AMERICAN UNIVERSITY OF BEIRUT

EFFECT OF ACUTE AEROBIC EXERCISE ON THE EXECUTIVE FUNCTIONS OF COLLEGE STUDENTS: ROLE OF SEX

by
SANDRA ELIZABETH KAMAL ZAKKA

A thesis
submitted in partial fulfillment of the requirements
for the degree of Master of Arts
to the Department of Psychology
of the Faculty of Arts and Sciences
at the American University of Beirut

Beirut, Lebanon
June 2018

AMERICAN UNIVERSITY OF BEIRUT

EFFECT OF ACUTE AEROBIC EXERCISE ON THE EXECUTIVE FUNCTIONS OF COLLEGE STUDENTS: ROLE OF SEX

by

SANDRA ELIZABETH KAMAL ZAKKA

Approved by:

____

Dr. Arne Dietrich, Professor and Chair — Advisor
Department of Psychology

____

Dr. Zahra Hussain, Assistant Professor — Member of Committee
Department of Psychology

____

Dr. Julien Besle, Assistant Professor — Member of Committee
Department of Psychology

Date of thesis/dissertation defense: June 14, 2018

AMERICAN UNIVERSITY OF BEIRUT

THESIS, DISSERTATION, PROJECT RELEASE FORM

Student Name:

Zakka	Sandra	Elizabeth
Last	First	Middle

☑ Master's Thesis ◯ Master's Project ◯ Doctoral Dissertation

☑ I authorize the American University of Beirut to: (a) reproduce hard or electronic copies of my thesis, dissertation, or project; (b) include such copies in the archives and digital repositories of the University; and (c) make freely available such copies to third parties for research or educational purposes.

☐ I authorize the American University of Beirut, to: (a) reproduce hard or electronic copies of it; (b) include such copies in the archives and digital repositories of the University; and (c) make freely available such copies to third parties for research or educational purposes after:

One ---- year from the date of submission of my thesis, dissertation, or project.
Two ---- years from the date of submission of my thesis, dissertation, or project.
Three ---- years from the date of submission of my thesis, dissertation, or project.

[signature] June 27th, 2018

Signature Date

ACKNOWLEDGMENTS

First, I would like to express my deepest gratitude, appreciation and respect to my supervisor Dr. Arne Dietrich for his continuous and valuable support, and patience in seeing my long-term project come to completion. His charisma and creativity as a scientist has instilled in me a passionate commitment to scientific research and has taught me the skills necessary to confidently and creatively approach new and existing challenges. I sincerely acknowledge his role as my undergraduate and graduate advisor in my growth as both a scientist and a person.

I am also especially grateful to Dr. Zahra Hussain for her precious time and availability during my research work. She has encouraged me to widen my research perspectives by her insightful comments, suggestions, and expertise in research design and statistical analyses.

I am also thankful to Dr. Julien Besle for his important contribution in shaping my Master’s thesis and his valuable feedback given to me during crucial phases of my thesis study. I sincerely appreciate his help and guidance during my research.

I would also like to extend my sincere gratitude to my undergraduate research assistant Rywa Safa for her commitment and valuable help during the data collection phase of my research study. I would like to especially thank her for bringing fun to routine laboratory work.

AN ABSTRACT OF THE THESIS OF

Sandra Elizabeth Kamal Zakka for Master of Arts
Major: Psychology

Title: Effect of Acute Aerobic Exercise on the Executive Functions of College Students: Role of Sex

The present study investigates whether biological sex moderates the effect of acute aerobic exercise on executive functions (EF). Healthy college students (*n* = 104) from the American University of Beirut (AUB) performed the Delis-Kaplan Executive Function System (D-KEFS) Color-Word Interference Test which is based on the Stroop Test, prior to and fifteen minutes after either an acute bout of aerobic exercise (cycling) that consisted of a 5-minute warm up, a 20-minute moderate intensity exercise (50-59% HRR), and a 5-minute cool-down (treatment group), or a 30-minute reading session (control group). *Results:* There was no significant group x time x sex interaction. Only a significant group x time interaction was found, where the exercise group performed significantly better, in comparison to the control group, on the posttest (after exercise) compared to the pretest (before exercise), equally for both females and males. *Discussion:* Inhibition, an aspect of executive functioning, improved after an acute bout of moderate intensity aerobic exercise and females and males were similarly sensitive to the exercise manipulation. Implications for the present findings are discussed.

CONTENTS

ILLUSTRATIONS

TABLES

CHAPTER I

LITERATURE REVIEW

Most students in college can now confine exercise solely to mental effort, work, and sweat. With mounting evidence indicating beneficial effects of exercise on the physical, cognitive, emotional, and mental health of young adults (Ji et al., 2017), the diminishing levels of physical activity have become one of the major health problems faced by college students today (Pengpid et al., 2015). For example, only 26.4% of students in major universities across Lebanon engage in physical exercise, leaving an alarming high of 73.6% physically inactive college students, with females leading more sedentary lives than males (Musharrafieh et al., 2008). As such, colleges worldwide are urged to promote levels of physical activity among both female and male students' everyday lives.

In addition to the long-term cognitive benefits of exercise widely examined in both human and animal studies (Audiffren & André, 2014; Basso & Suzuki, 2017), there has been recent interest in the way a single bout of exercise, or acute exercise, affects cognition. Though studies have yielded inconsistent results, the general trend suggests that acute exercise improves cognitive functions, and particularly executive functions (EF), or higher-order cognition (Chang, Labban, Gapin, & Etnier, 2012). This short review elaborates on the effects of acute exercise on EFs and on several primary moderators that have influenced these effects, including the (1) type of cognitive task, (2) timing of test administration relative to exercise, (3) mode of exercise, and (4) initial fitness levels.

Type and Timing of Cognitive Task

The type of cognitive task used in exercise research has resulted in some cognitive functions to be improved by exercise (Chang et al., 2014; Chang et al., 2011), and others to be impaired (Dietrich & Sparling, 2004) or unaffected (Stroth et al., 2009; Themanson & Hillman, 2006). To temporarily reconcile the confusing data, two axes must be kept apart (Dietrich & Audiffren, 2011). First is the distinction between tasks of EFs and other cognitive processes, and second is the timing at which each of these tasks is administered relative to exercise.

Executive Functions

Executive functions are higher-order, prefrontal operations that enable goal-directed behaviors and control over automatisms. Core EFs include inhibition, goal planning, sustained and focused attention, working memory, task-switching/set-shifting, and creativity. In exercise research, inhibitory control (Chang et al., 2015), working memory (Pontifex, Hillman, Fernhall, Thompson, & Valentini, 2009; Hogan, Mata, & Carstensen, 2013), and task-switching (Alves et al., 2012; Wang et al., 2015) aspects of EF are primarily targeted.

Executive Functions During Exercise.

Research on EFs during bouts of exercise is relatively recent. Dietrich & Sparling (2004) introduced this line of research as a direct test of the transient hypofrontality theory, or THT (Dietrich, 2003). The theory proposes that alterations to consciousness progressively downregulate brain networks involved in highest-order cognitive functions, i.e. networks in the prefrontal cortex (PFC), down the functional hierarchy, to more basic brain networks (Refer to “Effects of Acute Exercise on the Brain” below). Accordingly, it is hypothesized that performance on tasks measuring aspects of EFs would be selectively impaired during acute exercise.

Task-Switching.

Task-switching (TS) is a kind of cognitive flexibility that allows shifting attention from one task to another. The Wisconsin Card Sorting Test (WCST) is a classical neuropsychological test of mainly TS (i.e., set-shifting) and typically requires participants to sort cards according to three rules: color, number, or shape. The participant is asked to match the cards but is not told which of the three rules to use. Instead, the participant is only told if a match is correct or incorrect. The rule later switches after achieving 10 consecutive correct responses and the participant must shift sets to sort the cards according to the new rule. Dietrich & Sparling (2004) administered two neuropsychological tests to 24 male athletes, namely the (1) WCST, a direct test of EF (TS, working memory, and perseveration), and (2) Brief Kaufman Intelligence Test (K-BIT), a prefrontal-independent task. The tests were administered, in a counterbalanced order, after 25 minutes of moderate-intensity exercise. Test administration lasted approximately 25 minutes, and the subject continued to exercise until both tests were completed. The total exercise time was around 50 minutes.

In support of the THT, performance on the WCST was impaired when administered during the aerobic exercise conditions (cycling and running) but not for the controls. As for the K-BIT, the three groups did not significantly differ from one another, suggesting that different cognitive functions are affected to different degrees during acute exercise. It may be argued that the WCST is simply a more difficult task that requires more cognitive effort than the K-BIT. However, Dietrich & Sparling (2004) note that the K-BIT is a comprehensive and difficult task that has 1) a high ceiling, and 2) an equal completion time as the WCST. Moreover, the authors conducted informal posttest interviews with the subjects, in which subjects reported that the K-BIT was a cognitively demanding test. Thus, the results lend support to the proposal that higher-order, prefrontal-dependent cognitive functions are selectively impaired during exercise.

Working Memory.

In their second study, Dietrich & Sparling (2004) also found impaired working memory during bouts of aerobic exercise (running). Working memory (WM) describes the maintenance and manipulation of information that is currently in consciousness, for a brief amount of time until it is no longer useful. To measure it, Dietrich & Sparling (2004) used the Paced Auditory Serial Addition Task (PASAT), a measure of sustained attention, working memory, and speed of processing, which required participants to listen to an audiotaped presentation of a series of numbers from 1 to 9, and later add together the two preceding numbers to report the sum aloud. The Peabody Picture Vocabulary Test (PPVT-III) was also given, as a prefrontal independent measure of receptive vocabulary. Test administration followed the same procedure as their first study, except that (1) the cognitive tasks differed, (2) the duration of moderate-intensity running prior to test administration was increased to 40 minutes to create a more physically challenging situation for the athletes, and (3) the total exercise time was about 65 minutes. Performance on the PASAT was impaired during running, but not when these participants were in the control condition. Also, no significant differences emerged in the PPVT-III results across the conditions. Importantly, the PPVT-III, like the K-BIT, is a difficult test with a high ceiling and has an equal completion time as the PASAT. Thus, these findings are, again, consistent with THT, and indicative that different cognitive functions are differentially affected during acute exercise.

Inhibitory Control.

The above detrimental effects are also reported in tasks of inhibitory control (IC) (Davranche & McMorris, 2009; Pontifex & Hillman, 2007). IC is the ability to override automated behaviors (response inhibition) and keep out irrelevant information from long-term memory, action, and the environment (interference control) (Gazzaniga, Ivry,

& Mangun, 2014). The Eriksen Flanker Task (Eriksen & Eriksen, 1974) is a common test of IC and typically requires participants to respond to a target stimulus in three different conditions: the congruent stimulus (target is in same direction as flankers), incongruent stimulus (target is in different direction as flankers), and neutral stimulus (flankers do not evoke any response conflict). For example, Pontifex & Hillman (2007) administered a modified Eriksen Flanker Task to undergraduate students performing moderately intense aerobic exercise (cycling). During exercise, there was significantly decreased response accuracy for incongruent trials (measure of EF), compared to rest conditions, while no effect was found in congruent trials (prefrontal-independent).

Similarly, Davranche & McMorris (2009) administered the Simon task (Hommel, 2011), a measure of IC, during acute moderate-intensity exercise. This task requires participants to respond to a certain stimulus based on its color, while ignoring the location of the stimulus. That is, if a red stimulus appears on the screen, regardless of its location, participants are asked to respond by pressing the button on the right. In congruent trials, the red stimulus would appear on the right side, where participants would typically respond faster. In contrast, reaction times would increase on incongruent trials if the red stimulus would appear on the opposite side. Performance on this task also demonstrated impaired IC during exercise, compared to controls.

Executive Functions Post-Exercise.

In contrast to the above findings, acute exercise generally yields positive *post*-exercise effects on tasks of EF (Dietrich & Audiffren, 2011). These findings are nonetheless task-specific, showing more promising results for IC and WM aspects of EFs, in comparison to TS.

Task-Switching.

Performance on TS tasks in the post-exercise period has typically shown a lack of any improvement, and especially for young adults. For instance, the Trail Making Test (TMT) is a common neuropsychological test of TS and typically requires participants to connect a sequence of 25 consecutive targets by first connecting all target numbers in sequential order, and then alternating between numbers and letters. Alves et al. (2012) administered the TMT to healthy older women and found that both acute aerobic and strength exercises did not improve performance in TMT following exercise. Moreover, Wang et al. (2015) found no main effect following acute aerobic exercise on EFs of young and older adults, as assessed using the WCST.

Wang et al. (2015) offer two explanations to explain the above findings. First, the effect of acute exercise on EFs is influenced by the kinds of cognitive tasks administered, even when these tasks are measuring the same aspect of EF (i.e., acute exercise may affect performance on two types of TS tasks differently). For example, Pesce & Audiffren (2011) found enhanced performance on TS tasks after acute exercise, but only when these tasks demanded more executive control (e.g., in a cueing paradigm, when the sizes of the cue following target stimulus were mismatched rather than matched). Future studies may thus benefit from administering several cognitive tasks to measure one aspect of EF, such as TS. Second, cardiovascular fitness or motor coordination skills may influence the results, such that individuals with *lower* fitness and motor coordination benefit *less* from acute exercise on tasks of TS (e.g., Tsai et al., 2016). In fact, Kamijo & Takeda (2010) found that participants with higher levels of physical activity showed superior performance than sedentary participants on "predictable switching tasks", where participants had to switch predictably every *N* trials.

Working Memory.

In contrast, post-exercise *enhancements* on WM tasks are typically reported. Common tests include the N-Back task (Kirchner, 1958), Digit Span backward, and the Sternberg Task (Sternberg, 1969). For example, Pontifex et al. (2009) administered a modified Sternberg Task, where participants had to first encode a memory set containing three, five, or seven letters, and then decide whether a single probe letter was present in that set. Performance was significantly enhanced immediately and 30-minutes after moderate acute aerobic exercise, in comparison to the seated rest condition, and even more so on task conditions that required greater demands on WM capacity (i.e., encoding larger memory sets). This suggests that changes in cognitive function after acute exercise are significantly larger for tasks demanding greater amounts of executive control. Also, Hogan, Mata, & Carstensen (2013) revealed enhanced WM after acute exercise, as measured using the *N*-Back Test, which presents numbers on a screen one at a time and asks participants to indicate whether each new number appearing on the screen matches the one presented *N* (N=2) items previously. Furthermore, Samuel (2017) showed improved performance after exercise on the Digit Span Backwards task, which requires participants to repeat a list of numbers in their reverse order.

Inhibitory Control.

Similarly, studies administering tasks of IC have produced some of the most robust findings in the acute exercise and cognition literature; that is, regardless of age, performance on IC tasks is enhanced following acute aerobic exercise (e.g., Chang et al., 2014; Alves et al., 2012). In these studies, participants were given the Stroop Test, another commonly used test of IC, which typically consists of two conditions. In the first information-processing condition (congruent trial), participants are asked to read aloud written color names, and in the second executive function condition (incongruent trial), participants are asked to inhibit a dominant response to read out a word and instead select a weaker response to name the color of the ink in which the word appears. The primary measure used to assess performance on the Stroop Test is response time (RT), such that a faster RT indicates enhanced performance on the task (e.g., Chang et al., 2014; Yanagisawa et al., 2009). Particularly, in comparison to tests administered before exercise, participants performed significantly better on the EF condition following an acute bout exercise, in comparison to controls. The duration of the improvements on the EF condition lasts up to 15-minutes (Yanagisawa et al., 2009) and 52-minutes after exercise (Joyce, Graydon, McMorris, & Davranche, 2009).

Other Cognitive Processes

Though not part of the aims of the present study, a more complete understanding of the complex relationship between exercise and cognition warrants attention to the effects of exercise in other cognitive domains. Other cognitive processes reviewed in the literature include memory functions, perceptual organization, simple and complex decision-making, information-processing speed, and simple- and choice- response time (RT) paradigms (Tomporowski, 2003).

Effects During Exercise.

Performance on reaction time tasks and other simple decisional tasks is, unlike tasks of EF, improved during acute bouts of aerobic exercise, regardless of the type of reaction time task or kind of acute aerobic exercise used (Dietrich & Audiffren, 2011). In fact, this is one of the most robust findings of exercise psychology. According to Tomporowski’s (2003) review of the literature, performance on short-term memory, visual search, choice discrimination, simple RT, choice RT, and complex problem-solving tasks is facilitated during bouts of exercise. Other studies have suggested an inverted-U shape function, such that RT and decision-making speed is facilitated with increased exercise demands (Tenenbaum et al., 1993), until a certain point where exercise results in impaired performance (Tomporowski, 2003).

Post-Exercise Effects.

The same cannot be said about prefrontal-independent cognitive functions assessed *after* exercise, as some functions have even reversed into impairment after exercise that is prolonged and/or led to exhaustion (Dietrich & Audiffren, 2011). In general, basic perceptual functions for participants of all ages are less sensitive than EFs to the cognitive benefits of acute exercise. For example, Chang et al. (2012) reported no effects on perceptual processing, sensory processing, and memory retrieval tasks after acute exercise. Moreover, Tomporowski et al. (1987) found that, regardless of fitness level, there was no influence of aerobic exercise on participants' free-recall memory. Some studies have also suggested that the depletion of physiological energy stores compromises cognitive function (Cian et al., 2000), resulting in impaired cognition after prolonged exercise.

Summary

Taken together, two generalizations can be made. First, there is consensus that acute exercise is associated with impaired performances on tasks of EF *during* exercise. Conversely, performance on tasks of executive functioning is typically enhanced *following* acute exercise. These enhancements are nonetheless EF-specific, revealing more promising effects for IC and WM. Second, performance is facilitated on RT and simple decisional tasks *during* acute exercise. Research does not support this facilitation, however, for the post-exercise period.

After acknowledging the above two generalizations, readers are better prepared to understand complex relationship between exercise and cognition. However, despite the literature supporting these generalizations (Dietrich & Audiffren, 2011), they should be embraced with caution. After all, these are over-simplifications and cannot fully account for the variable existing data. This is because of the variety of cognitive tasks, with different cognitive loads (task difficulty), administered during and following exercise, and the different exercise protocols, intensities (low, moderate, or high), and modes (aerobic vs. anaerobic) used across studies.

Mode of Exercise

The influence of the mode of exercise is observed from studies that have either compared the effects of two different modes of exercise on cognition, or the effects of one mode of exercise relative to a sedentary control group. In both cases, researchers have mainly concentrated on the differential effects of aerobic and anaerobic exercise on EFs. For the purposes of the present study, EF assessed in the post-exercise period are discussed.

Aerobic Exercise

The American College of Sports Medicine (ACSM, 2010) defines aerobic exercise as “any activity that uses large muscle groups, can be maintained continuously, and is rhythmic in nature”. Examples include cycling, hiking, jogging, long-distance running, swimming, dancing, and walking. Acute aerobic exercise is typically associated with enhanced EFs (Chang et al., 2012), but these enhancements are confined to post-exercise assessment. Specifically, aspects of EFs, including IC (Yanagisawa et al., 2009), WM (Pontifex et al., 2009), and planning and problem-solving (Chang et al., 2011) are significantly improved followin*g* acute aerobic exercise, in comparison to controls. Moreover, there is consensus that aerobic exercise in the moderate-intensity range positively affects cognition the most (Brush et al., 2016). According to Davey (1973), exercise intensity, and its effect on arousal, influences cognition in an inverted-

U shape, such that moderate intensity exercise enhances cognitive functioning more than exercise at higher or lower intensities (McMorris et al., 2011).

Anaerobic Exercise

Anaerobic exercise, in contrast, is any kind of intense physical activity that lasts for a very short duration (ACSM, 2010). Examples include sprinting, high-intensity interval training, and power-lifting. Less studies have been devoted to the cognitive effects following anaerobic training; however, of these studies, the cognitive effects of resistance training, the main form of anaerobic exercise, are typically examined in the exercise literature. These studies suggest that post-anaerobic exercise effects on tasks of EFs, similarly to aerobic exercise effects, are task-specific. For instance, Chang & Etnier (2009a) revealed significantly improved processing speed and IC aspects of the Stroop Task, following acute resistance exercise. In contrast, these enhancements were not found for performances on shifting tasks, as measured using the Trail Making Test. Similarly, Alves et al. (2012) demonstrated that both acute aerobic and strength (resistance) exercises significantly improved cognitive performance, but only for selective attention and IC aspects of EFs, as measured using the Stroop Test. This enhancement was not found for TS aspects of EFs, measured using TMT, suggesting a possible moderating role of cognitive task type.

Other tasks of IC were also found to be sensitive to acute resistance exercise, such as the Simon task (Brush et al., 2016). However, Brush et al. (2016) reported no influence of acute resistance exercise on working memory, measured using the 1) Two-Back Task, and the 2) Verbal Running Span Task, which required participants to recall serially the last four consonants displayed to them within short and long lists of 6 or 8 and 10 or 12 consonants, respectively. Similarly, Pontifex et al. (2009) investigated immediate and delayed (30 minutes) effects of both acute aerobic and resistance exercise on WM, using a modified Sternberg task. While the authors found enhanced performance on the task following aerobic exercise (at both times), there were no effects of resistance exercise on task performance.

The above findings suggest that, like aerobic exercise, anaerobic exercises (e.g., resistance exercise) influence specific aspects of EFs. More studies, however, are needed to reconcile the inconsistences and provide a detailed understanding of the major moderators that may influence the effects of resistance exercise on cognition, as well as the underlying mechanisms involved in these effects (Brush et al., 2016). Nevertheless, exercise research has focused on acute aerobic exercise because of its quick accessibility, lack of required specialist knowledge and equipment, and its direct relation to cardiovascular fitness, which also positively correlates with EF (Guiney & Machado, 2013).

Initial Fitness Level

Cardiovascular fitness, or the ability to perform physical activity efficiently and without undue fatigue (ACSM, 2010), is linked to improved cognition and brain health (Åberg et al., 2009; Themanson & Hillman, 2006; Stroth et al., 2009). Consequently, the role of fitness level in the relationship between acute exercise and cognitive performance has gained attention.

Chu, Chen, Hung, Wang, & Chang (2015) employed a randomized control group posttest design to investigate the role of fitness in the effect of acute exercise on basic information processing and executive IC, as measured by the Stroop Test, of healthy older adults with higher and lower fitness levels. A significant interaction between "treatment" (within-subjects: control vs. exercise) and "fitness" (between-subjects: lower vs. higher fitness) was revealed, such that the exercise group performed significantly better on the Stroop Task, in comparison to the control group, with the higher fitness group displaying a significantly shorter response time on the Stroop Task (with additional benefits on the EF condition of the task), compared to the lower fitness group, but only in the exercise condition. This finding suggests that the level of fitness may moderate the relationship between acute aerobic exercise (cycling) and cognition.

However, the study's cross-sectional design precludes an establishment of a causal relationship. Still, findings from other studies have supported those of Chu et al. (2015). For example, Tsai et al. (2016) examined the effect of aerobic exercise on a TS protocol in young adults with different fitness levels. Participants were divided into three groups, namely a no-exercise control group, exercise group consisting of participants with high fitness levels, and an exercise group consisting of participants with low fitness levels. Prior to and after acute aerobic exercise (or the control group activity), Tsai et al. (2016) administered a TS protocol, where participants had to judge whether a digit (between 1 and 9, excluding 5) was higher or lower than five if it was surrounded by a solid square (low/high task), or whether the digit was odd or even if it was surrounded by a dashed square (odd/even task). Specifically, the protocol consisted of three conditions: two "pure" task conditions (i.e., only low/high or odd/even tasks) and one mixed-task condition (i.e., the task changed predictably every two trials from non-switching to switching trials). The authors found that, while acute aerobic exercise decreased response times in three conditions for both high fitness and low fitness exercise groups, only the exercise group consisting of high fitness level participants showed smaller switching costs (i.e., the difference between trials that required switching and trials that did not require switching) after acute exercise. This finding thus supports the proposition that the effects of acute aerobic exercise on cognition depend on fitness.

In contrast, Chang et al. (2014) revealed that the beneficial cognitive effect was observed for young adults regardless of fitness levels, on both congruent and incongruent trials of the Stroop Test administered after acute exercise. However, there was still a marginally significant effect of fitness on the incongruent trial, with those who were moderately fit performing the best on the EF aspect of the Stroop Test. Meanwhile, those with high fitness showed the slowest reaction times, suggesting moderate fitness to be associated with optimal performance on IC aspects of EF after acute exercise. This finding is inconsistent with other studies that have shown high fitness levels to improve cognitive functioning following aerobic exercise (e.g., Chu et al., 2015; Tsai et al., 2016). However, Chang et al. (2014) note that the fitness level defined as “high” in other studies was in fact equal to what was referred to as “moderate” in their study.

