The Magnitude and Time Course Effects of an Acute Bout of Moderate Intensity Resistance Training on Cognitive Function

by

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Author's Declaration

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

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Matthew Vonk

Abstract

Resistance training (RT) is a common form of physical activity that forms a core part of physical activity recommendations. RT has well-documented benefits to metabolic and musculoskeletal health. Emerging research also suggests that RT, when performed over a period of time, is associated with improvements in cognitive function. More recently, studies have examined the acute effect of RT on cognitive function, as characterized by behavioural and electroencephalography (EEG) measures. Studies to date have predominantly demonstrated acute benefits to behavioural measures of executive function after RT in older, untrained populations. Only one study also used concurrent EEG to examine underlying cortical changes in a young adult population. Results from this study suggest that an acute moderate intensity RT session promotes faster responses and increased P300 (P3) amplitude. The purpose of this thesis was to specifically examine the effects of acute moderate intensity RT on response inhibition among young adults, when compared to non-exercise rest and loadless (LL) movement controls. The first objective was to determine if acute RT altered cortical processing, as measured by P3 amplitude and latency during a modified Stroop task. The second objective was to investigate whether acute RT influences behavioural measures of response time and accuracy during a modified Stroop task. The final objective was to examine the time course of effects up to 40min after the intervention. Twenty-two physically active young adults performed three sessions: rest, LL activity (simulated RT), and moderate intensity RT over a 5-week period. The rest session was always performed first and the LL and RT sessions were then performed in randomized order. A modified Stroop task was

performed before the intervention and again 10, 20, 30, and 40min post-intervention with concurrent EEG. Outcomes (Stroop task response time and accuracy, P3 amplitude and latency) were analyzed with mixed effects linear regression models. Changes in cognitive function, as characterized by behavioural and EEG measures, were similar after RT, LL, and rest for most measures. P3 amplitudes increased over time, for the rest session only ($p<0.0041$). There were no differences between RT and LL activity. The reason for the lack of effects, in contrast to most prior studies, is unclear. However, it is possible that the lack of effects may be due to the simpler response inhibition task, the shorter rest during the RT session, or the lack of randomization of the rest session. Future research should further investigate the relative effects of RT, LL movement, and rest on cognitive function, with a fully randomized design. Studies should also investigate underlying mechanisms and relative differences between these conditions to better understand the influence of movement and exertion on cognitive function.

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List of Acronyms

ACTH- Adrenocorticotrophin hormone

AMPA-α-amino-3-hydroxy-5-methyl-4-isoxazolepropionic acid receptor

BDNF- Brain derived neurotrophic factor

DA- Dopamine

DLPFC- Dorsal lateral prefrontal cortex

E- Epinephrine

EEG- electroencephalography

EPSP- Excitatory post-synaptic potential

ERP- Event related potential

HR- Heart rate

IGF-1- Insulin growth factor-1

IPAQ- International physical activity questionnaire

LL- Loadless

NE- Norepinephrine

NMDA- N-methyl-D-aspartic receptor

P3- P300 event related potential

PAR-Q- Physical activity readiness questionnaire

RCT- Randomized control trial

RM- Repetition maximum

RPE- Rate of perceived exertion

RT- Resistance training

TrkB- Tropomyosin receptor kinase B

Section 1. Introduction

Physical activity can be defined as any movement causing energy expenditure to rise above the body's basal metabolic rate. Physical activity is associated with widespread health and functional benefits including body growth and development as well as prevention of chronic conditions such as diabetes, heart disease, and osteoporosis (Public Health Agency of Canada, 2014). Purposeful exercise, which is physical activity that is consciously planned through directed movements to improve physical fitness, can be divided into at least two types: aerobic exercise and RT (Public Health Agency of Canada, 2014). Aerobic exercise can be defined as using a large group of muscles to perform an activity that is rhythmic in nature and may be performed through many different modalities (running, walking, cycling, etc.) (American College of Sports Medicine, 2000). In contrast, RT is a series of simple or complex movements designed to work a muscle or muscle group against external resistance to improve muscular fitness and development (American College of Sports Medicine, 2010).

Growing evidence also suggests that exercise can induce changes in brain function and cognitive performance, likely driven by changes in both neuronal and vascular function and structure (Dishman et al., 2006; Kramer & Erickson, 2007). Improvements have been observed after chronic training interventions and after acute bouts of exercise in young and older adults (Chang, Labban, Gapin, & Etnier, 2012; S. Colcombe & Kramer, 2003). Most studies have focused on aerobic exercise and relatively little research has examined resistance training (RT).

Preliminary studies of RT suggests that both chronic and acute (single) sessions may also benefit cognitive function (Cassilhas et al., 2007; Chang, Chu, Chen, & Wang, 2011; Liu-Ambrose, Nagamatsu, Voss, Khan, & Handy, 2012; Tsai et al., 2014b). This thesis will examine the acute effects of RT on cognitive function (specifically, executive function) compared to both rest and loadless (LL) movement. Previous studies have shown positive effects on cognitive function after a single bout of RT using both behavioural and electrophysiological measures (Chang & Etnier, 2009b; Tsai et al., 2014b). These studies show that executive function tasks assessing working memory, planning, and inhibitory control are particularly sensitive to acute RT (Chang et al., 2011; Chang & Etnier, 2009b; Tsai et al., 2014b). However, studies have only measured changes in cognitive function once after RT. This thesis will specifically examine the magnitude and time-course of the cognitive effects after a single session of moderate intensity (70% 10-repetition maximum, RM) RT up to 40min after exercise. Electrophysiological and behavioural data will be collected before and 10, 20, 30, and 40min after RT. Results will demonstrate both the magnitude and time-course of the changes in executive function in young healthy adults after a session of RT in comparison to LL movement and non-exercise rest controls. Results will also give insights into the potential influences of movement and exertion on cognitive function.

Literature regarding the influence of physical activity in general as well as acute and chronic aerobic and RT on cognitive function will be reviewed. Potential mechanisms underlying observed changes will be discussed, followed by an overview

of the behavioural and electroencephalography (EEG) measures that will be used to characterize cognitive function in this thesis.

Section 2. Physical Activity and Cognitive Function

The earliest studies investigating the link between physical activity and cognitive function appeared almost a century ago (Tomporowski & Ellis, 1986). Of the following years, we have come to understand that physical activity also induces changes in cognitive function after both periods of exercise training and a single session of exercise (Casshilas et al., 2007; Chang et al., 2012; Colcombe & Kramer, 2003). As reviewed in Sections 2.1 to 2.3, substantially more research has examined the chronic and acute cognitive benefits of aerobic exercise compared to RT.

2.1 Prospective Cohort Studies of Physical Activity and Cognitive Function

Meta-analyses and reviews of longitudinal population studies indicate that older adults (generally defined as over the age of 65) with greater physical activity are less likely to develop significant cognitive decline or dementia over the next 6-10 years (Hamer & Chida, 2009; Kramer & Erickson, 2007). Most of these studies used self-report questionnaires to measure physical activity levels and most often captured general physical activity or aerobic exercise rather than RT. One of the first studies to characterize the longitudinal relationship between physical activity levels and the risk of cognitive decline was a study of older community-dwelling women. Women who were more physically active through stair climbing, walking, and leisure activity had a lower chance of experiencing a significant decline in global cognitive

function (based on a modified Mini-Mental State Examination, mMMSE) over 6-8 years of follow-up (Yaffe, Barnes, Nevitt, Lui, & Covinsky, 2001).

The relationship between physical fitness, physical activity, and incident cognitive impairment has also been replicated using objective measures. For example, in a study of older adults (55 and older), participants with poorer cardiorespiratory fitness at baseline experienced more decline in global cognitive function (measured with the mMMSE) and poorer performance on cognitive tests across a number of cognitive domains 6 years later (Barnes, Yaffe, Satariano, & Tager, 2003). Higher aerobic fitness was most strongly associated with better global cognitive function. Objective measures of physical activity (doubly labeled water or accelerometry) are also associated with reduced rates of incident cognitive impairment and dementia (Middleton et al. 2011, Buchman et al. 2012).

2.2 Controlled Trials of Aerobic Exercise and Cognitive Function

The disadvantages of observational studies is that there may be a variety of confounding factors related to physical activity levels that contribute to the relationship between physical activity and incident cognitive impairment, including subtle differences in health, behaviour, and cognitive status. Randomized controlled trials (RCT) of exercise interventions control for such confounding factors. Increasing literature shows that aerobic exercise interventions can improve cognitive and brain function among older adults (Angevaren, Aufdemkampe, Hjj, Aleman, & Vanhees, 2008; Forbes, Forbes, Morgan, Wood, & Culum, 2008; Forbes, Thiessen,

Blake, Forbes, & Forbes, 2013). The following section will discuss supporting research from clinical trials of aerobic exercise interventions for cognitive function.

2.2.1 Chronic Exercise Interventions and Cognitive Function

An increasing number of clinical trials, both randomized and not, suggest that aerobic exercise interventions can improve cognitive function among children, older healthy adults, and older adults with cognitive impairment (Ahamed et al., 2007; Angevaren et al., 2008; Davis et al., 2007; Forbes et al., 2013). In studies using elementary school children, one RCT was able to show that high-doses of aerobic exercise (40min 5 days/week) resulted in greater cognitive planning scores than low-dose, and control groups (Davis et al., 2007). Another study showed that giving children an extra 10min of exercise each day had no negative effects on their school performance while increasing health benefits (Ahamed et al., 2007). Similar positive effects of exercise are observed in older age groups (Angevaren et al., 2008; Colcombe & Kramer, 2003). However, the most recent Cochrane review concluded an inconclusive effect on cognitive function due to substantial variability across studies (Young, Angevaren, Rusted, & Tabet, 2015). The contrast in this recent Cochrane review compared to a number of other systematic reviews may be due to the fact that it was more selective in its criteria, which eliminated many studies from inclusion (Angevaren et al., 2008; Colcombe & Kramer, 2003; Young et al., 2015).

