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## A 10-Minute Single-Bout of Moderate to Very-Heavy Intensity Aerobic Exercise Improves Executive Function in Older Adults

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## Abstract

A 10-minute single-bout of moderate to very-heavy intensity aerobic exercise provides a boost to executive-related oculomotor control in young adults. Furthermore, some evidence shows that older adults (>65 years) can receive similar executive benefits post-exercise. It is, however, unclear if a specific exercise intensity can optimize executive function within this population. This represents an important question given that the population of older adults with executive dysfunction is expected to grow. To that end, this thesis had community-dwelling older adults perform a  $VO_{2peak}$  test to determine 10-minute participant-specific moderate, heavy, and very-heavy exercise intensities. Pre- and post- exercise executive control was measured via the antisaccade task (i.e., goal-directed eye movement mirror symmetrical to visual stimulus). Results showed a 23 ms reduction in post-exercise antisaccade RTs – a finding that was intensity-independent. Accordingly, older adults accrue an executive benefit following 10 minutes of exercise across a continuum of moderate to very-heavy intensities.

## Keywords

Executive Function

Aerobic Exercise

Older Adults

Antisaccades

Oculomotor

Single-bout

## Co-Authorship

The author, under the supervision and mentorship of Dr. Matthew Heath, conducted this Master's thesis. With the guidance of Dr. Matthew Heath, I designed the experiment, collected, analyzed and interpreted data, and prepared this thesis document.

## Acknowledgments

Two wiser men once wrote that this section was the most difficult section to write. As usual, they were onto something. Nothing is as easy as “1, 2, 3, 4... cinque”. The past two (and a little) years have provided me with many valuable learning opportunities. I am fortunate to have many special people to both challenge and support me during my graduate degree.

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To my parents, Rob and Sharon, thanks for helping me write my own story. I could begin by thanking you for giving me opportunities to see the world since I was young, however that doesn't do much justice. I guess nothing will, so I will try my best here. I am so privileged to have two parents as role models who reassure me when things go wrong or when I am overwhelmed. When I look back on the last two years, I appreciate how you have helped me to keep things in perspective. Thanks for always being in my corner.

“Other things may change us, but we start and end with family” – Anthony Brandt

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## List of Terms and Abbreviations

BDNF—Brain-derived neurotrophic factor

CV of RT – Coefficient of variation of reaction time

fMRI – Functional magnetic resonance imaging

ECG – Electrocardiogram

HRR – Heart rate reserve

IADL – Lawton-Brody-Instrumental activities of daily living

K4B<sup>2</sup>—COSMED breath-by-breath analyzer

LT – Estimated lactate threshold

METs – Metabolic equivalents

MMSE—Mini-Mental state examination

MoCA—Montreal Cognitive Assessment

MT – Movement time

RER – Respiratory exchange ratio

RPE – Rating of perceived exertion

RT – Reaction time

SC—Superior colliculus

VO<sub>2peak</sub>—Peak oxygen uptake

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# Introduction

By the year 2036, older adults (>65 years) are expected to represent 24-25% of the Canadian population (Statistics Canada, 2011). Therefore, the problems associated with longevity and the higher proportion of adults over 65 represent a pressing public health issue (Prince et al., 2015). For example, cognitive decline has been identified as one of the highest costs related to an aging society (Deary et al., 2009). As such, finding effective and efficient ways to promote and improve cognitive function in older adults is a burgeoning health care concern (Jackson et al., 2016). A mounting body of research has shown that aerobic and/or resistance exercise programs improve cognition in older adults (Kramer et al., 1999; Liu-Ambrose, Nagamatsu, Voss, Khan, & Handy, 2012; Hwang et al., 2016). More specifically, exercise has been shown to provide the greatest cognitive benefit to executive function (Colcombe & Kramer, 2003; Hall, Smith, & Keele, 2001). Executive function relates to an individual's ability to update and monitor working memory, attend to and process multiple stimuli, and inhibit responses to irrelevant stimuli (Norman & Shallice, 1986) – functions that are essential to activities of daily living. The neurobiological mechanisms linked the post-exercise benefit include: (1) increased concentration of brain-derived neurotrophic factor (BDNF) to support the development and survival of neurons (Knaepen, Goekint, Heyman, & Meeusen, 2010), (2) cell-proliferation and neurogenesis (van Praag, Kempermann, & Gage, 1999), and (3) increased synaptic connectivity and density in the frontoparietal regions supporting executive function (Colcombe & Kramer, 2003; Voss et al., 2010; Weinstein et al., 2012). Hence, the identification of exercise interventions that ameliorate or circumvent executive decline represents a current – and important – area of inquiry.

Chronic exercise programs have been shown to improve executive function. For example, Kramer et al. (1999) divided non-demented older adults (60-70 years) into two groups; a stretching (i.e., control) group and a brisk-walking intervention group (i.e., 3 times a week for 6-months). Executive function was – in part – examined by the Eriksen flanker<sup>1</sup> task and results

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<sup>1</sup> The Eriksen Flanker task is a response inhibition task examining a participant's ability to ignore task-irrelevant stimuli. In this task, a 'target' stimulus is surrounded by non-target stimuli that are spatially congruent or incongruent with the target and results show longer RTs for incongruent flanker trials.

demonstrated that the exercise group—but not the control group—showed a reduction in reaction time (RT) for incongruent flanker trials. Furthermore, Colcombe and Kramer (2004) used functional magnetic resonance imaging (fMRI) to contrast executive changes between non-demented, sedentary older adults that completed a 24-week aerobic exercise program (i.e., progressing from walking for 10 to 45 minutes, at an intensity of 40 to 70% heart rate reserve [HRR], 3 times a week) and those that completed a 24-week stretching program. The walking – but not stretching – group showed improved post-exercise executive function and modulation of task-related cortical activity. Similarly, Hall and colleagues’ (2001) literature review reported that older adults had post-exercise improvements on a choice RT task, but exhibited no post-exercise change in a simple RT task – a finding proposing that exercise elicits a specific improvement to tasks involving high-level executive function. Moreover, Colcombe and Kramer’s (2003) meta-analysis reported that executive function shows the largest and most reliable post-exercise improvement, whereas tasks assessing post-exercise memory, attention and perceptual-motor processing yield equivocal findings. Taken together, these findings indicate that aerobic exercise selectively improves the high-level cortical mechanisms supporting executive function.

In addition to chronic exercise, a growing body of literature has reported that a single-bout of exercise provides a reliable post-exercise executive benefit in healthy young and older adults (Chang et al., 2014; Johnson et al., 2016; Lambourne & Tomporowski, 2010). Lambourne and Tomporowski’s (2010) and Chang, Labban, Gapin, & Etnier’s (2012) meta-analyses concluded that a single-bout of exercise (i.e., aerobic, resistance, or multiple-modality) can produce a small – yet reliable – post-exercise benefit to cognition. In fact, Lambourne and Tomporowski (2010) and Chang et al. (2012) concluded that a primary moderator of the single-bout exercise benefit involves the use of a task that addresses executive function. For example, Chang et al. (2014) had participants (aged 58.1 years) complete the Stroop task<sup>2</sup> pre- and post a single-bout of resistance exercise (i.e., biceps and leg curls at 70% of their 10-repetition maximum) for 20-25 minutes (i.e., exercise condition). Additionally, on a separate day participants completed the Stroop task pre- and post a 30-minute rest interval (i.e., non-exercise

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<sup>2</sup> The Stroop Task is a RT task where a series of coloured words are printed in ink that is either congruent (i.e., standard word-naming task) or incongruent (i.e., non-standard word-naming task) to a written word (Stroop, 1935).

condition). Results showed that post-exercise and control condition RTs were less than their pre-test counterparts (i.e., 22% and 6% for exercise and control conditions, respectively); however, the magnitude of the improvement was significantly greater for exercisers. Thus, Chang et al. (2014) concluded that a single-bout of exercise provides a “more beneficial effect on cognition that involves executive control” (p. 51).

