RESEARCH ARTICLE

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Cognitive Function in Response to an Acute, High Intensity Exercise-Does Gender Plays a Role?

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ABSTRACT

The growing evidence favoring the positive effect of exercise on cognition is mostly based on men participants (75%). We therefore exposed females and males to acute exercise and evaluated gender cognitive response to this intervention.

Thirty- two adults (M=17; F=15) ages 18-34 participated in the study. The exercise consisted of ten repetitions: 10 seconds sprints at maximal speed, followed by 50 seconds active recovery. Stroop test (ST) 1-3; Trail-making test (TMT) 1-2; Word fluency were evaluated prior to; immediately post exercise; and at 45' recovery. Two-way ANOVA with repeated measures (three test points X 2 gender groups) was used to test the effect of exercise on cognitive performance.

All participants reached close to maximal heart rates at the end of the 10th sprint round. Stroop 1- 2 results improved for both males and females from pre to post exercise (p<0.01). After 45' males returned to pre-exercise while females retained high values. For Stroop 3 both genders improved from pre to post (p<0.01) and retained high values after 45'. For TMT-1 males showed no response while females' results improved immediately and at 45' post intervention (p<0.01). For TMT-2 both genders improved after exercise (p<0.01); however, only females continued improving at 45' recovery. Word fluency was positively affected by exercise in males only.

Acute bout of exercise has a positive immediate effect on cognitive performance both in males and females; whereas males returned to pre-intervention values at 45' min recovery, females retained the positive effect of exercise also after 45 minutes.

Keywords: cognitive performance, exercise intervention, gender cognitive response.

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I. INTRODUCTION

There is growing evidence favoring the positive effect of exercise on brain health and cognition in a wide range of age groups (Hillman *et al*., 2014) as well as reducing the risk of cognitive decline with age (Hillman *et al*., 2006.).In preadolescent children (Sallis, 2010; Donnelly *et al*., 2016), in youth (Hillman *et al*., 2009; Esteban-Cornejo *et al*., 2015), in young adults (Chang & Etnier, 2009), and among the elderly populations (Colcombe & Kramer, 2003), however the magnitude and consistency of this benefit varies among different populations.

Executive function (EF) is a broad aspect of cognition which refers to various high scale cognitive actions that accord with internal goals. Among others, it refers to working memory, planning, judgement, organization, governing emotions, and problem solving and inhibition of automated response-an index of cognitive flexibility (Tomporowski *et al*., 2008; Tomporowski *et al*., 2011).

Erickson and colleagues conducted a broad review studying the strength and weakness of scientific evidence regarding the beneficial effect of exercise and physical activity (PA) on cognitive performance, especially on executive functions, in various groups of age. (2018 Health and Human Services Physical Activity Guidelines for Americans Advisory Committee) (Erickson *et al*., 2019). In children 6–13 years moderate evidence exist regarding the effect of acute and chronic moderate-to-vigorous PA interventions to improve brain structure and function, as well as cognition; limited evidence exist for children 14–18 years both in quantity and quality (Li *et al*., 2017); and insufficient evidence to determine the effects of moderate-to-vigorous PA on cognition in young adults 18-50 years of age (Erickson *et al*., 2019). Interventions of aerobic exercise, resistance training, and multicomponent training all had significant implications and improved cognitive function in the over 50s, regardless of the cognitive status of participants (Northey *et al*., 2018).

When reviewing the literature on acute exercise and cognition there is strong evidence for a transient improvement during the post-recovery period (Erickson *et al*., 2019). However, there is still a debate among researchers regarding the optimal intensity and duration of the exercise session that will best affect cognitive performance. It is also questionable, what is the optimal time interval between the any exercise session and a cognitive task performance.

Higher scores for cognitive results were reported after 30 minutes of both aerobic and resistance exercise, as compared to the non-exercise session, in high school students (Harveson *et al*., 2016).

Interestingly, 30-minute exposure to the Loughborough Intermittent Shuttle Test had a greater beneficial effect compared to the 60-minute bout on a battery of cognitive testing (Cooper *et al*., 2019). Similarly, Chang and colleagues reported greatest improvement in accuracy and response time after 20 minutes aerobic exercise, as compared to 10-and 45-minutes duration (Chang *et al*., 2015a).