Many studies also have examined aerobic training programs to improve cognitive function among older adults with baseline cognitive impairment (Forbes et al., 2008, 2013), who seem to be more sensitive to the effects of aerobic exercise

compared to those with healthy cognitive function. A Cochrane review of RCTs suggests that aerobic exercise improves cognitive function and activities of daily living among older adults with dementia (Forbes et al., 2013). However, outliers and unexplained heterogeneity of findings lead to caution when interpreting results (Forbes et al., 2013). One example of such an RCT randomized older adults with Alzheimer's disease to a 6-month home-based exercise intervention or a usual hospital care control. Participants in the exercise intervention had better global cognitive function as measured by the Alzheimer Disease Assessment Scale–Cognitive Subscale post-intervention and at 18-month follow up than those randomized to a usual care control condition (Lautenschlager, Cox, Flicker, Foster, & Bockxmeer, 2008).

Aerobic exercise has been shown to preferentially benefit certain cognitive domains, specifically inducing the largest effects for executive function processes (Angevaren et al., 2008; Colcombe & Kramer, 2003). In brief, executive function describes the ability to produce goal-oriented behaviour through a combination of intrinsic and fundamental cognitive processes (Etnier & Chang, 2009). Measures used to capture executive function have varied across studies and include common clinical assessments as well as more precise timed measures (Roig, Nordbrandt, Sparre, & Bo, 2013). One study of 29 healthy older adults used the Eriksen Flanker task, a complex choice reaction task, to specifically quantify one component of executive function, inhibitory control (Colcombe et al., 2004). Inhibitory control refers to the action of deterring or preventing a habitual or expected response (Hommel, Ridderinkhof, & Theeuwes, 2002; Purves et al., 2013). This study found

that older adults assigned to an aerobic exercise intervention had significantly improved inhibitory control and greater task-related activity in areas of the brain associated with attentional control compared to a stretching and toning control group (Colcombe et al., 2004).

2.2.2 Acute Exercise Interventions and Cognitive Function

There is also evidence that a single session of aerobic activity can improve cognitive function. Recent meta-analyses concluded that a single session of aerobic exercise has a small positive effect on cognitive function (Chang et al., 2012; Lambourne & Tomporowski, 2010). After at least 20min of exercise (shorter durations of exercise did not elicit a significant effect), improvements in cognitive performance occurred during exercise, immediately after exercise, and after a delay post-exercise (Chang et al., 2012; Lambourne & Tomporowski, 2010).

Acute benefits crossed several cognitive domains including memory retrieval and executive function (Lambourne & Tomporowski, 2010). One meta-analysis of young adults suggested positive effects were greater for long-term memory than for processing speed or executive function (Lambourne & Tomporowski, 2010). In contrast, a more recent meta-analysis that included all age-groups indicated that the largest positive effects post-exercise were for tasks targeting executive function and found no significant effects for memory (Chang et al., 2012)

Over the last 15 years, a number of studies have examined the effect of exercise on cognitive function using EEG paired with behavioural measures. Most studies paired cognitive tests targeting the inhibitory control portion of executive

function with EEG monitoring of the P300 (P3) waveform (Kamijo, Nishihira, Higashiura, & Kuroiwa, 2007; Kamijo, Nishihira, Hatta, Kaneda, Wasaka, et al., 2004; Tsai et al., 2014b). A few other exercise studies using EEG examined the N140 (Akatsuka, Yamashiro, Nakazawa, Mitsuzono, & Maruyama, 2015) and contingent negative variation waveforms during tasks targeting either attention or the working memory component of executive function (Kamijo, O'Leary, Pontifex, Themanson, & Hillman, 2010; Tsai et al., 2014a). The P3 event related potential (ERP), which will be explained in more detail in Section 4.2, is an electrophysiological waveform used to quantify the cognitive processes used to interpret and analyze stimuli (Olejniczak, 2006). In most studies, the P3 amplitude was greater after aerobic exercise than after a rest session, which was generally interpreted as more attentional resources dedicated to the cognitive task (Hillman, Snook, & Jerome, 2003; Kamijo, Nishihira, Hatta, Kaneda, Wasaka, et al., 2004; Kamijo, Hayashi, Sakai, Yahiro, Tanaka, et al., 2009; Kamijo et al., 2007; Magnié et al., 2000). Most studies also observed a decrease in P3 latency, which is generally interpreted as quicker evaluation of the stimulus presented (Hillman et al., 2003; Kamijo et al., 2007; Magnié et al., 2000).

A number of moderators of the relationship between acute exercise and behavioural and neuroelectric measures of cognitive performance have been identified. Intensity appears to modify the acute effects of aerobic exercise on cognitive function (Chang et al., 2012). Among young adults, moderate intensity aerobic exercise is associated with the greatest improvement in both behavioural and neuroelectric measures of cognitive function (Kamijo, Hayashi, Sakai, Yahiro, & Tanaka, 2009; Kamijo et al., 2007; Kamijo, Nishihira, Hatta, Kaneda, Kida, et al., 2004;

Tsai et al., 2014a) . The increase in P3 amplitude is generally greater after moderate intensity exercise than after light or high intensity exercise, though the difference between light and moderate intensity was not significant in all studies (Kamijo et al., 2007; Kamijo et al., 2004; Olson et al., 2015). Interestingly, a recent meta-analysis indicated that the relationship between exercise intensity and cognitive function may be different depending when the post-exercise assessment was conducted (Chang et al., 2012). Specifically, light and moderate exercise were associated with a positive effect on cognitive function immediately after exercise whereas intensities from moderate to very intense were associated with cognitive benefits if measured after a delay (greater than one minute) (Chang et al., 2012).

Another moderator of the relationship between acute exercise and cognitive function is the difficulty of the cognitive tasks being performed. It has been suggested that executive function tasks of greater difficulty (i.e. incongruent trials of the flanker) are more sensitive to aerobic exercise effects than cognitive tasks requiring minimal effort (i.e. go/no-go tasks) (Hillman et al., 2003; Pontifex, Hillman, & Polich, 2009). The decrease in P3 latencies was significantly greater for incongruent trials of flanker tasks (more difficult) when compared to neutral or congruent conditions (less difficult) (Hillman et al., 2003; Kamijo et al., 2007). The same trend for augmented effects with more difficult tasks was observed for P3 amplitudes in more difficult conditions of a difficult visuospatial attention task (Tsai et al., 2014a).

Age may also alter acute aerobic exercise effects on cognitive function. Unlike chronic exercise studies, the majority of research regarding acute exercise is in young healthy adult populations (Lambourne & Tomporowski, 2010). The influence of age,

however, differs across studies. A meta-analysis suggested young adults may experience the least cognitive benefits (Chang et al. 2012) while individual studies suggest young adults benefit more than older adults (Kamijo et al., 2009).

In conclusion, evidence to date indicates that acute exercise likely induces a small beneficial effect on cognitive function. This cognitive effect may be greatest following moderate intensity exercise and for more cognitively demanding tasks, such as those that focus on executive function. Although relatively unexamined, the timing of the post-exercise measurement may further alter the relationships between these variables and the magnitude of cognitive effects observed. Therefore, the magnitude of the exercise benefits on cognitive function may depend on a combination of exercise, sample, and measurement characteristics (Chang et al., 2012).

2.3 Controlled Trials of RT and Cognitive Function

The impact of RT on cognitive function has received a recent surge of attention in the literature, in part because it is easily implemented into rehabilitation programs for older adults and, similar to aerobic exercise, has many health benefits (Liu-Ambrose & Donaldson, 2009a). RT improves physical function (muscle mass and strength), reduces joint pain, and contributes to the prevention of a number of chronic disease including osteoporosis, sarcopenia, and diabetes (Kraemer, Ratamess, & French, 2002; Winnett & Carpinelli, 2001). RT is feasible even for those with limited aerobic capacity and joint mobility (Liu-Ambrose et al., 2012). Emerging evidence suggests that the benefits of RT apply not only to physical health but also to

cognitive health. In 2003, a meta-analysis indicated that aerobic exercise interventions that were paired with RT were associated with greater cognitive benefits than those that were not (Colcombe & Kramer, 2003). The next two sections will discuss the evidence supporting chronic and acute RT as strategies to improve cognitive function.

2.3.1 Chronic Exercise Interventions and Cognitive Function

Chronic RT interventions (only studies at least 24 weeks in duration will be discussed) establish that RT can improve cognitive function (Cassilhas et al., 2007; Liu-Ambrose & Donaldson, 2009). To date, most longitudinal studies of RT have focused on older adults. Nevertheless, these RCTs offer some evidence of cognitive benefits and insights into how these benefits are altered by intensity, frequency, duration, and the cognitive task measured (Cassilhas et al., 2007; Liu-Ambrose et al., 2012; Liu-ambrose et al., 2010; Nagamatsu, Handy, Hsu, Voss, & Liu-Ambrose, 2012; Tsai, Wang, Pan, & Chen, 2015).

In contrast to aerobic exercise, there is less evidence that the intensity of RT alters training effects on cognitive function. One study of chronic RT showed similar benefits to memory and verbal concept formation whether moderate (50-60% 1-repeition maximum (RM)) or high (>80%+ 1RM) intensity RT was performed (Cassilhas et al., 2007). Other longitudinal studies did not investigate RT intensity as a modifier of cognitive effects and were not as specific with their intensity designation. However, these studies also suggest RT of either moderate or high

intensity improves executive function (Liu-ambrose et al., 2010; Liu-Ambrose et al., 2012; Nagamatsu et al., 2012; Tsai et al., 2015).