In addition to task-specificity, Lambourne and Tomporowski’s (2010) and Chang et al.’s (2012) meta-analyses identified that exercise duration and intensity serve as moderators of the single-bout exercise effect. In particular, Chang et al. (2012) reported that exercise durations longer than 20 minutes provide the greatest benefit to executive function, with reduced and null benefits observed for durations between 11-20 minutes and less than 10 minutes, respectively. More recent research, however, has shown that a positive post-exercise benefit can occur for durations of 10 minutes. For example, Johnson et al. (2016) had older adults (mean age: 72 years) complete 10- or 30-minutes of aerobic (i.e., cycle ergometer: Rating of Perceived Exertion (RPE) of 13-14 [i.e., “somewhat hard”]) or resistance (i.e., 60% 1 rep maximum for 2 minutes with 30 seconds of rest between sets: RPE of 13-14) training. Results showed a reliable post-exercise improvement in Stroop RTs for both modalities, and the magnitude of the improvement was consistent across the 10- and 30-minute exercise sessions. Similarly, work by our group (Samani & Heath, 2018) reported that younger adults who completed a 10-minute single-bout exercise session (i.e., cycle ergometer at 60-85% of participant’s heart rate maximum [i.e., Karvonen formula:  $[220 - \text{age}]$ ]) showed a post-exercise improvement specific to executive-related oculomotor control. Thus, these studies demonstrate that a brief, 10-minute bout of exercise improves executive function. It may be that the majority of previous work reporting a null exercise effect for durations less than 20 minutes employed ‘executive’ tasks (e.g., Tower of London, flanker, visual and acoustic oddball tasks) that require not only high-level executive control, but also non-executive functions such as sequential memory (i.e., Tower of London) and the top-down identification of perceptual novelty (i.e., oddball tasks). Accordingly, tasks involving conjoint executive and non-executive components may not provide sufficient resolution to detect subtle exercise-related executive changes following short-duration exercise. Further, Johnson et al. (2016) reported that the reduced level of physical fitness in their older adult population coupled with the deployment of a cognitive reserve might account for reduced exercise time needed to produce a positive post-exercise executive benefit.

As mentioned earlier, another moderator of the single-bout exercise effect is exercise intensity. Some research has reported that moderate intensity exercise provides the largest benefit to cognition due to an optimization of physiological and psychological arousal (Dietrich & Audiffren, 2011; McMorris, Sproule, Turner, & Hale, 2011; McMorris & Hale, 2012). However, replicating previous work has been difficult, as many studies have focused on absolute measures of exercise intensity (i.e., Karvonen formula, percentage of  $\text{VO}_2$ ) (Chang et al., 2014; Johnson et al., 2016; Samani & Heath, 2018)). As noted by Lambourne and Tomporowski (2010) the drawback of using an absolute measure is that it does not provide for between-participant equivalence in intensity. Furthermore, absolute measures often allow for an extreme range in intensity among different participants. As such, the majority of current work has not provided the opportunity to determine whether distinct relative measures of exercise intensity differentially influence the single-bout post-exercise executive benefit.

My thesis examined whether exercise intensity influences the *magnitude* by which a 10-minute single-bout of aerobic exercise elicits a short-term ‘boost’ to executive function in older adults. As mentioned above, older adults were selected based on evidence reporting that a “cognitive reserve” deployed in this population may result in differential exercise benefits relative to younger adults. In particular, cognitive reserve in older adults is defined as “...the adaptability of cognitive processes to explain differential susceptibility of cognitive abilities and day-to-day function” (Stern et al., 2018) and it is thought that exercise interventions – and possibly different exercise intensities – can positively affect cognitive reserve. To address this question, pre- and post-exercise executive function was examined via the antisaccade task. Antisaccades require that an individual complete a goal-directed eye movement (i.e., a saccade) mirror-symmetrical to the location of a visual stimulus (Hallett, 1978). Extensive behavioural and neuroimaging work in humans as well as electrophysiology from non-human primates has shown that antisaccades require the suppression of a stimulus-driven response (i.e., response suppression) and the visual remapping of a target’s coordinates (i.e., vector inversion) (for review see: Munoz & Everling, 2004) – constituent elements attributed to executive control. Moreover, the performance of directionally correct antisaccades has been linked to increased activation of executive-related frontoparietal networks (Ford, Goltz, Brown, & Everling, 2005; Weiler, Hassall, Krigolson, & Heath, 2015; Zhang & Barash, 2000; for review see: Munoz & Everling, 2004) – cortical regions that show modification following single-bout (Hiura, Mizuno,

& Fujimoto, 2010; Seifert & Secher, 2011) and long-term (Colcombe et al., 2004; Voss et al., 2010) exercise. The known neuroanatomical and behavioural components of antisaccades, coupled with the temporal resolution of eye-tracking, and the hands- and language-free nature of the task makes it an ideal tool for identifying subtle exercise-based changes to executive function. In addition, the present study employed a prosaccade task (i.e., saccade to a veridical target location) because such actions are controlled largely independent of top-down executive control (Pierrot-Deseilligny, Müri, Nyffeler, & Milea, 2005). As such, prosaccades serve as a natural control to antisaccades in determining whether a post-exercise change in saccade performance is specific to executive function.

To quantify exercise intensity, each participant performed a maximal test to volitional exhaustion to determine participant-specific peak oxygen consumption ( $VO_{2peak}$ ) and estimated lactate threshold (LT). The aforementioned values were used to determine participant-specific and sustainable moderate, heavy, and very-heavy exercise intensities. The moderate intensity was defined as 80% of participant-specific LT. In turn, the heavy intensity was 15% of the difference between LT and  $VO_{2peak}$ , whereas the very-heavy intensity was 50% of the difference between LT and  $VO_{2peak}$ . The moderate intensity session represents exercise below LT wherein oxygen uptake and blood lactate reach a steady state (Whipp & Wasserman, 1972). In contrast, the heavy and very-heavy intensities involve work rates above LT, wherein oxygen uptake and blood lactate increase and are in the proximity of maximal lactate steady state (Keir et al., 2015). The manipulation used here therefore equated exercise intensity for individual fitness levels and served as a continuum of sustainable – and metabolically distinct – power outputs.

The majority of work involving older adults has proposed that the largest post-exercise executive benefit is associated with moderate intensity exercise (Chang et al., 2012). As a result, an intensity-dependent prediction asserts that the largest magnitude reduction in post-exercise antisaccade RTs (and possibly directional errors) should be observed at the moderate intensity, with smaller and possibly null benefits observed at the heavy and very-heavy intensities, respectively. In turn, an intensity-independent explanation contends that the magnitude of the post-exercise antisaccade benefit is comparable across each exercise intensity. Importantly, I believe that the manipulation used here provides a framework for identifying the optimal level of

intensity that older adults who may be unable to commit to chronic exercise programs and/or are physically limited to short duration exercise sessions may accrue an executive benefit.

## Methods

Participants were recruited from London, Ontario via presentations to local seniors' exercise groups and recruitment posters. All participants were required to have no diagnosed neurological disorder or eye conditions (e.g., diplopia, glaucoma, cataracts), be in good health, and have normal or corrected-to-normal vision. As well, all participants had scores of greater than 26 and 24 on the Mini-Mental State Examination (MMSE) (Kurlowicz & Wallace, 1999), and Montreal Cognitive Assessment (MoCA) (Nasreddine et al., 2005) tools, respectively, and achieved full scores (8/8) on the Lawton-Brody-Independent Activity of Daily Living Questionnaire (IADL) (Lawton & Brody, 1969).

Participants were excluded from this study based on the following criteria: previous eye injury; diagnosis of mild cognitive impairment or dementia by a clinician or an MMSE score of < 24; neurological or psychiatric disorders; severe sensory impairment (i.e., blindness or low vision); a medical history of severe heart or orthopaedic conditions (i.e., myocardial infarction or osteoarthritis in the last year); or a resting blood pressure considered unsafe for exercise (>180/100mmHg or <100/60mmHg) (Pescatello et al., 2004). A total of 20 participants expressed interest in this study and 17 participants (9 female: age range: 66 – 85 years, mean=73, SD=6) met the study requirements and were included in the data analyses presented in the Results. Three participants were excluded from this study; one due to a self-reported eye condition (i.e., diplopia), and the other two because their gaze position (see details below) could not be reliably tracked or calibrated. A physician independently reviewed each participants' electrocardiogram prior to study admission to ensure that they could safely exercise. All participants were Caucasian, well-educated (>12 years of education) and demonstrated preserved cognitive function with scores of 29 (range: 27-30, SD: 2) and 28 (range: 26-30, SD: 2) on the MMSE and MoCA, respectively. Clinical characteristics of participants included that 59% had hypertension, 41% reported they had high cholesterol, and 29% were former smokers. **Table 1** describes the baseline demographics and clinical characteristics of participants.