CHAPTER II

GAPS IN THE CURRENT LITERATURE

All in all, acute exercise is mainly expected to either enhance or impair EFs, depending on the kind of exercise paradigm used and type of cognitive process tested. In addition, several other moderators beyond the aims of the present review, have been extensively studied in the literature. These include, but are not limited to, the design of the study (cross-sectional, longitudinal, and randomized controlled trials), sample characteristics (mental health, genetic predispositions, and age), intensity, and duration of the acute exercise session (Tan et al., 2016; Malchow et al., 2013; Kubesch et al., 2003; Chang et al., 2012). For example, Chang et al. (2012)'s review reports "age" to be a significant moderator in the acute exercise and cognition literature. Most studies have reported stronger effect sizes for high school students and older adults, in comparison to young adults, with small but still significant effects on young adult populations. This is mainly due to the more limited literature devoted to young adult populations, as most researchers assume that a ceiling effect exists in any kind of exercise-related improvements for college age students, who are neurologically at the peak of their cognitive development (Wang et al., 2014). However, this assumption is challenged with the data supporting the cognitive benefits of exercise on healthy young adults (Chang et al., 2012).

In addition to the above moderators, the inconsistency in the cognitive effects of aerobic exercise can also be related to several other overlooked factors, such as the biological differences between participants (Barha et al., 2017). Particularly, sex has been acknowledged as a possible moderator (Barha et al., 2017; Colcombe & Kramer, 2003), and for the purposes of the present study, sex as a potential moderating variable (and gap) in exercise research is discussed.

Sex in Exercise Research

The role of sex in the effect of acute exercise on EFs of healthy populations has not yet been directly studied, as most studies have either been confined to male- or female-only samples, with male-only exceeding that of female-only samples (Ellemberg & St-Louis-Deschênes, 2010). In fact, of the samples containing both females and males, there is generally a sex imbalance with fewer female participants in a sample (Soga, Shishido, & Nagatomy, 2015; Chang et al., 2014). Consequently, findings on acute exercise and cognition have mainly focused on male norms, despite researchers in the past ten years highlighting the need to address the sex imbalance (Ellemberg & St-Louis-Deschênes, 2010; Soga et al., 2015; Chang et al., 2014). Nonetheless, a sex difference has been identified in studies that have employed *long-term* exercise programs for *older adults* (e.g., Barha et al., 2017).

Chronic Exercise (CE).

Colcombe & Kramer's (2003) meta-analysis found in samples consisting of more females, the cognitive effect was found to be medium-to-large and when the sample consisted of more males, the effect was small. More recently, a larger meta-analysis consisting of randomized controlled trials (RCTs) on healthy older adults also suggested that studies with greater female percentages showed larger beneficial effects from different exercise interventions on EF tasks (Barha et al., 2017). For example, Barha et al. (2017) conducted a secondary analysis of data, which consisted of a RCT of an aerobic training program (AT) (3-times/week, 60-minute session) on a sample of older adults with mild Subcortical Ischemic Vascular Cognitive Impairment (SIVCI). Three executive functions (TS, IC, WM) were assessed using the Trail Making Test

(TMT), Stroop Test, and verbal digits forward and backward tests, respectively, at three time periods: 1) baseline, 2) aerobic training completion, and 3) after a 6-months follow up. Results showed a significant interaction between sex and group for performance on the TS task (TMT) only, such that aerobic training improved TS, in comparison to the control group. These enhancements were not found for other cognitive functions (IC and WM), which suggests that – like acute exercise – a moderating role of cognitive task type may exist. Moreover, in comparison to males, only females within the aerobic training group showed enhanced performance on the TMT. This TS enhancement persisted at the 6-month follow up assessment for females. Taken together, the findings suggest that regular exercise may benefit the cognitive health of older women more than males for both clinical and non-clinical populations.

Neurobiological Mechanisms Underlying Sex Differences.

Barha et al.'s (2017) study is the first of its kind to propose an underlying mechanism for the observed sex difference. Participants provided blood samples at each of the three time periods, to measure levels of brain-derived neurotrophic factor (BDNF) – a key protein from the neurotrophic family that is essential for the growth, survival, and differentiation of neurons (Dinoff, Herrmann, Swardfager, & Lanctôt, 2017). Results revealed an increase in BDNF levels from baseline assessment to AT completion in females but a decrease in males, indicating that biological mechanisms underlying the effects of AT may be sex-specific. Moreover, the AT-induced benefits on the TS tasks in females persisted at the 6-months follow-up, suggesting a possible permanent change to brain function in females.

To link the increased BDNF levels and improved TS seen in females, Barha et al. (2017) speculate an interaction between BDNF and the female sex hormone, estradiol. Specifically, estradiol may directly upregulate BDNF levels via the promoter region of the BDNF gene, which contains an estrogen response-like element (Sohrabji, Miranda, & Toran-Allerand, 1995). In fact, Berchtold et al. (2001) found that, in female rats, aerobic training increased BDNF concentrations, an effect that was even stronger when levels of estradiol were higher.

In addition to Barha et al.'s (2017) study, two recent meta-analyses using human studies explored whether sex influenced the effect of long-term exercise training on circulating BDNF (e.g., Szhuhany, Bugatti, Otto, 2015; Dinoff et al., 2016). Specifically, Szhuhany et al. (2016) suggested that after more than two weeks of aerobic training, BDNF levels increased more for females than males, although the difference did not reach statistical difference. However, Dinoff et al. (2016) found that sex did not moderate the effect of long-term exercise on increased BDNF levels. All in all, the discrepant results suggest the importance of considering sex as a variable in exercise research and that the relationship between aerobic training and BDNF is complex (Barha et al., 2017). Also, an explanation for why BDNF *decreased* for males in Barha et al.'s (2017) study was not addressed.

Acute Exercise.

To the best knowledge of the author, no studies examining sex as a moderator of acute exercise and executive functions were found in the literature. However, BDNF levels have also been implicated in the acute exercise literature, as a hypothesized mechanism through which acute exercise benefits cognition (Dinoff et al., 2017). A meta-analysis conducted by Dinoff et al. (2017) found an approximate 60% increase in peripheral blood concentrations of BDNF after acute exercise. Interestingly, the authors also note that this overall claim was influenced by sex, such that greater increases in BDNF concentrations were observed in studies consisting of a greater proportion of males. The authors point out that both estrogen and testosterone have been suggested to upregulate BDNF concentration (e.g., Rasika et al., 1999; Berchtold et al., 2001b; as cited in Dinoff et al., 2017). Thus, Dinoff et al. (2017) speculate that testosterone probably is a stronger inducer of BDNF than estrogen, as this would account for the greater reported level of serum BDNF found in males than females.

It is worth noting that more than 75% of the participants included in Dinoff et al.'s (2017) meta-analysis were identified as male. Thus, the authors suggest that their finding was severely limited by the sex imbalance (larger subgroup of males compared females) and that an effect in females could have been found if a greater number of females were included in the meta-analysis. This limitation is in line with the sex imbalance generally observed in the acute exercise literature (Soga, Shishido, & Nagatomy, 2015; Chang et al., 2014; Ellemberg & St-Louis-Deschênes, 2010) which has left this literature largely based on male patterns. Moreover, the meta-analysis does not include whether the changes in BDNF levels are accompanied by post-exercise improvements on cognitive tasks typically shown in the literature, and thus a sex difference in prefrontal-dependent behaviors following acute exercise has not yet been examined.

Future Directions in Sex and Exercise Research.

Sex and exercise research is mainly limited in the following ways. First, BDNF as a hypothesized mechanism through which long-term exercise benefits the cognitive health of females more than males is preliminary and the explanation provided by Barha et al. (2017) to explain the differences in BDNF levels across sexes is speculative. Second, it is unclear why BDNF levels decreased in males after long-term aerobic exercise, given that testosterone has also been found to induce BDNF expression. Third, sex has not yet been directly considered in the acute exercise literature, restricting the ability to draw conclusions regarding a sex difference. Fourth, the higher BDNF levels shown in males following an acute bout of exercise (Dinoff et al., 2017) were examined *immediately* following acute exercise, and, therefore, it is worth exploring whether such a sex difference – if present – endures after a delay period. Fifth, there are no studies examining how sex influences the effect of acute exercise on prefrontal-dependent *behaviors*.

CHAPTER III

AIMS AND HYPOTHESES

Aims

The present study asks whether executive functions might benefit from an acute aerobic exercise and, more specifically, whether females or males would be more, less, or similarly sensitive to the exercise manipulation. Executive functioning was assessed using a standard neuropsychological test: Delis-Kaplan Executive Function System (D-KEFS) Color-Word Interference Test which is based on the Stroop test, that measures information processing and inhibition. The present study thus consists of two aims: (1) to explore the effect of acute aerobic exercise on the EFs of college students, and (2) to explore the role of sex – i.e., the biological attributes that differentiate males and females – on the effect of acute aerobic exercise on EFs.

Hypotheses

Hypothesis 1.

Fifteen minutes following the cessation of acute aerobic exercise, the exercise group will perform significantly better on the D-KEFS Color-Word Interference Test (CWIT), in comparison to students in the control group (Chang et al., 2014; Yanagisawa et al., 2009). There was a 15-minute delay since results from a meta-analysis suggest that the strongest positive effects of exercise occur 11 to 20-minutes post-exercise (Chang et al., 2012).

Exploratory Hypothesis.

This study will also explore the effect of sex on the effect of acute aerobic exercise on performance on the D-KEFS CWIT, fifteen minutes following the cessation of exercise. Due to the sex imbalance typically documented in samples from the acute exercise literature, this hypothesis is left as exploratory.

CHAPTER IV

METHODS

Participants

The sample included 127 undergraduate and graduate students from the American University of Beirut (AUB). The participants were screened using a physical activity readiness screening questionnaire and were required to meet the following criteria: (a) between 18 and 25 years old, inclusive, (b) not currently taking medical and/or psychiatric medications, and (c) no history of medical, psychiatric, and/or physical difficulties. These criteria were set to ensure student's safety in participation, as instructed by ACSM (2010) *Guidelines for Exercise Testing and Prescription* and to minimize the confounds between acute exercise and cognition (e.g., age and mental health). Specifically, studies have revealed a moderating role of psychological disorders, such as ADHD, Autism Spectrum Disorder, Major Depressive Disorder, and schizophrenia (Tan et al., 2016; Malchow et al., 2013; Kubesch et al., 2003) on the cognitive effects of acute exercise, and therefore, students with mental conditions were excluded from the study. Participants who failed to meet the eligibility criteria of the study (i.e., not passing the exercise pre-participation health screening on the PAR-Q+) (n = 1) or who did not show up to complete the study (n = 22) were excluded from further analysis. The final sample included 104 participants (52 female, 52 male) from the Psychology 101/201 participant pool by convenience sampling (n = 92), and the remaining participants were volunteers from the AUB student body. Participants were randomly assigned to the control group (n = 52), consisting of 25 females and 27 males, or the exercise group (n = 52) consisting of 27 females and 25 males. The sample size was determined using an a priori power analysis on G*Power. The statistical test chosen was "ANOVA: Repeated measures, between factors" with the time of test (pretest, posttest) as the repeated measure, group (exercise, control) as the between-subjects factor, and sex (male, female) as the between-subjects factor. Since no studies have directly tested the role of sex, the effect size was obtained from studies that have examined the effect of acute aerobic exercise on pre- and posttests of the Stroop test. This effect size was obtained from Chang et al. (2014) (partial $\eta^2 = .11$) who investigated the relationship between acute exercise and cognition, measured using the Stroop task. Participants' ages ranged from 18 to 25 (M = 18.87, SD = 1.39). Participants identified their ethnicity as White (99%) and Asian (1%) (see Table 1 for more demographics). No females were pregnant or menstruating on test day. Participation in this study was on a voluntary basis. Compensation in the form of extra course credit was provided for participants from the Psychology 101/201 participant pool. This study was approved by the university's Institutional Review Board, and all participants provided informed consent.

Research Design

This study is a 2 x 2 x 2 (Group x Time x Sex) mixed factorial design. The first between-subject independent variable, "Group", consisted of 2 levels: exercise and control. Students were randomly assigned to either the exercise or control group. The second within-subject independent variable, "Time", consisted of 2 levels: pre- and post-exercise testing. The third between-subject independent variable, "Sex", consisted of 2 levels: female and male. The dependent variable was performance on the D-KEFS CWIT following acute aerobic exercise, in comparison to before exercise.

Instruments

Demographics.

Students were asked to answer relevant demographic questions pertaining to age, sex, ethnicity, class, GPA etc. to control for confounding variables, and for sample description purposes **(Refer to Appendix A)**.

Social History Form.

The purpose of the Social History Form was to control for potentially confounding variables (e.g., smoking, drinking or unhealthy eating behaviors) as these behaviors have been associated with executive functions and linked to decreased fitness levels, which is a major moderator of acute exercise effects of cognition **(Refer to Appendix B)**.

The Physical Activity Readiness Questionnaire for Everyone (PAR-Q+).

In accordance with ACSM (2010) guidelines for exercise testing, part of the exercise pre-participation health screening requires students to complete the PAR-Q+. The PAR-Q+ is a self-report, evidence-based tool, that was developed in part to reduce barriers for exercise and false positive screenings and identify students who are at risk for adverse exercise-related cardiovascular incidents (ACSM, 2010).

The questionnaire uses follow-up questions, based on relevant medical history and symptomatology, to better inform researchers on students' health statuses and pre-exercise recommendations. The sensitivity and specificity of the questionnaire for individuals with and without hypertension (high blood pressure) is high (0.90 and 1, respectively), such that the PAR-Q+ is effective in correctly identifying people with hypertension. Also, test-retest reliability over a three-month period was found to be high (r = 0.99). Finally, the PAR-Q+, in comparison to its older versions, reduced significantly the numbers of participants referred to further medical clearance by a physician.

Regardless of whether the student does or does not participate in “regular exercise”, which is defined as “planned, structured physical activity for at least 30 min at moderate intensity on at least 3 days/week for at least the last 3 months” (ACSM, 2010), students reporting the presence any cardiovascular (CV), metabolic, or renal disease, as well as signs or symptoms suggestive of CV, metabolic, or renal disease were excluded from the present study. In other words, students in need of further medical clearance were excluded from the study **(Refer to Appendix C)**.

International Physical Activity Questionnaire (IPAQ; International Physical Activity Questionnaire, 1998).

The IPAQ is a self-report form administered to 18 to 65-year-old adults, assessing physical activity levels across four different contexts: (1) leisure time physical activity, (2) domestic and gardening activities, (3) work-related physical activity, and (4) transport-related physical activity, as well as sedentary behaviors. The IPAQ form allows for both continuous and categorical indicators of physical activity, and the present study used the former. Specifically, a continuous indicator of physical activity is presented as the “median MET minutes/week” **(see Appendix D for scoring protocol)**. The Metabolic Equivalent of Task (MET) is a physiological measure that expresses how much more energy is expended by an individual during exercise in comparison to when that individual is resting. MET minutes is the time spent in an activity with respect to the number of METs. MET minutes per week is obtained by multiplying MET minutes by the number of days an individual participates in an activity. Means are not used as a measure of continuous indicators because of the non-normal distribution of energy expenditure across diverse populations. MET-minutes per week are interpreted as low (<600), moderate (600-1500), and high (>1500) levels of physical activity.

Test-retest reliability of the IPAQ over a one-week period shows Spearman correlation coefficients ranging from 0.96 to 0.46 (most around 0.8), indicating good test-retest reliability. Evidence for criterion validity, using objective data recorded on the Computer Science and Application's Inc. (Shalimar, FL) accelerometer (CSA model 7164), a tool used to detect the acceleration and deceleration of movement during exercise, shows fair to moderate agreement between the two measures. Moreover, the IPAQ shows high content validity, since frequency, intensity, and duration of physical activity are assessed, as well as sedentary behaviors. The IPAQ also has acceptable psychometric properties across developed and developing countries **(see Appendix E)**.

Acute Exercise Protocol.

The exercise mode, intensity, and duration components were established according to the ACSM (2010) guidelines. Aerobic exercise, using a cycling ergometer, was selected as the exercise modality. Cycling was used, as it is recommended for all adults, and requires minimal skill or physical fitness to perform. Moreover, aerobic exercise was chosen, since current evidence is insufficient regarding cardiovascular complications during other modes, such as resistance exercise, to ensure adequate prescreening recommendations.

One of the recommended methods for establishing intensity is the heart rate reserve (HRR) method. Heart rate reserve (HRR) is the difference between age-predicted maximal heart rate (HR_{max}) and resting HR (HR_{rest}). Maximal heart rate (HR_{max}) is calculated using the following equation: 220 – age. The intensity was set at 50-59% HRR, as this range is identified as the moderate intensity range (ACSM, 2010), and moderate intensity acute aerobic exercise has been especially linked to improved cognition. A range was used because, based on ACSM guidelines (ACSM, 2010), participants with different physical activity levels may experience moderate intensity exercise differently. Therefore, the intensity was set using specific %HRR, based on each participant's physical activity level (assessed using IPAQ). Target HRR for participants with high, moderate, and low activity levels were set at around 50, 54.5, and 59% HRR, respectively. These percentages were set in accordance with the exercise protocol set forth in the study conducted by Chang et al. (2011). To calculate the target heart rate (THR) for each student, the following formula was used: $[(HR_{max} – HR_{rest}) \times \%\ \text{intensity desired}] + HR_{rest}$.

The duration of the acute exercise session lasted 30 minutes and consisted of the following components: 5 minutes of warm-up (light-to-moderate intensity exercising), 20 minutes of the moderate intensity cycling, and 5 minutes of cool-down (light-to-moderate intensity exercising).

Heart Rate (HR) Monitor.

HR was monitored using the Fitbit Alta HR, which was used to provide an objective index of exercise intensity and to ensure that students remained in their calculated THR. The HR monitor was worn on the student's wrist. The participant's HR was displayed on the research investigator's iPhone application, which is connected to the Fitbit Alta HR. The work rate of the cycle ergometer was in turn adjusted as needed if the HR fell below or above THR. The HR monitor was worn by students during the entire experimental process. The experimenter recorded HR at 2-minute intervals. Using the HR monitor, three HR indices were identified: HR_{rest} (assessed after sitting comfortably and quietly in a chair for about 10 minutes), treatment HR (average HR assessed during exercise) and post-HR (HR assessed immediately before conducting the cognitive task at the posttest).

Ratings of Perceived Exertion (RPE; Borg, 1998).

The RPE is a subjective measure of perceived intensity used to confirm that all students experienced exercise as moderate in intensity. It was used in conjunction with %HRR to guide adjustments to exercise intensity. The RPE uses a numerical scale (ranging from 6 to 20), with accompanying adjectives (e.g. 6: no exertion at all, 9: very light, 13; somewhat hard), serving as anchors. The scale correlates well with HR during aerobic exercise in healthy young adults (Eston, 2012). RPE scores were obtained at 6-, 15- min, and at the end of the exercise session. There is consensus that perceived exertion ratings between 12 and 14 on the Borg Scale suggests perceived moderate intensity exercise. 9 corresponds to "very light" exercise (for a healthy person, this is like walking slowly at his/her own pace for some minutes). 13 is "somewhat hard" exercise, but it still feels OK to continue. 17 corresponds to "very hard" and is very strenuous (a healthy person can still go on, but he or she really must push him/herself. It feels very heavy, and the person is very tired). 19 on the scale is an extremely strenuous exercise level (for most people, this is the most strenuous exercise they have ever experienced). During activity, students assigned numbers to indicate how they felt. Instructions for the RPE were given verbally to each participant immediately before they started cycling **(Refer to Appendix F)**. To facilitate reading, the scale was printed on a large cardboard **(Refer to Appendix G)**. During the 20-minute moderate intensity exercise (excluding warm-up and cool-down), exercise intensity was increased if RPE was lower than 12, but it was held constant when RPE was between 12 and 14.

Cognitive Task: Delis-Kaplan Executive Function System (D-KEFS) Color-Word Interference Test (CWIT).

The CWIT is based on the Stroop (1935) test. The main executive function it assesses is inhibitory control, or the ability to inhibit a dominant verbal response (i.e.

reading) and instead select a weaker response of naming the dissonant ink colors in which the words are printed. This task consists of four conditions. Conditions 1 (Color Naming) and 2 (Word Reading) are baseline conditions that measure important component skills (i.e., information processing) needed for higher-level cognitive tasks. Since both conditions measure similar cognitive processes, only Condition 1 was administered in the present study. Condition 1 (Color Naming) is a measure of processing speed and visual processing, and it requires examinees to name 50 colored boxes (red, green, and blue) one by one as fast as possible. Condition 3 (Inhibition) contains 50 color names written in a different colored ink, for which the examinee must inhibit the dominant response to read the word and instead select a weaker response to name the dissonant color of the ink in which the word appears. Condition 3 (Inhibition) is a measure of inhibitory control (executive function condition). Lastly, Condition 4 (Inhibition/Switching) is a new executive-function task that assesses both inhibitory control and cognitive flexibility. However, considering that the present study only looks at inhibitory control as an aspect of executive functions, Condition 4 was excluded. For both conditions, participants were told to complete the task as quickly as possible without making any mistakes. The time each participant took to complete the task was recorded (using a stopwatch) and the number of errors (uncorrected and corrected) were also recorded.

The CWIT is a standardized paper-and-pencil neuropsychological test. This test comes with the *D-KEFS Examiner's Manual* (Delis et al., 2001b), which provides detailed and clear instructions of how to administer and score the CWIT. It incorporates standardized examiner prompts, discontinue rules and time limits to minimize examinee frustration. It also comes with detailed instructions on how to record examinee responses, accounting for nonsense words (e.g., “grue” or “breen”), completion time (in seconds), uncorrected errors, and self-corrected errors. Scaled scores based on completion times (primary measure used to analyze performance on this test) were obtained. Scaled scores based on completion times were obtained through recording the time it took for the examinee to complete a condition (in seconds). This corresponds to the raw score, which was later converted to scaled scores (age-corrected) using tables given in the *D-KEFS Examiner's Manual.* The directionality of the scaled scores are set so that higher scaled-score values indicate better performance, while the directionality of the raw scores (i.e., response times) are set so that a lower response time indicates enhanced performance. The inhibition score (Stroop effect), which was the main dependent variable of this study, was obtained by subtracting the scaled score on the first condition (color naming) from the scaled score on the third (inhibition). Next, the inhibition score was further converted into the "inhibition scaled score" (using tables provided in the Examiner's manual). This score reflects inhibition, while controlling for color naming speed and participant age.

The amount of errors was also considered to measure performance. Errors on the D-KEFS CWIT are categorized into two general types: (a) corrected and (b) uncorrected. In Condition 1 (Naming Errors), the entire D-KEFS normative sample made few corrected and uncorrected naming errors (69.2% of the entire sample was free of errors in this condition). Both types of errors are summed together to get a "naming error score". In Condition 3 (Inhibition Errors), making errors is more common with around 65.7% of the entire normative sample committing at least one error. Both types of errors (corrected and uncorrected) are summed together to get the "inhibition error score". The final error score is taken as the difference between the "inhibition error score" and "naming error score" to obtain an inhibition error score that is independent of the naming errors.

The D-KEFS standardization sample consisted of 1,750 individuals, aged 8-89 years. Most relevant to the present study, 175 adolescents and/or adults from the age 16 to 19 and 20 to 29 were included in the normative samples. The normative samples consisted of an approximately equal number of females and males. Performance in Condition 1 (Color Naming) was associated with rapid improvement with age, showing a peak at ages 16-19 years and remaining relatively stable through ages 30-39 years. Performance for all age groups dropped dramatically for Condition 3 (Inhibition) relative to Condition 1 (Color Naming), and especially for the youngest and oldest age groups.

The *D-KEFS Technical Manual* (Delis et al., 2001c) presents technical characteristics of the test with regards to reliability and validity. Evidence for validity shows high correlations between Conditions 1 and 2 at 0.62, and between Conditions 3 and 4 at 0.63. Moreover, test-retest reliability shows scores to be generally higher on the second testing, suggesting a role of test sensitization (practice effects). For ages 8-19, test-retest reliability is acceptable in Condition 1 ($r = 0.79$) and good in Condition 3 ($r = 0.90$). For ages 20-49, test-retest reliability is good in Condition 1 ($r = 0.86$) and acceptable in Condition 3 ($r = 0.71$) **(Refer to Appendix H)**.

Procedure

AUB students enrolled in Psychology 101/201 were recruited in accordance with the policies of the AUB Human Research Participation Program and the ethical guidelines of the American Psychological Association ("Interim Guidance for Access to the Psychology (101/201) Student Pool for Research") **(Refer to Appendix I)**. Other AUB students were also encouraged to participate via posters in key locations across campus **(Refer to Appendix J)**, such as the library, departmental bulletins, and social media posts on student-centered groups on Facebook (e.g. "AUB Psychology Students" and “AUB COURSES/TEACHERS GURU”) **(Refer to Appendix K)**. Students interested in participating in the study contacted the Investigator to coordinate an appointment. Interested students received the same email **(Refer to Appendix L)**.