There is some evidence that frequency of training sessions alters the effects of RT on cognitive and brain function (Liu-ambrose et al., 2010; Liu-Ambrose et al., 2012). One study of 12 months of RT once or twice a week examined cognitive change in a series of behavioural tasks as well as functional brain activity (using functional magnetic resonance imaging, fMRI) paired with an executive function task (modified Eriksen Flanker task) (Liu-ambrose et al., 2010; Liu-Ambrose et al., 2012). RT both once and twice a week improved cognitive function relative to a stretching and toning control group, though there was no difference in cognitive changes based on frequency of RT (Liu-ambrose et al., 2010). However, RT twice a week, when compared to training once a week and with the control condition, elicited greater improvements in a modified Eriksen Flanker task paired with fMRI. Participants showed corresponding functional changes of hemodynamic activity in regions of the cortex associated with executive function (Liu-Ambrose et al., 2012). Other studies have found significant cognitive benefits associated with RT either twice or three times a week (Cassilhas et al., 2007; Nagamatsu et al., 2012; Tsai et al., 2015).

A recent RT intervention (52 weeks in duration) was the first to assess neuroelectric measures (Tsai et al., 2015). Participants, split into exercise and control groups, performed an oddball task paradigm before and after the 52-week RT intervention. The P3 waveforms associated with the oddball task were evaluated. Compared with the control group, the exercise group exhibited faster response times and increased P3 amplitudes post-intervention. Results concluded that RT is a

promising strategy to prevent the attenuation of executive function older adults (Tsai et al., 2015).

The research to date suggests several aspects of cognitive function may be sensitive to chronic RT, with the most consistent effects to attention and executive functions. In one study, RT 3 times per week at either moderate or high intensity improved measures of executive function (verbal reasoning and working memory), short-term memory, and attention (Cassilhas et al., 2007). Three other studies found that RT once, twice, or three times weekly improved attention and executive function (inhibitory control or interference) (Liu-Ambrose et al., 2012; Liu-ambrose et al., 2010; Nagamatsu et al., 2012; Tsai et al., 2015).

No published study has previously studied the influence of a LL movement intervention as a control for either aerobic or resistance exercise. However, a number of studies have examined the influence of light intensity movement interventions on cognitive function (Ballesteros, Kraft, Santana, & Tziraki, 2015; Mortimer et al., 2012; Voelcker-Rehage, Godde, & Staudinger, 2011). More specifically, the effects of dance and movement interventions have shown improvements in cognitive facets such as response time for various executive function based tasks, including working memory (Ballesteros et al., 2015). A recent meta-analysis suggests that a weekly movement intervention, such as Tai Chi, may improve cognitive function through several neuropsychological measures (such as the Mattis Dementia attention score and trail making task) compared to other walking and social interaction interventions (Kelly et al., 2014; Mortimer et al., 2012).

In summary, there appears to be cognitive benefits to chronic RT. These cognitive effects were observed primarily in attention and executive function domains. Whether effects vary by dose is less clear. Of note, different durations of RT interventions have been used (between 6-12 months). However, no study specifically compared interventions of different durations.

2.3.2 Acute Exercise Interventions and Cognitive Function

Emerging research suggests that an acute session of RT can positively impact cognitive function, similar to aerobic exercise. To date, there are 8 studies of the acute effects of full-body RT on cognitive function (Chang, Tsai, Huang, Wang, & Chu, 2014; Chang et al., 2011; Chang, Ku, Tomporowski, Chen, & Huang, 2012; Chang & Etnier, 2009a, 2009b; Harveson et al., 2016; Pontifex, Hillman, Fernhall, Thompson, & Valentini, 2009; Tsai et al., 2014b), which have not yet been summarized in a review and arise primarily from a single research group. This section will review evidence regarding the effect of acute RT on cognitive function. The potential for selective effects by intensity and cognitive domain will be discussed. In general, RT sessions were 30 to 60min in duration, though duration has not been explored as a moderator of effects.

To our knowledge, the first study that assessed the cognitive effects of a single bout of RT was by Pontifex et al. (2009) but they did not find a significant effect on cognitive function. The study enrolled young healthy adults who each completed three experimental sessions: 1) 30min of moderate intensity aerobic training; 2) 30min of RT; and 3) 30min of seated rest. For the RT session, participants performed

3 sets of 8-12 repetitions at 80% 1-RM for seven different exercises. Cognitive function was measured with the Sternberg Task —which captures the working memory component of executive function—before, immediately after, and 30min after exercise. There were significant positive effects on cognitive function after aerobic exercise but not RT.

The next two studies of acute RT emerged from the same research group (Chang & Etnier, 2009a, 2009b). Both studies examined the effects of 30min of RT (2 sets of 10 repetitions for 6 exercises) in comparison to a rest condition. However, the first examined high intensity RT (at 75% of their estimated 1-RM,) among middle-aged adults (average age 49 years) and the latter examined three different intensities (low at 40% of 10-RM, moderate at 70% of 10-RM, and high at 100% of 10-RM) among healthy young adults (average age 25 years). (Of note for comparisons, 75% of 1-RM is approximately equal to 100% of 10-RM). Both studies assessed cognitive change using the Stroop task (a complex inhibitory choice reaction task that is used in this study and is discussed in more detail in Section 4.1) and either the Trail Making Task (former) or the Paced Auditory Serial Addition Task (latter), which can be used to assess information processing speed, executive function, and attention. For the Stroop Task, both studies found significant positive results for information processing conditions, with a linear-dose response between exercise intensity and improvement in easier task conditions in the latter study. For the executive function (response inhibition) condition (Stroop Word Color), effects in the first study (of high intensity among middle-aged adults) only neared significance ($p=0.09$) whereas the latter study (three intensities among young adults) found a quadratic dose-effect

relationship (often referred to as an inverted-U relationship) with the greatest positive effects induced by moderate intensity (70% of 10-RM) acute RT. The latter study also found a positive quadratic effect of acute RT on performance of the PASAT with maximum benefits again following moderate intensity RT. The differences in results between studies may be due to the age of participants (middle-aged versus young adults) or due to the intensities examined (high intensity versus optimal effects at moderate intensity). Supporting the latter possibility, the first study by Pontifex et al. (2009) that did not find significant positive effects also used high intensity RT (80% of 1-RM), which suggests that moderate intensity but not high intensity RT may elicit positive effects on cognitive function (Chang & Etnier, 2009a, 2009b).

From 2011 until the present, the same research group has published an additional three studies further probing the effects of acute RT on cognitive function (Chang et al., 2014; Chang et al., 2011, 2012). The studies all used sedentary middle-aged adults with cognitive assessments before and after exercise (once HR returned to resting levels) or rest. With slightly different experimental designs, all three studies again demonstrated and extended the evidence of an inverted-U relationship between RT intensity and cognitive function. However, these studies used a Tower of London (TOL) task and both low (40% of 10-RM) and moderate (70% of 10-RM) elicited similar, maximal changes (Chang et al., 2011, 2012). The TOL task is used to assess goal planning, another aspect of executive function. This further suggests that moderate intensity RT has more positive effect on executive function compared to rest or high intensity RT (Chang et al., 2011, 2012). When considered together, it

seems that moderate intensity RT (70% of 10-RM) elicits positive cognitive effects across several cognitive tests (Stroop Task, TOL, Paced Auditory Serial Addition Task) and across several cognitive domains (information processing speed, attention, and several elements of executive function: working memory, response inhibition, and goal planning) (Chang et al., 2011, 2012; Chang & Etnier, 2009a, 2009b). A subsequent study by this research group among late middle-aged adults indicated that the magnitude of effects was, however, greater for tasks requiring executive function (inhibitory control) compared to those requiring information processing only (Chang et al., 2014). The positive results in these three studies of middle-aged (or late middle-aged) adults also suggest that the positive effects of acute RT may span both young and middle-aged populations (Chang et al., 2014; Chang et al., 2011, 2012; Chang & Etnier, 2009a, 2009b).

A study of acute RT in 2014 was the first to pair EEG with cognitive tests. In this study, they examined the effects of acute RT among healthy young adults on the inhibitory control component of executive function using a modified Erickson Flanker task paired with EEG (Tsai et al., 2014b). Contrary to previous results, significant positive effects were observed after both moderate (50% 1-RM) and high (80% 1-RM) intensity RT, measured once participants' HR and body temperature neared pre-exercise levels. The reason for the difference in the effect of high intensity RT on cognitive function between this and prior studies is unclear but may be due to the difference in total training volume and rest periods. In the study by Pontifex et al. (2009), participants performed three sets of 8 to 12 repetitions for 7 exercises with only 60 seconds rest between sets and observed no significant effects on cognitive

function. The latter study by Tsai et al. (2014b) only performed two sets of 10 repetitions for 6 exercises with 90 seconds rest between sets and found positive changes in executive function. The latter study had approximately 30% fewer reps with greater rest than the prior study. As a result, participants were likely less fatigued at the completion of the session despite similar intensities, possibly contributing to the positive effects observed (Tsai et al. 2014b). Alternatively, it may be that the executive function (inhibitory control) task used by Tsai et al. (2014b) may be more sensitive to acute RT than the working memory task used by Pontifex et al. (2009).

The study by Tsai et al. (2014) was also the first to observe significant positive changes to EEG measures of cognitive processing concurrent to an executive function task. Both moderate and high intensity RT elicited significantly higher P3 amplitudes when compared to control, which suggests that there are more attentional resources dedicated to the task (Tsai et al., 2014b). Of note, the effect sizes observed for the P3 changes (0.7-0.8) was approximately double that observed for behavioural measures (0.3-0.5), making the P3 a more sensitive measure of the cognitive effects of exercise compared to behavioural measures.

The most recent study of RT was the first to use a youth sample. The research mimicked the design of Pontifex et al (2009), by comparing 30min sessions of moderate aerobic exercise, moderate RT, and a non-exercise intervention control in a repeated measures design (Harveson et al., 2016). Of note, there was no assessment of maximum fitness or strength, which may have led to inaccurate exercise prescriptions. Stroop task performance improved after both aerobic and RT

compared to the control condition. In addition, exploratory analyses suggested that boys experienced greater improvements in cognitive function after all interventions compared to girls. These results suggest that gender may modify the influence of acute RT on cognitive function (Harveson et al., 2016).

