g., quality of life, cardiovascular function, weight management, physical capacity), followed by 15 min of low-intensity active stretching exercise. No specific instructions about the benefits of exercise training on cognition were provided.

Statistical Analysis

After the normality and homogeneity of the variance were confirmed, the dependent variables were compared using a 2×3 mixed model (SAS 8.2, SAS Institute Inc., Cary, NC, USA). “Time” (i.e., pre- and postexercise) and “exercise type” (i.e., aerobic, strength, and control conditions) were considered as fixed factors and “subjects” were defined as a random factor. Possible order effects were also tested by a 2×3 mixed model with “time” (i.e., pre- vs. postexercise) and “sessions” (i.e., 1, 2, and 3) considered as fixed factors and “subjects” defined as a random factor. The mixed model is similar to repeated-measures ANOVA. However, mixed models allow modeling the correlation between measurements in the same experimental unit, while regular repeated-measures ANOVA assume a constant correlation between measurements. In addition, means and standard error estimates derived from mixed models are more precise than those from regular ANOVA (Ugrinowitsch, Fellingham & Ricard, 2004). Single-degree-of-freedom contrasts were used to determine whether the means significantly differed between sessions for Stroop Test performance (time and errors), TMT (time and errors) and HR. Cohen’s d (for time effect), F values, and partial eta-squared (η^2) (the latter two for interaction session by time) were used to determine the effect size of cognitive tests. Data are

expressed as mean \pm standard deviation. The level of significance to reject the null hypothesis was set at $p < .05$.

Results

As expected, no order effect was observed for any dependent variable (time to complete and numbers of errors) for Stroop “color” ($F_{(2, 123)} = 2.40, p = .09$ and $F_{(2, 123)} = 0.96, p = .38$, respectively), Stroop “non-color word” ($F_{(2, 123)} = 1.08, p = .34$ and $F_{(2, 123)} = 1.69, p = .18$, respectively), and Stroop “color word” ($F_{(2, 123)} = 1.74, p = .18$ and $F_{(2, 123)} = 1.69, p = .19$, respectively), as well as TMT “A” ($F_{(2, 120)} = 0.06, p = .94$ and $F_{(2, 120)} = 1.25, p = .29$, respectively) and TMT “B” ($F_{(2, 90)} = 1.15, p = .32$ and $F_{(2, 90)} = 2.91, p = .07$, respectively).

As showed in Table 2, HR was significantly higher after the aerobic exercise session when compared with strength exercise ($p < .0001$), and control sessions ($p < .0001$), whereas HR was higher after strength session vs. control session ($p < .0001$). The RPE average for each strength exercise was 8.6 ± 1.3 .

Table 2 Mean Resting and Maximal* Heart Rates (HR) and the HR Immediately After Each Experimental Condition, in Beats per Minute (bpm)

Resting HR (bpm)	67.8 \pm 11.3
Maximal HR (bpm)	170.9 \pm 4.7
HR after the aerobic exercise (bpm)	128.6 \pm 8.8
HR after the strength exercise (bpm)	110.4 \pm 20.8
HR after the control condition (bpm)	78.9 \pm 11.7

*Estimated according to previous descriptions (Tanaka, Monahan, & Seals, 2001).

Figures 1 and 2 illustrate data regarding the Stroop Test and TMT, respectively. There were no main effects or interactions among aerobic (Cohen’s $d = -0.46$), strength (Cohen’s $d = -0.33$) and control sessions (Cohen’s $d = 0.05$) ($F_{(2, 123)} = 5.68, \eta^2 \leq 0.01, p = .53$) for time to complete Stroop “Color.” However, there were significant interactions for both the Stroop “non-color word” and “color word” ($F_{(2, 123)} = 29.7, p < .001$, and $F_{(2, 123)} = 17.82, p < .001$, respectively). Post hoc analysis revealed that after the aerobic (Cohen’s $d = -0.97$) and strength (Cohen’s $d = -0.33$) exercises sessions, the time to complete the Stroop “non-color word” was significantly lower when compared with that of the control (Cohen’s $d = 0.08$) ($p = .0002, \eta^2 = 0.08$ and $p = .02, \eta^2 = 0.03$, respectively). Moreover, after the aerobic (Cohen’s $d = -0.78$) and strength (Cohen’s $d = -0.71$) exercises sessions, the time to complete the Stroop “color word” was lower when compared with that of the control (Cohen’s $d = 0.01$) ($p = .007, \eta^2 = 0.04$ and $p = .009, \eta^2 = 0.04$, respectively). However, no significant difference between aerobic and strength exercises sessions was observed for “Color” ($p = .95, \eta^2 = 0.00$), “non-color word” ($p = .12, \eta^2 = 0.01$), and “color word” ($p = .94, \eta^2 = 0.00$).