**Table 1.** Baseline demographics and clinical characteristics.

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Variables <sup>a</sup>	
Demographics	
Age, years	73(6)
Females	9(53%)
MoCA, score ( /30) <sup>b</sup>	28(2)
Visuospatial/Executive ( /5)	4(1)
Naming ( /3)	3(0)
Attention ( /6)	5(0)
Language ( /3)	2(1)
Abstraction ( /2)	2(1)
Delayed recall ( /5)	4(2)
Orientation ( /6)	6(0)
≤ 12 years of education	0(0%)
MMSE, score	29(2)
Resting systolic BP, mmHg	131(17)
Resting diastolic BP, mmHg	78(10)
Weight, kg	71(11)
Height, cm	169(7)
BMI, kg/m <sup>2</sup>	25(3)
Medical history, <i>n</i> (%)	
Hypertension	10(59%)
Heart problems	1(6%)
High cholesterol	7(41%)
Type 2 diabetes	1(6%)
Former smoker	5(29%)
Current smoker	0(0%)
Fall in the past 12 months	1(6%)
Respiratory problems	1(12%)
Concussion	0(0%)

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Abbreviations: MMSE, Mini-Mental Status Examination; MoCA, Montreal Cognitive Assessment; BP, blood pressure; BMI, body mass index

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<sup>a</sup> Data presented either as mean (standard deviation: SD) or no. (%).

<sup>b</sup> Domain-specific MoCA scores presented as median and interquartile range.

For every study visit, participants were asked to take their usual medications (if applicable), refrain from participating in strenuous exercise for 24 hours prior to a study visit, and to not consume caffeine or alcohol at least 12 hours before all visits. As well, participants were instructed to get seven or eight hours of sleep before each exercise session. Testing sessions were completed between 12:00pm and 3:00pm and were scheduled at the same time for each subject. Prior to data collection, participants read a letter of information and signed a consent form approved by the Health Sciences Research Ethics Board, University of Western Ontario, and this work was conducted according to the Declaration of Helsinki.

### *Exercise intervention*

Eligible participants were scheduled for four experimental sessions, each 1 to 1.5 hours in length. During Session 1, participants provided informed consent, completed global cognitive assessments (i.e., MoCA and MMSE), a brief medical history, and the IADL. In addition, demographic information was collected (**Table 1**). For all visits, participants had their resting blood pressure measured using an automatic cuff (BPM-100, BPTru Medical Devices, Coquitlam, BC, Canada). Three resting measurements were recorded, two minutes apart and the last two measures were averaged. Following this, participants were to complete an exercise test to volitional exhaustion (i.e.,  $VO_{2peak}$ ) on a treadmill (Quinton Q-Stress TM55, Milwaukee, WI, USA). All participants completed their test to volitional exhaustion via a protocol specially developed for older adults (Paterson, Cunningham, Koval, & St. Croix, 1999; Stathokostas, Jacob-Johnson, Petrella, & Paterson, 2004). In particular, participants were instructed about the ramp-incremental protocol, the location of the treadmill hand grips, and familiarized with the modified Borg RPE scale of 1-10 (Chodzko-Zajko et al., 2009). The RPE was used to self-monitor effort, and RPE was reported to the experimenter every 1.5 minutes during an exercise session. Further, participants were instructed that if they felt faint, had chest or joint pain, or trouble breathing, they were to notify the experimenter (via hand wave) and the exercise session would immediately end.

For each exercise session heart rate was continuously recorded via a 12-lead electrocardiogram (ECG). All exercise sessions began with a 2.5-minute warm-up, wherein the participant walked at 1.5 miles per hour. For Session 1 (i.e., the test of volitional exhaustion), participants were instructed that the speed and slope of the treadmill would increase to 1.7 mph at a 0% grade for the first 4 minutes of exercise. Subsequently, a grade or velocity increase (or a combination of the two) in specific small increments were used to mimic a ramp incremental protocol until volitional exhaustion. The ramp incremental test was designed to increase  $\text{VO}_2$  demands each minute by  $1\text{-}3\text{mLO}_2 \cdot \text{min}^{-1}$  so that volitional exhaustion was achieved in 8- to 12-minutes (see Stathokostas, Jacob-Johnson, Petrella, & Paterson, 2004). Verbal encouragement was provided and breathing parameters were measured during exercise by the COSMED K4B<sup>2</sup> (COSMED, USA Inc., Chicago, IL).

The COSMED K4B<sup>2</sup> is a real-time (i.e., 2 second delay) portable, lightweight breath-by-breath analyzer, which was placed on participants' chest along with a breathing mask, turbine flowmeter, and battery-pack placed on the participant's back during exercise (see **Figure 1**). The COSMED K4B<sup>2</sup> was used to measure oxygen uptake, carbon dioxide production, and respiratory exchange ratio (RER). An hour before each testing session, the COSMED K4B<sup>2</sup> was calibrated using a three litre calibration syringe (COSMED K4B<sup>2</sup>). The calibration process involved four procedures: room air calibration, reference gas calibration, turbine calibration, and breath-by-breath calibration. The composition of the reference gas (Praxair, Mississauga, Canada) was 16%  $\text{O}_2$  and 5%  $\text{CO}_2$ . Breath by breath analysis of inspired and expired gases was collected continuously and analyzed for  $\text{O}_2$  and  $\text{CO}_2$  specific concentrations. Real-time gas exchange data was collected by the COSMED K4B<sup>2</sup> unit every 2 seconds and the system collated the breathing parameters. Heart rate was displayed via ECG (Quinton Q-Stress TM55) in real time.

The ramp incremental test provided breathing data to quantify peak oxygen uptake ( $\text{VO}_{2\text{peak}}$ ) and estimated lactate threshold (LT) to determine the participant-specific moderate, heavy, and very-heavy exercise intensities for Sessions 2-4.  $\text{VO}_{2\text{peak}}$  was defined as the highest oxygen uptake level achieved during the ramp incremental protocol. Estimated LT was determined when blood lactate accumulated quicker than it could be removed and was quantified via the Simplified V-Slope Method (i.e., when the slope of carbon dioxide output plotted against  $\text{VO}_2$  departs from a slope of 1.00 [Schneider & Phillips, 1993]). Estimated LT was visually

inspected using data from the COSMED K4B<sup>2</sup> by two researchers familiar with the procedure.  $VO_{2peak}$  and estimated LT were used to determine the three participant-specific exercise intensities: (1) 80% of estimated LT (i.e., moderate intensity), (2) 15% of the difference between estimated LT and  $VO_{2peak}$  (i.e., heavy intensity), and (3) 50% of the difference between estimated LT and  $VO_{2peak}$  (i.e., very-heavy intensity). The moderate work rate simulates steady state oxygen uptake and blood lactate levels, since the exercise occurs below LT (Whipp & Wasserman, 1972). The heavy and very-heavy exercise intensities represent work rates above LTs wherein oxygen uptake and blood lactate increase and are in the proximity of the maximal lactate steady state (Whipp & Wasserman, 1972; Keir et al., 2015). The order that the different exercise intensities were performed was randomized and all testing sessions were separated by at least 24 hours.

For Sessions 2-4, participants completed a 2.5 minute warm-up at 1.5 mph (0% grade), followed by a square-wave transition to a 10-minute bout of aerobic exercise at participant-specific moderate, heavy, or very-heavy intensities. Following an exercise session, blood pressure was measured at 2 minute intervals for 10 minutes to ensure a safe return to resting blood pressure. Only one participant was unable to exercise for the full 10-minutes, due to shortness of breath; this individual instead exercised for 9 minutes and 30 seconds for the very-heavy exercise intensity. Furthermore, one participant did not wear the COSMED K4B<sup>2</sup> during one testing session (i.e., 80% of estimated LT), as they reported claustrophobia when wearing the mask that day.

#### *Oculomotor assessment*

On Sessions 2-4, participants completed oculomotor assessment pre- and post-exercise. Participants sat in front of a tabletop (height: 775mm) with their head placed in a head/chin rest in a quiet and dimly lit room. The experimenter adjusted the head/chin rest to comfortably suit each participants' morphological characteristics. A 30-inch LCD monitor (60Hz, 8ms response rate, 1,280 x 960 pixels; Dell 3007WFP, Round Rock, TX, USA) located 550 mm from the head/chin rest presented visual stimuli to participants. The gaze position of participants' left eye was collected via a video-based eye-tracking system (Eye-Trac6: Applied Sciences Laboratories, Bedford, MA, USA) sampling at 360Hz. Two additional monitors visible only to the

experimenter provided real-time point of gaze information, trial-by-trial saccade kinematics (i.e., displacement and velocity), and the accuracy of the eye-tracking system (i.e., to perform a recalibration when necessary). Computer events and visual stimuli were controlled via MATLAB (7.6: The MathWorks, Natick, MA, USA) and the Psychophysics Toolbox extensions (ver. 3.0; Brainard, 1997).