The influence of an acute LL movement intervention has yet to be examined. Although chronic literature suggests movement-based intervention as a possible method to improve cognitive function, the effects of a single session are completely unknown. To the best of our knowledge, the present study is the first to implement a low intensity RT-based intervention (LL) to control for the movements of the RT session.

In summary, evidence to date suggests that moderate and possibly low and high intensity acute RT can improve cognitive function across several domains, with the greatest effects on executive function (Chang et al., 2014; Chang et al., 2011, 2012; Chang & Etnier, 2009b, Harveson et al., 2016). The influence of intensity may interact with the total volume of work and rest time to influence cognitive function but needs further investigation. Results from one study suggest that EEG data (P3 amplitude) is particularly sensitive to RT effects (Tsai et al., 2014b). However, whether behavioural and neurological effects last beyond the immediate post-exercise period requires further research. Assessing cognitive function, and particularly executive function paired with EEG, for a prolonged period after a RT session will help to determine the time-course of effects.

Section 3. Potential Mechanisms

This section will discuss the potential mechanisms underlying the cognitive effects of RT, including the contributions of insulin growth factor (IGF-1) and brain derived neurotrophic factor (BDNF), cortisol, and catecholamines. It is likely that a combination of these mechanisms contribute to the cognitive response following an acute bout of RT.

3.1 Growth and Neurotrophic Factors

IGF-1 and BDNF are thought to be the key mechanism underlying the cognitive response to long-term aerobic exercise and RT (Cotman, Berchtold, & Christie, 2007; Cotman & Berchtold, 2002). However, there is also evidence to suggest that these factors may also contribute to the acute cognitive response to RT through the stimulation of excitatory post-synaptic potentials (EPSP), increasing the likelihood of neuronal action potential firings and inducing short-term plasticity (Cotman & Berchtold, 2002; Fernandez & Torres-Alemán, 2012).

3.1.1 IGF-1

IGF-1 is a peptide hormone that is primarily produced by hepatocytes in the liver. In addition to roles in metabolism and tissue remodeling, IGF-1 is involved in functions of the brain, including neuronal plasticity, learning, and development of glial structure across the lifespan (Cassilhas, Tufik, & de Mello, 2015; Fernandez & Torres-Alemán, 2012; Huang, Larsen, Ried-Larsen, Møller, & Andersen, 2014). In adulthood, there is a low expression of IGF-1 mRNA and a wide expression of IGF

receptors in the brain (Valentino, Ocrant, & Rosenfeld, 1990), which suggests that IGF-1 is primarily produced peripherally and crosses the blood brain barrier to act in the brain (Fernandez & Torres-Alemán, 2012).

Many studies have examined IGF-1 following RT, though the results vary. Some studies indicate that IGF-1 increases after RT whereas others indicate no change (Kraemer et al., 1991; Kraemer & Ratamess, 2005; Kraemer et al., 1990; Rojas Vega, Knicker, Hollmann, Bloch, & Strüder, 2010) . It is possible the IGF-1 only increases after growth hormone synthesis and release from the liver has occurred, which would occur minutes or hours after exercise (Kraemer & Ratamess, 2005; Tsai et al., 2014b). One recent study examined acute IGF-1 release in relation to cognitive function after exercise and demonstrated an increase in serum IGF-1 after RT of varying intensities, which was associated with the observed improvement in executive function (Tsai et al., 2014b).

Though the evidence is limited to date, it is reasonable to propose that IGF-1 after RT may be linked to improvements in cognitive function. Peripheral IGF-1 can cross the blood brain barrier as soon as 15 to 30min after exercise (Cotman & Berchtold, 2002; Fernandez & Torres-Alemán, 2012). IGF-1 can bind to IGF-1 receptors on the endothelium of brain blood vessels to pass through via a transcytosis mechanism. Astrocytes can then translocate IGF-1 to neighboring neurons where they bind to IGF-1 receptors located on pre- and post-synaptic neurons (Fernandez & Torres-Alemán, 2012). Binding of IGF-1 modulates the excitability of central neurons by inducing the release of glutamate, an excitatory neurotransmitter, from the pre-synaptic cell. The increased glutamate can then bind

to its post-synaptic N-methyl-D-aspartic (NMDA) and α-amino-3-hydroxy-5-methyl-4-isoxazolepropionic acid receptor (AMPA) receptors, which causes an influx of positive sodium and calcium ions into the post-synaptic cell, creating an excitatory post-synaptic potential (EPSP) and making the neuron more likely to fire (Cotman & Berchtold, 2002; Molteni, Ying, & Gómez-Pinilla, 2002; Hall, 1998). Although the localization of effects is not well understood, it is reasonable to expect that IGF-1 release helps increase the firing rate of neurons in areas associated with cognitive function and, specifically, executive function (such as the dorsal lateral prefrontal cortex, DLPFC).

3.1.2 BDNF

BDNF is the most active member of the protein based neurotrophin family. Neurotrophins are present both centrally and peripherally and are primarily responsible for stimulating and controlling neuronal and synaptic growth and differentiation (Cotman & Berchtold, 2002, 2007). It is now generally accepted that BDNF is necessary for neurogenesis and associated changes in learning and cognitive function after periods of aerobic training (Cotman & Berchtold, 2007;Cotman et al., 2007; Kramer & Erickson, 2007). However, the role of BDNF in the cognitive response to chronic RT interventions is less clear. Only a minority of RT interventions show a central or peripheral increase in BDNF (Cassilhas et al., 2012; Huang et al., 2014; Walsh et al., 2015).

It is thought that peripheral IGF-1 may cross the blood brain barrier and act as an upstream mediator to stimulate an increase of BDNF in the brain (Cotman et al.,

2007; Pan, Banks, Fasold, Bluth, & Kastin, 1998). As a result, any increase in IGF-1 due to acute RT may stimulate BDNF levels in the brain. A resulting increase in BDNF could alter neuronal activity and cognitive function in similar mechanisms to IGF-1. Binding of BDNF to tropomyosin receptor kinase B (TrkB) receptors promotes the release of glutamate and alters post-synaptic NMDA sensitivity. As discussed earlier, the release of glutamate and its binding to NMDA receptors causes an influx of positive ions and induces EPSPs, making neurons more likely to fire (Cotman et al., 2007; Jovanovic, Czernik, Fienberg, Greengard, & Sihra, 2000; Levine, Dreyfus, Black, & Plummer, 1995). Although most research has focused on acute BDNF action in the hippocampus, NMDA and AMPA receptors are also present in the frontal cortex so it is likely that cognitive functions associated with this frontal cortex (i.e. executive function) would also be enhanced by BDNF signaling (Cotman & Berchtold, 2007; Jovanovic et al., 2000; Levine et al., 1995).

3.2 Cortisol

Cortisol is a glucocorticoid hormone released by the adrenal gland in response to arousal or stress. Its primary purpose is to regulate the release of other corticosteroids as part of the hypothalamic-pituitary-adreno-cortical axis (Henckens, van Wingen, Joëls, & Fernández, 2012; Lambourne & Tomporowski, 2010). For example, rising levels of cortisol are generally associated with decreased levels of adrenocorticotrophin hormone (ACTH) during stressful events (Henckens et al., 2012; Lambourne & Tomporowski, 2010). Exercise, including aerobic and RT, is an example of a stressor (McMorris, Collard, Corbett, Dicks, & Swain, 2008). RT is

generally accepted to be a powerful stimulator of the cortisol levels due to physiological stress, but the degree of stimulation depends on the intensity, sets and repetitions, and rest during the RT session (Kraemer & Ratamess, 2005). Although the one prior study examining the effects of RT on the P3 found that cortisol decreased immediately after and 20min after both moderate and high intensity RT sessions(Tsai et al., 2014b). These findings are inconsistent with most studies of RT and cortisol. A recent review suggested that cortisol levels increase or remain the same after a session of RT (O'Leary & Hackney, 2014). Different effects by gender may partially explain variability of results, where one recent study found that men experienced increases in cortisol for up to 30min after RT whereas women showed no change (Benini, Prado Nunes, Orsatti, Barcelos, & Orsatti, 2015).

Regulation of glutamate release by adrenal steroids including cortisol may contribute to synaptic plasticity (McEwen, 2007). Central cortisol binds to various mineralcorticoid and glucocorticoid receptors causing upstream neurochemical interactions that lead to the pre-synaptic release of glutamate. The increase in excitatory neurotransmitters in the synapse, as discussed previously with IGF-1 and BDNF, will promote the influx of positive ions through post-synaptic AMPA and NMDA receptors (McEwen, 2007). This influx will induce depolarization of the post-synaptic neuron and, thus, lead to EPSPs which make neurons more likely to fire action potentials (McEwen, 2007).

3.3 Catecholamines

Catecholamines (including norepinephrine, epinephrine, dopamine, and serotonin) are released by the adrenal gland peripherally and by the neuroglia centrally in response to stress and arousal (McMorris, Collard, Corbett, Dicks, & Swain, 2008; O'Leary & Hackney, 2014; McMorris et al., 2008). Norepinephrine (NE), epinephrine (E), and dopamine (DA), which are catecholamine neurotransmitters, are understood to be augmented during and after times of stress and arousal (Heijnen, Hommel, Kibele, & Colzato, 2016; Kraemer & Ratamess, 2005), including exercise. Some attribute acute improvements in cognitive function after aerobic exercise to increases in catecholamines (Davranche & McMorris, 2009; Lambourne & Tomporowski, 2010; McMorris et al., 2008; McMorris, Tomporowski, & Audiffen, 2009). The changes in cognitive function due to stress and arousal are hypothesized to follow an inverted-U distribution, where moderate aerobic exercise, or stress in general, will result in the greatest improvement on cognitive function. The relative ineffectiveness of lower or higher intensity aerobic exercise may be due to limited neural activation and neural noise, respectively, resulting in fewer positive effects on cognitive function (Henckens, van Wingen, Joëls, & Fernández, 2012; Lambourne & Tomporowski, 2010; McMorris, Sproule, Turner, & Hale, 2011).