The students were asked to visit the laboratory at the AUB Psychology Department (Jesup 107), for two sessions. In the first session, each student privately and voluntarily provided informed consent and were instructed to complete the demographic, social history form, PAR-Q+, and IPAQ. A copy of the consent form was kept with the student. At the end of the questionnaire booklet, students were asked to provide their email addresses and names **(Refer to Appendix M)**. Then, students wore the HR monitor to record their HR_{rest}, measured after sitting comfortably and quietly in a chair for 10 minutes. The first session lasted approximately 45 minutes. To make the environment in the second session as familiar as possible, all students were asked to lightly practice on the cycle ergometer, and they were given instructions and practice trials on the D-KEFS CWIT. The purpose of the first session was to collect baseline data and ensure the safety of each student’s participation in the study. This session was carried out by the Investigator and Undergraduate Research Assistant (URA).

During the 10-minute waiting period where students were resting and having their HR measured, the research staff reviewed the answers on the questionnaires to ensure eligibility. Students were told on the consent document that the researchers would review their responses and at the end of the session would be privately told of their eligibility status. Students who were eligible to participate in the study were told in-session and were also contacted via e-mail by the Investigator to set an appointment for the second session. In this email, eligible students were given the following written instructions: refrain from ingesting food, alcohol, caffeine or tobacco products within 3 hours of testing, avoid significant exertion or exercise on the day of the assessment, wear appropriate clothing, and drink ample fluids within 24 hours of testing to ensure normal hydration **(Refer to Appendix N)**. The purpose of providing these instructions was to allow students to prepare adequately for the second session. Students who were ineligible to participate in the study were also told in-session and were thanked for their time as well as provided with an explanation for their ineligibility and a brochure with recommendations and strategies to promote physical activity **(Refer to Appendix O)**. An email was also sent to those who were ineligible with information regarding the purpose of the study and possibilities to inquire on the study's results **(Refer to Appendix P)**. Each student performed the experiment (i.e. testing session) independently. However, the timing of experimentation was conducted uniformly across students in the morning. The testing session took place in the morning, because a meta-analysis by Chang et al. (2012) showed that the time of day when testing occurred had a significant effect on the results, with significantly larger effects observed for exercise performed during the morning and effects not significantly different from zero when exercise was performed either in the afternoon or in the evening. The experiment consisted of two test conditions: cycling (n = 52) and sedentary controls (n = 52), and students were randomly assigned in the second session to one of the two test conditions. Random assignment was ensured by a chance procedure (flipping a coin). No specific instructions about the benefits of acute exercise on cognition were provided.

In the second session, a 24-h history form was provided, requesting information on medications, exercise, diet, sleep, and general feeling of well-being **(Refer to Appendix Q)**. The purpose of this form was to ensure that no students were feeling tired and/or sick on test day. Before the student was administered the pretest, the answers they provided on this form were reviewed by the URA and Investigator to make sure that all students were physically and mentally capable of taking part in the study. For example, if a student has eaten right before testing, it was advised that they terminate their participation to avoid nausea. However, no students in the present study were excluded for this reason. Each student was then given instructions and demonstrations on the D-KEFS CWIT. The students were administered the D-KEFS CWIT (2 conditions) for pretest data. Next, the students in the exercise group were instructed to perform an acute bout of a cycling ergometer protocol, designed according to ACSM guidelines. Heart rate was measured throughout the exercise and control condition. In contrast, those randomly assigned to the control group were asked to sit on a chair in the lab and were given reading material (e.g., magazines and newspapers) to read for the same amount of time as the exercise group (i.e. 30 minutes). The research staff stayed away from the visual field of the student, minimizing any conversation with the participant. Fifteen minutes following the cessation of the cycling ergometer protocol or the control group reading activity, heart rate was measured once again, and the students were asked to complete the D-KEFS CWIT again for posttest data (2 conditions). The second session lasted approximately 60 minutes. Water and towels were provided for those exercising. At the end of the second session, the students were thanked for their participation and an oral "end of study statement" was given **(Refer to Appendix R)**.

Ethical Considerations

The present study conformed to the exercise research guidelines set by the latest version of the *ACSM's Guidelines for Exercise Testing and Prescription* to ensure students' safety in participating. The students also gave informed consent to voluntarily participate in the experiment, which was reviewed by the American University of Beirut Institutional Review Board. The study also met the latest standards of the Declaration of Helsinki.

Statistical Analyses

This study is a 2 x 2 x 2 (Group x Time x Sex) mixed factorial design, with Group and Sex as between-subject independent variables, and Time as a within-subject variable. The main analysis was a mixed higher-order factorial ANOVA (test for a three-way interaction), to observe whether the interaction between group and time was the same for both sexes. In the presence of interaction effects, simple effect analyses were conducted. In total, five sets of statistical analyses were conducted.

Cell Equivalence Before Experimental Manipulation.

Ensuring homogeneity of seventeen students' characteristics across each cell (i.e., female control, female exercise, male control, male exercise) before experimental testing was tested based on an analysis of each scale variable using a 2 (sex: male, female) x 2 (group: exercise, control) analysis of variance (ANOVA). Also, the Chi-Square Test was used to determine whether there was a significant relationship between (1) a new variable "Cell" which was computed with four levels (female control, female exercise, male control, male exercise) and (2) each of the categorical variables included in the study (i.e., class, major, GPA, caffeine, alcohol, tobacco, sleep, and dietary habits). However, one of the assumptions of the Chi-Square Test is that all expected counts should be greater than 1 and no more than 20% of expected counts should be less than 5 (Field, 2009). If this assumption was violated, Fisher's exact test was used.

Exercise Intensity Manipulation Check.

The exercise intensity manipulation check was tested based on an analysis of HR using a 2 (group: exercise, control) x 3 (time: HRbefore, HRduring, HRafter) x 2 (sex) mixed analysis of variance (ANOVA).

Task Difficulty Check.

To ensure that the CWIT was an appropriate measure of both information processing and executive functioning (i.e., to ensure that, in comparison to the Color Naming condition, students had higher response times and more errors on the Inhibition condition), a difficulty check at pretest was tested based on analysis of response time and errors using a 2 (group: exercise, control) x 2 (task condition: condition 1, condition 3) x 2 (sex: female, male) mixed analysis of variance (ANOVA). Like the standardization sample of the cognitive task, it was expected that participants in the present study would have higher response times and error rates on condition 3 compared to 1.

Main Analysis: Effect of Acute Aerobic Exercise: Role of Sex.

The effect of sex, group, and time on cognitive performance on the CWIT was analyzed using a mixed 2 (sex: male, female) x 2 (time: pre-test, post-test) x 2 (group: exercise, no-exercise) mixed ANOVA. To control for lower-level cognitive processes, the analysis was conducted on each of: the 1) inhibition scores (measure of EF while controlling for lower-level processes), and 2) final error scores (difference between Inhibition errors and Naming errors) before and after the experimental manipulation.

To further examine whether the effects of acute exercise are task-specific, the effect of sex, group, and time on cognitive performance on the CWIT was analyzed separately for each task condition – i.e. Naming condition and Inhibition condition – using a 2 (sex: male, female) x 2 (time: pre-test, post-test) x 2 (group: exercise, no-exercise) mixed ANOVA. The analysis was conducted on the response times (seconds) and error scores obtained for each of the Naming and Inhibition conditions before and after the experimental manipulation. A lower response time indicates enhanced performance.

$p < 0.05$ is used as the level of statistical significance for significant interactions and main effects. Effect sizes of omega-squared (ω^2) and partial eta-squared (η^2) are reported for significant effects. The data were analyzed using the Statistical Package for the Social Sciences (SPSS).

CHAPTER V

RESULTS AND DISCUSSION

Results

Preliminary Analyses

A Missing Value Analysis (MVA) was conducted to examine the percentage of missing values. No data were missing. An analysis of univariate outliers (having *z*-scores greater than |3.29|) indicated the presence of 9 univariate outliers. After analyzing the data with and without the outliers, no significant changes in results and assumptions were found. Moreover, upon inspection of the data, the outliers appear to represent valid extreme observations due to random variability and are thus more likely to be representative of the entire population. Thus, the present data analysis keeps and treats the outliers in the same way as the other observations.

Participant Characteristics

Sample Descriptives.

Refer to Table 1 below for descriptives of categorical variables across each cell (i.e., male controls, female controls, male exercisers, female exercisers). Overall, the class status of participants included 14 freshmen (13.5%), 63 sophomores (60.6%), 17 juniors (16.3%), 8 seniors (7.7%), and 2 graduate students (1.9%). Majors included Biology (29.8%), Chemistry (13.5%), Psychology (2.9%), Business (2.9%), Chemical Engineering (2.9%), Computer and Communications Engineering (2.9%), Industrial Engineering (2.9%), Economics (1.9%), and others (40.3%). Most participants reported obtaining a cumulative GPA between 81-85 (28.8%). Other participants reported a cumulative GPA between 66-70 (3.8%), 71-75 (14.4%), 76-80 (17.3%), 86-90 (21.2%), and greater than 90 (14.2%). No students reported a cumulative GPA below 60%. Upon inspecting the social intake form, most participants reported caffeine intake (75%), no alcohol consumption (63%), no tobacco use (90%), 6 to 8 hours of sleep (79%), and eating healthy at least once or twice everyday (55%). Based on the responses on the social intake form, most participants in this study generally lead healthy lifestyles.

Table 1: Frequencies (Freq.) and Percentages (%) for Categorical Descriptives per Cell

		Control Group				Exercise Group			
		Male (*n* = 27)		Female (*n* = 25)		Male (*n* = 25)		Female (*n* = 27)	
Variable		Freq.	%	Freq.	%	Freq.	%	Freq.	%
Class	Freshman	1	3.7	4	16	1	4	8	29.6
	Sophomore	18	66.7	14	56	19	76	12	44.4
	Junior	5	18.5	4	16	3	12	5	18.5
	Senior	3	11.1	2	8	1	4	2	7.4
	Graduate	-	-	1	4	1	4	-	-
Major	Biology	7	25.9	8	32	9	36	7	25.9
	Chemistry	4	14.8	3	12	6	24	1	3.7
	Other	16	59.3	14	56	10	40	19	70.4
GPA	66-70	3	11.1	1	4	-	-	-	-
	71-75	4	14.8	3	12	4	16	4	14.8
	76-80	7	25.9	3	12	4	16	4	14.8
	81-85	6	22.2	10	40	4	16	10	37
	86-90	6	22.2	6	24	5	20	5	18.5
	90+	1	3.7	2	8	8	32	4	14.8
Caffeine	Yes	15	55.6	23	72	20	80	20	74.1
Alcohol	No	14	51.9	15	60	14	56	20	74.1
Tobacco	No	24	88.9	21	84	19	76	26	96.3
Sleep	3-6	6	22.2	-	-	8	32	3	11.1
	6-8	19	70.4	23	92	14	56	23	85.2
Dietary Habits	Healthy once or twice every day	15	55.6	12	48	11	44	17	63
	Healthy almost every day	-	-	8	32	4	16	4	14.8

Note: Caffeine, alcohol, and tobacco measured using “yes/no” questions; Sleep assessed using number of hours of sleep per night

Scale Descriptives.

Refer to Table 2 below for descriptives of scale variables across each cell. Overall, participants’ heights (meters), weights (Kilograms), and BMI ranged from 1.57

to 1.97 (*M* = 1.73, *SD* = .097), 44.0 to 105.0 (*M* = 68.50, *SD* = 13.66), and 13.89 to 32.41 (*M* = 22.88, *SD* = 3.46), respectively. Physical activity levels, measured using MET minutes/week, ranged from 411.0 to 5941.0 (*M* = 1651.08, *SD* = 1615.04). Resting heart rate (HRrest), measured after sitting comfortably for 10 minutes, ranged from 48.0 to 111.0 (*M* = 72.44, *SD* = 9.42), and heart rate measured immediately before experimental manipulation (i.e., either reading or exercising) ranged from 52.0 to 97.0 (*M* = 72.48, *SD* = 8.17). Pretest scores on Inhibition, Naming Errors, and Inhibition Errors ranged from 2.0 to 15.0 (*M* = 10.74, *SD* = 2.29), 0.0 to 4.0 (*M* = .33, *SD* = .69), and 0.0 to 6.0 (*M* = 1.42, *SD* = 1.45), respectively. Pretest Error Differences (i.e. Pretest Inhibition Error – Pretest Naming Error) ranged from -2.00 to 6.00 (*M* = 1.10, *SD* = 1.55). Pretest scores (response time in seconds) for the Naming condition and Inhibition condition of the CWIT ranged from 17.59 to 40.51 (*M* = 27.19, *SD* = 4.36) and 27.25 to 111.86 (*M* = 47.20, *SD* = 15.23), respectively.

Table 2: Means and Standard Deviations for Scale Descriptives per Cell

	Control Group				Exercise Group			
	Male (*n* = 27)		Female (*n* = 25)		Male (*n* = 25)		Female (*n* = 27)	
Variable	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Age	18.96	1.37	18.80	1.08	19.00	2.04	18.70	0.09
Height	1.79	0.06	1.67	0.07	1.80	0.07	1.64	0.05
Weight	75.30	11.60	58.92	10.15	77.30	12.61	62.40	10.59
BMI	23.23	3.13	21.2	3.45	23.83	3.25	23.20	3.63
IPAQ	2323.9	1973.5	1544.4	1641.6	1575.4	1504.4	1147.2	1054.0
HRrest	72.40	11.62	71.68	7.82	72.12	6.73	73.48	10.79
HRbefore	71.33	9.54	72.04	6.79	72.08	8.07	74.40	8.08
Pretest Inhibition	11.11	2.01	11.08	1.97	10.40	2.90	10.37	2.20
Pretest Naming Error	0.26	0.71	0.32	0.48	0.16	0.47	0.56	0.93
Pretest Inhibition Error	1.74	1.75	1.40	1.55	1.16	1.31	1.37	1.15

Pretest Error Difference	1.48	1.67	1.08	1.66	1.00	1.38	.81	1.49
Pretest Naming Condition	26.84	4.01	26.49	4.59	28.39	4.87	27.01	3.97
Pretest Inhibition Condition	44.91	14.72	44.87	14.38	50.93	18.89	48.20	12.52

Note: BMI, body mass index; IPAQ, International Physical Activity Questionnaire assessed in MET/wk.; MET, Metabolic equivalent; HRrest assessed after sitting comfortably for ten minutes in the lab; HRbefore assessed before pre-cognitive testing; Pretest Error Difference computed by subtracting pretest naming errors from pretest inhibition errors. Pretest Naming Condition and Pretest Inhibition Condition measured using completion times in seconds.

Cell Equivalence Before Manipulation

Sample Descriptives per Cell.

Results from the Chi-Square Test on Each of the Categorical Variables.

A chi-square test was conducted to investigate whether females in the control group, females in the exercise group, males in the control group, and males in the exercise group significantly differed on categorical variables. There was no significant association between class status and each cell (control male, control female, exercise male, exercise female) (p = .22, Fisher's exact test). There was no significant association between GPA and cell (p = .28, Fisher's exact test). There was a significant association between caffeine intake and cell (p = .004, Fisher's exact test), such that male controls reported "no caffeine intake" more than expected and female controls reported "no caffeine intake" less than expected. There was no significant association between alcohol consumption and cell ($\chi^2(3) = 31.43$, p = .19). There was no significant association between tobacco use and cell (p = .09, Fisher's exact test). There was a significant association between sleep and cell (p = .01, Fisher's exact test), such that female controls reported sleeping for around "3 to 6 hours" significantly less than expected. There was a significant association between food and cell (p = .01, Fisher's exact test), such that male controls ate "healthy almost every day" less than expected and female controls ate "healthy almost every day" more than expected.

Scale Descriptives per Cell.

Testing for the assumptions of the three-way factorial ANOVA (Normality Assumption and Homogeneity of Variances) can be found in the Appendices of the present study **(Refer to Appendix S)**. However, the F test is robust to violations of normality when the group sizes are equal in each cell (Field, 2009). In the current sample, since the groups are of equal/almost equal size, the non-normality of the dependent variables does not pose a problem and the analysis can be continued. Also, according to Field (2009), for "violations of the assumption of homogeneity of variance, ANOVA is fairly robust in terms of the error rate when sample sizes are equal" (p. 360). Thus, in the current sample, since the groups are of equal/almost equal size, the heterogeneity of variances of the DV across the groups of the IV did not a problem and the analysis was continued.

Results from the two-way factorial ANOVA on Each of the Scale Variables.

Refer to Table 3 below for detailed results from the two-way ANOVA on each of the scale variables. Specifically, a two-way factorial ANOVA was conducted to investigate the effects of sex and group on each scale variable (age, height, weight, BMI, MET, HRrest, HRbefore, pretest inhibition, pretest naming error, pretest inhibition error, and pretest error difference), to test for cell equivalence before experimental manipulation. For this reason, only interaction effects are considered to establish cell equivalence. For all scale variables, there were no significant interaction effects. There was also a significant main effect of sex for height ($F(1,100) = 135.24$, $p < .01$, $\omega^2 = .39$), weight ($F(1,100) = 50.17$, $p < .01$, $\omega^2 = .19$), and BMI (($F(1,100) = 4.06$, $p = .047$, $\omega^2 = .01$). Therefore, participants in each cell did not significantly differ from one another prior to experimental manipulation.

Table 3: Results from the two-way ANOVA on Each of the Scale Variables Before Manipulation

Variable	Effect or Interaction	*F*	*p*
Age	Sex	.70	.41
	Group	.012	.91
	Sex*Group	.06	.81
Height	Sex	135.24	$p < .01$
	Group	1.43	.24
	Sex*Group	1.27	.26
Weight	Sex	50.17	$p < .01$
	Group	1.50	.22
	Sex*Group	.112	.74
BMI	Sex	4.06	.047
	Group	3.84	.053
	Sex*Group	1.12	.30
MET	Sex	3.80	.054
	Group	3.42	.07
	Sex*Group	.32	.57
HRrest	Sex	.03	.87
	Group	.17	.69
	Sex*Group	.31	.58
HRbefore	Sex	.89	.35
	Group	.94	.34
	Sex*Group	.25	.62
PI	Sex	.005	.95
	Group	2.49	.12
	Sex*Group	.00	.99
Pre-NE	Sex	2.90	.09
	Group	.26	.61
	Sex*Group	1.60	.22
Pre-IE	Sex	.05	.82
	Group	1.14	.29
	Sex*Group	.93	.34
Pre-N	Sex	.97	.33
	Group	1.52	.22
	Sex*Group	.33	.56
Pre-I	Sex	.21	.64

	Group	2.44	.12
	Sex*Group	.20	.66
Pre-Error	Sex	.92	.34
	Group	1.49	.26
	Sex*Group	.13	.72

Note: PI, pretest inhibition scaled score; Pre-NE, pretest naming errors; Pre-IE, pretest inhibition errors; Pre-N, pretest naming condition (seconds); Pre-I, pretest inhibition condition (seconds); Pre-Error, pretest error difference (pretest inhibition error – pretest naming error).

Intensity Manipulation Check

Testing for the assumptions of the three-way mixed factorial ANOVA (Normality Assumption and Homogeneity of Variances) can also be found in Appendices **(Refer to Appendix S)**. Similarly, the *F* test is robust to violations of normality and homogeneity (Field, 2009). Thus, the analysis continued even in the presence of violations to these assumptions.

Results from the three-way mixed ANOVA on Participants' Heart Rates.

Refer to Table 4 below for descriptives of the intensity manipulation check. A three-way mixed factorial ANOVA was conducted to investigate the effects of sex, group, and time (HRbefore, HRduring, and HRafter) on participants' heart rates. Mauchly's Test of Sphericity was significant (p <.001), and therefore the Greenhouse-Geisser correction was used. There were significant main effects for time (F(1.68, 168.3) = 627.57, $p < .001$, $\eta p^2 = .86$), group (F(1, 100) = 209.08, $p < .001$, $\eta p^2 = .68$) and significant interaction effects for time x group (F(1.68, 168.3) = 421.84, $p < .001$, $\eta p^2 = .81$) and time x group x sex (F(1.68, 168.3) = 3.44, $p = .04$, $\eta p^2 = .03$). Specifically, participants in both the control and exercise group showed significant increases in heart rate during exercise – compared to before and after exercise – with females in the control group showing larger increases than males in the control group, and those in exercise group (both females and males) showing larger significant increases than females and males in the control group. Given that there was a significant three-way interaction effect, follow-up simple effects were used to decompose the interaction of time x group x sex.

Table 4: Descriptive Statistics for the Intensity Manipulation Check

	Control Group				Exercise Group			
	Male (n = 27)		Female (n = 25)		Male (n = 25)		Female (n = 27)	
Variable	Mean	SD	Mean	SD	Mean	SD	Mean	SD
HRbefore	71.33	9.54	72.04	6.79	72.08	8.07	74.41	8.07
HRduring	77.19	9.60	79.52	13.35	139.12	3.93	134.76	17.8
HRafter	73.70	10.01	73.96	7.68	82.60	10.89	86.63	11.54

Note: HRbefore, measured before pretest; HRduring, average HR measured at 2-minute intervals either during the exercise manipulation or reading activity; HRafter, measured immediately before posttest.

Task Difficulty Check

Testing for the assumptions of the three-way mixed factorial ANOVA (Normality Assumption and Homogeneity of Variances) can also be found in the Appendices **(Refer to Appendix S).**

Results from the three-way mixed factorial ANOVA on Pretest Data.

Pretest Response Time (in seconds).

A three-way mixed factorial ANOVA was conducted to investigate the effects of sex, group, and task (condition 1, condition 3) on participants' response times to check that condition 3 (EF task) took longer to complete than condition 1 (information processing task). There was a significant main effect of condition ($F(1, 100) = 246.70$, $p < .001$, $\eta p^2 = .71$), with condition 3 ($M = 47.2$; $SE = 1.50$) taking more time to complete than condition 1 ($M = 27.20$, $SE = .43$). No other significant main effects or interaction effects were found.

Pretest Errors.

A three-way mixed factorial ANOVA was conducted to investigate the effects of sex, group, and task (condition 1, condition 3) on participants' commitment of errors. There was a significant main effect of condition ($F(1, 100) = 51.23$, $p < .001$, $\eta p^2 = .34$), with participants committing more errors in condition 3 ($M = 1.42$; $SE = .14$) than in condition 1 ($M = .32$, $SE = .07$). No other significant main effects or interaction effects were found.

Main Analysis: Effect of Acute Aerobic Exercise: Role of Sex

Testing for the assumptions of the three-way mixed factorial ANOVA (Normality Assumption and Homogeneity of Variances) can also be found in the Appendices **(Refer to Appendix S).** Considering that there are only two levels of time, the assumption of Sphericity holds.

Results from the three-way mixed ANOVA on Cognitive Task Performance.

Refer to Table 5 below for descriptive statistics for CWIT performance per cell. A three-way mixed factorial ANOVA was conducted to investigate the effects of sex, group, and time (pretest, posttest) on participants' performance on the CWIT. Performance was measured using: (1) inhibition scores and 2) final inhibition error scores before and after the experimental manipulation.

Table 5: Descriptive Statistics for the Main Analysis

	Control Group				Exercise Group			
	Male (n = 27)		Female (n = 25)		Male (n = 25)		Female (n = 27)	
Variable	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Pretest Inhibition	11.11	2.01	11.08	1.98	10.40	2.90	10.37	2.20
Posttest Inhibition	11.11	2.19	10.76	2.03	11.72	2.53	12.52	1.74
Pretest Naming	0.26	0.71	0.32	0.48	0.16	0.47	0.56	0.93

Error								
Posttest Naming Error	0.15	0.46	0.16	0.37	0.04	0.20	0.11	0.42
Pretest Inhibition Error	1.74	1.75	1.40	1.55	1.16	1.31	1.37	1.15
Posttest Inhibition Error	0.96	1.37	1.12	1.30	0.44	1.04	0.37	0.74
Pretest Final Inhibition Error	1.48	1.67	1.08	1.66	1.00	1.38	.81	1.49
Posttest Final Inhibition Error	.81	1.44	.96	1.24	.40	1.08	.26	.90

Note: Performance on the D-KEFS CWIT before and after either exercising at moderate intensity for 30 minutes or reading for 30 minutes. Performance is assessed using the following scores: scaled inhibition scores (derived from response times), and final inhibition error scores (computed by subtracting the Naming Error scores from the Inhibition Error scores).

Inhibition Scores.