Visual stimuli included a central white fixation cross ( $1^\circ$ :  $135 \text{ cd/m}^2$ ) and target stimuli (i.e., yellow crosses  $127 \text{ cd/m}^2$ ,  $2.7^\circ$  in diameter) presented  $10.5^\circ$  (i.e., proximal target) and  $15.5^\circ$  (i.e., distal target) to the left and right of the fixation and in the same horizontal meridian. Two different target eccentricities were used to prevent participants from adopting a stereotyped response. A trial began with onset of the fixation cross. After a stable gaze was recorded ( $\pm 1.5^\circ$  for 420ms), a randomized foreperiod between 1,000 to 2,000 ms was initiated after which time a target stimulus was briefly presented (i.e., 50 ms). The target stimuli were presented for a brief duration (50 ms) to equate pro- and antisaccades for the absence of extraretinal feedback (Weiler, Holmes, Mulla, & Heath, 2011). The onset of the target stimulus cued participants to pro- (i.e., saccade to veridical target location) or antisaccade (i.e., saccade to the mirror-symmetrical of the target stimulus location) as quickly and accurately as possible.

Pro- and antisaccades were completed at pre- and post-exercise sessions in separate and randomly ordered blocks and within each block, 20 trials were completed to each target location (i.e., left and right of fixation) and eccentricity (i.e., proximal and distal) combination. Target location and eccentricity were ordered randomly. After the pre-exercise oculomotor assessment, participants had their resting blood pressure assessed and then immediately started their single-bout of exercise for 10-minutes. Following a cool-down period, participants completed their post-exercise oculomotor assessment. Depending on the exercise intensity a participant engaged in, the time between the completion of the exercise intervention and post-exercise oculomotor assessment was between one to four minutes after cool-down – an interval used to allow the participants' heart rate to return to baseline. Pre- and post-exercise oculomotor assessments required between 15 and 25 minutes. This time range reflects that some participants requested a brief break during the oculomotor assessment.

*Oculomotor data reduction, dependent variables, and statistical analyses*

Oculomotor data were filtered offline via a dual-pass Butterworth filter, with a low-pass cut-off frequency of 15 Hz. Acceleration and velocity data were computed via a five-point central-finite difference algorithm. Saccade onset was determined by velocity and acceleration values of greater than  $30^\circ/\text{s}$  and  $8,000^\circ/\text{s}^2$ , respectively. Saccade offset occurred when velocity values were less than  $30^\circ/\text{s}$  for 15 consecutive samples (i.e., 42 ms). Trials with missing data, signal noise (i.e., blinking), or anticipatory saccades (i.e.,  $\text{RT} < 85\text{ms}$ ) were excluded from the analyses (Munoz, Broughton, Goldring, & Armstrong, 1998). Trials with directional errors were not included in the analysis for RT and MT since trials involving antisaccade directional errors were mediated by planning mechanisms that are distinct from their directionally correct counterparts (DeSimone, Weiler, Aber, & Heath, 2014).

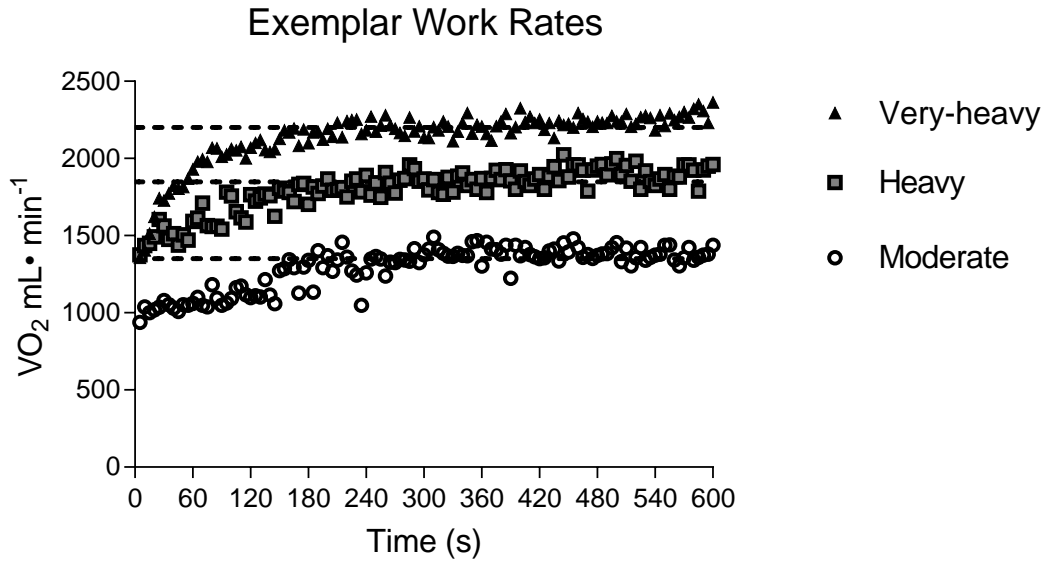
Dependent variables were: RT (time from stimulus onset to saccade onset), coefficient of variation (CV) of RT (i.e., standard deviation/mean  $\times$  100%), percentage of directional errors (i.e., a prosaccade instead of an instructed antisaccade or vice versa), movement time (MT: time from movement onset to movement offset), saccade amplitude and amplitude variability in the primary (i.e., horizontal) movement direction. Dependent variables were examined via 2 (task: prosaccade, antisaccade), by 2 (time of assessment: pre-exercise, post exercise), by 3 (exercise intensity: moderate, heavy, very-heavy), by 2 (target eccentricity: proximal, distal) repeated measures ANOVAs. An alpha level of .05 was used for statistical significance and simple-effects were employed to decompose main effects and interactions.

## Results

### *Exercise intensity: peak oxygen uptake & rating of perceived exertion*

**Figure 1** demonstrates an exemplar participant's oxygen uptake as a function of time for the moderate, heavy, and very-heavy intensities and demonstrates that each intensity was associated with different—and eventual steady-state—oxygen consumption. For MET and RPE values, one-way ANOVAs demonstrated reliable effects of exercise intensity, all  $F(2,32)=133.75$  and  $78.82$  for METs and RPEs, respectively,  $ps < .001$ ,  $\eta_p^2 = .89$  and  $.83$ , such that values increased from the moderate to heavy intensity, all  $t(16)=13.78$  and  $7.46$ ,  $ps < .001$ , and from the

heavy to very-heavy intensity, all  $t(16) = 5.89$  and  $6.46$ ,  $ps < .001$ . Results therefore demonstrate that exercise intensities were associated with distinct physiological and psychological costs.



**Figure 1.** An exemplar participant’s oxygen uptake ( $\text{VO}_2\text{mL}\cdot\text{min}^{-1}$ ) at 5 s intervals during moderate, heavy, and very-heavy exercise intensities. The figure shows that for each intensity the participant attained different – and eventual steady state – levels of oxygen consumption across each exercise intensity. The moderate intensity was a work rate at 80% of the participant’s estimated lactate threshold (i.e., 5 METs). The heavy intensity was 15% of the difference between estimated LT and  $\text{VO}_{2\text{peak}}$  (i.e., 7 METs). The very-heavy intensity was 50% of the difference between estimated LT and  $\text{VO}_{2\text{peak}}$  (i.e., 8 METs).

**Table 2.** Participant-specific results for the ramp incremental treadmill tests. Participant-specific absolute and relative  $\text{VO}_{2\text{peak}}$ , weight, ventilation threshold, peak aerobic power (converted into METs;  $\text{VO}_{2\text{peak}}/3.5$ ), and RPEs are reported.