Since adolescent period is characterized by rapid development of the brain, the influence of exercise on brain health and function may play a significant role in future neural and cognitive outcomes (Megan and Xiaofang, 2017).

The time interval between termination of exercise and cognitive challenge is also debatable. According to Cooper and colleagues' response times for the simple level of the Stroop test were significantly quicker 45 minutes after exercise, whereas for the complex stage, response times were quicker immediately following exercise (Cooper *et al*., 2016). In contrast, Samuel and colleagues (2017) exposed young subjects to maximal aerobic test and reported reduction in complex tasks performance immediately after the exercise bout which then returned to baseline after one hour of rest.

When studying the cognitive response to the exercise stimuli, one should also consider the intensity of the exercise session relative to one's aerobic capacity. In a previous study from our laboratory, we therefore evaluated the effect of aerobic exercise, adjusted to the maximal power of each subject, on a battery of executive function tests (Pilz-Burstein *et al*., 2020). Based on our findings acute exercise at 70% of initial maximal aerobic power positively affects some executive functions in young, male adults; complex cognitive tasks were affected to a greater extent compared to the simple ones. When considering the absolute aerobic capacity of participants, higher concentrations of blood BDNF were analyzed in subjects who had higher VO2 peak following an acute bout of aerobic and resistance exercise of (Dinoff *et al*., 2017).

To summarize, literature is broadly discussing children, adolescents, and older adults' response to an exercise intervention, but there is less evidence on the effect of exercise on cognition in young and middle-aged adults (18–50 yrs) (Erickson *et al*., 2019). Moreover, quite surprisingly, 75% of participants across studies are male (Dinoff *et al*., 2017) thus, sex differences with regard to cognitive response to the exercise stimulus have not been widely studied.

In this study we therefore focused on the effect of acute moderate-intense exercise on cognitive performance in a young, middle-age group of women and men , and raised the question whether gender plays a role in this intervention.

II. Materials and Methods

A. *Participants*

Thirty-two young adults, B.Ed. students, 17 males and 15 females participated in the study. They were selected based on the following inclusion criteria: age range 18–35 years, good health conditions, maintaining an active lifestyle, and none of them participated in any top competitive sport. After presenting the purpose and details of the study, each participant completed a health status questionnaire and then signed a written informed consent. The study protocol was reviewed and approved by the ethic committee of the institution.

B. *Design and Procedures*

Participants visited the field study site once.

Upon arrival, the subject was cited for a 10-minute rest before the study protocol was applied. All tests were performed between 17:00-19:00 hours in the training field of the Givat Washington Academic Education College.

C. *Exercise Protocol*

Exercise protocol consisted of 10 seconds sprints at maximal speed, followed by 50 seconds of active recovery, walking at a relatively fast pace. Ten consecutive repetitions of this protocol were performed by each subject.

D. *Cognition Testing:*

To evaluate cognitive performance, we applied a battery of three executive function (EF) tests: Stroop test (ST) parts 1–3; Trail-making test (TMT) parts 1–2; and Word fluency.

1) The ST (Stroop, 1935) is based on three tasks, 60 seconds each. For the first and the simplest task, participants were asked to read color words printed in Hebrew letters in black ink. Twenty words are set in each of five vertical columns. For the second task, subjects were instructed to read the colors of symbol XXX printed in blue, green and red that appear again in five 20 words each vertical column. For the third and most complicated task, subjects were presented with color words but the word that expressed the color was printed in a different color. For example, the word green was printed in blue ink. Participants were instructed to read laud the color and not the printed word. In all three stages words should be read from top to bottom and from right to left. Parts 1-2 of the Stroop test evaluate processing speed; part 3 raises a conflict between the reflexive response: reading the word, and the naming of the ink color. Thus, as stated by Barella et al., it evaluates response inhibition which is one of executive function parameters (Barella *et al.*, 2010). The ST is a validated tool and has been widely used in research for assessing selective attention and cognitive flexibility.
2) The Trail- making test (TMT) consists of two parts: in part 1 participants are asked to draw lines that connect between 25 circled numbers. In part 2, participants are instructed once again to draw lines but this time they alternate between numbers and letters (e.g., 1, A, 2, B, 3, C, etc.). Since our participants are non-English speakers, the test which includes alphabetic may impose some limitations as previously mentioned by Kim and colleagues (2014). Thus, we slightly adjusted Kim's concept and used a similar version with yellow and pink rather than the black and white colors. In our study, subjects were instructed to draw a line between 25 circled numbers, alternating between the two colors. For completing the TMT, subjects need to rapidly shift between two lanes of thoughts reflecting the ability for scanning speed, processing information and cognitive flexibility (Salthouse, 2011).
3) The Word fluency test (Brucki & Rocha, 2004) is based on three English letters: F, A, S, and participants are asked to state as many words as possible that start with those letters within 60 seconds. Names, and numbers cannot be included, and verbs can be mentioned ones only for every letter. Again, considering the limitations of non-English speakers' participants, we substituted to Hebrew letters that sound like B, G and P instead of the original English letters. The Word fluency test reflects semantic memory and language.