There was a significant main effect for time ($F(1, 100) = 22.31$, $p < .001$, $\eta p^2 = .18$), but no main effects for group ($F(1, 100) = .35$, $p = .56$) or sex ($F(1, 100) = .06$, $p = .81$). A significant interaction effect for time x group was found ($F(1, 100) = 46.57$, $p < .001$, $\eta p^2 = .24$). No significant interaction effect for time x sex ($F(1, 100) = .58$, $p = .45$), group x sex ($F(1, 100) = .513$, $p = .48$), or time x group x sex ($F(1, 100) = 2.97$, $p = .08$) were found (See Figures 1 & 2 below).

Given that there was a significant two-way interaction effect for group x time, follow-up simple effects were used to decompose the interaction. A significant effect for time was found for the exercise group ($F(1, 102) = 54.41$, $p < .001$), but not for the control group ($F(1,102) = .42$, $p = .52$) (see Figures 1 & 2). Participants in the exercise group performed significantly better at posttest compared to pretest ($M_{posttest} = 12.14$, $SD_{posttest} = 2.17$; $M_{pretest} = 10.38$, $SD_{pretest} = 2.54$), while participants in the control group performed somewhat similarly at both times ($M_{posttest} = 10.94$, $SD_{posttest} = 2.10$; $M_{pretest} = 11.10$, $SD_{pretest} = 1.97$).

Figure 1. Results of Three-Way Mixed ANOVA on Inhibition Scores Using Error Bars to Represent Precision of the Resulting Estimates

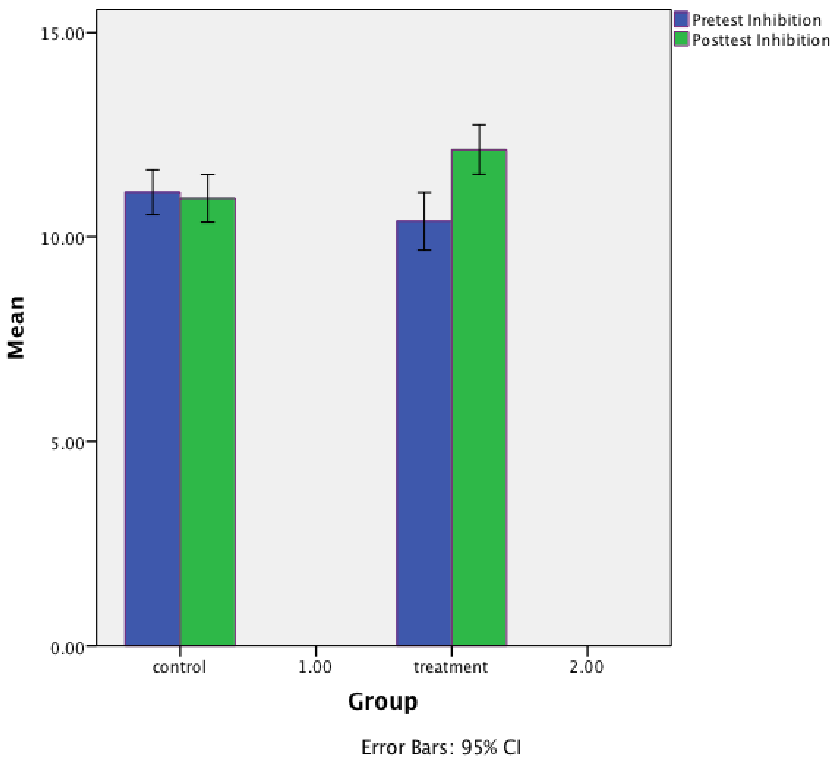


Figure 1. A significant interaction effect for time x group was found ($F(1, 100) = 46.57$, $p < .001$, $\eta p^2 = .24$). Specifically, a significant effect for time for the exercise group was found ($F(1, 102) = 54.41$, $p < .001$), but not for the control group ($F(1,102) = .42$, $p = .52$). Participants in the exercise group performed significantly better at posttest compared to pretest ($M_{posttest} = 12.14$, $SD_{posttest} = 2.17$; $M_{pretest} = 10.38$, $SD_{pretest} =$

2.54), while participants in the control group performed similarly at both times ($M_{posttest}$ = 10.94, $SD_{posttest}$ = 2.10; $M_{pretest}$ = 11.10, $SD_{pretest}$ = 1.97).

Figure 2. Results of Three-Way Mixed ANOVA on Inhibition Scores Per Cell Using Error Bars to Represent Precision of the Resulting Estimates

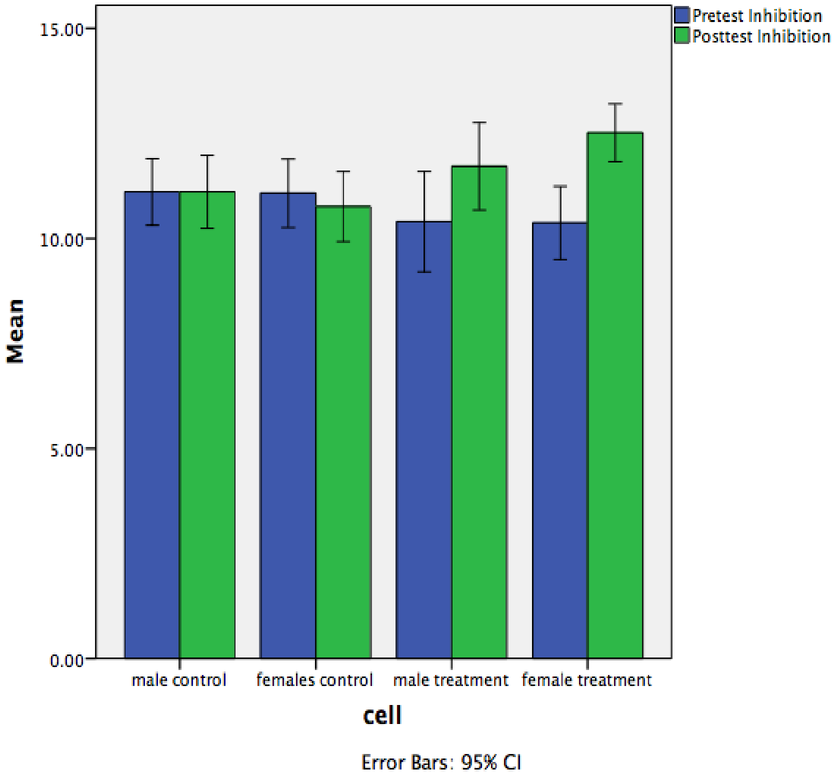


Figure 2. No significant interaction effect for time x sex (*F*(1, 100) = .58, *p* = .45), group x sex (*F*(1, 100) = .513, *p* = .48), or time x group x sex (*F*(1, 100) = 2.97, *p* = .08) were found. Females and males in the exercise (treatment) group performed significantly better on the cognitive task, measured using scaled inhibition scores, in comparison to females and males in the control group. There is a trend, although non-significant, for females in the exercise group performing better after exercise than males in the exercise group compared to before exercise.

Final Inhibition Error Scores.

There was a significant effect of time only (F(1,100) = 11.37, p = .001, ηp^2 = .10), with participants at the posttest committing less errors than at the pretest ($M_{pretest}$ = 1.10, $SD_{pretest}$ = 1.55; $M_{posttest}$ = .61, $SD_{posttest}$ = 1.20). No other main effects or interactions effects were reported (See Figure 3 below).

Figure 3. Results of Three-Way Mixed ANOVA on Final Inhibition Error Scores Per Cell Using Error Bars to Represent Precision of the Resulting Estimates

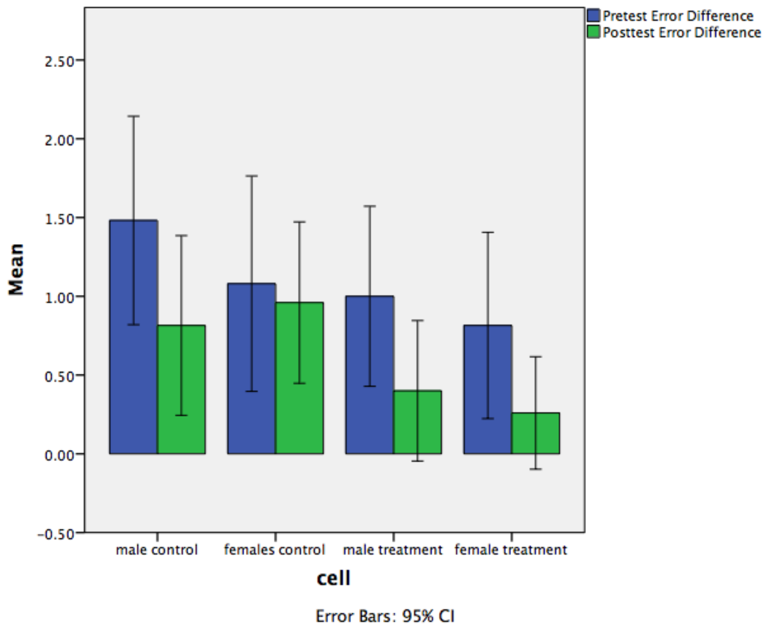


Figure 3. There was a significant effect of time only (F(1,100) = 11.37, p = .001, ηp^2 = .10), with participants at the posttest committing less errors than at the pretest. No other main effects or interactions effects were reported.

Results from the three-way mixed ANOVA on Performance on Each Condition.

A three-way mixed factorial ANOVA was conducted to investigate the effects of sex, group, and time (pretest, posttest) on participants' performance separately on the Naming condition and Inhibition condition of the CWIT. Performance was measured using response time (in seconds) AND error scores obtained for each of the Naming and

Inhibition conditions before and after the experimental manipulation. A lower response time indicated enhanced performance.

Condition 1: Naming.

There was a significant main effect for time (F(1, 100) = 72.70, $p < .001$, ηp^2 = .42) and a significant interaction effect for time x group (F(1, 100) = 10.84, $p = .001$, $\eta p^2 = .098$). No other main effects or interaction effects were found.

Given that there was a significant two-way interaction effect for group x time, follow-up simple effects were used to decompose the interaction. A significant effect for time was found for the exercise group (F (1, 102) = 66.79, $p < .001$), with participants in the exercise group performing significantly better at posttest compared to pretest ($M_{posttest} = 25.22$, $SD_{posttest} = 4.50$; $M_{pretest} = 27.70$, $SD_{pretest} = 4.43$). A significant effect for time was also found for the control group (F (1, 102) = 13.41, $p < .001$), with participants in the control group performing significantly better – but showing a slightly smaller improvement than the exercise group – at posttest compared to pretest ($M_{posttest}$ = 25.57, $SD_{posttest} = 3.84$; $M_{pretest} = 26.67$, $SD_{pretest} = 4.26$).

Condition 3: Inhibition.

There was a significant main effect for time (F (1, 100) = 141.34, $p < .001$, ηp^2 = .59) and a significant interaction effect for time x group (F(1, 100) = 84.17, $p < .001$, $\eta p^2 = .46$). No other main effects or interaction effects were found.

Given that there was a significant two-way interaction effect for group x time, follow-up simple effects were used to decompose the interaction. A significant effect for time was found for the exercise group (F (1, 102) = 226.50, $p < .001$), with participants in the exercise group performing significantly better at posttest compared to pretest ($M_{posttest} = 36.40$, $SD_{posttest} = 12.03$; $M_{pretest} = 49.51$, $SD_{pretest} = 15.80$). However, a marginally significant effect for time was found for the control group (F (1, 102) = 3.80,

p = .054), with participants in the control group performing only slightly better at posttest compared to pretest ($M_{posttest}$ = 43.19, $SD_{posttest}$ = 14.21; $M_{pretest}$ = 44.89, $SD_{pretest}$ = 14.42).

Naming Errors.

There was a significant effect of time only (F(1,100) = 9.19, p = .003, ηp^2 = .08), with participants at the posttest committing less errors than at the pretest ($M_{pretest}$ = .32, $SE_{pretest}$ = .07; $M_{posttest}$ = .16, $SE_{posttest}$ = .04). No other main effects or interactions effects were reported.

Inhibition Errors.

There was a significant effect of time only (F(1,100) = 28.99, p < .001, ηp^2 = .23), with participants at the posttest committing less errors than at the pretest ($M_{pretest}$ = 1.42, $SE_{pretest}$ = .14; $M_{posttest}$ = .72, $SE_{posttest}$ = .11). No other main effects or interactions effects were reported.

Discussion

There is a vast literature on the cognitive benefits of acute exercise. However, no studies have explored the potential for sex to influence the effects of acute exercise on cognitive performance. Therefore, the purpose of the present study was to investigate whether acute exercise-induced enhancements in cognition, and specifically EFs, are sex-dependent.

Specifically, the present study examined inhibition as an aspect of EF through administering a standardized test of inhibition: Color-Word Interference Test (CWIT). The task difficulty check conducted in this study showed that participants, like the standardization sample of the CWIT, had in fact more difficulties in the prefrontal-dependent condition (Inhibition) than in the prefrontal-independent condition (Naming) before the experimental manipulation, as evident by the significantly increased response times and errors rates on the Inhibition compared to the Naming condition. This check suggests that the task was an appropriate examination of whether acute moderate intensity aerobic exercise improves executive functions (inhibition). Moreover, the intensity manipulation check *primarily* showed that in comparison to before exercising, both females' and males' heart rates were significantly higher during moderate intensity exercise with a 63.57 increase in beats per minute (bpm). In contrast, while females' and males' heart rates did significantly increase during the control group activity (reading) in comparison to before reading, heart rate only increased by 6.63 bpm. The significant increase in HR for the control group may be explained by factors such as boredom, being in a new environment, stress, or anxiety.

More importantly, the main analysis revealed three main findings for the present study. First, in comparison to the control group, the exercise group performing a single bout of moderate intensity aerobic exercise performed significantly better at posttest, compared to at pretest, on the Color-Word Interference Test (CWIT). Hypothesis 1 of the present study was thus supported. More specifically, the acute exercise-induced enhancement was reflected by a higher scaled inhibition score, or a smaller difference in response times between the Inhibition (prefrontal-dependent condition) and Naming (prefrontal-independent condition) conditions. The scaled inhibition score is the primary scoring measure used to assess performance on the CWIT (Delis et al., 2001b) because the inhibition score reflects performance on the prefrontal-dependent condition (i.e., EF condition), while controlling for lower-level prefrontal-independent processes. Hence, the higher scaled inhibition score observed after acute exercise suggests the presence of acute exercise-induced improvements specifically on higher-order cognition.

Second, performance on the CWIT was also assessed using a final inhibition error score, defined as the difference in error rates between the prefrontal-dependent

(Inhibition) and prefrontal-independent (Naming) conditions. Though not part of the initially proposed hypotheses, it was interesting to observe that the final inhibition error score decreased at posttest, compared to at pretest, for all participants, regardless of the group they were randomly assigned to. This finding suggests that the acute exercise-induced enhancements in inhibition aspects of EFs are specific to the *speed* of inhibition and not necessarily to *accuracy*. Also, since all participants – regardless of group membership – committed less errors at posttest, practice effects may explain this finding. Nonetheless, because the number of errors did not increase at posttest, compared to at pretest, for the exercise group, the exercisers' improved speed did not compromise their accuracy on the task. In other words, the exercisers did not simply speed up their performance on the task at the cost of their accuracy.

More specifically, an analysis of group, sex, and time on response times (in seconds) of each of the task conditions (i.e., Naming and Inhibition) showed that for the Naming condition, participants in both the exercise and control groups significantly improved on the condition, with exercisers showing a slightly greater improvement. However, an analysis of response time on the EF condition (i.e., Inhibition) showed that exercisers significantly improved by 13.11 seconds, while readers only improved by 1.7 seconds. These findings demonstrate that the effect of acute moderate intensity aerobic exercise on cognition is task-specific, showing larger improvements on EF tasks. Moreover, the error rates on each of the conditions significantly decreased at posttest, compared to at pretest, for all participants, regardless of their assigned groups.

Third, the primary purpose of the present study was to examine whether the causal relationship between acute exercise and executive functions was sex-dependent. The present study found no significant differences between females and males in the exercise group, compared to females and males in the control group. This finding suggests that while executive functions benefitted from an acute bout of aerobic exercise, females (n = 52) and males (n = 52) were similarly sensitive to the exercise manipulation. This finding does not support Dinoff et al.'s (2016) meta-analysis which suggested that greater increases in BDNF concentrations were observed in studies consisting of a greater proportion of males. However, considering that more than 75% of the participants included in their review were male, the authors note that their finding is severely limited by the sex imbalance. Since the present study included an equal number of females and males, this study questions the validity of the sex difference reported in Dinoff et al. (2016). Also, the meta-analysis did not specify the effects of acute aerobic exercise on prefrontal-dependent *behaviors* and whether these behaviors were accompanied by increases in BDNF levels. In fact, BDNF increases as an indicator of enhanced performance on EF tasks is even uncertain (see "Effects of Acute Exercise on the Brain" below).

Still, the present study is the first of its kind to examine sex as a moderator of acute exercise and cognition. While the present study suggests an absence of any sex difference, this finding is preliminary and encourages replication, in terms of prefrontal-dependent behaviors (as examined in the present study) as well as sex differences in brain mechanisms following an acute bout of exercise. Nonetheless, this study continues to lend support to the literature suggesting significant acute exercise-induced improvements on IC tasks, and finds that both females and males are similarly sensitive to the exercise manipulation. To better understand *why* this enhancement occurs after exercise, a brief review of the primary mechanisms proposed in the literature are discussed.

Effects of Acute Exercise on the Brain

Consensus about the underlying brain mechanisms of acute exercise-induced effects on EF is far-fetched in a literature that remains highly fragmented. For the purposes of this study, this discussion narrows the literature to primarily focus on 1) aerobic exercise, 2) healthy adults, and 3) the effects of acute aerobic exercise on prefrontal-dependent *behaviors*. Specifically, three major mechanisms underlying the EF enhancements typically documented *following* acute exercise are discussed (Basso & Suzuki, 2017). Also, for a more complete understanding of the mechanisms proposed in the acute exercise literature, one proposed mechanism underlying the impaired EF performance typically observed *during* acute exercise is discussed.

EF Performance *After* Acute Exercise

Insights from Electrophysiological and Functional Imaging Studies.

Research using neuroimaging and electrophysiological techniques in humans has improved our understanding of the effects of acute aerobic exercise on brain activity patterns during tasks of executive functioning *after* exercise. The present discussion includes findings from electroencephalography (EEG) and functional near-infrared spectroscopy (fNIRS) studies (Basso & Suzuki, 2017).

EEG Studies.

EEG, recorded at scalp, is a non-invasive tool used to record electrical activity of an underlying brain region (Gazzaniga et al., 2014). The electroencephalogram is a continuous recording of *overall* brain activity. Event-related potentials (ERP) are tiny signals embedded in the continuous EEG signal that reflect neural activity that is *specifically* related to, for instance, the cognitive event that triggered it (Gazzaniga et al., 2014). For example, the P300 or P3 component is evoked during the process of decision-making and consists of (1) a positive deflection in amplitude and (2) a latency between 250 and 500 ms after the onset of a stimulus (e.g., cognitive event). Larger amplitudes and shorter latencies represent better cognitive performance (Basso & Suzuki, 2017).

Kamijo et al. (2009) investigated the effects of acute low and moderate intensity aerobic exercise on the P300 wave during a modified flanker task in both healthy younger and older adults. Compared to resting baseline (i.e., before exercise) and low-intensity exercise, only moderate-intensity exercise decreased response times in both younger and older adults following the exercise session. This improvement was accompanied by decreased P300 latencies in both age groups as well as increased P300 amplitudes in young adults only, indicating superior cognitive performance (Kamijo et al., 2009). Other studies have also observed that, following acute exercise, the P300 amplitude increases and the P300 latency decreases during cognitive tasks, such as the Go/No Go task and Eriksen flanker task (as cited in Basso & Suzuki, 2017).

However, since ERPs are better at addressing the time course of cognition rather than at localizing precise neural origins, the neural origins of the P300 component are unknown (Basso & Suzuki, 2017). Nonetheless, Basso and Suzuki's (2017) review suggests that the P300 component reflects a synchronized firing of massive groups of excitatory cortical pyramidal neurons, which appear to be facilitated by (1) connections between the frontal and temporal/parietal cortices and (2) neurotransmitters, such as dopaminergic and noradrenergic inputs. Thus, one proposed mechanism underlying the acute aerobic exercise-induced enhancements in prefrontal-dependent cognition could be the facilitation of synchronous firing between large groups of neurons in the cortex (Basso & Suzuki, 2017).

fNIRS Studies.

fNIRS is a relatively new non-invasive optical neuroimaging technique that uses near-infrared light to measure the hemodynamic responses, evoked by neural activity, in the cerebral cortex (Jahani et al., 2017; Basso & Suzuki, 2017). Yanagisawa et al. (2009) used fNIRS as the first study ever to observe the neural substrates of acute aerobic exercise-induced improvements in executive functioning. Specifically, the researchers used fNIRS during the administration of the Stroop task both before and 15 minutes after an acute bout of moderate-intensity aerobic exercise (cycling) or control group activity (resting). Results showed that, in comparison to the control group activity, acute aerobic exercise significantly improved performance on the Stroop task, and this enhancement was accompanied by increased activation in the left dorsolateral prefrontal cortex, which is a brain region critical for executive functioning.

More recently, Byun et al. (2014) examined whether low intensity aerobic exercise may have a beneficial effect on executive functioning (measured using the Stroop task) with fNIRS. The study also examined the relationship between psychological state changes, acute aerobic exercise, and cortical activation. To measure changes in psychological mood states, the Two-Dimensional Mood Scale (TDMS) was completed by all participants before each Stroop task. The TDMS is a self-report measure that uses a Likert scale, ranging from 0 ("Not at all") to 6 ("Extremely"), to assess words for both pleasure and arousal (e.g., energetic, lethargic, relaxed, nervous). The participants had to indicate how they were currently feeling before each Stroop task. Findings revealed that the acute bout of mild intensity exercise significantly enhanced performance on the Stroop task, as indicated by a reduction in response time. Importantly, the arousal level – measured using TDMS – was also significantly increased in participants who exercised. In addition, the increased arousal was found to positively correlate with improved performance on the Stroop task, and significantly coincided with intensified Stroop-task-related cortical activations in the related left dorsolateral prefrontal cortex and left frontal polar area. Therefore, the authors propose that exercise-induced increases in arousal may improve task-related cortical activations, which in turn lead to enhanced performance on that cognitive task.

However, it is worth noting that the above EEG and fNIRS findings do not give direct information on the neural *mechanisms* underlying the acute exercise-induced cognitive enhancements. At best, the findings provide insight into the possible brain regions underlying the enhanced performance on cognitive tasks after exercise, but not on *how* acute exercise causes these observed improvements in executive functioning.

Insights from BDNF Studies.

Studies that have implicated BDNF in the exercise-induced improvements of cognitive functions have mainly been limited to (1) animal studies, (2) chronic exercise paradigms, and (3) non-executive tasks in acute exercise research (Basso & Suzuki, 2017; Dinoff et al., 2016). While a brief account of findings from animal studies is important, the present discussion includes studies using acute exercise protocols and EF tasks on healthy adult populations.

Most acute exercise studies have focused on BDNF because of its critical role in brain plasticity (Basso & Suzuki, 2017). However, there are much fewer studies that have specifically assessed the relationship between acute exercise-induced increases in BDNF levels and prefrontal-dependent behaviors. In brief, it is hypothesized that acute exercise benefits cognitive performance through increasing concentration levels of BDNF in the brain (Dinoff et al., 2016; Basso & Suzuki, 2017). A collection of evidence in support of the hypothesis first emerged in animal studies, which demonstrated that exercise increased BDNF levels in several brain regions, including the hippocampus

(Fang et al., 2013; Marlatt et al., 2012) and prefrontal cortex (Geng et al., 2013) – areas involved mainly in learning/memory and higher-order cognition, respectively.

However, findings from human studies are more inconsistent, with some studies reporting increased peripheral BDNF concentrations after exercise (e.g., Griffin et al., 2011; Cho et al., 2012; Coelho et al., 2012; Schmolesky et al., 2013) and others reporting no significant alterations in BDNF levels following exercise (e.g., Correia et al., 2010; Bos et al., 2011; Schuch et al., 2015). Nonetheless, in a recent meta-analysis conducted by Dinoff et al. (2016) regarding BDNF and acute exercise in humans, the general trend suggested that levels of peripheral BDNF were significantly higher following an acute bout of exercise. Specifically, the authors found that acute exercise caused BDNF levels in peripheral blood to increase by about 60%, with exercise sessions of a greater duration (i.e., greater than 30 minutes) resulting in greater increases in BDNF in comparison to exercise sessions of shorter durations (30 minutes or less).

Limitations of BDNF Studies in Humans.