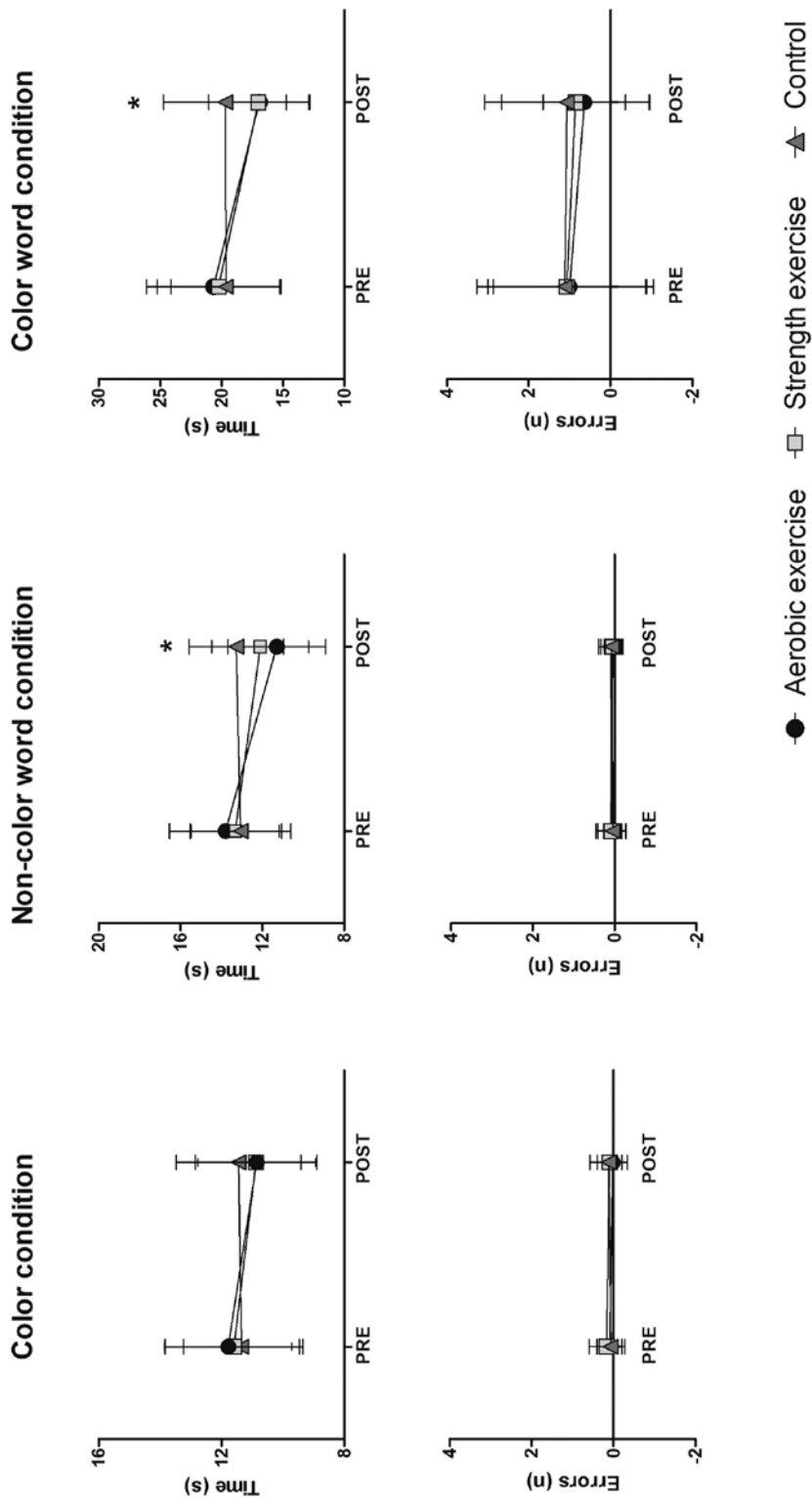
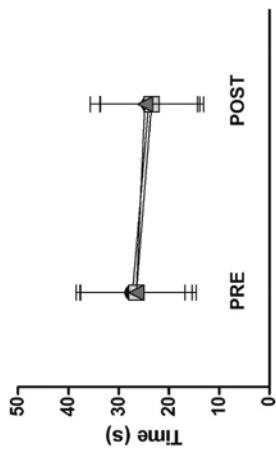
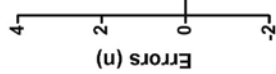
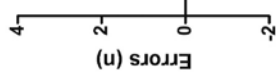
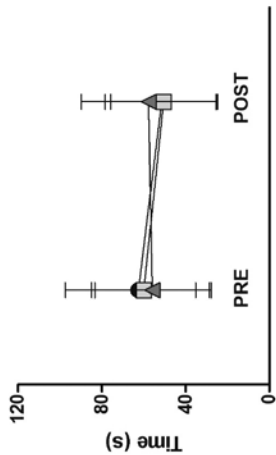