E. Measurements

1) Heart rate (HR) was measured using the Polar Watch at time 0 after 10 minutes rest at a sitting position. Then HR was measured prior to and immediately at the end of every 10 second's sprint.
2) Rate of Perceived Exertion (RPE) based on the Borg Scale (Borg, 1982) was documented twice: after the 5^{th} and after the 10^{th} sprints to evaluate the subjective sensation of the subject to the exercise performed.
3) Cognitive testing was performed 3 times for each participant: Firstly, upon arrival after 10 minutes of rest and HR measurements; secondly, immediately upon termination of the sprint's performance; thirdly, at 45 minutes recovery, after sprints termination.

III. Statistical Analysis

The IBM SPSS version 26 was used to analyze the data. Each depended on variable was examined for normality assumption via skewness (<[2.0]) and kurtosis (<7.00) procedures The mean differences among male and female at the pre-intervention stage were tested by an independent t-test. A mixed Repeated Measures (RM) analysis of variance (ANOVA) analysis (three test points X 2 gender groups) was used to test the effect of an acute moderate-intense exercise on immediate and delayed (45 min) cognitive performance. Two sets of paired t-test were conducted as a post hoc test, to examine the immediate effect (pre-post) and the delayed (pre–45 min) effect of the exercise intervention.

Cohen's d coefficients were calculated to reveal the standardized differences between means when effects reached significance level (p<0.05). Cohen's d<0.30 was considered a low effect; 0.30–0.70 a moderate effect, and>0.70 was considered a strong effect.

IV. Results

First, pre-intervention gender was examined using a set of independent samples t -tests. The analyses revealed no differences between male and female in all variables except for the Word fluency test. Stroop 1, t(30)=--0.34, P=0.74, d=-0.12, Stroop 2, t(30)=-0.46, P=0.65, d=0.16, Stroop 3, t(30)=-0.91, P=0.37, d=-0.32, Trail- making test 1 t(30)=-1.17, P=0.25, d=0.41, Trail- making test 2, t(30)=-0.12, P=0.90, d=0.04, Word fluency test, t(30)=-2.04, P=0.05, d=0.72.

Both males and females reached close to maximal heat rates at the end of the 10^{th} running round. This finding and the Rate of Perceived Exertion- RPE at the end of the effort (range 16–20 males, 13–20 females) indicates that the exercise stimulation was at a high level of effort for both sexes. No significant differences were found between the sexes in resting HR, final heart rate, and RPE at the 5th running round. Unexpectedly, the mean RPE of the women's group after the 10th running round was lower than the men's group (see Table I).

TABLE I: DECEPTIVE STATISTICS (MEANS AND SD) OF RPE RATING AND HR BY GENDER

	Male		Female			
	M	SD	M	SD	t	d
Rest HR	63.90	±6.57	63.50	±8.26	0.11	0.05
LAST_HR	176.29	±13.22	180.47	±8.98	-1.03	-0.37
RPE 5	14.88	±1.69	14.13	±2.07	1.13	0.40
RPE 10	18.06	±1.14	16.47	±2.07	2.74**	0.97

Next, we conducted a two-way analysis of variance with repeated measures for all the dependent variables. Descriptive statistics is presented in Table II and Inferential statistics is presented in Tables III and III:

TABLE II: DECEPTIVE STATISTICS (MEANS AND SD) FOR COGNITIVE PERFORMANCE BY GENDER OVER TIME

Gender	Male			Female		
Time	PRE	Immed. - Post	45' Recovery	PRE	Immed. - Post	45' Recovery
Test						
Stroop 1	145.59±(14.2)	152.12±(14.3)	146.76±(19.6)	147.60±(19.1)	159.40±(19.4)	152.87±(18.5)
Stroop 2	98.94±(11.9)	107.41±(15.7)	102.24±(13.5)	96.67±(16.3)	112.40±(26.9)	103.00±(19.6)
Stroop 3	61.24±(11.9)	71.88±(12.7)	71.47±(9.6)	65.27±(13.3)	73.13±(13.2)	71.80±(14.1)
Trail- making test 1	29.76±(7.1)	25.29±(8.3)	25.65±(10.0)	26.73±(7.6)	23.53±(5.3)	21.80±(7.3)
Trail- making test 2	65.29±(17.3)	54.53±(15.0)	54.94±(14.4)	64.47±(20.6)	56.80±(13.6)	52.07±(13.4)
Word fluency test	15.53±(4.3)	18.18±(3.9)	16.47±(4.1)	12.73±(3.2)	14.20±(3.4)	14.20±(5.1)

TABLE III: INFERENTIAL STATISTICS FOR COGNITIVE PERFORMANCE BY GENDER

Factor	Time			Gender			Time *gender		
Test	*F*	*P*	η^2	*F*	*P*	η^2	*F*	*P*	η^2
Stroop 1	11.97	0.00	0.29	0.773	0.386	0.025	1.06	0.35	0.03
Stroop 2	8.11	0.00	0.21	0.049	0.826	0.002	0.73	0.49	0.02
Stroop 3	14.42	0.00	0.32	0.238	0.629	0.008	0.51	0.60	0.02
Trail- making test 1	5.56	0.01	0.16	1.754	0.195	0.055	0.26	0.77	0.01
Trail- making test 2	11.36	0.00	0.27	0.010	0.922	0.000	0.52	0.60	0.02
Word fluency test	3.18	0.05	0.10	7.733	0.01	0.205	0.568	0.57	0.02

The results in Table II revealed significant time effect, nonsignificant gender effect except for Word fluency test and non-significant interaction effect for all dependent variables. These findings indicate that acute moderate-intense exercise had a similar effect on boys and girls over time.

Post-hoc for the time effect was conducted by 2 sets of paired t- test for males and female separately. The first t-test examined the immediate effect of the exercise (pre-post) and the second examined the delayed effect of the exercise (pre- 45 min). The results are presented in Fig. 1.

Stroop 1 results show that both male and female improved significantly from pre to post test *(male t=-2.86, p=0.01, d=-0.69, female t=-5.37, p<0.01, d=-0.-1.39)*. After 45' minutes recovery, males returned to pre-values t=*-0.36, p=0.72, d=-0.09*) while females retained high values compared to the pre-intervention results (*t=-1.91, p=0.08, d=-0.49)*.

Stroop 2 results show the same trend. Both males and females improved significantly from pre to post test *(male t=-3.19, p=0.01, d=-0.77, female t=-2.50, p=0.03, d=-0.-0.65)* and after 45' minutes recovery, males returned to pre values *t=-1.43, p=0.17, d=-0.35*) whereas females retained high values (*t=-2.55, p=0.02, d=-0.66)*.

Similar pattern for males and females was observed for the Stroop 3 results. Both genders improved from pre to post *(male t=-6.25, p<0.01, d=-1.52, female t=-1.96, p=0.07, d=-0.-0.51)* and retained high values after 45 min recovery, (*male t=-4.48, p<0.01, d=-1.09, female t=-1.82, p=0.09, d=-0.-0.47*).

The results for the Trail- making test part1 revealed different exercise effect for males and females. Males showed no immediate or delayed response to the exercise stimulus *(t=1.89, p=0.08, d=0.49)* while for female the results showed significand immediate *(t=2.64, p=0.02, d=0.68*) and significant delayed effect of the intervention *(t=3.44, p<0.01, d=0.89*)

The results for the Trail- making test part 2 revealed a significant immediate and delayed effect of exercise in males (*pre-post t=4.08, p<0.01, d=0.98, pre-45 min t=3.13, p=0.01, d=0.76)*; for females while the immediate exercise effect was marginal *(t=1.89, p=0.08, d=0.49)* they continued improving results so that the delayed effect was significant *(t=2.62, p=0.02, d=0.68)*. It is worth mentioning that for Trail making tests 1 and 2 the positive effect of exercise in the female group continued after 45 min of recovery.