Peripheral serum and plasma concentrations of NE and E also increase after RT, with magnitude of the release dependent on intensity and rest intervals (Klisczewicz et al., 2016; Kraemer & Ratamess, 2005; Kraemer et al., 2013). One study suggested NE and E levels in the brain are positively correlated with peripheral E after aerobic exercise (Pagliari & Peyrin, 1995), which may also be the case after

RT. Possible increases in NE and E would likely promote the release of pre-synaptic glutamate and increase the activity of NMDA receptors. This would increase the influx of positive calcium ions into the post-synaptic cell and induce EPSPs (McEwen, 2007). Similarly to the previously discussed mechanisms, the resultant increase in the likelihood of neuronal firing could improve cognitive function (Luck, 2005; McEwen, 2007).

Section 4. Measurement of Executive Function

Evidence from both acute and chronic RT studies suggest that exercise may preferentially benefit executive function relative to other cognitive domains. This section will discuss the concept of executive function and introduce the measures of executive function that will be used in this thesis.

Executive function is a general term used to describe the cognitive processes that guide goal-directed behaviour through decision-making and attention to perform appropriate actions (Etnier & Chang, 2009; Purves et al., 2013). Executive function encompasses cognitive activities such as planning, scheduling, working memory, reasoning, and inhibitory control that require evaluating stimuli in the environment and processing the information presented (Dishman et al., 2006; Purves et al., 2013). Cognitive processes underlying executive function are thought to arise primarily in the frontal lobe (Etnier & Chang, 2009). The purpose of this study is to determine the impact acute RT has on one component of executive function: inhibitory control.

Inhibitory control is a component of executive function that involves the suppression or rejection of relevant stimuli to achieve a goal-related behavior (Hommel et al., 2002; Purves et al., 2013). Inhibitory control is a general term used to encompass response inhibition and interference control. Response inhibition (internal inhibition) refers to the ability to suppress automatic responses while interference control (external inhibition) refers to the ability to ignore irrelevant external stimuli (Corbetta & Shulman, 2002). The response inhibition aspect of inhibitory control performance will be assessed through a behavioural task paired with measures of cortical processing (EEG) before, 10, 20, 30, and 40min after the intervention (RT, LL, and rest). Prior literature has demonstrated that inhibitory control is sensitive to both aerobic exercise and RT using both behavioural and neuroelectric measures (Kamijo et al., 2007; Kamijo et al., 2004; Tsai et al., 2014b). In this study, it was hypothesized that inhibitory control will be enhanced after a session of moderate intensity RT through cognitive assessments up to 50 min post-intervention.

4.1 Behavioural Measures of Executive Function

Behavioural measures of executive function are highly variable and can range from easily implemented clinical tasks to highly sensitive speeded tasks. Speeded tasks, quantified by reaction time or response time and sometimes other parameters, are often considered to be particularly sensitive to change. A computer-delivered modified Stroop task was used to quantify change in inhibitory control in this study. Accuracy and response time was measured. The behavioural task was paired with

EEG (explained in section 4.2) to better understand changes in cortical processing that may contribute to behavioural change.

Stroop Task

A modified Stroop (or colour naming) task was used to assess response inhibition in this study (Stroop, 1935). This measure was sensitive to exercise effects in prior studies, specifically acute RT (Chang et al., 2014; Chang & Etnier, 2009b, Harveson et al., 2016). In this task, the person must inhibit the habitual response of reading the word stimulus and must respond appropriately to the colour characteristic of the stimulus (Stroop, 1935). Participants were presented a stimulus that is a word that is the name of a colour. This word may be presented either in the same colour that the word denotes (congruent) or a different colour (incongruent). More specific details are explained in the methods (section 7.4.2).

4.2 Electroencephalography Measures

EEG is a method to graphically view voltage signals created by cerebral neurons (Olejniczak, 2006). EEG can be analyzed in many ways to assess cognitive processing, but this thesis will focus on ERPs and, specifically, the P3 waveform. An ERP is a change in electrical potential recorded at the scalp that is time-locked to stimulus presentation (Herrmann & Knight, 2001; Luck, 2005). The P3 ERP evoked by the modified Stroop Task will be examined. The P3 during the modified Stroop task would be more sensitive to exercise-related cognitive effects than behavioural measures alone (Donchin, 1981; Herrmann & Knight, 2001, Tsai et al., 2014b).

The P3 is defined as a positive waveform that peaks between 350 and 750ms after the presentation of a task relevant stimulus. The P3 waveform reflects the context and memory updating process that occurs each time new sensory information is presented and a response is selected (Luck, 2005). The amplitude of the waveform is generally interpreted as the amount of attentional resources dedicated to the stimulus, where P3 amplitudes generally increase as stimulus probability decreases or difficulty increases (Hillman et al., 2003; Luck, 2005). While P3 latency is generally interpreted as the time for stimulus assessment, it is not always associated with the time required to select and execute a behavioural response (Herrmann & Knight, 2001; Luck, 2005). An indication of improved cortical processing during an executive function task would be indicated by an increased P3 amplitude, showing that a larger portion of the finite attentional resources have been dedicated to the task specific stimulus, or by decreased P3 latency, showing faster speed of stimulus evaluation (Donchin, 1981; Luck, 2005).

Section 5. Study Rationale

Evidence suggests that physical activity may be a simple means to maintain and improve cognitive and brain function (Angevaren et al, 2008; Cotman & Berchtold, 2002; Forbes et al., 2013; Kramer & Erickson, 2007). RT, a common form of exercise, is accessible to populations with limited mobility and can improve functional abilities whilst being known to prevent diseases such as osteoporosis and sarcopenia (Kraemer et al., 2002; Liu-Ambrose & Donaldson, 2009b). Emerging evidence indicates that acute bouts of RT can elicit benefits to executive function and

especially inhibitory control (Chang et al., 2014; Tsai et al., 2014b). Most consistently, moderate intensity RT is associated with significant improvements in behavioural and electrophysiological measures of executive function immediately after exercise (Chang et al., 2011; Chang, Etnier, & Barella, 2009; Tsai et al., 2014b). However, the time-course of the cognitive effects after a moderate intensity RT session has yet to be explored. This thesis compared executive function performance (behavioural and electrophysiological measures) before, 10, 20, 30, and 40min following a moderate (70% 10-RM) bout of RT among young healthy adults. This thesis is also the first to compare the acute cognitive effects of RT compared to LL movement. These results provide insight regarding the relative contribution of movement and physical exertion to the cognitive effects of RT.

Section 6. Objectives and Hypotheses

Objectives

1) To compare the change in cortical processing (P3 amplitude, latency) during a modified Stroop cognitive task from before to after a 30minute session of moderate intensity RT, LL movement, and rest.
2) To characterize the time-course of the effects to cortical processing (P3 amplitude and latency) and compare the effects at four time points: 10, 20, 30, and 40min after a session of moderate intensity RT, LL movement, or rest.
3) To compare the change in response time and accuracy during a modified Stroop cognitive task from before to after a 30min session of either moderate intensity RT, LL movement, or rest.

4) To characterize the time-course of the effects to response time and accuracy and compare the effects at four time points: 10, 20, 30, and 40min after a session of moderate intensity RT, LL movement, or rest.

Hypotheses

1) There will be an improvement in the cortical processing underlying inhibitory control (as shown through increased amplitude and decreased latency of the P3 waveform during performance of the modified Stroop task) after 30min of moderate intensity RT and the improvement will be greater than after a LL movement, or rest session.
2) There will be a decrease in response time (during the modified Stroop task) after 30min of moderate intensity RT and the decrease will be greater than after a LL movement or rest session. There will be no changes in accuracy after the moderate intensity RT, LL movement, or rest sessions.
3) Significant improvements (as stated in hypothesis 1 and 2) will be observed 10min after the moderate intensity RT session and the improvements will continue to be present up to 40min post-intervention.

Section 7. Materials and Methods

7.1 Participants

Twenty-two young healthy adults (11 females; mean age±SD: 23±2.4years) were recruited for this study between January 8th and April 30th 2015. All participants were recruited from the University of Waterloo. Recruitment was performed through word of mouth and recruitment posters (see Appendix A). The full list of inclusion and exclusion criteria is included in Appendix B. In brief, participants were free of musculoskeletal disorders that would interfere with RT, had no concussions in the last year, and did not take any medications that would alter heart rate or blood pressure.

7.2 Sample Size

Sample size was based on the expected difference in the change in P3 amplitude from pre to immediately post-exercise between the RT and rest sessions. The one prior study of RT on P3 changes demonstrated an effect size 0.71 (Tsai et al., 2014b). We used this effect size along with an alpha of 0.05 and a beta of 0.8 to estimate a minimum sample size of 18. In order to allow for 20% loss due to dropout or data problems, 22 participants were recruited to the study.

7.3 Study Design

This study used a repeated measures experimental design. All participants attended three sessions over 5-weeks. The baseline session was the same for all

participants but the latter two sessions, the RT and LL sessions, were in randomized order. Participants performed all sessions at the same time of day (to minimize circadian rhythm effects) and on the same day of the week. Sessions were performed every other week in order to minimize task learning between sessions. All participants were asked to refrain from exercise and consumption of stimulants and depressants (e.g., caffeine, ephedrine, or tetrahydrocannabinol) on the days of testing. A diagram of the study design is provided in Appendix C.

7.3.1 Baseline Session

Participants began the baseline session by completing the consent form (Appendix D) and the Physical Activity Readiness Questionnaire Plus (PAR-Q+, Appendix E). Next, they reported demographic information and had height and weight measured (Appendix F). They then reported activity levels using the International Physical Activity Questionnaire (IPAQ, Appendix G). Lastly, participants completed a RT questionnaire probing the frequency, duration, and intensity of their most recent RT experiences (Appendix H).