						Intensities (METs) <sup>b</sup>		
Sex	$\text{VO}_{2\text{peak}}$ ( $\text{mLO}_2$ )	Weight (kg)	$\text{VO}_{2\text{peak}}$ ( $\text{mLO}_2/\text{kg}\cdot\text{min}$ ) <sup>a</sup>	Ventilation Threshold ( $\text{mLO}_2$ )	Peak Aerobic	Moderate	Heavy	Very Heavy

		Power (METs)									
						METs	RPE	METs	RPE	METs	RPE
F	2200	71	31	1600	9	5	4	7	5	8	6
F	1550	62	25	1450	7	5	3	7	5.5	7	7
F	1950	50	39	1400	11	6	3	8	5	10	7
F	1800	72	25	1500	7	5	5	6	7	7	8.5
F	1750	59	30	1200	9	5	4	6	5	7	8
F	1750	64	27	1250	8	4	3	6	4	7	5.5
F	1600	60	27	1500	8	6	2	7	5	7	8
F	1800	74	24	1400	7	4	1	6	4.5	6	9
F	2400	80	32	1600	9	5	4	6	7	7	7
M	2600	92	28	1900	8	5	3	6	5	7	6.5
M	2700	76	36	2100	10	6	4.5	8	6	9	9
M	2200	83	27	1800	8	5	5	6	7	7	8
M	3000	76	39	1900	11	6	3	8	6	9	7
M	2350	85	28	1700	8	5	1	6	7	7	8
M	1900	69	28	1250	8	4	3.5	6	5	7	6
M	2600	73	36	1750	10	5	2	7	4.5	9	6
M	2600	69	38	2200	11	7	4	9	5	10	9
Mean	2224	72	31	1637	9	5	3	7	5	8	8
SD	477	12	5	313	1	1	1	1	1	1	1

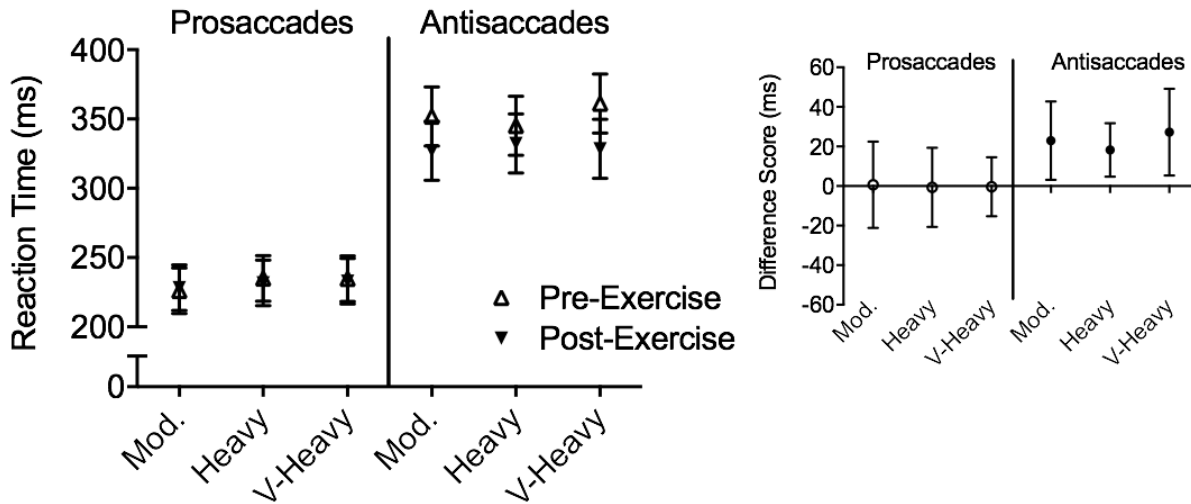
<sup>a</sup> VO<sub>2peak</sub> mL O<sub>2</sub> · min<sup>-1</sup> (Peak oxygen uptake in litres per minute).



<sup>b</sup> Intensities defined as: moderate (power output: 80% of LT), heavy (power output: 15% of the difference between LT and  $VO_{2peak}$ ), and very-heavy intensity (power output: 50% of the difference between LT and  $VO_{2peak}$ ).

*Oculomotor data: reaction time, directional errors and amplitude*

Results for RT indicated main effects for task  $F(1,16)=75.37, p<.001, \eta_p^2=0.82$ , time of assessment  $F(1,16)=33.92, p<.001, \eta_p^2=0.70$ , and target eccentricity  $F(1,16)=73.21, p<.001, \eta_p^2=0.82$ . For target eccentricity, RTs for the proximal target (274 ms,  $SD=40$ ) were less than the distal target (297 ms,  $SD=42$ ). In addition, **Figure 2** shows an interaction between task and time  $F(1,16)=6.15, p=.025, \eta_p^2=0.28$ : prosaccade RTs did not reliably vary with time of assessment ( $t(16)=1.34, p=.19$ ), whereas antisaccade RTs decreased from pre- to post-exercise assessment ( $t(16)=4.75, p<.001$ ). In light of the primary objective of this study, I also would like to note that there was not a main effect or higher-order interaction involving exercise intensity, all  $F(2, 32)<1.00, ps>.70$ , all  $\eta_p^2<0.03$ .

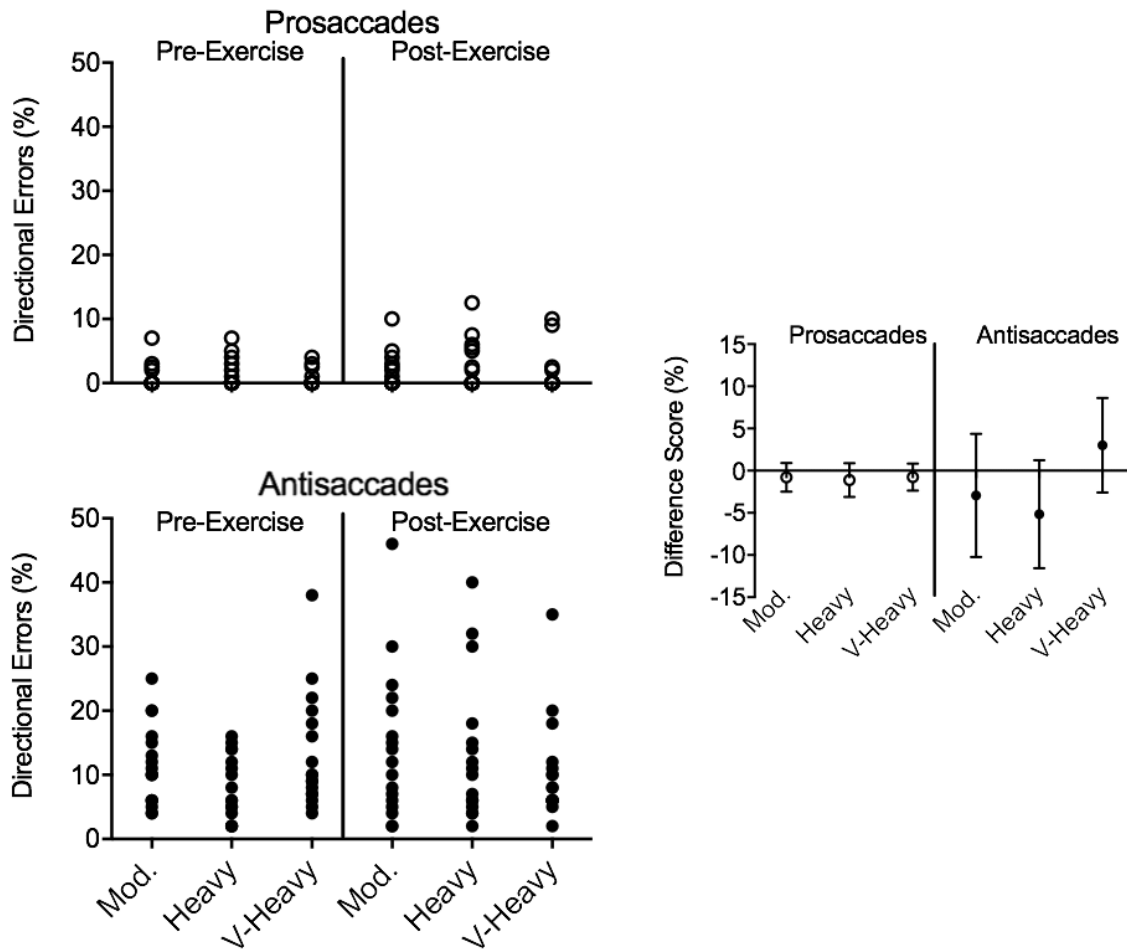


**Figure 2.** The large main panels show pro- and antisaccade reaction times (RT: ms) for pre- and post-exercise assessments at moderate, heavy, and very-heavy exercise intensities. Error bars represent 95% within-participant confidence intervals. The smaller offset panels show mean pro- and antisaccade RT difference scores (pre-exercise minus post-exercise) and associated 95% between-participant confidence intervals computed separately for each exercise intensity. In the offset panel, the absence of overlap between an error bar and zero (i.e., horizontal line) is inclusive to a test of the null hypothesis (Cumming, 2013).