The results for the Word fluency test revealed significant immediate exercise effect for males *(t=-2.29, p=0.04, d=-0.56)* which did not remain at 45 min recovery *(t=-0.67, p=0.51, d=-0.16)*. Exercise intervention had no effect on the female group immediately nor at 45 min recovery *(pre-post t=-1.70, p=0.11, d=-0.44, pre-45 min t=-1.25, p=0.23, d=-0.32)*.

We conducted personal correlation between RPE at the end of the 10th exercise round and the cognitive performance to check if the degree of subjective feeling of the effort has some relation to the change in post-exercise cognitive performance. The low correlation observed: [$r_{(stroop1)}$=-0.30; $r_{(stroop2)}$=-0.18; $r_{(stroop3)}$=-0.30; $r_{(Trail\text{-}making1)}$=-0.07; $r_{(Trail\text{-}making2)}$=0.06; $r_{(Word\ fluency)}$=-0.37]may suggest that the sensation of the exercise effort has only a minor effect, if at all, on performance.

Based on the present results we may conclude that acute-moderate bout of exercise has a positive immediate effect on cognitive performance as indicated by the Stroop, Trail making both in males and females and by-Word fluency test in males only. Whereas males returned to pre-intervention values at 45' min of recovery, females retained the positive effect of exercise also after 45 minutes. Whether the beneficial effect of the exercise session in females continued for a longer period of time still remains to be studied.

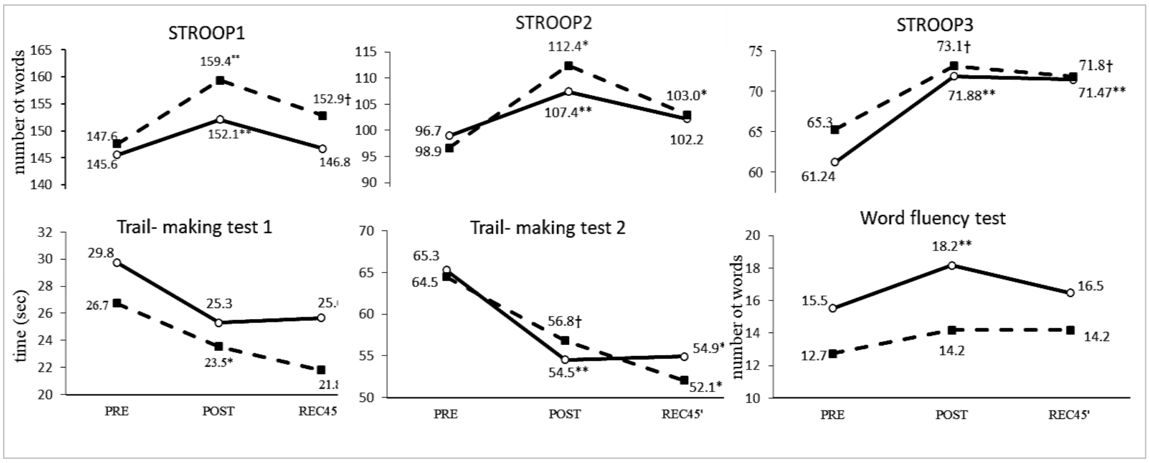

Fig. 1. Cognitive performance over time by gender. **p*<0.05 ** *p*<0.01 marginal difference (0.06-).

V. Discussion

In the present work we studied the acute effect of a moderate-intense exercise intervention on cognitive performance in a group of young middle-aged subjects. We focused on specific reaction of women and men aiming to answer whether gender plays a role in response to the exercise intervention.

The exercise stimulation was based on a short version of the Loughborough Intermittent Shuttle Test where subjects, both females and males reached close to maximal heat rates at the end of the 10th running round (range 155-206 beats/min). This high intensity effort was reflected also by subjective sensation as indicated by the Rate of Perceived Exertion- RPE (range 13–20) where unexpectedly, the mean RPE of the women's group was lower than the men's group. Summarizing the results of the cognitive testing battery we may conclude that short, moderate-intense bout of exercise positively affects a series of executive functions both in females and males, when performed immediately after the exercise session. The challenging Stroop test 3, for example, raises a conflict between the reflexive response: reading the word, and the naming of the ink color, it therefore evaluates response inhibition which is an index of executive function (Barella *et al*., 2010, Scarpina & Tagini, 2017). Similarly, the Trail making test-TMT where subjects are maintaining two lanes of thoughts simultaneously and shift between the two as fast as possible, reflects information on visual scanning, speed of processing, and mental flexibility, thus mirrors another executive function skill (Salthouse, 2011).