Figure 1 — Stroop test performance. *Significant differences after aerobic and strength exercise in comparison with control.

Trail A



Trail B



● Aerobic exercise □ Strength exercise ▲ Control

Figure 2 — Trail making test performance. No significant differences were found between the three experimental conditions for any variable.

Corroborating the previous findings, there were significant interactions for both the Stroop “non-color word”/“color” ratio and Stroop “color word”/“color” ratio ($F_{(2, 123)} = 6.49, p = .002$, and $F_{(2, 123)} = 4.2, p = .01$, respectively). Following the aerobic (Cohen’s $d = -0.85$) and strength (Cohen’s $d = -0.31$) sessions, Stroop “non-color word”/“color” ratio was significantly lower than that of the control (Cohen’s $d = 0.09$) ($p < .001, \eta^2 = 0.10$ and $p = .03, \eta^2 = 0.04$, respectively). In addition, after the aerobic (Cohen’s $d = -0.50$) and strength (Cohen’s $d = -0.49$) exercises sessions, the Stroop “color word”/“color” ratio was lower when compared with that of the control (Cohen’s $d = -0.01$) ($p = .02, \eta^2 = 0.02$ and $p = .03, \eta^2 = 0.04$, respectively). Aerobic and strength sessions were comparable as regards both the Stroop “non-color word”/“color” ratio ($p = .25; \eta^2 = 0.00$) and Stroop “color word”/“color” ratio ($p = .91, \eta^2 = 0.00$).

The number of errors was not significantly different among aerobic (Cohen’s $d = -0.01, 0.00$ and -0.40), strength (Cohen’s $d = -0.02, -0.05$, and -0.21) and control (Cohen’s $d = 0.00, 0.02$, and -0.05) sessions with respect to the Stroop “color” ($p = .73, F_{(2, 123)} = 0.31, \eta^2 \leq 0.01$), “non-color word” ($p = .53, F_{(2, 123)} = 0.63, \eta^2 \leq 0.01$), and “color word” ($p = .68, F_{(2, 123)} = 0.39, \eta^2 \leq 0.01$), respectively.

Thirty-one voluntaries were able to complete the TMT “B” condition. No significant differences were observed between the three experimental conditions with respect to the time to complete the TMT “A” and “B” conditions ($p = .94, F_{(2, 120)} = 2.4$, and $p = .96, F_{(2, 90)} = 5.7$, respectively). The number of errors was not significantly different after TMT “A” ($p = .09, F_{(2, 120)} = 2.41$) and “B” conditions ($p = .30, F_{(2, 90)} = 1.19$). There were no main effects or interactions among aerobic (Cohen’s $d = -0.11$), strength (Cohen’s $d = -0.11$) and control sessions (Cohen’s $d = 0.24$) ($F_{(2, 90)} = 1.36, \eta^2 \leq 0.01, p = .26$) for time to complete as regards the TMT “B”/TMT “A” ratio.

Discussion

To our knowledge, this is the first study to compare the acute effects of aerobic vs. strength exercise on selected executive functions in healthy middle-aged women. Our main finding was that both exercise types can improve the performance in two conditions of the Stroop test, Victoria version. On the other hand, both exercise types were unable to improve the performance in TMT, suggesting that the benefit of acute exercise may be task dependent.