According to Dinoff et al. (2016), an increase in BDNF concentrations in the central nervous system (CNS) are suggested to result in enhanced synaptogenesis and neuronal survival, leading to improved cognition and structural variations. While the general trend reported in their meta-analysis support the hypothesis that concentration levels of BDNF increase in the blood following acute exercise, this finding could not generalize to increased BDNF concentrations in the *brain* after acute exercise. Though Pillai et al. (2010) suggested that peripheral and central BDNF levels are correlated in humans, research on humans remains scarce. Also, the human blood brain barrier (BBB) is structurally and functionally distinct from animal BBB, and thus it cannot be inferred – from animal studies – that BDNF can cross the human BBB. Since the role of peripheral BDNF is not well-defined, researchers are encouraged to investigate whether BDNF can cross the human BBB to evaluate the significance of the findings from peripheral BDNF studies (Dinoff et al., 2016).

Moreover, Dinoff et al. (2016) focus on the effects of acute exercise on BDNF levels and do not specifically address the involvement of BDNF levels in the effects of acute exercise on prefrontal-dependent *behaviors*. In fact, Tsai et al. (2016) examined whether acute exercise-induced enhancements on cognitive tasks were accompanied with changes in BDNF levels after acute exercise. The study showed no association between changes in BDNF concentrations and the superior performance seen on cognitive tasks of executive functions (task-switching). Nonetheless, considering that Tsai et al. (2016) measured BDNF levels 20 minutes after exercise cessation, it is worth noting that the reported increases in peripheral BDNF after acute exercise is transient (Dinoff et al., 2016) and are found to resume to the baseline concentrations after approximately 15 to 60 minutes of rest after the cessation of the exercise session (Gold et al., 2003; Brunelli et al., 2012). Therefore, the timing of cognitive test administration relative to exercise may be critical in terms of the effects mediated by changes in BDNF levels (Chang et al., 2012). As such, more studies are needed to determine the role of BDNF on the effects of acute aerobic exercise on prefrontal-dependent behaviors at different time periods after exercise.

EF Performance *During* Acute Exercise

The Reticular-Activating Hypofrontality (RAH) Model of Acute Exercise.

Dietrich & Audiffren (2011) proposed the reticular-activating hypofrontality (RAH) model of acute exercise to account for the impaired performance on EF tasks typically reported *during* aerobic exercise. The RAH model suggests that when the brain is strained by exercise, or over exhausted by prolonged, strenuous, full-body motion, any resources not directly involved or critically needed in the control of movement during exercise are down-regulated, which according to THT (Dietrich, 2003), are areas of the PFC. It follows that exercise involving larger muscle mass, intensity and duration would result in more profound concomitant down-regulation in exercise-unrelated areas (i.e. prefrontal regions). EF impairment, then, is greatest when exercise: (1) involves the entire body, i.e. uses large muscle groups, (2) lasts for a long duration, and is (3) performed at the highest possible intensity to be maintained for that duration. This results in impaired performance on tasks of EFs during moderate-to-high intensity aerobic exercise, consistent with findings previously mentioned (Dietrich & Sparling, 2004; Audiffren, Tomporowski, & Zagrodnik, 2009; Davranche & McMorris, 2009; Pontifex & Hillman, 2007).

According to Audiffren (2016), the use of fMRI and PET techniques during acute exercise is not feasible, as these techniques do not allow for head movements typically associated with running and cycling (McMorris, 2015). However, there are many studies in the literature that have used NIRS to measure prefrontal oxygenation during a single bout of exercise (Audiffren, 2016). For example, NIRS studies have consistently shown a decrease in PFC oxygenation during acute exercise (Subudhi, Dimmen, & Roach, 2007; Rupp & Perrey, 2008; Oussaidene et al., 2013; Tempest, Eston, & Parfitt, 2014). Moreover, a recent study conducted by a Brazilian team constructed a novel cycle ergometer that allowed the researchers to measure functional magnetic resonance imaging (fMRI) – a more sophisticated technique that NIRS – during exercise (Fontes et al., 2013). Fontes et al. (2014) revealed decreased activation in the PFC during exercise. Therefore, the above results lend support to the hypofrontality hypothesis.

Still, the above findings do not consider whether the decrease in prefrontal oxygenation (NIRS) or prefrontal deactivation (fMRI) are accompanied with impaired performances on cognitive tasks of EFs. According to Audiffren (2016), only one study using NIRS reported that the decrease in cerebral oxygenation observed in PFC at high intensity exercise was independent of the enhanced performance seen on the Eriksen Flanker task during exercise (Ando et al., 2011). However, before making any conclusions, there are two key points worth mentioning. First, Ando et al. (2011) used a type of visual stimuli that differed from other studies that have reported impaired performance on the Eriksen Flanker task during exercise (e.g., Davranche et al., 2009). Specifically, Ando et al. (2011) asked participants to respond to orientations of a central arrow embedded in an array of five arrows – a task that is like the conventional two-choice task, which is far less complex than tasks used by other researchers. Davranche et al. (2009), for example, asked participants to respond to the color of the central target while ignoring the colors of the flankers surrounding it – a task that is more prefrontal-dependent and complex. Hence, the simplicity of the task used by Ando et al. (2011) may account for the absence of any impairment typically documented during exercise (e.g., Dietrich & Sparling, 2004; Pontifex & Hillman, 2007; Davranche & McMorris, 2009). Second, cerebral oxygenation was only measured over the right frontal cortex during exercise, neglecting other regions typically recruited during performance on the Erikson Flanker task, such as the anterior cingulate cortex (Colcombe et al., 2004). Moreover, even a slight variation in the placement of NIRS probes could affect the results. Ando et al. (2011) noted that they could not rule out the prospect that a slight variation in probe placements could have influenced the cerebral oxygenation changes observed during exercise, given that cerebral oxygenation was measured on two distinct days. As such, more experiments are needed to examine whether the observed hypofrontality can be applied to the prefrontal-dependent behavioral deficits observed during acute exercise.

CHAPTER VI

IMPLICATIONS AND LIMITATIONS

Implications

The main findings of this study have important practical implications. The present findings indicate some optimal strategies that can be used to maximize the beneficial effects of acute exercise on EFs. That is, an acute bout of cycling consisting of a 5-minute warm-up, 20-minute moderate intensity cycling (50-59% HRR), and a 5-minute cool-down, followed by 15 minutes of resting can significantly enhance cognitive performance equally for both female and male young adults. Also, an important implication for the present findings is the ability to not only improve aspects of short-term cognition in populations where cognitive aspects are compromised (e.g., age-related cognitive decline, depression, ADHD), but also to enhance cognition in "normal" young adults who are assumed to be neurologically at the peak of their cognitive development. As such, the exercise protocol used in this study could serve as an effective intervention to further improve brain functioning in both female and male *healthy* college students.

Furthermore, Musharrafieh et al. (2008) found that most college students in major universities across Lebanon report being physically inactive. Since both females and males equally benefitted from the exercise manipulation, the present findings also have implications for the development of effective strategies to encourage physical activity among students. Several strategies may include exercise counseling aimed at informing students about ways to promote exercise and the benefits of exercise on their cognition, advertising healthy and effective ways of staying in shape, including physical activity classes, and promoting the use of on-campus sport facilities. In addition, promoting acute exercise interventions may also provide ways to optimize study breaks or free time before class, both of which require maximal executive functioning. Finally, such findings may act as an efficient liaison to lifelong, chronic physical activity and health.

Limitations

Nonetheless, the present study has some limitations. First, only one aspect of EF was examined, and thus the absence of any sex difference reported here could not be generalized to global executive function. Moreover, only the CWIT was administered in the present study to assess IC, limiting the ability to compare the present findings to other studies, due to the variety of measurement tools used in the literature even when the same aspect of EF (i.e., IC) is being assessed. Second, the short-term effects of exercise on cognition were only assessed at one point in time (i.e., fifteen minutes after exercise cessation). Given that the sex-specific changes in BDNF levels were measured immediately after exercising, the time of test administration may be critical in terms of identifying a sex difference in prefrontal-dependent behaviors after acute exercise. Third, the cognitive task was administered to all participants by the experimenter using paper-and-pencil, which may have been susceptible to the subjectivity of the rater.

CHAPTER VII

FUTURE DIRECTIONS AND CONCLUSION

Future Directions

Given that this is the first study to explore sex as a moderator of the effects of acute aerobic exercise on inhibition, replication in this area of research is needed. Importantly, future researchers are recommended to consider different types of computerized tasks, either to measure different aspects of EF, such as working memory and cognitive flexibility, or the same aspect of EF (i.e., administering both the Stroop and Eriksen Flanker test to measure IC). Moreover, while the present study focuses on acute exercise-induced improvements on prefrontal-dependent behaviors, future studies are encouraged not only to investigate the mechanisms underlying the improvement and whether they differ according to sex, but to also understand the relationship between these mechanisms and the accompanied behavioral improvements on cognitive tasks seen after acute exercise.

Conclusion

In comparison to females and males in the control group, females and males in the exercise group performed significantly better on the Color-Word Interference Test (CWIT) after fifteen minutes of exercise cessation, compared to before exercise. Moreover, the acute exercise-induced enhancement was not found to be influenced by the sex of the participant. Importantly, enhanced cognitive performance was only found when response time was taken as the primary measure of performance. In contrast, acute exercise did not reduce the amount of errors committed by the participants. Interestingly, the error rates decreased for both participants in the control group and the exercise group, suggesting the probable interference of practice effects. All in all, an acute bout of moderate intensity aerobic exercise for moderate duration (30 minutes) significantly enhanced performance on an inhibition task for healthy young college students.

Appendices

Appendix A

Demographics

Directions: Please answer each question as accurately as possible by placing a check near the correct answer or filling in the space provided.

1. What is your age? _____

2. What is your sex? _____ Female _____ Male

3. What is your ethnicity?

_____ White (including Middle Eastern)

_____ Asian

_____ Black or African American

_____ Other, please specify:

4. What is your highest level of educational attainment?

_____ High School Diploma

_____ Bachelor's degree, BS, BA, DEA

_____ Master's degree, MS, MA, DESS

_____ Doctoral degree, PhD, MD

_____ Some University attainment

_____ Vocational degree

_____ Other, please specify

5. What is your current class status?

_____ Freshman _____ Sophomore _____ Junior _____ Senior _____ Graduate

6. What is your major(s) and minor(s) (if any)?

Major(s): ______________________, ______________________ Minor(s): _____________________, _____________________

7. What is your current overall average?

_____ <60%

_____ 60-65%

_____ 66-70%

_____ 71-75%

_____ 76-80%

_____ 81-85%

_____ 86-90%

_____ >90%

8. What is your height (cm)? _____________

9. What is your weight (kg)? ______________

Appendix B

Social History Form

1. How would you describe your caffeine intake (select all that apply)?

______ None ______ Coffee ______ Tea ______ Caffeinated Sodas

2. Do you drink alcohol? ______ Yes ______ No

3. Do you use tobacco? ______ Yes ______ No

4. How many hours of sleep do you normally get?

_____ 1-3 _____ 3-6 _____ 6-8 _____ 8+

5. How would you describe your eating habits?

_____ All my meals are healthy almost every day.

_____ At least one or two meals (including snacks) are healthy every day (e.g., home cooked lunch, salad, grilled chicken)

_____ At least one or two meals (including snacks) are NOT healthy (e.g., "grab-and-go" sandwiches, man2oushe, fries, chocolate, fizzy drinks)

_____ My meals and snacks are mostly "junk food" or processed food almost every day (e.g., high-sugar drinks, fried food, etc.)

Appendix C

Physical Activity Readiness Questionnaire for Everyone (PAR-Q+)

2017 PAR-Q+

The Physical Activity Readiness Questionnaire for Everyone

The health benefits of regular physical activity are clear; more people should engage in physical activity every day of the week. Participating in physical activity is very safe for MOST people. This questionnaire will tell you whether it is necessary for you to seek further advice from your doctor OR a qualified exercise professional before becoming more physically active.

GENERAL HEALTH QUESTIONS

Please read the 7 questions below carefully and answer each one honestly: check YES or NO.	YES	NO
1) Has your doctor ever said that you have a heart condition ☐ OR high blood pressure ☐?	☐	☐
2) Do you feel pain in your chest at rest, during your daily activities of living, **OR** when you do physical activity?	☐	☐
3) Do you lose balance because of dizziness **OR** have you lost consciousness in the last 12 months? Please answer **NO** if your dizziness was associated with over-breathing (including during vigorous exercise).	☐	☐
4) Have you ever been diagnosed with another chronic medical condition (other than heart disease or high blood pressure)? **PLEASE LIST CONDITION(S) HERE:** ____________	☐	☐
5) Are you currently taking prescribed medications for a chronic medical condition? **PLEASE LIST CONDITION(S) AND MEDICATIONS HERE:** ____________	☐	☐
6) Do you currently have (or have had within the past 12 months) a bone, joint, or soft tissue (muscle, ligament, or tendon) problem that could be made worse by becoming more physically active? Please answer **NO** if you had a problem in the past, but it ***does not limit your current ability*** to be physically active. **PLEASE LIST CONDITION(S) HERE:** ____________	☐	☐
7) Has your doctor ever said that you should only do medically supervised physical activity?	☐	☐

If you answered NO to all of the questions above, you are cleared for physical activity.
You do not need to complete Pages 2 and 3.

- Start becoming much more physically active – start slowly and build up gradually.
- Follow International Physical Activity Guidelines for your age (www.who.int/dietphysicalactivity/en/).
- You may take part in a health and fitness appraisal.
- If you are over the age of 45 yr and **NOT** accustomed to regular vigorous to maximal effort exercise, consult a qualified exercise professional before engaging in this intensity of exercise.
- If you have any further questions, contact a qualified exercise professional.

If you answered YES to one or more of the questions above, COMPLETE PAGES 2 AND 3.

Delay becoming more active if:

- You have a temporary illness such as a cold or fever; it is best to wait until you feel better.
- You are pregnant - talk to your health care practitioner, your physician, a qualified exercise professional, and/or complete the ePARmed-X+ at **www.eparmedx.com** before becoming more physically active.
- Your health changes - answer the questions on Pages 2 and 3 of this document and/or talk to your doctor or a qualified exercise professional before continuing with any physical activity program.

2017 PAR-Q+

FOLLOW-UP QUESTIONS ABOUT YOUR MEDICAL CONDITION(S)

1. Do you have Arthritis, Osteoporosis, or Back Problems?

If the above condition(s) is/are present, answer questions 1a-1c — If **NO** ☐ go to question 2

1a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments)	YES ☐ NO ☐
1b.	Do you have joint problems causing pain, a recent fracture or fracture caused by osteoporosis or cancer, displaced vertebra (e.g., spondylolisthesis), and/or spondylolysis/pars defect (a crack in the bony ring on the back of the spinal column)?	YES ☐ NO ☐
1c.	Have you had steroid injections or taken steroid tablets regularly for more than 3 months?	YES ☐ NO ☐

2. Do you currently have Cancer of any kind?

If the above condition(s) is/are present, answer questions 2a-2b — If **NO** ☐ go to question 3

2a.	Does your cancer diagnosis include any of the following types: lung/bronchogenic, multiple myeloma (cancer of plasma cells), head, and/or neck?	YES ☐ NO ☐
2b.	Are you currently receiving cancer therapy (such as chemotheraphy or radiotherapy)?	YES ☐ NO ☐

3. Do you have a Heart or Cardiovascular Condition? *This includes Coronary Artery Disease, Heart Failure, Diagnosed Abnormality of Heart Rhythm*

If the above condition(s) is/are present, answer questions 3a-3d — If **NO** ☐ go to question 4

3a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments)	YES ☐ NO ☐
3b.	Do you have an irregular heart beat that requires medical management? (e.g., atrial fibrillation, premature ventricular contraction)	YES ☐ NO ☐
3c.	Do you have chronic heart failure?	YES ☐ NO ☐
3d.	Do you have diagnosed coronary artery (cardiovascular) disease and have not participated in regular physical activity in the last 2 months?	YES ☐ NO ☐

4. Do you have High Blood Pressure?

If the above condition(s) is/are present, answer questions 4a-4b — If **NO** ☐ go to question 5

4a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments)	YES ☐ NO ☐
4b.	Do you have a resting blood pressure equal to or greater than 160/90 mmHg with or without medication? (Answer **YES** if you do not know your resting blood pressure)	YES ☐ NO ☐

5. Do you have any Metabolic Conditions? *This includes Type 1 Diabetes, Type 2 Diabetes, Pre-Diabetes*

If the above condition(s) is/are present, answer questions 5a-5e — If **NO** ☐ go to question 6

5a.	Do you often have difficulty controlling your blood sugar levels with foods, medications, or other physician-prescribed therapies?	YES ☐ NO ☐
5b.	Do you often suffer from signs and symptoms of low blood sugar (hypoglycemia) following exercise and/or during activities of daily living? Signs of hypoglycemia may include shakiness, nervousness, unusual irritability, abnormal sweating, dizziness or light-headedness, mental confusion, difficulty speaking, weakness, or sleepiness.	YES ☐ NO ☐
5c.	Do you have any signs or symptoms of diabetes complications such as heart or vascular disease and/or complications affecting your eyes, kidneys, **OR** the sensation in your toes and feet?	YES ☐ NO ☐
5d.	Do you have other metabolic conditions (such as current pregnancy-related diabetes, chronic kidney disease, or liver problems)?	YES ☐ NO ☐
5e.	Are you planning to engage in what for you is unusually high (or vigorous) intensity exercise in the near future?	YES ☐ NO ☐

2017 PAR-Q+

6. Do you have any Mental Health Problems or Learning Difficulties? *This includes Alzheimer's, Dementia, Depression, Anxiety Disorder, Eating Disorder, Psychotic Disorder, Intellectual Disability, Down Syndrome*

If the above condition(s) is/are present, answer questions 6a-6b — If **NO** ☐ go to question 7

6a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments)	YES ☐ NO ☐
6b.	Do you have Down Syndrome **AND** back problems affecting nerves or muscles?	YES ☐ NO ☐

7. Do you have a Respiratory Disease? *This includes Chronic Obstructive Pulmonary Disease, Asthma, Pulmonary High Blood Pressure*

If the above condition(s) is/are present, answer questions 7a-7d — If **NO** ☐ go to question 8

7a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments)	YES ☐ NO ☐
7b.	Has your doctor ever said your blood oxygen level is low at rest or during exercise and/or that you require supplemental oxygen therapy?	YES ☐ NO ☐
7c.	If asthmatic, do you currently have symptoms of chest tightness, wheezing, laboured breathing, consistent cough (more than 2 days/week), or have you used your rescue medication more than twice in the last week?	YES ☐ NO ☐
7d.	Has your doctor ever said you have high blood pressure in the blood vessels of your lungs?	YES ☐ NO ☐

8. Do you have a Spinal Cord Injury? *This includes Tetraplegia and Paraplegia*

If the above condition(s) is/are present, answer questions 8a-8c — If **NO** ☐ go to question 9

8a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments)	YES ☐ NO ☐
8b.	Do you commonly exhibit low resting blood pressure significant enough to cause dizziness, light-headedness, and/or fainting?	YES ☐ NO ☐
8c.	Has your physician indicated that you exhibit sudden bouts of high blood pressure (known as Autonomic Dysreflexia)?	YES ☐ NO ☐

9. Have you had a Stroke? *This includes Transient Ischemic Attack (TIA) or Cerebrovascular Event*

If the above condition(s) is/are present, answer questions 9a-9c — If **NO** ☐ go to question 10

9a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments)	YES ☐ NO ☐
9b.	Do you have any impairment in walking or mobility?	YES ☐ NO ☐
9c.	Have you experienced a stroke or impairment in nerves or muscles in the past 6 months?	YES ☐ NO ☐

10. Do you have any other medical condition not listed above or do you have two or more medical conditions?

If you have other medical conditions, answer questions 10a-10c — If **NO** ☐ read the Page 4 recommendations

10a.	Have you experienced a blackout, fainted, or lost consciousness as a result of a head injury within the last 12 months **OR** have you had a diagnosed concussion within the last 12 months?	YES ☐ NO ☐
10b.	Do you have a medical condition that is not listed (such as epilepsy, neurological conditions, kidney problems)?	YES ☐ NO ☐
10c.	Do you currently live with two or more medical conditions?	YES ☐ NO ☐

PLEASE LIST YOUR MEDICAL CONDITION(S) AND ANY RELATED MEDICATIONS HERE: ______________________

GO to Page 4 for recommendations about your current medical condition(s) and sign the PARTICIPANT DECLARATION.

OSHF Ontario Society for Health and Fitness

01-01-2017

2017 PAR-Q+

If you answered NO to all of the follow-up questions about your medical condition, you are ready to become more physically active - sign the PARTICIPANT DECLARATION below:

- It is advised that you consult a qualified exercise professional to help you develop a safe and effective physical activity plan to meet your health needs.
- You are encouraged to start slowly and build up gradually - 20 to 60 minutes of low to moderate intensity exercise, 3-5 days per week including aerobic and muscle strengthening exercises.
- As you progress, you should aim to accumulate 150 minutes or more of moderate intensity physical activity per week.
- If you are over the age of 45 yr and **NOT** accustomed to regular vigorous to maximal effort exercise, consult a qualified exercise professional before engaging in this intensity of exercise.

If you answered **YES** to **one or more of the follow-up questions** about your medical condition:

You should seek further information before becoming more physically active or engaging in a fitness appraisal. You should complete the specially designed online screening and exercise recommendations program - the **ePARmed-X+ at www.eparmedx.com** and/or visit a qualified exercise professional to work through the ePARmed-X+ and for further information.

Delay becoming more active if:

- You have a temporary illness such as a cold or fever; it is best to wait until you feel better.
- You are pregnant - talk to your health care practitioner, your physician, a qualified exercise professional, and/or complete the ePARmed-X+ **at www.eparmedx.com** before becoming more physically active.
- Your health changes - talk to your doctor or qualified exercise professional before continuing with any physical activity program.

- You are encouraged to photocopy the PAR-Q+. You must use the entire questionnaire and NO changes are permitted.
- The authors, the PAR-Q+ Collaboration, partner organizations, and their agents assume no liability for persons who undertake physical activity and/or make use of the PAR-Q+ or ePARmed-X+. If in doubt after completing the questionnaire, consult your doctor prior to physical activity.

For more information, please contact
www.eparmedx.com
Email: eparmedx@gmail.com

Citation for PAR-Q+
Warburton DER, Jamnik VK, Bredin SSD, and Gledhill N on behalf of the PAR-Q+ Collaboration. The Physical Activity Readiness Questionnaire for Everyone (PAR-Q+) and Electronic Physical Activity Readiness Medical Examination (ePARmed-X+). Health & Fitness Journal of Canada 4(2):3-23, 2011.

The PAR-Q+ was created using the evidence-based AGREE process (1) by the PAR-Q+ Collaboration chaired by Dr. Darren E. R. Warburton with Dr. Norman Gledhill, Dr. Veronica Jamnik, and Dr. Donald C. McKenzie (2). Production of this document has been made possible through financial contributions from the Public Health Agency of Canada and the BC Ministry of Health Services. The views expressed herein do not necessarily represent the views of the Public Health Agency of Canada or the BC Ministry of Health Services.

Key References

1. Jamnik VK, Warburton DER, Makarski J, McKenzie DC, Shephard RJ, Stone J, and Gledhill N. Enhancing the effectiveness of clearance for physical activity participation; background and overall process. APNM 36(S1):S3-S13, 2011.
2. Warburton DER, Gledhill N, Jamnik VK, Bredin SSD, McKenzie DC, Stone J, Charlesworth S, and Shephard RJ. Evidence-based risk assessment and recommendations for physical activity clearance; Consensus Document. APNM 36(S1):S266-s298, 2011.
3. Chisholm DM, Collis ML, Kulak LL, Davenport W, and Gruber N. Physical activity readiness. British Columbia Medical Journal. 1975;17:375-378.
4. Thomas S, Reading J, and Shephard RJ. Revision of the Physical Activity Readiness Questionnaire (PAR-Q). Canadian Journal of Sport Science 1992;17:4 338-345.