As has been previously reported in the literature, the beneficial effect of the exercise stimulus differs between studies and is related to the exercise duration, exercise intensity, type of cognitive performance assessed, and participants fitness level (Chang *et al*., 2012) It also relates to the time interval between the end of exercise and the cognitive challenge. In our study, best results in the Stroop tests were achieved for both women and men immediately upon exercise termination. This partly accords with Cooper and colleagues reporting that for the complex stage of the Stroop test, response times were quicker immediately following exercise (Cooper *et al*., 2016). Yet, these findings contradict with others that found impaired performance when tests were applied immediately after the exercise bout and returned to baseline only after one hour rest (Samuel et al., 2017).

When considering practical implications of the exercise benefits on cognitive performance, one should also analyze the duration of this effect. In agreement with others, duration of the positive effect of intervention is related to the level of task complexity. In the more complicated level 3 Stroop enhanced performance has been maintained also after 45 minutes of recovery by both women and men. However, in the men's group this was not the case in the less challenging cognitive targets. Here gender differences should be highlighted: in females only, in Stroop 1–2 which is the less challenging target, improved performance compared to the pre-intervention results was obtained also at 45 minutes recovery. Moreover, for TMT 1-2, further improvement has been recorded as indicated by the results at 45 minutes compared to those upon exercise termination. None of these responses have been seen in the men's group. It may thus be of interest to follow up cognitive achievements among females for a longer recovery period in order to trace the duration of the exercise impact on cognition.

Difference between genders was observed also in semantic memory and language as reflected by the Word fluency test. Controlled Oral Word Association Test (COWAT) relates to a number of executive functions that are known to improve throughout childhood and into adulthood. Unlike similarity in pre-exercise values in all other EF tests between females and males, differences were indicated for semantic memory and language with better results seen in men compared to women. While exercise stimuli resulted in improved performance in the men's group, no such effect has been seen for women.

Porter and colleagues (2011) studied changes in cortical thicknesses that support verbal fluency at middle childhood, adolescent and young adulthood emphasizing on separate developmental trajectories for males and females.

Although brain structural development is beyond the scope of our study, differential structure–function relationships between males and females are documented, as there is evidence that adult males and females exhibit different overall verbal fluency performance abilities (Loonstra *et al*., 2001; Rodríguez-Aranda & Martinussen 2006).

Considering limited data that has been reported in the literature on female's cognitive response to exercise stimuli, we exposed young adult women and men to a same absolute exercise intensity. No gender differences were observed at baseline, prior to the exercise stimulation in any of the executive function parameters except for the semantic memory, as indicated by the Word fluency test. The positive change in response to our intervention well correlated with the degree of cognitive challenge. Based on our findings we should highlight gender difference at the end of recovery period: in both the Stroop 1-2-3 and in TMT 1-2 women maintained enhanced performance after 45 minutes of recovery compared to pre-exercise results; moreover, for the TMT improvement continued when compared to results immediately post exercise. None of these reactions were observed in the men's group that successfully maintained post exercise achievement at the end of recovery, only after the most challenging task of Stroop-3.

We may thus conclude that females benefit from positive effect of exercise intervention for a longer duration compared to men.

In summary, in the present study we aimed to answer whether gender plays a role in cognitive response to acute exercise intervention. In accord with previous literature, we also observed the positive relation between the response and the complexity of the task. The effect of exercise on cognition was not related to the subjective sensation of the physical effort, as indicated by RPE of both genders. Tet, this work emphasizes the sustained reaction of women to this intervention which lasted to a longer period of recovery compared to men. For practical applications one should therefore consider the duration of the exercise impact and the differences between genders in this aspect.

Recommendation: Engaging more women in future research in this growing field of exercise and brain functioning, will enlighten gender versatility and the specific response of women as compared to men, to a cognitive function after exercise intervention.

VI. Acknowledgment

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Conflict of Interest

None.

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