The CV of RT yielded main effects for task  $F(1,16)=20.19$ ,  $p<.001$ ,  $\eta_p^2=0.56$ , and target eccentricity,  $F(1,16)=11.24$ ,  $p<.01$ ,  $\eta_p^2=0.41$ . Values were larger for prosaccades (35,  $SD=12$ ) than antisaccade (24,  $SD=6$ ), and were larger for the proximal (31,  $SD=12$ ) rather than the distal target (28,  $SD=10$ ). As well, results indicated that exercise intensity did not produce a main effect or any higher-order interactions, all  $F(2,32)<1$ ,  $ps>.39$ , all  $\eta_p^2<0.03$ .

The main panels of **Figure 3** show the percentage of pro- and antisaccade directional errors for each participant as a function of pre- and post-exercise assessments and exercise intensity. The figure demonstrates that many participants did not commit prosaccade errors. In particular, the percentage of prosaccades collapsed as a function of exercise intensity, time of assessment and target eccentricity was 3% ( $SD=3$ ) and this was less than those associated with

antisaccades (13%, SD=10) ( $t(16)=3.54$ ,  $p<.01$ ). Given the low number of prosaccade directional errors I limited my ANOVA model to only examine antisaccades. Results showed that neither exercise intensity,  $F(2,32)=1.56$ ,  $p=.22$ ,  $\eta_p^2=0.09$ , time of assessment,  $F(1,16)=1.22$ ,  $p=.28$ ,  $\eta_p^2=.05$ , nor their interaction,  $F(2,32)=0.75$ ,  $p=.46$ ,  $\eta_p^2=.04$ , reliably influenced the percentage of antisaccade directional errors. In addition, the offset panel of **Figure 3** presents time of assessment difference scores (pre-exercise minus post-exercise) – and associated 95% confidence intervals – for pro- and antisaccades across each exercise assessment. The figure demonstrates that pre- and post-exercise pro- and antisaccade directional errors did not vary with exercise intensity.

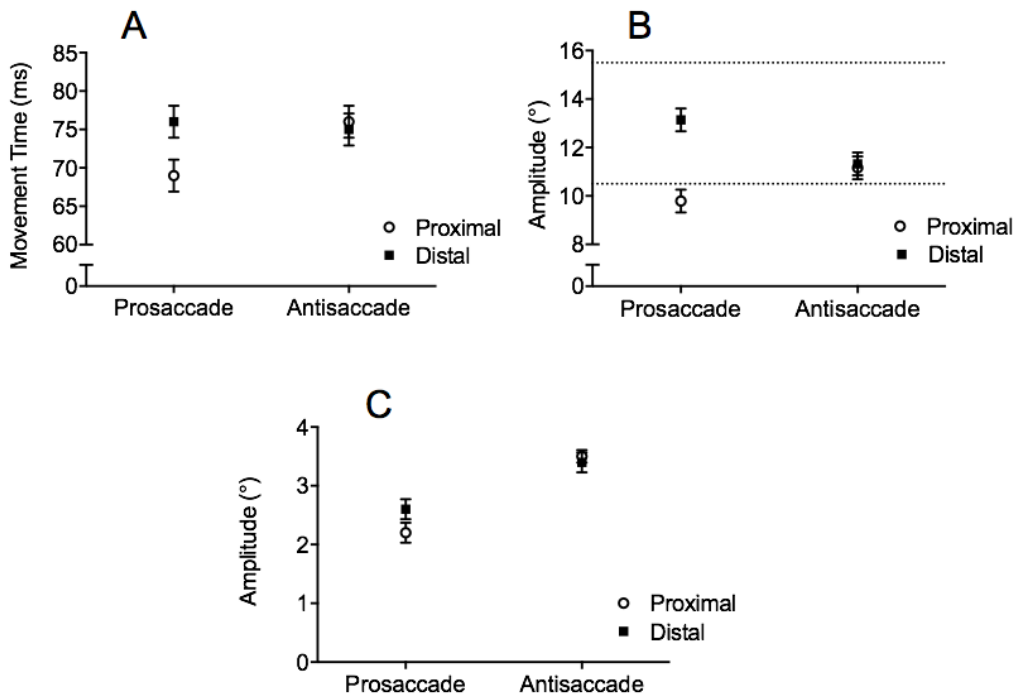


**Figure 3.** The large main panels show the percentage of pro- (top panel) and antisaccade (bottom panel) directional errors for individual participants as a function of exercise intensity. The smaller offset panels show mean pro- and antisaccade directional errors and 95% between-participant confidence intervals as a function of exercise intensity. The absence of overlap between an error bar and zero (i.e., horizontal line) can be interpreted inclusive to a test of the null hypothesis (Cumming, 2013).

MT and amplitude produced main effects of target eccentricity, all  $F(1,16)=32.48$  and  $190.12$ , for MT and saccade amplitude, respectively,  $ps<.001$ ,  $\eta_p^2=.67$  and  $.92$ , and task by target eccentricity interactions, all  $F(1,16)=63.37$  and  $201.31$ ,  $ps<.001$ ,  $\eta_p^2=.80$  and  $.92$ . The top panels of **Figure 4** (see A and B) show that prosaccade MTs and amplitudes (all  $t(16)=5.18$  and  $16.45$ ,  $ps<.001$ ) increased from the proximal to the distal target eccentricity. In contrast, antisaccade

MTs and amplitudes (all  $t(16)=-1.13, 1.33, p_s=0.27$  and  $0.20$ ) did not reliably vary with target eccentricity.

Amplitude variability produced main effects of task,  $F(1,16)=73.26, p<.001, \eta_p^2=.82$ , target eccentricity,  $F(1,16)=6.24, p=.024, \eta_p^2=.28$ , and their interaction,  $F(1,16)=18.97, p<.001, \eta_p^2=.54$ . The bottom panel of **Figure 4** (see C) shows that amplitude variability was less for prosaccades ( $2.4^\circ, SD=0.6$ ) than antisaccades ( $3.4^\circ, SD=0.7$ ), and the former showed an increase in variability from the proximal to the distal target ( $t(16)=3.66, p=.002$ ), whereas the latter did not vary with target eccentricity ( $t(16)=-2.04, p=.058$ ).

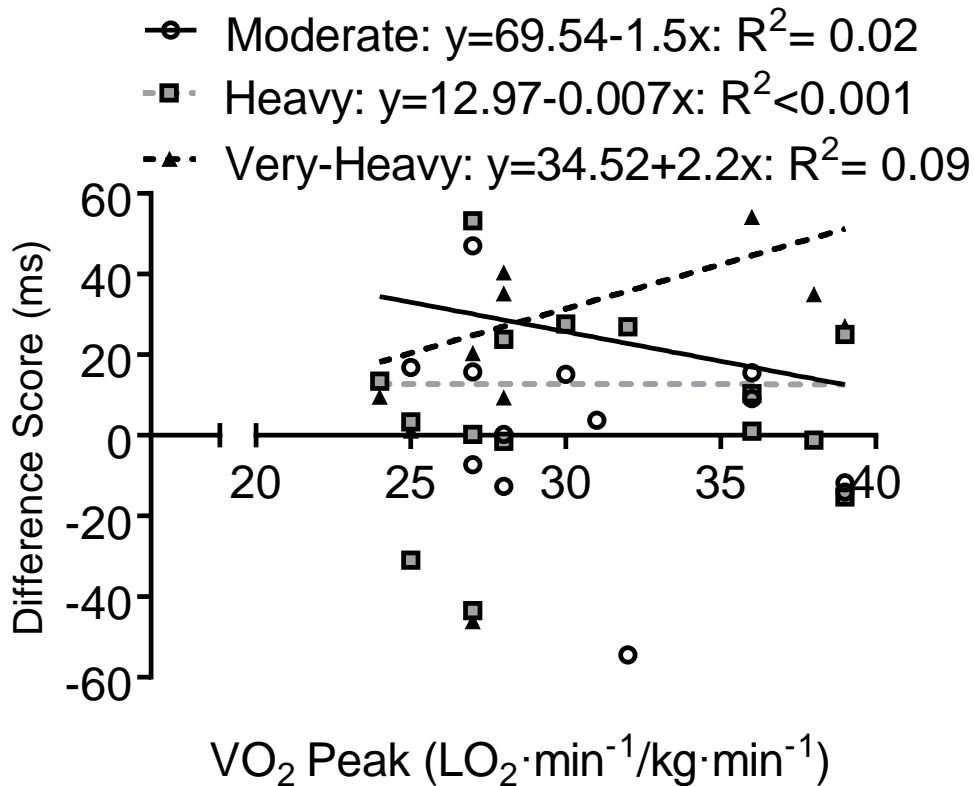


**Figure 4.** The top left (A), right (B), and bottom (C) panels show mean pro- and antisaccade MTs (ms), amplitudes ( $^\circ$ ), and amplitude variability, respectively, at pre- and post-exercise assessments for moderate, heavy, and very-heavy exercise intensities to the proximal and distal target eccentricities. Error bars represent 95% within-participant confidence intervals. In panel B,

the horizontal dotted lines shows veridical target amplitudes for the proximal (10.5°) and distal (15.5°) targets.