OSHF

Appendix D

International Physical Activity Questionnaire (IPAQ) Scoring Protocol

Continuous Score

Expressed as MET-minutes per week: MET level x minutes of activity/day x days per week

MET levels

Walking at work= 3.3 METs

Cycling for transportation= 6.0 METs

Moderate yard work= 4.0 METs

Vigorous intensity in leisure= 8.0 METs

Sample Calculation

MET-minutes/week for 30 min/day, 5 days

3.3*30*5 = 495 MET-minutes/week
6.0*30*5 = 900 MET-minutes/week
4.0*30*5 = 600 MET-minutes/week
8.0*30*5 = 1,200 MET-minutes/week
TOTAL = 3,195 MET-minutes/week

<u>Domain Sub Scores</u>

Total MET-minutes/week at **work** = Walk (METs*min*days) + Mod (METs*min*days) + Vig (METs*min*days) at work

Total MET-minutes/week for **transportation** = Walk (METs*min*days) + Cycle (METs*min*days) for transportation

Total MET-minutes/week from **domestic and garden** = Vig (METs*min*days) yard work + Mod (METs*min*days) yard work + Mod (METs*min*days) inside chores

Total MET-minutes/week in **leisure-time** = Walk (METs*min*days) + Mod (METs*min*days) + Vig (METs*min*days) in leisure-time

<u>Walking, Moderate-Intensity and Vigorous-Intensity Sub Scores</u>

Total **Walking** MET-minutes/week = Walk MET-minutes/week (at Work + for Transport + in Leisure)

Total **Moderate** MET-minutes/week = Cycle MET-minutes/week for Transport + Mod MET- minutes/week (Work + Yard chores + Inside chores + Leisure) + Vigorous Yard chores MET- minutes

Note: The above is a total moderate activities only score. If you require a total of all moderate-intensity physical activities you would sum Total Walking and Total Moderate

Total **Vigorous** MET-minutes/week = Vig MET-minutes/week (at Work + in Leisure)

Total Physical Activity Score

Total Physical Activity MET-minutes/week = **Walking** MET-minutes/week + **Moderate** MET- minutes/week + Total **Vigorous** MET-minutes/week

Total Physical Activity MET-minutes/week = Total MET-minutes/week (at Work + for Transport + in Chores + in Leisure)

Categorical Score- three levels of physical activity are proposed

1. Low

- No activity is reported OR
- Some activity is reported but not enough to meet Categories 2 or 3.

2. Moderate

Either of the following 3 criteria

- 3 or more days of vigorous-intensity activity of at least 20 minutes per day OR
- 5 or more days of moderate-intensity activity and/or walking of at least 30 minutes per day OR
- 5 or more days of any combination of walking, moderate-intensity or vigorous-intensity activities achieving a minimum of at least 600 MET-min/week.

3. High

Any one of the following 2 criteria

- Vigorous-intensity activity on at least 3 days and accumulating at least 1500 MET-minutes/week OR
- 7 or more days of any combination of walking, moderate- or vigorous- intensity activities accumulating at least 3000 MET-minutes/week

Appendix E

International Physical Activity Questionnaire (IPAQ)

INTERNATIONAL PHYSICAL ACTIVITY QUESTIONNAIRE

We are interested in finding out about the kinds of physical activities that people do as part of their everyday lives. The questions will ask you about the time you spent being physically active in the **last 7 days**. Please answer each question even if you do not consider yourself to be an active person. Please think about the activities you do at work, as part of your house and yard work, to get from place to place, and in your spare time for recreation, exercise or sport.

Think about all the **vigorous** and **moderate** activities that you did in the **last 7 days**. **Vigorous** physical activities refer to activities that take hard physical effort and make you breathe much harder than normal. **Moderate** activities refer to activities that take moderate physical effort and make you breathe somewhat harder than normal.

PART 1: JOB-RELATED PHYSICAL ACTIVITY

The first section is about your work. This includes paid jobs, farming, volunteer work, course work, and any other unpaid work that you did outside your home. Do not include unpaid work you might do around your home, like housework, yard work, general maintenance, and caring for your family. These are asked in Part 3.

1. Do you currently have a job or do any unpaid work outside your home?

☐ Yes

☐ No ➔ ***Skip to PART 2: TRANSPORTATION***

The next questions are about all the physical activity you did in the **last 7 days** as part of your paid or unpaid work. This does not include traveling to and from work.

2. During the **last 7 days**, on how many days did you do **vigorous** physical activities like heavy lifting, digging, heavy construction, or climbing up stairs **as part of your work**? Think about only those physical activities that you did for at least 10 minutes at a time.

_____ **days per week**

☐ No vigorous job-related physical activity ➔ ***Skip to question 4***

3. How much time did you usually spend on one of those days doing **vigorous** physical activities as part of your work?

_____ **hours per day**
_____ **minutes per day**

4. Again, think about only those physical activities that you did for at least 10 minutes at a time. During the **last 7 days**, on how many days did you do **moderate** physical activities like carrying light loads **as part of your work**? Please do not include walking.

_____ **days per week**

☐ No moderate job-related physical activity ➔ ***Skip to question 6***

LONG LAST 7 DAYS SELF-ADMINISTERED version of the IPAQ. Revised October 2002.

5. How much time did you usually spend on one of those days doing **moderate** physical activities as part of your work?

_____ **hours per day**
_____ **minutes per day**

6. During the **last 7 days**, on how many days did you **walk** for at least 10 minutes at a time **as part of your work**? Please do not count any walking you did to travel to or from work.

_____ **days per week**

☐ No job-related walking → ***Skip to PART 2: TRANSPORTATION***

7. How much time did you usually spend on one of those days **walking** as part of your work?

_____ **hours per day**
_____ **minutes per day**

PART 2: TRANSPORTATION PHYSICAL ACTIVITY

These questions are about how you traveled from place to place, including to places like work, stores, movies, and so on.

8. During the **last 7 days**, on how many days did you **travel in a motor vehicle** like a train, bus, car, or tram?

_____ **days per week**

☐ No traveling in a motor vehicle → ***Skip to question 10***

9. How much time did you usually spend on one of those days **traveling** in a train, bus, car, tram, or other kind of motor vehicle?

_____ **hours per day**
_____ **minutes per day**

Now think only about the **bicycling** and **walking** you might have done to travel to and from work, to do errands, or to go from place to place.

10. During the **last 7 days**, on how many days did you **bicycle** for at least 10 minutes at a time to go **from place to place**?

_____ **days per week**

☐ No bicycling from place to place → ***Skip to question 12***

LONG LAST 7 DAYS SELF-ADMINISTERED version of the IPAQ. Revised October 2002.

11. How much time did you usually spend on one of those days to **bicycle** from place to place?

_____ **hours per day**
_____ **minutes per day**

12. During the **last 7 days**, on how many days did you **walk** for at least 10 minutes at a time to go **from place to place**?

_____ **days per week**

☐ No walking from place to place → ***Skip to PART 3: HOUSEWORK, HOUSE MAINTENANCE, AND CARING FOR FAMILY***

13. How much time did you usually spend on one of those days **walking** from place to place?

_____ **hours per day**
_____ **minutes per day**

PART 3: HOUSEWORK, HOUSE MAINTENANCE, AND CARING FOR FAMILY

This section is about some of the physical activities you might have done in the **last 7 days** in and around your home, like housework, gardening, yard work, general maintenance work, and caring for your family.

14. Think about only those physical activities that you did for at least 10 minutes at a time. During the **last 7 days**, on how many days did you do **vigorous** physical activities like heavy lifting, chopping wood, shoveling snow, or digging **in the garden or yard**?

_____ **days per week**

☐ No vigorous activity in garden or yard → ***Skip to question 16***

15. How much time did you usually spend on one of those days doing **vigorous** physical activities in the garden or yard?

_____ **hours per day**
_____ **minutes per day**

16. Again, think about only those physical activities that you did for at least 10 minutes at a time. During the **last 7 days**, on how many days did you do **moderate** activities like carrying light loads, sweeping, washing windows, and raking **in the garden or yard**?

_____ **days per week**

☐ No moderate activity in garden or yard → ***Skip to question 18***

17. How much time did you usually spend on one of those days doing **moderate** physical activities in the garden or yard?

_____ **hours per day**
_____ **minutes per day**

18. Once again, think about only those physical activities that you did for at least 10 minutes at a time. During the **last 7 days**, on how many days did you do **moderate** activities like carrying light loads, washing windows, scrubbing floors and sweeping **inside your home**?

_____ **days per week**

☐ No moderate activity inside home → ***Skip to PART 4: RECREATION, SPORT AND LEISURE-TIME PHYSICAL ACTIVITY***

19. How much time did you usually spend on one of those days doing **moderate** physical activities inside your home?

_____ **hours per day**
_____ **minutes per day**

PART 4: RECREATION, SPORT, AND LEISURE-TIME PHYSICAL ACTIVITY

This section is about all the physical activities that you did in the **last 7 days** solely for recreation, sport, exercise or leisure. Please do not include any activities you have already mentioned.

20. Not counting any walking you have already mentioned, during the **last 7 days**, on how many days did you **walk** for at least 10 minutes at a time **in your leisure time**?

_____ **days per week**

☐ No walking in leisure time → ***Skip to question 22***

21. How much time did you usually spend on one of those days **walking** in your leisure time?

_____ **hours per day**
_____ **minutes per day**

22. Think about only those physical activities that you did for at least 10 minutes at a time. During the **last 7 days**, on how many days did you do **vigorous** physical activities like aerobics, running, fast bicycling, or fast swimming **in your leisure time**?

_____ **days per week**

☐ No vigorous activity in leisure time → ***Skip to question 24***

23. How much time did you usually spend on one of those days doing **vigorous** physical activities in your leisure time?

_____ **hours per day**
_____ **minutes per day**

24. Again, think about only those physical activities that you did for at least 10 minutes at a time. During the **last 7 days**, on how many days did you do **moderate** physical activities like bicycling at a regular pace, swimming at a regular pace, and doubles tennis **in your leisure time**?

_____ **days per week**

☐ No moderate activity in leisure time → ***Skip to PART 5: TIME SPENT SITTING***

25. How much time did you usually spend on one of those days doing **moderate** physical activities in your leisure time?
_____ **hours per day**
_____ **minutes per day**

PART 5: TIME SPENT SITTING

The last questions are about the time you spend sitting while at work, at home, while doing course work and during leisure time. This may include time spent sitting at a desk, visiting friends, reading or sitting or lying down to watch television. Do not include any time spent sitting in a motor vehicle that you have already told me about.

26. During the **last 7 days**, how much time did you usually spend **sitting** on a **weekday**?

_____ **hours per day**
_____ **minutes per day**

27. During the **last 7 days**, how much time did you usually spend **sitting** on a **weekend day**?

_____ **hours per day**
_____ **minutes per day**

This is the end of the questionnaire, thank you for participating.

LONG LAST 7 DAYS SELF-ADMINISTERED version of the IPAQ. Revised October 2002.

Appendix F

Oral Instructions for Borg Rating of Perceived Exertion (RPE) Scale

While doing physical activity, we want to rate your perception of exertion. This feeling should reflect how heavy and strenuous the exercise feels to you, combining all sensations and feelings of physical stress, effort, and fatigue. Do not concern yourself with any one factor such as leg pain or shortness of breath, but try to focus on your total feeling of exertion.

Look at the rating scale below while you are engaging in an activity; it ranges from 6 to 20, where 6 means “no exertion at all” and 20 means “maximal exertion.” Choose the number from below that best describes your level of exertion. This will give you a good idea of the intensity level of your activity, and you can use this information to speed up or slow down your movements to reach your desired range.

Try to appraise your feeling of exertion as honestly as possible, without thinking about what the actual physical load is. Your own feeling of effort and exertion is important, not how it compares to other people’s. Look at the scales and the expressions and then give a number.

Appendix G

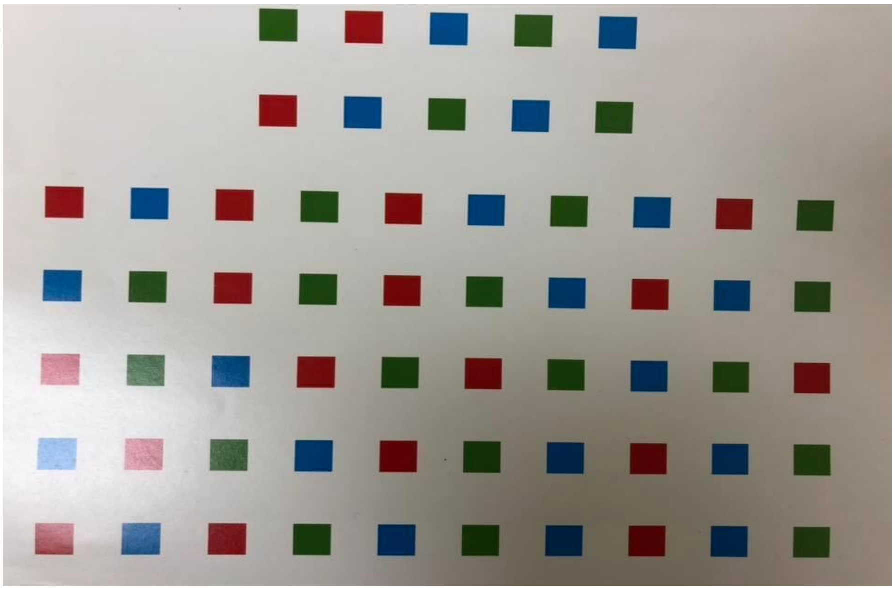
Borg Rating of Perceived Exertion (RPE) Scale

#	Level of Exertion
6	**No exertion at all**
7	
7.5	**Extremely Light**
8	
9	**Very Light**
10	
11	**Light**
12	
13	**Somewhat Hard**
14	
15	**Hard (heavy)**
16	
17	**Very Hard**
18	
19	**Extremely Hard**
20	**Maximal Exertion**

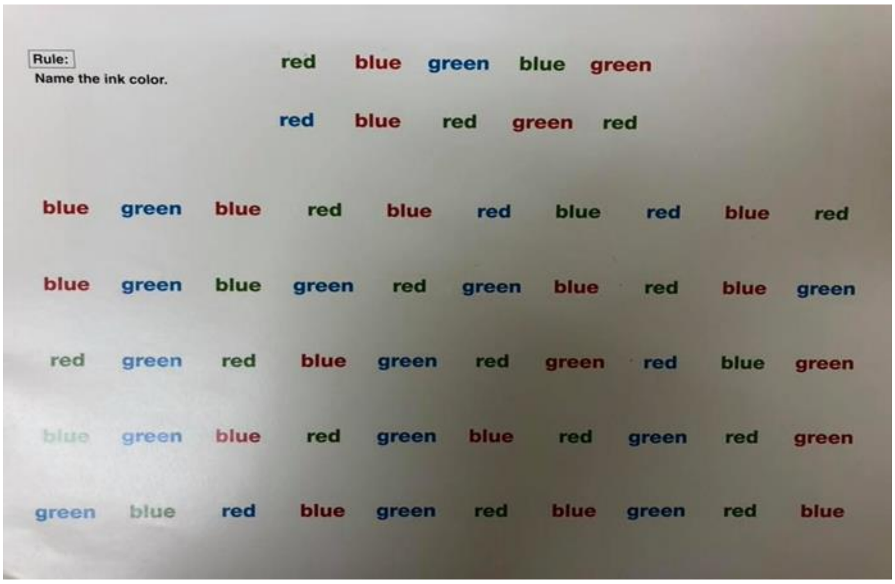
Appendix H

Color-Word Interference Test

Condition 1: Color Naming



Condition 3: Inhibition



Appendix I

Flyer for Psychology 101/201 Participant Pool

INTERESTED IN BEING PART OF A RESEARCH PROJECT?

You are invited to participate in a research study that aims to examine the role of sex on the effect of the acute aerobic exercise on executive functions (EFs). This notice is for an AUB-IRB Approved Research Study for Dr. Arne Dietrich (Principal Investigator) and Sandra Zakka (Co- Investigator). **It is not an Official Message from AUB.** The study is purely for research purposes. You will be asked to participate in 2 sessions, and both will take place in the AUB psychology lab (Jesup Hall 107). The time commitment for each participant is expected to last approximately 60 minutes per session. Around 60 students are expected to participate.

ELIGIBILITY: To participate, you must be between 18 and 25 years of age (inclusive). If you are currently taking medical and/or psychiatric medications, and/or reporting any history of medical and/or psychological difficulties, you will be **excluded** from the study. Female students who are currently pregnant or menstruating will also be **excluded**.

RISKS: There are **no** foreseeable physical or psychological risks involved with participating in this study that exceed minimal risks ordinarily encouraged in daily life or during performance of moderate intensity physical exercise, although the possibility of some unforeseeable risks exists.

BENEFITS: The results of this study will offer implications for the development of effective strategies to improve EFs among college students as well as encourage physical activity among students, and particularly, female students. You will also receive up to 3 course credits (added to your Psych 101/201 course grade) for your participation in this study. **To earn your extra credit:** upon participating, you will be asked to provide the research investigators with your name and email address. **The research investigators will provide your name and email address to Dr. May Awaida who will then give your contact information to your psychology instructor, who will provide you with the extra credit.**

ALTERNATIVES: If you are **not** interested in participating in this study and would still like the opportunity to earn extra credit, you could participate in another advertised study or write a brief report on an article in a psychological journal. For more information on other research studies or writing a brief report, please contact Dr. May Awaida at **mawaida@aub.edu.lb** or 01- 350000 ext. 4374/4360.

Your participation in this study is **voluntary.** Refusal or withdrawal from the study will involve no loss of benefits to which you are otherwise entitled nor will it affect your relationship with AUB, your instructor or your grades.

If you have any questions about participation, please contact either:

Arne Dietrich, PhD (Principal Investigator)

Professor and Chair of Psychology, AUB

Email: ad12@aub.edu.lb

Ext: 4369, Jesup 109

Sandra Zakka, MA candidate (co- Investigator)

Graduate Student in Psychology, AUB

Email: sxz00@mail.aub.ed

Interested in Participation? *Please contact* ***Sandra Zakka*** *at sxz00@mail.aub.edu*

Appendix J

Social Media Post

SEEKING VOLUNTEERS FOR A RESEARCH STUDY

Dear AUB students,

You are invited to participate in a voluntary research study that aims to examine the role of sex on the effect of acute aerobic exercise on executive functions.

To participate in this research, you must:

• Be an AUB student
• Be 18 to 25 years of age
• Have NO history of mental/physical disorders

Participants will:

• Come to two morning sessions (1 hour each)
• Come to the AUB Psychology Lab (Jesup 107)
• Exercise on a cycle ergometer for 30 minutes
• Complete a cognitive task

Study Title: Effect of Acute Aerobic Exercise on the Executive Functions of College Students: Role of Sex
Principal Investigator: Arne Dietrich, PhD
Co-Investigator: Sandra Zakka, MA Candidate

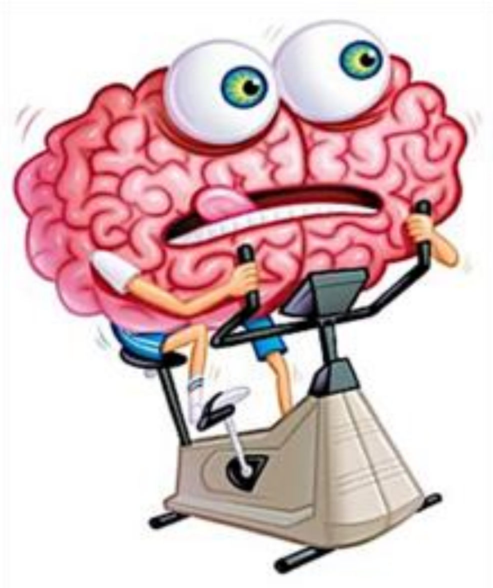
If you are interested in participating in this study, and/or would like to find out more about this study, please contact Sandra Zakka at: sxz00@mail.aub.edu

Appendix K

Flyer

SEEKING VOLUNTEERS FOR A RESEARCH STUDY

You are invited to participate in a **voluntary research study** that aims to examine the role of sex in the effect of acute aerobic exercise on executive functions.



To participate in this research, you must:

- Be an AUB student
- Be 18 to 25 years of age
- Have **no** history of mental/physical disorders

Participants will:

- Come to two morning sessions (1 hour each)
- Come to the AUB Psychology Lab (Jesup 107)
- Exercise on cycle ergometer for 30 minutes
- Complete a cognitive task

Study Title: Effect of Acute Aerobic Exercise on the Executive Functions of College Students: Role of Sex
Principal Investigator: Arne Dietrich, PhD
Co-Investigator: Sandra Zakka, MA Candidate

If you are interested in participating in this study, and/or would like to find out more information about this study, please contact Sandra Zakka at:

sxz00@mail.aub.edu

Appendix L

Email to Interest Students

Dear Student,

Thank you for your interest in participating in the study: "Effect of Acute Aerobic Exercise on the Executive Functions of College Students: Role of Sex"! This notice is for an AUB-IRB Approved Research Study for Dr. Arne Dietrich (Principal Investigator) and Sandra Zakka, MA Candidate (co-Investigator) at AUB. ***It is not an Official Message from AUB***

The purpose of this study is to identify whether executive functions (EFs), or higher-order cognition, might benefit from an acute bout of aerobic exercise, and more specifically, whether females or males would be more, less, or similarly sensitive to the exercise manipulation. To demonstrate this, students will perform an EF task, prior to and fifteen-minutes after exercising on a cycle ergometer for 30 minutes at moderate intensity.

The study consists of two sessions, each expected to last no more than one-hour. In the first session, you will be given details regarding the experiment's procedures and your rights as a participant. You will also be asked to fill out four questionnaires that will ask you questions related to relevant demographics (e.g., age, gender, GPA), physical activity readiness, social history, and physical fitness levels. Your resting heart will also be measured. In the second session, you will be randomly assigned to one of two groups: an exercise group, where you will exercise at moderate intensity on a cycle ergometer for 30 minutes, or a control group, where you will be given reading materials (newspapers) for 30 minutes. In both cases, you will be administered a task of cognitive functioning, prior to and fifteen-minutes after exercising/reading. It is also expected that the second session will last no more than one hour.

To be eligible for participation in the study, students may be of any race or ethnicity. However, students currently taking medical and/or psychiatric medications, and/or reporting any history of medical and/or psychological difficulties **will be excluded**. Female students who are currently pregnant or menstruating **will also be excluded**. Students must be between 18 and 25 years of age, inclusive.

Note that both sessions will take place between Mondays to Fridays, in the Psychology Lab (Jesup Hall 107). The second session will be in the morning.
If you are still interested in taking part of the study, kindly reply to this email with ALL DAYS AND TIMES that you are available between Mondays to Fridays, to carry out the first session.

Kindly note that your participation in this study is completely voluntary. You may withdraw your consent to participate in this research at any point without any explanation and without any penalty. You are also free to walk out of the experiment at any point in time without any explanation.

Thank you for considering participating in this study.

With best regards,

Sandra Zakka, MA Candidate

Appendix M

Request for Contact Details

Thank you for completing this survey! You will be contacted (via email) to set a date and time (morning) for the second session, if eligible to participate in this study. To be eligible for participation in the present study, students must NOT be currently taking any medical and/or psychiatric medications, and/or reporting any history of medical and/or psychological difficulties. Also, female students who are currently pregnant or menstruating will be excluded. Students must between 18 and 25 years of age (inclusive). If not eligible, you will be thanked for your participation, provided with an explanation for your ineligibility, and given a brochure including recommendations on ways to promote and incorporate physical activity into your everyday life.

Preferred e-mail address: ______________________________

Please note that your email address will only be used for contact purposes and will be erased once you have completed, if applicable, the second (testing) session. If you are ineligible to take part in this study, your email address will be erased as soon as you have been contacted to thank you for your time.

****If you are part of the Psych 101/201 participant pool****

Full name: ______________________________

Course Instructor: ______________________________

Preferred e-mail address: ______________________________

Please note that your name is only used according to "Interim Guidance for Access to the Psychology 101/201 Student Pool for Research", which requires that a list of student names must be submitted to the Participant Pool Coordinator (PPC) upon completing data collection, along with the number of hours he/she has participated. The PPC, will in turn provide this list of names to the course instructor, who will provide the student with his/her credit. The list of names will be kept in the Research Investigator's password protected laptop, who will delete this list once it has been given to the PPC and course instructor.

Appendix N

Invitation Email/ Eligible Participants

Subject: Session 2: Effect of Acute Aerobic Exercise on the Executive Functions of College Students: Role of Sex

Dear Student,
Thank you for completing the first part of the study titled "Effect of Acute Aerobic Exercise on the Executive Functions of College Students: Role of Sex"!

This is an email regarding your participation in the second session. Please review carefully the procedures in this next session, as described to you on the information sheet you have been provided with in the first session.

<u>**This second session will be carried out in the MORNING, from Mondays to Fridays, in the Psychology Lab (Jesup 107). Please reply to this email, specifying ALL days and times in which you can participate in the morning. It is expected that your participation will last no more than 1 hour.**</u>

If you decide to complete this study, you are kindly asked to:

- Refrain from ingesting food, alcohol, caffeine, or tobacco products within <u>**3 hours of testing**</u>
- Avoid significant exertion or exercise <u>**on the day of the assessment**</u>
- Wear appropriate sports clothing
- Drink ample fluids <u>**within 24 hours**</u> of testing to ensure normal hydration

Kindly note that your participation in this study is completely voluntary. You may withdraw your consent to participate in this research at any point without any explanation and without any penalty. You are also free to walk out of the experiment at any point in time without any explanation.

Thank you for considering participating in this study.