After the questionnaires were complete, the EEG cap was set up, cap impedances were checked (details in Section 7.4.3), and the participant put on a heart rate monitor (Polar H1, 2013). The participants then completed a Simple Response Time task (details in section 7.4.2). The purpose of this task was to quantify changes in simple information processing and the corticospinal pathway, potentially influenced by the exercise intervention. After thorough instruction was

given, participants then practiced 24 trials of the modified Stroop task. After sufficient practice, participants completed the modified Stroop task (details in section 7.4.2) before 30min quiet sitting (rest). After the 30min rest, EEG impedances were checked then the participant performed the simple response time task and 24 practice trials of the modified Stroop task followed by the modified Stroop at 10, 20, 30, and 40min post-rest. One final simple response time task was performed after the last block of the modified Stroop task. EEG was recorded concurrently throughout all trials of the Stroop task to assess associated ERP (P3 waveform). HR was recorded throughout, and immediately after the rest period as well as at 30, and 50min post-rest.

Finally, participants proceeded to UW Fitness in the Lyle Hallman Institute, where each participant's 10-RM for 6 RT exercises was assessed (detailed in section 7.4.1). The six exercises were leg press, pull downs, hamstring curls, horizontal chest press, bicep curls, and tricep pushdown.

7.3.2 Exercise Sessions

Participants performed two separate exercise sessions, the RT session and the LL session, with similar session design in randomized order. First, the EEG cap was set up (details in Section 7.4.3) and the participant put on a heart rate monitor. Participants then completed the Simple Response Time task, followed by practice and testing blocks of the modified Stroop task with concurrent EEG monitoring (as per rest session). Participants then walked to UW Fitness to perform the 30min RT or

LL intervention. Participants were only informed which exercise session they were performing once they arrived at UW Fitness just before they started the intervention.

The exercise portion of both sessions started with a 5minute whole body warm-up. The warm up consisted of biking for 3.5 min at 150-200W (100rpm). They then performed 3 sets of alternating 10 jumping jacks and 10 band pull-aparts. After the warm up, participants performed two sets of ten repetitions for each of the 6 exercises with 60s of rest in between sets and 90s of rest between exercises. During the LL session, the participant performed the movements with the absolute lowest weight possible on the machines. During the moderate intensity RT session, the participant lifted weights corresponding to 70% of their 10-RM (identified during the baseline session), which elicited the greatest cognitive response in most prior studies (Chang et al., 2014; Chang et al., 2012; Chang et al., 2011). HR and rate of perceived exertion (RPE) were recorded after each set.

After each exercise intervention, the participant returned to the lab. EEG impedances were checked before the participants completed cognitive testing again with EEG monitoring, as per rest session, including the Simple Response Time task, 24 practice trials of the modified Stroop task, and testing blocks of the modified Stroop task at 10, 20, 30, and 40min post-intervention, followed by a final Simple response time task. Post-intervention HR was recorded once subjects returned to the lab and at 30, and 50min post-intervention.

7.4 Assessments

7.4.1 10-RM Assessment

This assessment was completed in accordance with the 10-RM testing procedure of the National Strength and Conditioning Association (NSCA, 2000), which includes 4 to 5 sets of each exercise at increasing weight. The 10-RM was identified as the maximal weight at which the participant could perform the exercise for no more than 10 repetitions. If a participant could not complete the full ten repetitions before fatigue, a repetition scheme calculator was used to estimate the 10-RM (Elite FTS, 2015). The participant rested 2-3 min between sets.

7.4.2 Behavioural Cognitive Tasks

Cognitive function was assessed using a modified Stroop Task with concurrent EEG and a simple response task. For all cognitive assessments, participants sat 185cm away from a 40-inch computer monitor. A response pad was placed on a table on their dominant side. The tasks were generated and delivered using Stim2 software. Participants were instructed to respond as quickly as possible to the stimulus in both tasks. Accuracy and response time were determined using Stim2 software. Trials with errors or with no registered response within the 1000ms window were considered incorrect. Tasks were performed in a dark room with dividers on both sides to reduce distraction and horizontal eye movement. Participants wore moldable earplugs and over-the-ear headphones to reduce auditory noise during the task.

Modified Stroop Task

A modified Stroop task was the main behavioural outcome. The Stroop Task is primarily a measure of response inhibition, one component of executive function. Participants were instructed to look at a small white fixation-cross presented in the middle of a black screen where the target stimuli appeared. Each stimulus consisted of a single word (red, blue, green, or yellow) in one of four colours (same colours as the words). Words were 5cm high and between 10 and 15cm wide and were presented in the middle of the screen. Participants had to determine whether the stimulus was congruent (word written in the colour that matches its meaning) or incongruent (word written in a different colour which does not match its meaning). Examples of congruent and incongruent trials are included in Appendix I. Participants pressed the button labeled '1' with their index finger for incongruent stimuli and the button labeled '2' with their middle finger for congruent stimuli.

The modified Stroop task had a congruent to incongruent ratio of 3:1. The congruent to incongruent ratio of 3:1 was chosen to increase the magnitude of the Stroop effect, where responses to incongruent trials are slower and less accurate (Bélanger, Belleville, & Gauthier, 2010; Lansbergen & Kenemans, 2008). Each stimulus was displayed for 150ms with a 1000ms response window. There was a 2000ms inter-trial duration. Three blocks of 100 stimuli were delivered prior to the intervention (RT, LL, or rest) and two blocks of 100 stimuli were delivered at 10, 20, 30, and 40min post-intervention. For consistency and to reduce practice effects, only the latter two blocks of the pre-intervention Stroop task were used in the behavioural analysis. The timing of the Stroop task stimulus was marked on EEG

recordings in order to generate ERPs. There was a 60s break between blocks and 120s break between time points. Participants were allowed to stand briefly between assessment time points.

Simple Response Time Task

The simple response time task was delivered pre, immediately upon return to the lab post-intervention, and 50min post-intervention (after all modified Stroop tasks were complete) to quantify changes in simple processing. Stimuli were presented on a white background. Participants were instructed to look at a small black fixation cross in the middle of the screen. The participants were instructed to press the button labeled '1' with their index finger as quickly as possible when a black circle (10 cm in diameter) appeared overtop of the fixation cross. Each testing block included 12 stimuli presented for 150ms each with a 1000ms response window. There was a 2000ms inter-trial duration.

7.4.3 EEG Setup

The EEG signal was recorded using a QuikCap (Compumedics Neuroscan, Charlotte, NC), secured with surgifix. EEG signal was collected at the Fz, F3, F4, Cz, C3, C4, Pz, P3, P4 and Oz electrodes arranged in the International 10-20 system (Appendix J). This electrode selection was chosen to represent the two sides and the four regions of the brain. Electrodes were also placed above and below the left eye and lateral to both eyes for the electrooculogram (EOG) to capture blinks and eye

movements to aid in artifact detection. Electrodes on the mastoids were collected as reference electrodes. The impedances for each electrode were less than 5 kΩ.

7.5 Analysis

7.5.1 EEG Analysis

EEG data was analyzed using the Curry Neuroimaging Suite 7.0.9 and 7.0.10SB software. The EEG signal was collected at a 500 Hz sampling rate and was digitally filtered with a high pass filter of 0.5 Hz and a low pass filter of 30 Hz. Each electrode was referenced to the mastoids. Epochs were extracted from 100ms prior to stimulus onset to 1000ms post-stimulus. Baseline correction to the 100ms pre-stimulus interval was performed.

Due to the high number of blinks, artifact rejection would have resulted in excessive data loss. Instead, a covariance regression reduction method was first run for each condition to subtract artifact contamination (± 75μV) (Moretti et al., 2003; Compumedics Neuroscan, 2015). Each epoch was then visually assessed for excessive noise and artifacts. If artifacts were still present within the P3 window, the epoch was rejected from the analysis. Trials with response errors were also rejected. The remaining trials were averaged. The P3 amplitude of the averaged epoch was defined as the most positive peak occurring 350 to 750ms after stimulus presentation, measured in microvolts (μV). Latency of the P3 was defined as the time in ms at which this maximal positive peak occurred. P3 information at both Pz and Fz was used for analyses.

7.5.2 Statistical Analysis

Statistical analysis was performed with SAS 9.4. Participant and exercise characteristics (IPAQ, RT questionnaire, HR, and RPE) were presented as mean and standard deviations or percent (n), as appropriate. Differences in exercise characteristics across sessions were determined using a mixed effects linear regression model. Behavioural (response times and accuracy) and EEG measures (P3 amplitude and latency) were visually inspected using individual participant plots to understand data distribution, within and between subject variability, and to visualize trends. Plots were also assessed for normality through histograms and probability plots and for homogeneity of variances with Mauchly's sphericity test. Due to significant violations of sphericity, a mixed regression analysis was used instead of Analysis of Variance (ANOVA) as it does not require homogeneity of variance. No violations of normality were observed.

Pre-intervention values were compared for all outcomes (P3 amplitude, P3 latency, Stroop and Simple response times and response accuracies). If there were no significant difference in pre-intervention values, absolute data was analyzed using a mixed effects linear regression model with factors for session (3-level: rest, LL and RT) and time (5-level: Pre, 10,20,30,40min post). If there were significant differences in pre-intervention values, data normalized to pre-intervention values, shown as a percent (ie. T2-T1/T1 x 100) were used. Separate analyses were conducted for congruent and incongruent stimuli of the Stroop task. Post hoc analyses were performed using Tukey's test, and values were shown as a mean ± standard error

(SE). A significance level of p= 0.05 was used for all analyses.

Section 8. Results

8.1 Participant Characteristics

Twenty-two participants were recruited to the study. Participants were an average age of 23.4 years (range: 20–30 years) and 50% were female. All participants completed the study and had data for behavioural outcomes. However, two participants (1 male, 1 female) had to be removed from analysis of EEG outcomes due to technical issues, leaving 20 people with complete data. Participant characteristics are displayed in **Table 1**, and 10-RM characteristics are displayed in **Table 2.**

8.2 Exercise Characteristics

Characteristics of participants during the exercise session are displayed in **Table 3**. During the interventions, the intensity (load) of exercise was significantly different between sessions ($F_{1,21}$=6703.79, p<0.0001), as expected. HR and RPE during the intervention were significantly different between sessions ($F_{2,42}$=451.81, p<0.0001 and $F_{1,21}$=497.92, p<0.0001, respectively) as were heart rates immediately, 30min, and 50min post-intervention ($F_{2,42}$=18.91, p<0.0001; $F_{2,42}$=7.10, p=0.0022 and $F_{2,42}$=3.82, p=0.030, respectively). Load, HR, and RPE were higher in the 70%RT session (p<0.041) compared to LL and rest sessions.