*The influence of cardiovascular fitness on executive function*

Some work has shown that high-fit individuals produce a larger post-exercise executive benefit following a single-bout of exercise (Chang et al., 2012); however, a recent meta-analysis has reported that low- and high-fit individuals demonstrate an equivalent post-exercise benefit. In the present work, I addressed this issue by examining the relationship between participants' measure of cardiorespiratory fitness (i.e.,  $VO_{2peak}$ ) and their antisaccade RT difference scores (pre-exercise minus post-exercise) for each exercise intensity. **Figure 5** demonstrates that cardiorespiratory fitness values did not reliably relate to difference scores for moderate ( $r^2= 0.02$ ,  $p= 0.6$ ), heavy ( $r^2= -0.001$ ,  $p= 1.0$ ), or very-heavy ( $r^2= 0.09$ ,  $p= 0.2$ ) intensities.



**Figure 5.** Regression of participant-specific cardiovascular fitness as determined via  $VO_{2peak}$  and antisaccade RT difference scores (pre-exercise minus post-exercise RTs) for moderate, heavy, and very-heavy exercise intensities.

## Discussion

The present investigation sought to determine whether a 10-minute single-bout of participant-specific moderate, heavy, and very-heavy exercise intensities differentially influence the *magnitude* of a post-exercise executive benefit in older adults. To begin, I will first discuss the general differences between pro- and antisaccades, and then discuss how exercise intensity and cardiorespiratory fitness influenced post-exercise pro- and antisaccade performance.

### *Pro- and antisaccades exhibit distinct planning times and endpoint properties*

Prosaccades had shorter RTs and produced fewer directional errors than antisaccades. Moreover, prosaccade amplitudes were less variable than antisaccades and showed amplitude scaling to target eccentricity. These results are entirely in line with previous work (Hallett, 1978; Fischer & Weber, 1992; Dafoe, Armstrong & Munoz, 2007; Gillen & Health, 2014) and are taken to reflect that pro- and antisaccades are mediated via distinct mechanisms. In particular, the shorter RTs associated with prosaccades are thought to reflect that the direct stimulus-response relations associated with such actions renders motor output supported via the direct retinotopic projections of the superior colliculus (SC) – a visuomotor network that operates largely independent of top-down cortical control (Pierrot-Deseilligny et al., 2005). In turn, the longer RTs of antisaccades are interpreted to reflect the time-consuming and executive demands of response suppression and vector inversion and their mediation via an extensive frontoparietal network (for review see Munoz & Everling, 2004). As well, the increased number of directional errors for antisaccades have been shown to reflect a failure to deploy the frontal-based executive networks necessary for suppressing a response (Ford, Gati, Menon, & Everling, 2009; Hallett, 1978). Furthermore, that prosaccades produced less variable amplitudes and more accurate scaling to target eccentricity is consistent with evidence that such actions are mediated via the direct and absolute retinotopic maps of the SC. In turn, the amplitude findings for antisaccades indicate that the task's top-down nature renders the specification of target amplitude via visual

information (i.e., relative) that is functionally distinct from prosaccades (Gillen & Heath, 2014). Accordingly, the observed differences between pro- and antisaccades demonstrates a framework for comparing how non-executive and executive-based oculomotor tasks are influenced by a single-bout of aerobic exercise.

*A single-bout of aerobic exercise selectively influences antisaccade planning times*

In terms of prosaccades, pre- and post-exercise performance did not reliably differ across any performance metric (i.e., RT, directional errors, movement time, saccade amplitude, and amplitude variability). This result is in accord with previous work demonstrating that single-bout (Samani & Heath, 2018) and chronic exercise (Heath, Weiler, Gregory, Gill, & Petrella, 2016; Shellington, Heath, Gill, & Petrella, 2017) training does not influence prosaccades. Indeed, and although single-bout (Hillman, Kamijo, & Scudder, 2011) and chronic training studies (Colcombe et al., 2004) have shown exercise-based functional and structural changes to cortical and subcortical regions (i.e., the hippocampus), to my knowledge no previous work has reported an exercise-related change to the midbrain structure (i.e., SC) governing prosaccades. Accordingly, the present study demonstrates that the single-bout effect did not influence prosaccade planning or execution.

Antisaccades showed a 23 ms reduction in post exercise RTs. This finding is similar to previous work by our group (Samani & Heath, 2018) showing that young adults who complete a 10 minute single-bout of exercise (via cycle ergometer at 60-85% of heart rate maximum) produced a 27 ms reduction in antisaccade RTs, whereas non-exercise controls did not exhibit such changes (i.e., participants read a magazine for an equivalent period of time). The post-exercise change in antisaccade RTs are not likely attributed to a practice-related improvement in a non-standard task-set for at least two reasons. First, Klein and Berg (2001) showed that the deliberate practice of an antisaccade task across a four-week time period does not influence planning times (see also: Roy-Byrne, Radant, Wingerson, & Cowley, 1995). Second, and as previously reported, work by our group (Samani & Heath, 2018) showed that antisaccade RTs completed prior to and following a 10-minute rest-interval do not reliably differ. In other words, the decrease in antisaccade RTs was specific to the exercise condition. As well, I note that the post-exercise change in antisaccade RTs cannot be attributed to a speed-accuracy trade-off given



that directional errors and amplitudes (and amplitude variability) did not vary from pre- to post-exercise assessments. In other words, participants did not decrease their post-exercise antisaccade RTs at the cost of increased directional errors and less accurate endpoints. Instead, the present findings support the contention that 10-minutes of exercise improves performance on an executive-related oculomotor task.

*Exercise intensity did not influence the magnitude of the antisaccade benefit*

The primary objective of this experiment was to determine whether exercise intensity differentially influenced the *magnitude* of the post-exercise improvement in executive function in older adults. To accomplish that objective I determined moderate, heavy, and very-heavy exercise intensities via participant-specific measures of LT and  $VO_{2peak}$ . The basis for this inquiry stems from some research in younger and older adults showing that moderate intensity provides the largest boost to cognitive performance (Arent & Landers, 2003; Chang et al., 2015; Chang, Etnier, & Barella, 2009; Kamijo et al., 2009; McMorris & Hale, 2012; Peiffer, Darby, Fullenkamp, & Morgan, 2015), whereas other research has shown that heavy to very-heavy intensities produce the greatest benefit (Hwang et al., 2016; Tsukamoto et al., 2016). **Figure 1** shows an exemplar participant's oxygen consumption for the moderate, heavy, and very-heavy intensities used here. The figure demonstrates that the participant reached a steady-state of oxygen consumption and maintained it for the duration of the exercise session. Accordingly, my results show that each exercise intensity was associated with metabolically distinct work rates. In spite of the different intensities, the post-exercise reduction in antisaccade RTs did not vary with intensities. In fact, the RT reduction was 22, 19, and 27 ms for the moderate, heavy, and very-heavy intensities, respectively. Thus, results suggest that an exercise intensity across the continuum of moderate to very-heavy did not influence the *magnitude* of the post-exercise executive benefit. Furthermore, the F-ratio for the main effect of exercise intensity and all higher-order interactions involving this variable (all  $F < 1$ ) indicated that the absence of a reliable effect cannot be attributed to an inadequate replication sample size (Keppel, 1991). Instead, these results indicate that a continuum of exercise intensities positively impacts post-exercise antisaccade performance.

Hyodo et al.'s. (2012) study showed that light-intensity exercise (i.e., 40-59%  $VO_{2max}$ ) on a stationary bike improved older adults' Stroop task performance after 10-minutes exercise. This finding compliments my work and suggests that older adults accrue a post-exercise benefit across the continuum of light to very-heavy intensities. Of course, what is unclear from when comparing my work to Hyodo et al. is whether the magnitude of the post-exercise benefit at a light intensity is comparable to those associated with moderate to very-heavy intensities.