With best regards,

Sandra Zakka, MA Candidate

Appendix O

Brochure

Behavioral Strategies to Promote Exercise

We all face multiple barriers to physical activity. Some of these include cost, high workload, transportation, or lack of motivation. Fortunately, the American College of Sports Medicine (ACSM) has proposed several behavioral strategies that you could use to promote and incorporate exercise into your daily life.

1. **Gym memberships cost too much.**
Make use of the exercise facilities on campus. As an AUB student, you have access to the gymnasium, exercise equipment, swimming pool, tennis and squash courts, and the green field. Moreover, explore free alternatives; these aerobic exercises include walking and jogging.

2. **I don't have enough time as a student.**
Modify the frequency and durations of the recommended exercises; create a list of your priorities; consider motivational interviewing

3. **I am not motivated.**
Consider reinforcements; write down or share with others your goals and expectations

4. **I do not know how to exercise.**
Explore aerobic exercises that require minimal fitness and skill (e.g., cycling & walking); consider help from a personal trainer or a fit friend

5. **I cannot find anyone to exercise with me.**
Develop an exercise buddy system; join the H.O.P.E. club at AUB which offers free exercise services for students; identify exercises you can do on your own

For more information

Please contact:

Arne Dietrich, PhD (Principle Investigator)

Professor & Chair of Psychology, Department of Psychology, AUB

Email: ad12@aub.edu.lb

Phone: 01-350000 Ext. 4369

Sandra Zakka, MA candidate (Co-Investigator)

Graduate Student in General Psychology, Department of Psychology, AUB

Email: sxz00@mail.aub.edu

Other resource you may find useful:

American College of Sports Medicine (ACSM)'s Guidelines for Exercise Testing and Prescription, Tenth Edition (www.acsm.org)

AMERICAN COLLEGE OF SPORTS MEDICINE · FOUNDED 1954 SM

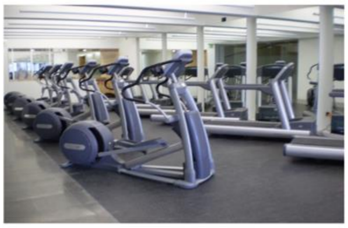
Exercise. Give your brain a makeover.

For young adults (18-25)

- Benefits of Aerobic Exercise
- Pre-Exercise Safety Considerations
- Recommendations for an Effective Exercise Routine
- Behavioral Strategies to Promote Exercise

The Benefits of Aerobic Exercise on Your Brain

- Improved cognitive function, and particularly higher-order cognitive functions (e.g., task-switching, inhibition, working memory, creativity). These improvements can be found both immediately after exercise and after a delay.
- Decreased anxiety and depression
- Enhanced feelings of well-being and mood
- Prevents the onset of age-related cognitive decline in older adults
- Slows the progression of cognitive deficits present in older adults
- Chronic exercise associated with enhanced academic performance among college students
- Used as a treatment for clinical patients (e.g., Major Depressive Disorder, ADHD)
- Individuals who are physically fit benefit significantly more from the cognitive effects of exercise than those who are less fit



Pre-Exercise Safety Considerations

The benefits of aerobic exercise are manifold. Nonetheless, the American College of Sports Medicine (ACSM) has identified several crucial pre-exercise safety precautions that all individuals must consider before engaging in physical activity.

A. Get a medical history and risk factor assessment by a professional.

B. Physical examinations and laboratory tests should be conducted by a physician or other professional health care provider (e.g., blood pressure, cholesterol levels, blood profile analyses, and pulmonary function)

In the absence of professional help, self-guided methods can be used (The Physical Activity Readiness Questionnaire for Everyone, PAR-Q+)

Four Aerobic Exercise Recommendations

1. **Frequency:** at least 5 days/week (moderate intensity), or at least 3 days/week (vigorous intensity), or a combination of both (3 — 5 days/week)
2. **Intensity:** moderate (i.e., 40%-59% heart rate reserve [HRR]) or vigorous (i.e., 60%-89% HRR); if inactive: light intensity (i.e., 30%-39% HRR) — *to measure your recommended intensity, see below***
3. **Duration:** 30—60 minutes/day of moderate intensity; 20—60 mins/day of vigorous intensity
4. **Mode:** endurance activities with minimal skill (e.g., cycling, walking), endurance and vigorous intensity with minimal skill (e.g., jogging, elliptical exercise, fast dancing), endurance exercise requiring skill and fitness (e.g., swimming, skiing)

**Target heart rate (THR): $[(HR_{max} - HR_{rest}) \times \%$ intensity desired$] + HR_{rest}$

$(HR_{max}) = 220$ - age

Appendix P

Thank You Email/ Ineligible Participants

Dear Student,

Thank you for completing the first part of the study titled “Effect of Acute Aerobic Exercise on the Executive Functions of College Students: Role of Sex”.

This study is designed to investigate the extent to which acute aerobic exercise influences executive functions, measured using a standardized neuropsychological test of inhibitory control, of college students. In addition, it examines sex as a moderating factor that might impact the effect of acute aerobic exercise on executive functions. Your privacy and the confidentiality of your answers in the questionnaires you have completed are ensured.

We thank you for your participation.

If you are interested in learning about the outcome of the study, you may also contact Sandra Zakka at this email address (sxz00@mail.aub.edu). After data analysis is completed, a summary of the results could be emailed to you upon request.

All the best for the upcoming semester!

With best regards,

Sandra Zakka, MA Candidate

Appendix Q

24-hour History Form

Directions: Please answer each question as accurately and honestly as possible by circling the correct answer.

1. How have you been feeling in the last 24 hours?

	Disagree	Slightly disagree	Neutral	Slightly agree	Agree
Comfort					
Able to breathe easily	1	2	3	4	5
Have had a good sleep	1	2	3	4	5
Could enjoy food	1	2	3	4	5
Feel rested	1	2	3	4	5
Emotions					
Having a feeling of general well-being	1	2	3	4	5
Feeling comfortable	1	2	3	4	5

2. Have you had any of the following in the last 24 hours?

	No	Somewhat	Yes
Comfort			
Nausea	1	2	3
Vomiting	1	2	3
Feeling restless	1	2	3
Shaking or twitching	1	2	3
Shivering	1	2	3
	No	**Somewhat**	**Yes**
Feeling too cold	1	2	3

Feeling dizzy	1	2	3

	No	**Somewhat**	**Yes**
Emotions			
Feeling anxious	1	2	3
Feeling angry	1	2	3
Feeling stressed	1	2	3
Feeling depressed	1	2	3
Had difficulty falling asleep	1	2	3

Pain			
Moderate pain	1	2	3
Severe pain	1	2	3
Headache	1	2	3
Muscle pains	1	2	3
Backache	1	2	3
Sore throat	1	2	3

3. Have you taken any medication in the last 24 hours (prescription or over the counter)?

________ Yes ________ No

If Yes, please list: ______________________

4. Have you taken any recreational drugs within the last 24 hours?

________ Yes ________ No

If Yes, please list: ________________________

5. Did you drink alcohol today?

________ Yes ________ No

6. Did you smoke a cigarette today?
________ Yes ________ No

7. Did you drink coffee today?
________ Yes ________ No

8. Did you arrive to this session feeling tired?
________ Yes ________ No

9. Did you spend any time doing moderate to vigorous physical exercise today?
________ Yes ________ No

10. Did you eat today?
________ Yes ________ No

11. In the last 24 hours, approximately how many cups of water did you drink?
________ cups of water

12. Are you currently menstruating?
_______ Yes _______No _______ N/A

13. Are you or have reason to believe that you are pregnant?
_______ Yes _______No _______ N/A

Appendix R

End of Study Statement

This study you have just completed was designed to investigate the extent to which acute aerobic exercise influences executive functions, measured using a standardized neuropsychological test of inhibitory control, of college students. In addition, it examines sex as a moderating factor that might impact the effect of acute aerobic exercise on executive functions. Your privacy and the confidentiality of your answers in this questionnaire are ensured. The research staff cannot link your contact information to the data you have provided.

We thank you for your participation and for not sharing the contents of the study with others. If you have any questions about the study, please feel free to contact Sandra Zakka at sxz00@aub.edu.lb. If you would like to be notified of this study's results, you may also contact Sandra Zakka.
Thank you.

Appendix S

Assumptions of Normality and Homogeneity

Cell Equivalence Before Manipulation

Scale Descriptives per Cell.

Normality Assumption.

Normality of each scale variable across each cell was tested using the Shapiro-Wilk (SW) test. For males in the control group, normality was met for the variables height, weight, BMI, HRrest, and HRbefore. The following SW test statistics were collected and normality was inferred:

Height: $W(27) = .96$, $p > .05$, *ns*

Weight: $W(27) = .98$, $p > .05$, *ns*

BMI: $W(27) = .98$, $p > .05$, *ns*

HRrest: $W(27) = .98$, $p > .05$, *ns*

HRbefore: $W(27) = .96$, $p > .05$, *ns*

For males in the control group, normality was not met for the variables age, MET, pretest inhibition, pretest naming error, and pretest inhibition error. The following SW test statistics were reported:

Age: $W(27) = .71$, $p < .05$

MET: $W(27) = .80$, $p < .05$

Pretest inhibition: $W(27) = .73$, $p < .05$

Pretest naming error: $W(27) = .43$, $p < .05$

Pretest inhibition error: $W(27) = .86$, $p < .05$

For males in the exercise group, normality was met for the variables height, weight, BMI, HRrest, and HRbefore. The following SW test statistics were collected and normality was inferred:

Height: $W(25) = .97$, $p > .05$, *ns*

Weight: $W(25) = .96$, $p > .05$, *ns*

BMI: $W(25) = .97$, $p > .05$, *ns*

HRrest: $W(25) = .96$, $p > .05$, *ns*

HRbefore: $W(25) = .94$, $p > .05$, *ns*

For males in the exercise group, normality was not met for the variables age, MET, pretest inhibition, pretest naming error, and pretest inhibition error. The following SW test statistics were reported:

Age: $W(25) = .56$, $p < .05$

MET: $W(25) = .68$, $p < .05$

Pretest inhibition: $W(25) = .85$, $p < .05$

Pretest naming error: $W(25) = .39$, $p < .05$

Pretest inhibition error: $W(25) = .81$, $p < .05$

For females in the control group, normality was met for the variables height, weight, BMI, HRrest, HRbefore, and pretest inhibition. The following SW test statistics were collected and normality was inferred:

Height: $W(25) = .93$, $p > .05$, *ns*

Weight: $W(25) = .94$, $p > .05$, *ns*

BMI: $W(25) = .95$, $p > .05$, *ns*

HRrest: $W(25) = .97$, $p > .05$, *ns*

HRbefore: $W(25) = .97$, $p > .05$, *ns*

Pretest inhibition: $W(25) = .96$, $p > .05$, *ns*

For females in the control group, normality was not met for the variables age, MET, pretest naming error, and pretest inhibition error. The following SW test statistics were reported:

Age: W(25) = .75, $p < .05$

MET: W(25) = .67, $p < .05$

Pretest naming error: W(25) = .59, $p < .05$

Pretest inhibition error: W(25) = .84, $p < .05$

For females in the exercise group, normality was met for the variables weight, HRbefore, and pretest inhibition. The following SW test statistics were collected and normality was inferred:

Weight: W(27) = .94, *ns*

HRbefore: W(27) = .93, n*s*

Pretest inhibition: W(27) = .97, *ns*

For females in the exercise group, normality was not met for the variables age, height, MET, HRrest, pretest naming error, and pretest inhibition error. The following SW test statistics were reported:

Age: W(27) = .78, $p < .05$

Height: W(27) = .92, $p < .05$

BMI: W(27) = .91, $p < .05$

MET: W(27) = .57, $p < .05$

HRrest: W(27) = .89, $p < .05$

Pretest naming error: W(27) = .64, $p < .05$

Pretest inhibition error: W(27) = .89, $p < .05$

Assumption of Homogeneity of Variances.

The homogeneity of variances of age, height, weight, BMI, MET, HRrest, HRbefore, pretest inhibition, pretest naming errors, and pretest inhibition errors were assessed using Levene’s tests.

Levene's test revealed that for age, the variances were not statistically different across cells (male control, male exercise, female control, female exercise), F (3, 100) = 2.05, *ns*. Therefore, the assumption of homogeneity of variances is met.

Levene's test revealed that for height, the variances were not statistically different across cells (male control, male exercise, female control, female exercise), F (3, 100) = .55, *ns*. Therefore, the assumption of homogeneity of variances is met.

Levene's test revealed that for weight, the variances were not statistically different across cells (male control, male exercise, female control, female exercise), F (3, 100) = .17, *ns*. Therefore, the assumption of homogeneity of variances is met.

Levene's test revealed that for BMI, the variances were not statistically different across cells (male control, male exercise, female control, female exercise), F (3, 100) = .31, *ns*. Therefore, the assumption of homogeneity of variances is met.

Levene's test revealed that for HRrest, the variances were not statistically different across cells (male control, male exercise, female control, female exercise), F (3, 100) = 2.01, *ns*. Therefore, the assumption of homogeneity of variances is met.

Levene's test revealed that for HRbefore, the variances were not statistically different across cells (male control, male exercise, female control, female exercise), F (3, 100) = .52, *ns*. Therefore, the assumption of homogeneity of variances is met.

Levene's test revealed that for pretest inhibition, the variances were not statistically different across cells (male control, male exercise, female control, female exercise), F (3, 100) = 1.34, *ns*. Therefore, the assumption of homogeneity of variances is met.

Levene's test revealed that for pretest naming errors, the variances were statistically different across cells (male control, male exercise, female control, female exercise), *F* (3, 100) = 3.67, p < .05. Therefore, the assumption of homogeneity of variance is violated.

Levene's test revealed that for pretest inhibition errors, the variances were not statistically different across cells (male control, male exercise, female control, female exercise), *F* (3, 100) = 1.84, *ns*. Therefore, the assumption of homogeneity of variances is met.

Intensity Manipulation Check

Assumption of Normality.

Normality of each scale variable (HRbefore, HRduring, HRafter) across each cell was tested using the Shapiro-Wilk (SW) test. For males in the control group, normality was met for all the variables HRbefore, HRduring, and HRafter. The following SW test statistics were collected and normality was inferred:

HRbefore: W(27) = .96, *ns*

HRduring: W(27) = .97, n*s*

HRafter: W(27) = .99, *ns*

For males in the exercise group, normality was met for all the variables HRbefore, HRduring, and HRafter. The following SW test statistics were collected and normality was inferred:

HRbefore: W(25) = .94, *ns*

HRduring: W(25) = .92, n*s*

HRafter: W(25) = .94, *ns*

For females in the control group, normality was met for the variables HRbefore and HRafter. The following SW test statistics were collected and normality was inferred:

HRbefore: W(25) = .97, *ns*

HRafter: W(25) = .96, *ns*

For females in the control group, normality was not met for the variable HRduring. The following SW test statistic was reported:

HRduring: W(25) = .69, $p < .05$

For females in the exercise group, normality was not met for all the variables HRbefore, HRduring, and HRafter. The following SW test statistic were reported:

HRbefore: W(27) = .93, $p = .05$

HRduring: W(27) = .55, $p < .05$

HRafter: W(27) = .91, $p < .05$

Assumption of Homogeneity of Variances.

The homogeneity of variances of HRbefore, HRduring and HRafter were assessed using Levene's tests. Levene's test revealed that for HRbefore, the variances were not statistically different across groups, F (3, 100) = .52, *ns*. Therefore, the assumption of homogeneity of variances is met. Levene's test revealed that for HRduring, the variances were not statistically different across groups, F (3, 100) = 1.61, *ns*. Therefore, the assumption of homogeneity of variances is met. Levene's test revealed that for HRafter, the variances were statistically different across groups, F (3, 100) = 2.67, p < .05. Therefore, the assumption of homogeneity of variance is violated.

Task Difficulty Check

Response Time.

Assumption of Normality.

Normality of each scale variable (pretest time 1, pretest time 3) across each cell was tested using the Shapiro-Wilk (SW) test. For males in the control group, normality was met for the variable pretest time 1. The following SW test statistics were collected and normality was inferred:

Pretest time 1: W(27) = .94, *ns*

For males in the control group, normality was not met for the variable pretest time 3. The following SW test statistic was reported:

Pretest time 3: W(27) = .58, $p < .05$

For males in the exercise group, normality was met for the variable pretest time 1. The following SW test statistics were collected and normality was inferred:

Pretest time 1: W(25) = .98, *ns*

For males in the exercise group, normality was not met for the variable pretest time 3. The following SW test statistic was reported:

Pretest time 3: W(25) = .81, $p < .05$

For females in the control group, normality was met for the variable pretest time 1. The following SW test statistics were collected and normality was inferred:

Pretest time 1: W(25) = .93, *ns*

For females in the control group, normality was not met for the variable pretest time 3. The following SW test statistic was reported:

Pretest time 3: W(25) = .69, $p < .05$

For females in the exercise group, normality was met for the variable pretest time 1. The following SW test statistics were collected and normality was inferred:

Pretest time 1: W(27) = .97, *ns*

For females in the exercise group, normality was not met for the variable pretest time 3. The following SW test statistic was reported:

Pretest time 3: W(27) = .73, $p < .05$

Assumption of Homogeneity of Variances.

The homogeneity of variances of pretest time 1 and pretest time 3 were assessed using Levene's tests. Levene's test revealed that for pretest time 1, the variances were not statistically different across groups, F (3, 100) = .55, *ns*. Thus, the assumption of homogeneity of variances is met. Levene's test revealed that for pretest time 3, the variances were not statistically different across groups, F (3, 100) = 1.19, *ns*. Thus, the assumption of homogeneity of variances is met.

Amount of Errors.

Assumption of Normality.

Normality of each scale variable (pretest naming error, pretest inhibition error) across each cell was tested using the Shapiro-Wilk (SW) test.

For males in the control group, normality was not met for the variables pretest naming error and pretest inhibition error. The following SW test statistic were reported:

Pretest naming error: W(27) = .43, $p < .05$

Pretest inhibition error: W(27) = .86, $p < .05$

For males in the exercise group, normality was not met for the variables pretest naming error and pretest inhibition error. The following SW test statistic were reported:

Pretest naming error: W(25) = .39, $p < .05$

Pretest inhibition error: W(25) = .80, $p < .05$

For females in the control group, normality was not met for the variables pretest naming error and pretest inhibition error. The following SW test statistic were reported:

Pretest naming error: W(25) = .59, $p < .05$

Pretest inhibition error: W(25) = .84, $p < .05$

For females in the exercise group, normality was not met for the variables pretest naming error and pretest inhibition error. The following SW test statistic were reported:

Pretest naming error: W(27) = .64, $p < .05$

Pretest inhibition error: W(27) = .89, $p < .05$

Assumption of Homogeneity of Variances.

The homogeneity of variances of pretest naming error and pretest inhibition error were assessed using Levene's tests. Levene's test revealed that for pretest naming errors, the variances were statistically different across groups, F (3, 100) = 3.67, p < .05. Therefore, the assumption of homogeneity of variance is violated. Levene's test revealed that for pretest inhibition errors, the variances were not statistically different across groups, F (3, 100) = 1.84, *ns*. Thus, the assumption of homogeneity of variances is met.

Main Analysis

Inhibition Scores.

Assumption of Normality.

Normality of each scale variable (pretest inhibition, posttest inhibition) across each cell was tested using the Shapiro-Wilk (SW) test.

For males in the control group, normality was not met for the variables pretest inhibition and posttest inhibition. The following SW test statistic were reported:

Pretest inhibition: W(27) = .73, $p < .05$

Posttest inhibition: W(27) = .70, $p < .05$

For males in the exercise group, normality was not met for the variables pretest inhibition and posttest inhibition. The following SW test statistic were reported:

Pretest inhibition: W(25) = .85, $p < .05$

Posttest inhibition: W(25) = .77, $p < .05$

For females in the control group, normality was met for the variable pretest inhibition. The following SW test statistics was collected and normality was inferred:

Pretest inhibition: W(25) = .96, *ns*

For females in the control group, normality was not met for the variable posttest inhibition. The following SW test statistic was reported:

Posttest inhibition: W(25) = .91, $p < .05$

For females in the exercise group, normality was met for the variables pretest inhibition and posttest inhibition. The following SW test statistics were collected and normality was inferred:

Pretest inhibition: W(27) = .97, *ns*

Posttest inhibition: W(27) = .96, *ns*

Assumption of Homogeneity of Variances.

The homogeneity of variances of pretest inhibition and posttest inhibition were assessed using Levene's tests. Levene's test revealed that for pretest inhibition, the variances were not statistically different across groups, F (3, 100) = 1.34, *ns*. Therefore, the assumption of homogeneity of variance is met. Levene's test revealed that for posttest inhibition, the variances were not statistically different across groups, F (3, 100) = .23, *ns*. Thus, the assumption of homogeneity of variances is met.

Naming Errors.

Assumption of Normality.

Normality of each scale variable (pretest naming errors, posttest naming errors) across each cell was tested using the Shapiro-Wilk (SW) test.

For males in the control group, normality was not met for the variables pretest naming errors and posttest naming errors. The following SW test statistic were reported:

Pretest naming errors: W(27) = .43, $p < .05$

Posttest naming errors: W(27) = .37, $p < .05$

For males in the exercise group, normality was not met for the variables pretest naming errors and posttest naming errors. The following SW test statistic were reported:

Pretest naming errors: W(25) = .39, $p < .05$

Posttest naming errors: W(25) = .20, $p < .05$

For females in the control group, normality was not met for the variables pretest naming errors and posttest naming errors. The following SW test statistic were reported:

Pretest naming errors: W(25) = .59, $p < .05$

Posttest naming errors: W(25) = .45, $p < .05$

For females in the exercise group, normality was not met for the variables pretest naming errors and posttest naming errors. The following SW test statistic were reported:

Pretest naming errors: W(27) = .64, $p < .05$

Posttest naming errors: W(27) = .29, $p < .05$

Assumption of Homogeneity of Variances.

The homogeneity of variances of pretest naming errors and posttest naming errors were assessed using Levene's tests. Levene's test revealed that for pretest naming errors, the variances were statistically different across groups, F (3, 100) = 3.67, $p < .05$. Therefore, the assumption of homogeneity of variance is violated. Levene's test revealed that for posttest naming errors, the variances were not statistically different across groups, F (3, 100) = 2.13, *ns*. Thus, the assumption of homogeneity of variances is met.

Inhibition Errors.

Assumption of Normality.

Normality of each scale variable (pretest inhibition errors, posttest inhibition errors) across each cell was tested using the Shapiro-Wilk (SW) test.

For males in the control group, normality was not met for the variables pretest inhibition errors and posttest inhibition errors. The following SW test statistic were reported:

Pretest inhibition errors: W(27) = .86, $p < .05$

Posttest inhibition errors: W(27) = .72, $p < .05$

For males in the exercise group, normality was not met for the variables pretest inhibition errors and posttest inhibition errors. The following SW test statistic were reported:

Pretest inhibition errors: W(25) = .81, $p < .05$

Posttest inhibition errors: W(25) = .46, $p < .05$

For females in the control group, normality was not met for the variables pretest inhibition errors and posttest inhibition errors. The following SW test statistic were reported:

Pretest inhibition errors: W(25) = .84, $p < .05$

Posttest inhibition errors: W(25) = .81, $p < .05$

For females in the exercise group, normality was not met for the variables pretest inhibition errors and posttest inhibition errors. The following SW test statistic were reported:

Pretest inhibition errors: W(27) = .87, $p < .05$

Posttest inhibition errors: W(27) = .57, $p < .05$

Assumption of Homogeneity of Variances.

The homogeneity of variances of pretest inhibition errors and posttest inhibition errors were assessed using Levene's tests. Levene's test revealed that for pretest inhibition errors, the variances were not statistically different across groups, F (3, 100) = 1.84, *ns*. Therefore, the assumption of homogeneity of variance is met. Levene's test revealed that for posttest inhibition errors, the variances were statistically different across groups, F (3, 100) = 3.91, $p < .05$. Thus, the assumption of homogeneity of variances is violated.

Effect of Acute Aerobic Exercise on Each Task Condition

Condition 1: Naming

Assumption of Normality.

Normality of each scale variable (pretest naming, posttest naming) across each cell was tested using the Shapiro-Wilk (SW) test.

For males in the control group, normality was met for the variables pretest naming and posttest naming. The following SW test statistics was collected and normality was inferred:

Pretest naming: $W(27) = .94$, *ns*

Posttest naming: $W(27) = .96$, *ns*

For males in the exercise group, normality was met for the variables pretest naming and posttest naming. The following SW test statistics was collected and normality was inferred:

Pretest naming: $W(25) = .98$, *ns*

Posttest naming: $W(25) = .99$, *ns*

For females in the control group, normality was met for the variables pretest naming and posttest naming. The following SW test statistics was collected and normality was inferred:

Pretest naming: $W(25) = .93$, *ns*

Posttest naming: $W(25) = .96$, *ns*

For females in the exercise group, normality was met for the variables pretest naming and posttest naming. The following SW test statistics was collected and normality was inferred:

Pretest naming: $W(27) = .97$, *ns*

Posttest naming: $W(27) = .96$, *ns*

Assumption of Homogeneity.