As expected, the aerobic exercise promoted a beneficial effect (with medium-to-large effect sizes) on the Stroop Test performance. These data corroborate previous findings in literature (Hogervorst, Riedel, Jeukendrup, & Jolles, 1996; Yanagisawa et al., 2010) and support the hypotheses that moderate aerobic exercise can lead to improvements on speed processing and aspects of inhibitory control (Kashihara, Maruyama, Murota, & Nakahara, 2009). We also noted a similar improvement with strength exercise in the Stroop Test “non-color word” and “color word” conditions, but not in the Stroop test “color” condition. Both “non-color word” and the “color-word” conditions are “executive” because, as compared with the “non-executive” (i.e., “color” condition), they involve interference control, even though at a different degree, with the “color-word” being the executively most challenging condition. Thus, altogether these findings corroborate the speculation that the benefit of acute exercise may be cognitive task dependent (Tomprowski, 2003), with exercise

effects being more pronounced in executive functions, particularly those related to selective attention and susceptibility to interference (i.e., Stroop “non-color word” condition and Stroop “color word condition”) than in nonexecutive functions (i.e., Stroop “color” condition).

As opposed to our findings, Pontifex et al. (2009) did observe improvements on a working memory task after an acute aerobic exercise session, but not following a strength exercise bout, suggesting that only the former can beneficially affect the working memory in young adults. According to the authors, such a speculation is supported by the fact that moderate-intensity aerobic physical activities may substantially increase the cerebral blood flow (Ide & Secher, 2000), whereas there is evidence that strength exercise may elicit lower levels of blood flow and oxygen consumption (at least at the skeletal muscle level) (Pontifex et al., 2009; Rowland & Fernhall, 2007). However, caution should be exercised in concluding that acute aerobic exercise is more effective for improving cognition than strength exercise since strength exercise–induced improvements in selective attention tasks have been demonstrated in the current study and in others (Chang & Etnier, 2009).

These abovementioned findings are hard to reconcile, but age differences between the studies (i.e., young adults in the Pontifex study vs. middle-aged adults in the current study) might account for these conflicting outcomes. In this respect, one should note that the current study is one of the few studies to investigate the role of acute exercise in older population. Importantly, the present results support the beneficial effects of exercise seen in younger populations and extend this notion to older individuals. Moreover, it is possible that cognitive task differences may partially explain some contradictory results regarding the efficacy (current study and Chang’s study) or not (the Pontifex et al. study) of strength training upon cognitive performance. For instance, it has been shown that tasks requiring shifting of attention activate the parietal lobes and left dorsolateral prefrontal cortex, whereas working memory processes activate the superior frontal cortex (McMorris, Sproule, Turner, & Hale, 2011). Indeed, additional studies need to compare the role of strength and aerobic exercise on a broader range of cognitive aspects as well as the (distinct) mechanisms underlying these exercise types. The possible combined effects of both aerobic and strength exercises also remain to be explored.

It is also important to note that neither strength nor aerobic exercise improved the performance in TMT. These findings are in accordance with previous reports about acute strength exercise (Chang & Etnier, 2009) and the current study extends this knowledge to aerobic exercise as well. Even though some components of both Stroop (i.e., “color word” and “non-color word” conditions) and TMT (i.e., “B” condition) tests are thought to evaluate the same executive functions, it has been suggested that the TMT “B” condition could primarily represent a function described as task-set inhibition, which requires the ability to shift the attention and to inhibit current task goals (Arbuthnott & Frank, 2000). Conversely, the Stroop test “non-color word” and “color word” conditions do not specifically assess inhibition but rather measure the susceptibility to interference from conflicting stimuli (Sibley, Etnier, & Le Masurier, 2006). In support of this hypothesis, Sibley et al. (2006) were able to distinguish between inhibition and interference functions in the Stroop test by using an additional negative priming task. These authors observed a significant exercise-induced improvement in the Stroop “interference task,” but not in the Stroop “inhibition condition.” These findings would help explain why only

the Stroop test was beneficially affected by exercise whereas the TMT remained unchanged. Alternatively, one cannot rule out the hypothesis that the TMT was less sensitive than the Stroop test in detecting exercise-induced changes on executive functions in our sample.

On the whole, both acute aerobic and strength exercise equally improved selected executive functions (i.e., selective attention and susceptibility to interference) in middle-aged women. Future studies should clarify which executive functions can be more influenced by exercise training, as well as the most valid measures to assess cognition in exercised subjects.

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