*Cardiovascular fitness was not related to executive benefits*

Some work has reported that individuals with higher levels of fitness demonstrate larger benefits to post-exercise executive function than those of lower fitness (for meta-analysis see: Chang et al., 2012). Accordingly, I sought to determine whether cardiorespiratory fitness (as measured via  $VO_{2peak}$ ) was related to the post-exercise antisaccade benefit. To accomplish that goal, I computed antisaccade difference scores (i.e., pre-exercise minus post exercise) separately for each participant and for each exercise intensity and correlated those values to participant-specific measures of  $VO_{2peak}$ . Results showed that antisaccade differences scores were not reliably related to cardiorespiratory fitness – a result that was consistent across each exercise intensity. In accounting for this result, I note that a most recent meta-analysis by Ludyga et al. (2016) concluded that both high- and low-fit individuals can expect a similar post-exercise benefit to executive function. Indeed, it is important to recognize that Chang et al.'s (2012) meta-analysis accounted for physical fitness as a moderator of executive tasks “only when the task was administered during exercise” (p.1622), and did not include studies on older adults. In contrast, Ludyga and colleagues (2016) examined post-exercise executive function across the lifespan and when executive function was assessed post-exercise. Thus, convergent evidence suggests that a post-exercise executive benefit can be expected across low- and high-fit individuals.

As mentioned above, I sought to examine whether cardiovascular fitness (via  $VO_{2peak}$ ) and executive function influence the single-bout post-exercise benefit in older adults. In addressing this issue it is important to recognize that older adults have more variable  $VO_{2peak}$  values than young adults due to genetic and age-related factors and that such variability is exacerbated by health conditions such as cardiac, pulmonary, and peripheral arterial diseases (Chodzko-Zajko et al., 2009; Kenney, Wilmore, & Costill, 2015; Nelson et al., 2007; Vanhees et

al., 2012). Notably, however, the older adults that participated in this experiment had average to high aerobic fitness for their age groups (males: mean = 38 mL $O_2$ /kg·min, range = 25-49; females: mean = 36 mL $O_2$ /kg·min, range = 24-46). Therefore, in older adults the inclusion of participants along a more extreme continuum of cardiovascular fitness might be required to establish a relationship between fitness and the magnitude of a single-bout post-exercise improvement in executive function.

#### *Age does not influence post-exercise executive control*

Ludyga et al.'s (2016) meta-analysis concluded that age is not a moderator of the post-exercise executive benefit. For example, the magnitude of post-exercise RT improvements in Samani & Heath (2018) was 27 ms and my study demonstrated an average post-exercise antisaccade RT reduction of 23 ms. These results are in accordance with work demonstrating that following a 6-month multi-modality exercise program older adults with a subjective cognitive complaint elicit a 23 ms reduction in their antisaccade RTs (Heath et al., 2017). What is more, Ludyga and colleagues (2016) reported that older adults “had the greatest improvements in response time” for tasks requiring executive control (i.e., Stroop, modified flanker task) after a single aerobic exercise session (p.1621). Most recently, our group examined (Heath et al., 2018) the same moderate, heavy, and very-heavy intensities used here in younger adults (i.e., 19 – 27 years) and found that 10-minutes of exercise across all intensities produced reliable post-exercise antisaccade RT reduction of 21 ms. Thus, it would appear that the magnitude of an exercise-related antisaccade performance benefit is consistent across young and older adults and when assessed following single-bout and chronic exercise interventions.

#### *Study limitations and future directions*

The participants involved in this research were Caucasian, highly-fit, had preserved global cognition, and had >12 years of education. Thus, in order to extend our findings to a broader category of older adults, future research should include a more ethnically diverse population, across a range of educational and fitness levels as well as persons with objective or subjective cognitive impairment. For example, our group's previous work has recruited a wide range of participants with varying levels of cognitive decline (i.e., cognitive-impairment-not-dementia, mild cognitive impairment) and results have demonstrated that chronic aerobic and/or resistance

exercise training programs can improve oculomotor executive function in these populations (Heath et al., 2016; 2017). Accordingly, those with more advanced cognitive decline might receive a larger post-exercise executive benefit (due to cognitive reserve) following a specific intensity of single-bout exercise (see review: Stern, 2009). In addition, it is still unclear whether the magnitude of intensity (i.e., very-light to maximal exercise) provides a differential executive benefit from 10 minutes of aerobic exercise. This is particularly important to discern, as older populations can have difficulty committing to long-term exercise programs or may have physical limitations or frailty issues that prevent them from exercising for longer than 10-minutes, or at intensities greater than light to moderate levels. As well, the present study examined the post-exercise executive benefit at one time point, and it is thus unknown for how long the benefit might persist. Subsequent work should determine whether the benefit persists for vary intervals (i.e., from 20 minutes to 2 hours) following exercise.

### *Conclusions*

A 10-minute single-bout of participant-specific aerobic exercise at moderate, heavy, and very-heavy exercise intensities improves antisaccade – but not prosaccade – RTs, and the magnitude of the RT benefit did not reliably vary as a function of exercise intensity. Moreover, the antisaccade RT benefit occurred without concomitant changes in directional errors or endpoint accuracy. Therefore, the antisaccade task demonstrates that exercise durations as brief as 10 minutes provide a reliable ‘boost’ to executive function in older adults and this benefit is observed across a continuum of moderate to very-heavy intensities.

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# Appendices

**Appendix A: Approval notice from the Office of Research Ethics, The University of Western Ontario**



**Western  
Research**

Research Ethics

**Western University Health Science Research Ethics Board  
HSREB Full Board Initial Approval Notice**

**Principal Investigator:** Dr. Matthew Heath  
**Department & Institution:** Health Sciences/Kinesiology, Western University

**Review Type:** Full Board  
**HSREB File Number:** 109259  
**Study Title:** The Antisaccade Task with Acute Aerobic Exercise in Older Adults

**HSREB Initial Approval Date:** June 12, 2017  
**HSREB Expiry Date:** June 12, 2018

**Documents Approved and/or Received for Information:**

Document Name	Comments	Version Date
Western University Protocol		2017/06/06
Letter of Information & Consent		2017/05/27
Recruitment Items	Recruitment Poster	2017/06/05
Recruitment Items	Appendix A Scripts for participant recruitment May 2017	2017/05/27
Data Collection Form/Case Report Form	MMSE	2017/05/27
Data Collection Form/Case Report Form	MoCA	2017/05/27
Instruments	Brief Medical History	

The Western University Health Science Research Ethics Board (HSREB) has reviewed and approved the above named study, as of the HSREB Initial Approval Date noted above.

HSREB approval for this study remains valid until the HSREB Expiry Date noted above, conditional to timely submission and acceptance of HSREB Continuing Ethics Review.

The Western University HSREB operates in compliance with the Tri-Council Policy Statement Ethical Conduct for Research Involving Humans (TCPS2), the International Conference on Harmonization of Technical Requirements for Registration of Pharmaceuticals for Human Use Guideline for Good Clinical Practice Practices (ICH E6 R1), the Ontario Personal Health Information Protection Act (PHIPA, 2004), Part 4 of the Natural Health Product Regulations, Health Canada Medical Device Regulations and Part C, Division 5, of the Food and Drug Regulations of Health Canada.

Members of the HSREB who are named as Investigators in research studies do not participate in discussions related to, nor vote on such studies when they are presented to the REB.

The HSREB is registered with the U.S. Department of Health & Human Services under the IRB registration number IRB 00000940.



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# Curriculum Vitae

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**Post-secondary Education and Degrees:** The University of Western Ontario  
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2012-2016 B.A. Hons. Spec.

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**Honours and Awards:** PSAC Local 610 Community Involvement Scholarship  
September 2018

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Graduate Teaching Assistant Award  
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Western Graduate Research Scholarship  
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## **Publications:**

Heath, M., **Petrella, A.**, Blazevic, J., Lim, D., Pelletier, A., & Belfry, G.R. (2018). A post-exercise facilitation of executive function is independent of aerobically supported metabolic costs. *Neuropsychologica*, *120*, 65-74.

**Petrella, A.F.M.,** Gill, D.P., & Petrella, R.J. (2018). Evaluation of the Get Active Questionnaire in Community-Dwelling Older Adults. *Applied Nutrition, Physiology and Metabolism*, 43(6), 587-594.

Stathokostas, L., **Petrella A.F.M.,** Blunt, W., & Petrella R.J. (2018). Perceptions of Exercise Screening Among Older Adults. *Applied Physiology, Nutrition, and Metabolism*, 43(6), 580-586.

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