The homogeneity of variances of pretest naming and posttest naming were assessed using Levene's tests. Levene's test revealed that for pretest naming, the variances were not statistically different across groups, F (3, 100) = .56, *ns*. Therefore, the assumption of homogeneity of variance is met. Levene's test revealed that for posttest naming, the variances were not statistically different across groups, F (3, 100) = .89, *ns*. Thus, the assumption of homogeneity of variances is met.

Condition 3: Inhibition

Assumption of Normality.

Normality of each scale variable (pretest inhibition task, posttest inhibition task) across each cell was tested using the Shapiro-Wilk (SW) test.

For males in the control group, normality was not met for the variables pretest inhibition task and posttest inhibition task. The following SW test statistics were found:

Pretest inhibition task: W(27) = 58, $p < .05$

Posttest inhibition task: W(27) = .64, $p < .05$

For males in the exercise group, normality was not met for the variables pretest inhibition task and posttest inhibition task. The following SW test statistics were found:

Pretest inhibition task: W(25) = .81, $p < .05$

Posttest inhibition task: W(25) = .82, $p < .05$

For females in the control group, normality was not met for the variables pretest inhibition task and posttest inhibition task. The following SW test statistics were found:

Pretest inhibition task: W(25) = .69, $p < .05$

Posttest inhibition task: W(25) = .71, $p < .05$

For females in the exercise group, normality was met for the variable posttest inhibition. The following SW test statistic was collected and normality was inferred:

Posttest inhibition task: W(27) = .99, *ns*

For females in the exercise group, normality was not met for the variable pretest inhibition. The following SW test statistics were found:

Pretest inhibition task: W(27) = .73, $p < .05$

Assumption of Homogeneity.

The homogeneity of variances of pretest inhibition task and posttest inhibition task were assessed using Levene's tests. Levene's test revealed that for pretest inhibition task, the variances were not statistically different across groups, F (3, 100) = 1.19, *ns*. Therefore, the assumption of homogeneity of variance is met. Levene's test revealed that for posttest inhibition task, the variances were not statistically different across groups, F (3, 100) = 1.27, *ns*. Thus, the assumption of homogeneity of variances is met.

References

Åberg, M. A., Pedersen, N. L., Torén, K., Svartengren, M., Bäckstrand, B., Johnsson, T., Kuhn, C., Åberg, D., Nilsson, M., & Kuhn, H. G. (2009). Cardiovascular fitness is associated with cognition in young adulthood. *Proceedings of the National Academy of Sciences, 106*, 20906-20911. doi: 10.1073 pnas.0905307106

American College of Sports Medicine, In Riebe, D., In Ehrman, J. K., In Liguori, G., & In Magal, M. (2018). ACSM's guidelines for exercise testing and prescription.

Ando, S. & Kokubu, M. & Yamada, Y. & Kimura, M. (2011). Does cerebral oxygenation affect cognitive function during exercise? *European Journal of Applied Physiology, 111*, 1973-82. 10.1007/s00421-011-1827-1.

Audiffren, M. & André, N. (2014). The strength model of self-control revisited: Linking acute and chronic effects of exercise on executive functions. *Journal of Sport and Health Science, 4*, 30-46. doi: 10.1016/j.jshs.2014.09.002

Alves, C.R, Gualano, B., Takao, P.P., Avakian, P., Fernandes, R.M., Morine, D., & Takito, M.Y. (2012). Effects of acute physical exercise on executive functions: A comparison between aerobic and strength exercise. *Journal of Sport & Exercise Psychology, 34,* 539-549.

Barha, C., Davis, J., Falck, R., Nagamatsu, L., & Liu-Ambrose, T. (2017). Sex differences in exercise efficacy to improve cognition: A systematic review and meta-analysis of randomized controlled trials in older humans. *Frontiers in Neuroendocrinology, 46,* 71-85. doi: 10.1016/j.yfrne.2017.04.002

Barha, C., Hsiung, G.Y., Best, J., Davis, J., et al. (2017). Sex difference in aerobic exercise efficacy to improve cognition in older adults with vascular cognitive impairment: secondary analysis of a randomized controlled trial. *Journal of Alzheimer's Disease*, 60, 1-13. doi: 10.3233/JAD-170221.

Basso, J. & Suzuki, W. (2017). The effects of acute exercise on mood, cognition, neurophysiology and neurochemical Pathways: A review. *Brain Plasticity. 2.* 1-26. doi: 10.3233/BPL-160040.

Berchtold, N.C., Kesslak, J.P., Pike, C.J., Adlard, P., & Cotman, C.W. (2001). Estrogen and exercise interact to regulate brain-derived neurotrophic factor mRNA and protein expression in the hippocampus. *The European Journal of Neuroscience, 14*, 1992-2002.

Borg, G. (1998). Borg's perceived exertion and pain scales. Champaign, IL, US: Human Kinetics

Bos, I., Jacobs, L., Nawrot, T., de Geus, B., Torfs, R., Int Panis, L., Degraeuwe, B. & Meeusen, R. (2011). No exercise-induced increase in serum BDNF after cycling near a major traffic road. *Neuroscience Letters*, *500*, 129-132. doi: 10.1016/j.neulet.2011.06.019.

Brunelli, A., Dimauro, I., Sgrò, P., Emerenziani, G. P., Magi, F., Baldari, C., Guidetti, L., Luigi, L., Parisi, P. & Caporossi, D. (2012). Acute exercise modulates BDNF and pro-BDNF protein content in immune cells. *Medicine and Science in Sports and Exercise. 44.* 1871-1880. doi: 10.1249/MSS.0b013e31825ab69b

Brush, C., Olson, R., Ehmann, P., Osovsky, S., & Alderman, B. (2016). Dose-response and time course effects of acute resistance exercise on executive function. *Journal of Sport & Exercise Psychology, 38,* 396-408. doi: 10.1123/jsep.2016-0027

Byun, K., Hyodo, K., Suwabe, K., Genta, O., Sakairi, Y., Kato, M., Dan, I. & Soya, H. (2014). Positive effect of acute mild exercise on executive function via arousal-related prefrontal activations: An fNIRS study. *NeuroImage, 98,* 336-345, doi: 10.1016/j.neuroimage.2014.04.067.

Chang, Y.K., Chi, L., Etnier, J., Wang, C.C., Chu, C.H., Zhou, C. (2014). Effect of acute aerobic exercise on cognitive performance: Role of cardiovascular fitness. *Psychology of Sport and Exercise, 15,* 464-470. doi: 10.1016/j.psychsport.2014.04.007

Chang, Y.K., Chu, C.H., Wang, C.C., Wang, Y.C., Song, T.F., Tsai, C.L., & Etnier, J.L. (2015). Dose-response relation between exercise duration and cognition. *Medicine and Science in Sports and Exercise, 47*, 159-165.

Chang, Y.K. & Etnier, J. (2009a). Exploring the dose-response relationship between resistance exercise intensity and cognitive function. *Journal of Sport and Exercise Psychology, 31,* 640-656

Chang, Y.K., Labban, J.D., Gapin, J.I., & Etnier, J.L. (2012). The effects of acute exercise on cognitive performance: A meta-analysis. *Brain Research, 1453,* 87-101. doi: 10.1016/j.brainres.2012.02.068

Chang, Y.K., Tsai, C.L., Hung, T.M., So, E.C., Chen, F.Z., & Etnier, J.L. (2011). Effects of acute exercise on executive function: A study with a tower of London task. *Journal of Sport and Exercise Psychology, 33,* 847-865.

Cho, H., Kim, J., Kim, S., Hee Son, Y., Lee, N. & Jung, S. (2012). The concentrations of serum, plasma and platelet BDNF are all increased by treadmill VO2max performance in healthy college men. *Neuroscience Letters, 519,* 78-83. doi: 10.1016/j.neulet.2012.05.025.

Chu, C.H., Hung, T.M., Chen, A.G., Wang, C.C. & Chang, Y.K. (2015). Exercise and fitness modulate cognitive function in older adults. *Psychology and Aging, 30,* 842-848. doi: 10.1037/pag0000047

Cian, C., Koulmann, N., Barraud, P.A., Raphel, C., Jimenez, C., Melin, B. (2000). Influences of variations in body hydration on cognitive function: Effects of hyperhydration, heat stress, and exercise-induced dehydration. *Journal of Psychophysiology*, 14, 29–36.

Coelho, F., Pereira, D., Lustosa, L., Da Silva, J., Dias, J., Dias, R., Queiroz, B., Teixeira, M., & Pereira, L. (2012). Physical therapy intervention (PTI) increases plasma brain-derived neurotrophic factor (BDNF) levels in non-frail and pre-frail elderly women. *Archives of Gerontology and Geriatrics*, *54*, 415-20. doi: 10.1016/j.archger.2011.05.014.

Colcombe, S. & Kramer, A.F. (2003). Fitness effects on the cognitive function of older adults: A meta-analytic study. *Psychological Science*, *14*, 125-130.

Colcombe, S., Kramer, A., Erickson, K., Scalf, P., Mcauley, E. & Cohen, N. (2004). Cardiovascular fitness, cortical plasticity, and aging. *Proceedings of the National Academy of Sciences of the United States of America*, *101,* 3316-3321.

Correia, P. R., Pansani, A., Machado, F., Andrade, M., da Silva, A. C., Scorza, F. A., … Arida, R. M. (2010). Acute strength exercise and the involvement of small or large muscle mass on plasma brain-derived neurotrophic factor levels. *Clinics, 65*, 1123–1126. doi: 10.1590/S1807-59322010001100012

Davranche, K., Hall, B., & McMorris, T. (2009). Effect of acute exercise on cognitive control required during an Eriksen flanker task. *Journal of Sport and Exercise Psychology*, *31,* 628-639.

Davey, C.P. (1973). Physical exertion and mental performance. *Ergonomics, 16,* 595-599.

Delis, D. C., Kaplan, E., & Kramer, J. H. (2001b). *Delis-Kaplan Executive Function System (D-KEFS) examiner's manual* (pp. 1-218). San Antonio, TX: The Psychological Corporation.

Delis, D. C., Kaplan, E., & Kramer, J. H. (2001c). *Delis-Kaplan Executive Function System (D-KEFS) technical manual* (pp. 1-132). San Antonio, TX: The Psychological Corporation.

Dietrich, A. (2003). Functional neuroanatomy of altered states of consciousness: The transient hypofrontality hypothesis. *Consciousness and Cognition, 12,* 231-256. doi: 10.1016/S1053-8100(02)00046-6

Dietrich, A. & Audiffren, M. (2011). The reticular-activating hypofrontality (RAH) model of acute exercise. *Neuroscience and Biobehavioral Reviews, 35,* 1305-1325. doi: 10.1016/j.neubiorev.2011.02.001

Dietrich, A. & Sparling, P.B. (2004). Endurance exercise selectively impairs prefrontal-dependent cognition. *Brain and Cognition, 55,* 516-524. doi: 10.1016/j.bandc.2004.03.002

Dinoff, A., Herrmann, N., Swardfager, W., Lanctôt, K.L. (2017). The effect of acute exercise on blood concentrations of brain-derived neurotrophic factor in healthy adults: a meta-analysis. *European Journal of Neuroscience, 46,* 1635-1646.

Dinoff, A., Herrmann, N., Swardfager, W., Liu, C.S., Sherman, C., Chan, S., et al. (2016). The effect of exercise training on resting concentrations of peripheral brain-derived neurotrophic factor (BDNF): A meta-analysis. *PLOS One, 11,* doi: 10.1371/journal.pone.0163037

Ellemberg, D. & St-Louis-Deschênes, M. (2010). The effect of acute physical exercise on cognitive function during development. *Psychology of Sport and Exercise, 11,* 122-126. doi: 10.1016/j.psychsport.2009.09.006

Eriksen, B. & Eriksen, C. (1974). Effects of noise letters upon the identification of a target letter in a nonsearch task. *Perception & Psychophysics, 16,* 143-149.

Eston, R. (2012). Use of ratings of perceived exertion in sports. *International Journal of Sports Physiology and Performance, 7,* 175-182.

Fang, Z., Lee, C., Seo, M.K., Cho, H., Lee, J.G., Lee, B.J., Park, S. & Kim, Y.H. (2013). Effect of treadmill exercise on the BDNF-mediated pathway in the hippocampus of stressed rats. *Neuroscience Research, 76,* 184-194. doi: 10.1016/j.neures.2013.04.005.

Field, A. (2009). Discovering statistics using SPSS. 3rd Edition. Sage Publications Ltd., London.

Fontes, E., Okano, A., De Guio, F., Schabort, E., Min, Li., Basset, F., Stein, D. & Noakes, T. (2013). Brain activity and perceived exertion during cycling exercise: An fMRI study. *British Journal of Sports Medicine, 49,* 556-560. doi: 10.1136/bjsports-2012-091924.

Fontes, M.T., Silva, T.B., Mota, M.M., Barreto, A.D., Rossoni, L.V., & Santos, M. (2014). Resistance exercise acutely enhances mesenteric artery insulin-induced relaxation in healthy rats. *Life Sciences, 94,* 24-9. doi: 10.1016/j.lfs.2013.11.017.

Gazzaniga, M., Ivry, R., & Mangun, G. (2014). United States of America: W.W. Norton & Company

Geng, Y.M., Yu, F. & Wang, Z. (2013) Effect of exercise on BDNF, HSP70, and oxidative stress level in prefrontal cortex of depression rat. *Journal of Xi'an Institute of Physical Education, 30,* 448–452.

Gold, S.M., Schulz, K., Hartmann, S., Mladek, M., Lang, U.E., Hellweg, R., Reer, R., Braumann, K. et al. (2003) Basal serum levels and reactivity of nerve growth factor and brain-derived neurotrophic factor to standardized acute exercise in multiple sclerosis and controls. Journal of Neuroimmunology., 138, 99–105.

Griffin, É., Mullally, S., Foley, C., Warmington, S., O'Mara, S. & Kelly, A. (2011). Aerobic exercise improves hippocampal function and increases BDNF in the serum of young adult males. *Physiology & Behavior, 104,* 934-41. doi: 10.1016/j.physbeh.2011.06.005.

Guiney, H. & Machado, L. (2013). Benefits of regular aerobic exercise for executive functioning in healthy populations. *Psychonomic Bulletin & Review, 20,* 73-86. doi: 10.3758/s13423-012-0345-4

Hogan, C. L., Mata, J., & Carstensen, L. L. (2013). Exercise holds immediate benefits for affect and cognition in younger and older adults. *Psychology and Aging, 28,* 587-594. doi:10.1037/a0032634

Hommel, B. (2011). Attention and spatial stimulus coding in the simon task: A rejoinder to van der lubbe and abrahamse (2010). *Acta Psychologica, 136,* 265-268. doi:10.1016/j.actpsy.2010.10.002

Jahani, S., Fantana, A., Harper, D., Ellison, J., Boas, D., Brent, F. & Meryem, A.Y. (2017). fNIRS can robustly measure brain activity during memory encoding and retrieval in healthy subjects, *Scientific Reports, 7,* doi: 10.1038/s41598-017-09868-w

Ji, L.U., Li, X.L., Liu, Y., Sun, X.W., Wang, H.F., Chen, L., & Gao, L. (2017). Time-dependent effects of acute exercise on university students' cognitive performance in temperate and cold environments. *Frontiers in Psychology, 8,* 1-11. doi: 10.3389/fpsyg.2017.01192

Jorgenson, C., Davis, J., Opella, J., & Angerstein, G. (1981). Hemispheric asymmetry in the processing of Stroop stimuli: An examination of age and gender differences. *The International Journal of Neuroscience, 13,* 113-6. doi: 10.3109/00207458109043309.

Joyce, J., Graydon, J., McMorris, T., & Davranche, K. (2009). The time course effect of moderate intensity exercise on response execution and response inhibition. *Brain and cognition, 71,* 14-19. doi:10.1016/j.bandc.2009.03.004

Kahan, D. (2015). Adult physical inactivity prevalence in the Muslim world: Analysis of 38 countries. *Preventive Medicine Reports, 2,* 71-75. doi: 10.1016/j.pmedr.2014.12.007

Kamijo, K., Hayashi, Y., Sakai, T., Yahiro, T., Tanaka, K., & Nishihira, Y. (2009). Acute effects of aerobic exercise on cognitive function in older adults. *Journals of Gerontology - Series B Psychological Sciences and Social Sciences*, *64,* 356-363. doi: 10.1093/geronb/gbp030.

Kamijo, K., & Takeda, Y. (2010). Physical activity effects on executive function during task switching in young adults: 1875. *Medicine & Science in Sports & Exercise, 42,* 430. doi:10.1249/01.MSS.0000384958.42883.2e

Kirchner, W. K. (1958). Age differences in short-term retention of rapidly changing information. *Journal of Experimental Psychology, 55,* 352-358. doi: 10.1037/h0043688.

Kubesch, S., Bretschneider, V., Freudenmann, R., Weidenhammer, N., Lehmann, M., Spitzer, M., & Grön, G. (2003). Aerobic endurance exercise improves executive functions in depressed patients. *Journal of Clinical Psychiatry, 64,* 1005-1012.

MacLeod, C. M. (1991). Half a century of research on the Stroop effect: An integrative review. *Psychological Bulletin, 109*, 163-203.

Malchow, B., Erkelenz, D.R., Knöchel, V.O., Keller, K., Hasan, A., Schmitt, A., Scheewe, T.W., Cahn, W., Kahn, R., & Falkai, P. (2013). The effects of physical exercise in schizophrenia and affective disorders, *European Archives of Psychiatry and Clinical Neuroscience, 263,* 451-467. doi: 10.1007/s00406-013-0423-2

Marlatt, M., Potter, M., Lucassen, P. & van Praag, H. (2012). Running throughout middle-age improves memory function, hippocampal neurogenesis, and BDNF levels in female C57BL/6J mice. *Developmental Neurobiology, 72,* 943-52. doi: 10.1002/dneu.22009.

McMorris, T., Sproule, J., Turner, A., & Hale, B. (2011). Acute, intermediate intensity exercise, and speed and accuracy in working memory tasks: A meta-analytical comparison of effects. *Physiology & Behavior, 102,* 421-428. doi: 10.1016/j.physbeh.2010.12.007

McMorris, T. (Ed.). (2015). Exercise-cognition interaction: Neuroscience perspectives. Academic Press.

Musharrafieh, U., Tamim, H., Rahi, A., El-Hajj, M., Al-Sahab, B., El-Asmar, K., & Tamim, H. (2008). Determinants of university students physical exercise: A study from Lebanon. *International Journal of Public Health, 53,* 208-213. doi: 10.1007/s00038-008-7037-x

Oussaidene, K., Prieur, F., Bougault, V., Borel, B., Matran, R., Mucci, P. (2013). Cerebral oxygenation during hyperoxia-induced increase in exercise tolerance for untrained men. *European Journal of Applied Physiology, 113,* 2047-56. doi: 10.1007/s00421-013-2637-4.

Pengpid, S., Peltzer, K., Kassean, H.K., Tsala, J.P., Sychareun, V., & Müller-Riemenschneider, F. (2015). *International Journal of Public Health, 60,* 539-549. doi: 10.1007/s00038-015-0680-0

Pesce, C., & Audiffren, M. (2011). Does acute exercise switch off switch costs? A study with younger and older athletes. *Journal of Sport & Exercise Psychology, 33,* 609-626.

Pillai, A., Kale, A., Joshi, S., Naphade, N., Raju, M.S., Nasrallah, H., & Mahadik, S.P. (2010). Decreased BDNF levels in CSF of drug-naïve first-episode psychotic subjects: Correlation with plasma BDNF and psychopathology. *The International Journal of Neuropsychopharmacology, 13*, 535-9. doi: 10.1017/S1461145709991015.

Pontifex, M.B., & Hillman, C.H. (2007). Neuroelectric and behavioral indices of interference control during acute cycling. *Clinical Neurophysiology, 118,* 570-580. doi: 10.1016/j.clinph.2006.09.029

Pontifex, M.B., Hillman, C.H., Fernhall, B., Thomspon, K.M., & Valentini, T. (2009). The effect of acute aerobic and resistance exercise on working memory. *Medicine & Science in Sports & Exercise, 41(4),* 927-934. doi: 10.1249/MSS.0b013e3181907d69

Rupp, T. & Perrey, S. (2008). Prefrontal cortex oxygenation and neuromuscular responses to exhaustive exercise. *European Journal of Applied Physiology, 102,* 153-63. doi: 10.1007/s00421-007-0568-7.

Samuel, R.D., Zavdy, O., Levav, M., Reuveny, R., Katz, U., & Dubnov-Raz, G. (2017). The effects of maximal intensity exercise on cognitive performance in children. *Journal of Human Kinetics, 57,* 85-96. doi: 10.1515/hukin-2017-0050

Schmolesky, M. T., Webb, D. L., & Hansen, R. A. (2013). The effects of aerobic exercise intensity and duration on levels of brain-derived neurotrophic factor in healthy men. *Journal of Sports Science & Medicine, 12*, 502–511.

Schuch, F.B., da Silveira, L.E., de Zeni, T.C., da Silva, D.P., Wollen- haupt-Aguiar, B., Ferrari, P., Reischak-Oliveira, A. & Kapczinski, F. (2015) Effects of a single bout of maximal aerobic exercise on BDNF in bipolar disorder: a gender-based response. *Psychiatry Research, 229,* 57– 62.

Soga, K., Shishido, T., & Nagatomi, R. (2015). Executive function during and after acute moderate aerobic exercise in adolescents. *Psychology of Sport and Exercise, 16,* 7-17. doi: 10.1016/j.psychsport.2014.08.010

Sternberg, S. (1969). Memory-scanning: Mental processes revealed by reaction-time experiments. *American Scientist, 57,* 421-457.

Stroth, S., Kubesch, S., Dieterle, K., Ruchsow, M., Heim, R., Kiefer, M. (2009). Physical fitness, but not acute exercise modulates event-related potential indices for executive control in healthy adolescents. *Brain Research, 1269,* 114-124. doi:10.1016/j.brainres.2009.02.073

Subudhi, A., Dimmen, A., Roach, R. (2007). Effects of acute hypoxia on cerebral and muscle oxygenation during incremental exercise. *Journal of Applied Physiology, 103,* 177–183.

Szuhany, K., Bugatti, M., & Otto, M. (2015) A meta-analytic review of the effects of exercise on brain-derived neurotrophic factor. *Journal of Psychiatric Research, 60,* 56–64.

Tempest, G.D., Eston, R.G., & Parfitt, G. (2014). Prefrontal cortex hemodynamics and affective responses during exercise: A multi-channel near infrared spectroscopy study. *PLOS One, 9,* doi: 10.1371/journal.pone.0095924

Tenenbaum, G., Yuval, R., Elbaz, G., Gareli, M. and Weinberg, R. (1993). The relationship between cognitive characteristics and decision-making. *Canadian Journal of Applied Physiology*, *18,* 48–62.

Themanson, J.R. & Hillman, C.H. (2006). Cardiorespiratory fitness and acute aerobic exercise effects of neuroelectric and behavioral measures of action monitoring. *Neuroscience, 141,* 757-767. doi: 10.1016/j.neuroscience.2006.04.004

Tomporowski, P. D., Ellis, N. R., & Stephens, R. (1987). The immediate effects of strenuous exercise on free recall memory. *Ergonomics*, *30*, 121–129.

Tomporowski, P. D. (2003). Effects of acute bouts of exercise on cognition. *Acta Psychologica, 112,* 297-324. doi: 10.1016/S0001-6918(02)00134-8

Tsai, C., Pan, C., Chen, F., Wang, C., & Chou, F. (2016). Effects of acute aerobic exercise on a task-switching protocol and brain-derived neurotrophic factor concentrations in young adults with different levels of cardiorespiratory fitness. *Experimental Physiology, 101*, 836-850. doi:10.1113/EP085682

Wang, C.C., Shih, C.H., Pesce, C., Song, T.F., Hung, T.M., & Chang, Y.K. (2015). Failure to identify an acute exercise effect on executive function assessed by the Wisconsin Card Sorting Test. *Journal of Sport and Health Science, 4,* 64-72. doi: 10.1016/j.jshs.2014.10.003

Yanagisawa, H., Dan, I., Tsuzuki, D., Kato, M., Okamoto, M., Kyutoku, Y., Soya, H. (2009). Acute moderate exercise elicits increased dorsolateral prefrontal activation and improves cognitive performance with Stroop test. *NeuroImage, 50*, 1702-1710. doi: 10.1016/j.neuroimage.2009.12.023