Table 1: Participant characteristics (n=22).

Characteristics	**Mean ± SD or % (n)**
Age (years)	23.4 ± 2.42
Sex (% females)	50.0% (11)
Education (years)	17.5 ± 1.50
Handedness (% right)	95.4% (21)
Resting HR (bpm)	68.2 ± 8.19
Glasses/contacts (%)	22.7% (5)
BMI (kg/ m^2)	24.1± 10.0
IPAQ (mets-min/wk)	3930.8 ± 3064.7
IPAQ High Fitness	68.2% (15)
Current RT (% yes)	80.0% (16)
Any RT experience (% yes)	91.0% (20)

Table 2: Participant 10-RM characteristics.

Exercise	**Male** Mean ± SD	**Female** Mean ± SD
Leg Press	418.6 ± 60.6	221.8 ± 67.8
Lat. Pull-down	138.6 ± 16.3	85.0 ± 21.9
Hamstring Curl	119.5 ± 15.7	77.5 ± 21.1
Vertical Chest Press	144.3 ± 35.4	70.9 ± 27.4
Bilateral Bicep Curl	93.3 ± 19.2	44.5 ± 20.4
Bilateral Tricep Extension	128.5 ± 17.4	71.4 ± 23.6

Table 3: Exercise characteristics by session.

Characteristic	Baseline	Loadless	Resistance Training	p-value
Percent of 10-RM	-	7.67 ± 4.0	70.0 ± 0.8	<0.0001
Intervention RPE	-	6.5 ± 0.9	13.7 ± 0.9	<0.0001
Pre-exercise HR	70.1 ± 7.8	71.6 ± 9.1	69.8 ± 7.9	0.38
Intervention HR	69.5 ± 10.0	91.6 ±12.4	119.7 ± 12.9	<0.0001
Immediately Post HR	70.7 ± 8.6	70.1 ± 9.1	77.6 ± 9.6	<0.0001
30min Post HR	71.2 ± 9.8	71.8 ± 10.5	76.3 ± 9.4	0.002
50min Post HR	71.5 ± 9.7	71.1 ± 9.1	75.0 ± 10.2	0.03

8.3 EEG

P3 Amplitude at Pz

The Stroop effect was confirmed through an effect of congruency ($F_{1,18}$=58.70, p<0.0001), where incongruent trials had a larger P3 amplitude than congruent trials. P3 amplitudes for congruent and incongruent conditions were analyzed separately.

The grand-average and individual P3 waveforms for pre-intervention in the 70%RT session are displayed in **Figure 1.** P3 amplitudes by session, congruency, and time are displayed in **Table 4.**

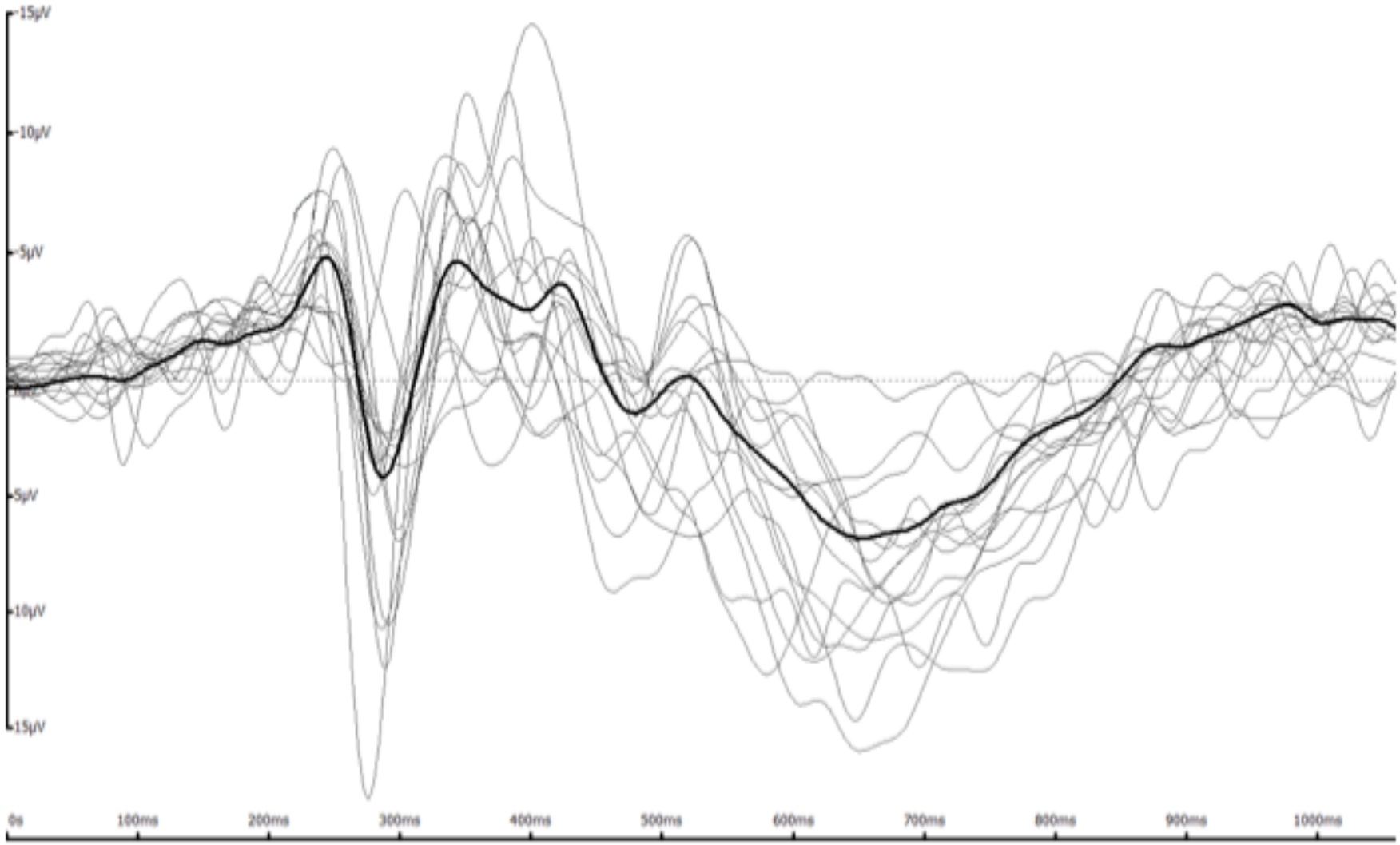

Figure 1: Grand averaged (bold, black line) and individual ERP (grey line) at Pz electrode pre-intervention during the RT session.

Table 4: P3 Amplitudes (μV) at Pz for incongruent and congruent trials by session, condition, and time.

Time	Rest	Loadless	Resistance Training
		Incongruent	
Pre	12.1 ± 0.7	12.9 ± 0.7	13.2 ± 0.7
10min Post	12.7 ± 0.7	13.6 ± 0.7	14.4 ±0.7
20min post	13.7 ± 0.8	14.7 ± 0.8	13.6 ± 0.8
30min post	14.4 ± 0.8	14.2 ± 0.8	14.6 ± 0.8
40min post	14.6 ± 0.9	14.4 ± 0.8	14.9 ± 0.9
		Congruent	
Pre	9.5 ± 0.6	9.3 ± 0.5	9.1 ± 0.6
10min Post	10.3 ± 0.6	9.8 ± 0.5	10.2 ± 0.7
20min post	10.3 ± 0.7	9.7 ± 0.6	9.9 ± 0.7
30min post	10.2 ± 0.6	9.7 ± 0.6	9.7 ± 0.7
40min post	10.6 ± 0.6	10.0 ± 0.5	9.9 ± 0.7

Incongruent

There was no significant difference in pre-intervention P3 amplitudes across sessions (p=0.12) so absolute data was used for analyses. Mixed effects regression analyses revealed a main effect of time ($F_{4,76}$=6.17, p=0.0002). Post-hoc analyses revealed that P3 amplitude was larger at 20min (14.0±0.6), 30min (14.4±0.6) and 40min (14.6±0.6) after the intervention compared to pre-intervention (12.7±0.5). There was also a significant session x time interaction ($F_{8,152}$=2.04, p=0.045). Post-

hoc results showed that P3 amplitude increased over time for the rest session ($p<0.041$) but not for the RT or LL sessions ($p>0.33$). In the rest session, P3 amplitude was larger at 30min (14.4±0.8) and 40min post-rest (14.6±0.9) than pre-rest (12.1±0.7). There was no significant effect of session ($p=0.76$). P3 amplitude by time and session at Pz incongruent trials is displayed in **Figure 2**.

Congruent

There was no significant difference in P3 amplitudes at pre-intervention across sessions ($p=0.71$) so absolute data were used for analyses. Mixed effects regression

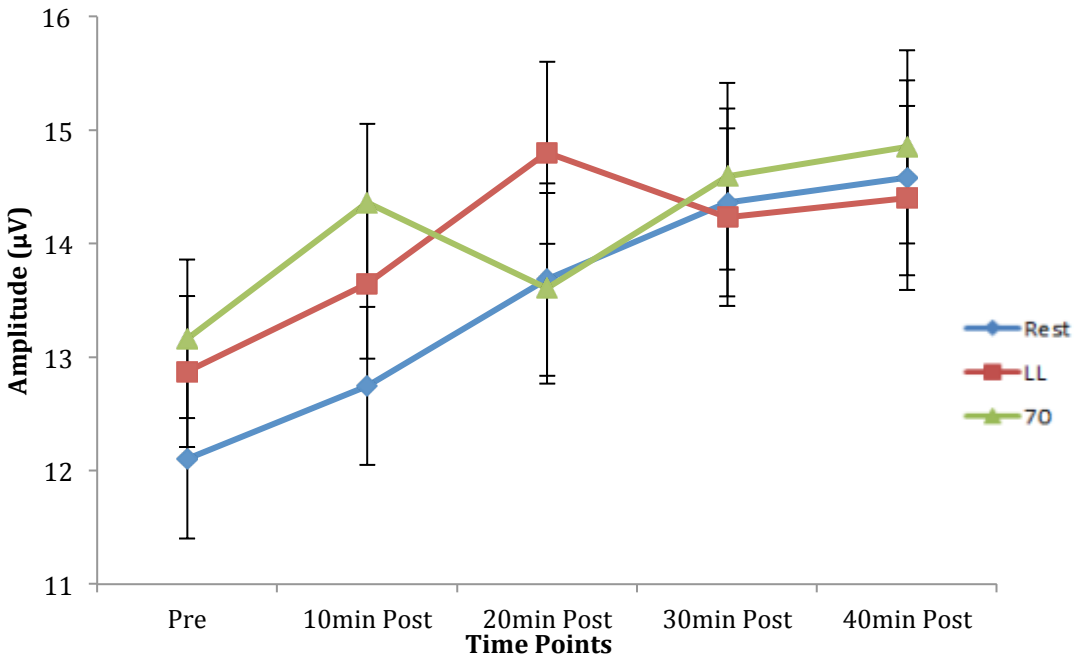

Figure 2: P3 incongruent amplitude at Pz by time and session. (mean±SE)
Note a main effect of time ($p=0.0002$), where P3 amplitude is larger at 20, 30 and 40min after exercise than pre-exercise for all interventions.

analyses revealed a main effect of time ($F_{4,76}$=4.53, p=0.0025). Post-hoc analyses indicated that P3 amplitude was larger at 10min (10.08±0.45) and 40min (10.19±0.44) after the intervention when compared to pre-intervention (9.30±0.40) (p<0.024). Effects of session and session x time were not statistically significant (p>0.37).

P3 Amplitude at Fz

Stroop effect was confirmed through an effect of congruency ($F_{1,18}$=34.40 p<0.0001), where incongruent trials showed a significantly higher amplitude than congruent trials. P3 amplitudes for congruent and incongruent conditions were analyzed separately.

Incongruent

There was no significant difference in P3 amplitudes at pre-intervention across sessions (p=0.30), so absolute data was used for analyses. Mixed effects regression analyses revealed no significant effect of session, time, or session x time (p>0.28).

Congruent

There was no significant difference in P3 amplitudes at pre-intervention across sessions (p=0.20), so absolute data was used for analyses. Mixed regression analyses revealed a significant effect of session x time ($F_{8,152}$=3.92, p=0.0003). However, post-hoc analyses did not identify a significant trend for time within any

individual session (p>0.10), only nearing significance within the rest session (p=0.10). Session and time effects were not statistically significant (p>0.38).

P3 Latency at Pz

The Stroop effect was confirmed through an effect of congruency ($F_{1,18}$=54.99, p<0.0001), where incongruent trials had a significantly longer latency than congruent trials. P3 latencies for congruent and incongruent conditions were analyzed separately. P3 latencies by session, congruency and time are displayed in **Table 5.**

Incongruent

There was no significant difference in P3 latencies at pre-intervention across sessions (p=0.41), so absolute data was used for analyses. Mixed effects regression analyses indicated a significant session x time interaction ($F_{8,152}$=2.13, p=0.036). However, post-hoc analyses did not identify a significant trend for time within any individual session (p>0.48). Session and time effects did not reach statistical significance (p>0.09). P3 latency by time and session for Pz incongruent trials is displayed in **Figure 3**.

Table 5: P3 latencies (ms) at Pz for incongruent and congruent trials by session, condition, and time.

Time	Rest	Loadless	Resistance Training
		Incongruent	
Pre	569.6 ± 16.8	575.4 ± 13.9	556.7 ± 16.5
10min Post	574.9 ± 17.8	565.4 ± 14.7	544.5 ±17.5
20min post	588.3 ± 15.3	553.7 ± 12.7	560.6 ± 15.1
30min post	555.2 ± 18.1	592.4 ± 15.0	548.9 ± 17.8
40min post	555.7 ± 19.3	565.0 ± 16.0	529.7 ± 19.0
		Congruent	
Pre	477.3 ± 22.1	474.3 ± 19.8	480.6 ± 19.1
10min Post	471.9 ± 19.0	482.3 ± 17.0	475.0 ± 16.4
20min post	466.0 ± 22.0	470.9 ± 19.7	479.8 ± 19.0
30min post	487.8 ± 20.1	466.3 ± 18.0	453.8 ± 17.3
40min post	481.6 ± 19.9	499.3 ± 17.9	481.2 ± 17.2

Congruent

There was no significant difference in P3 latencies at pre-intervention across sessions ($p=0.97$), so absolute data was used for analyses. Mixed effects regression analyses revealed no significant effects of session, time, or session x time ($p>0.45$).

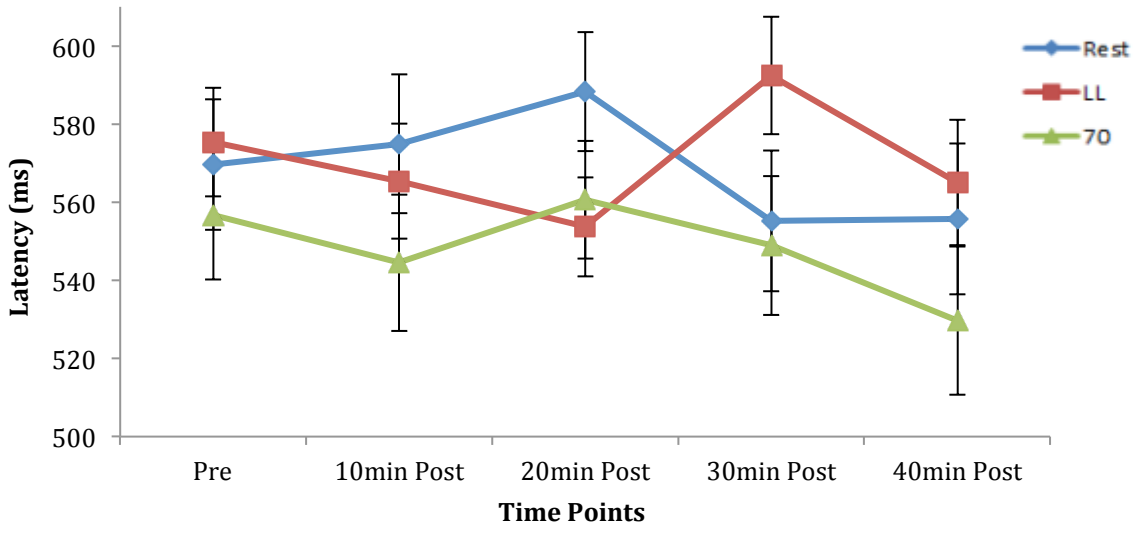

Figure 3: P3 incongruent latency at Pz by time and session. (mean±SE)

P3 Latency at Fz

The Stroop effect was confirmed through an effect of congruency ($F_{1,18}$=13.87, p=0.0014), where incongruent trials showed a significantly longer latency than congruent trials. P3 latencies for congruent and incongruent conditions were analyzed separately.

Incongruent

There was no significant difference in P3 latency at Pz at pre-intervention across sessions (p=0.20), so absolute data was used for analyses. Mixed regression analyses revealed no significant effects of session, time, or session x time (p>0.31).

Congruent

There was no significant difference in P3 latency at Fz at pre-intervention across sessions (p=0.10), so absolute data was used for analyses. Mixed regression analyses revealed no effects of session, time, or session x time (p>0.51).

8.4 Behavioural

Stroop Task Response Times

The Stroop effect was confirmed through an effect of congruency ($F_{1,20}$=376.68, p<0.0001), where incongruent trials showed a significantly longer response time latency than congruent trials. Response time latencies of congruent and incongruent trials were analyzed separately.

Stroop Response times by session, condition and time are displayed in **Table 6.**

Incongruent

There was a significant difference in Stroop response times at pre-intervention across sessions ($F_{2,42}$=8.77, p=0.0007), so data normalized to pre-intervention values were used for analyses. Mixed effects regression analyses of normalized data revealed a main effect of time ($F_{3,63}$=3.31, p=0.026). Post-hoc analyses revealed that response times dropped more compared to pre-intervention values at 10min post-intervention (-2.25% ±0.56) compared to 30min post-intervention (-0.67% ±0.72) (p=0.017). Session and session x time effects were not

significant (p>0.42). Response times by time and session for incongruent trials are displayed in **Figure 4**.

Table 6: Response Times (ms) for incongruent and congruent trials by session, condition, and time.

Time	Rest	Loadless	Resistance Training
		Incongruent	
Pre	633.0 ± 12.8	602.8 ± 11.9	594.8 ± 11.9
10min Post	616.9 ± 11.7	590.1 ± 10.8	580.0 ± 10.9
20min post	621.2 ± 12.2	599.9 ± 11.0	585.5 ± 11.0
30min post	621.2 ± 12.2	600.1 ± 11.4	593.7 ± 11.4
40min post	614.7 ± 10.6	599.7 ± 9.9	583.6 ± 9.9
		Congruent	
Pre	539.0 ± 13.1	502.4 ± 10.2	499.0 ± 11.3
10min Post	517.5 ± 11.9	490.1 ± 9.2	479.9 ± 10.2
20min post	521.1 ± 11.6	499.7 ± 9.0	485.3 ± 10.0
30min post	520.6 ± 11.9	503.2 ± 9.3	495.8 ± 10.3
40min post	512.7 ± 10.8	501.4 ± 8.4	488.2 ± 9.3

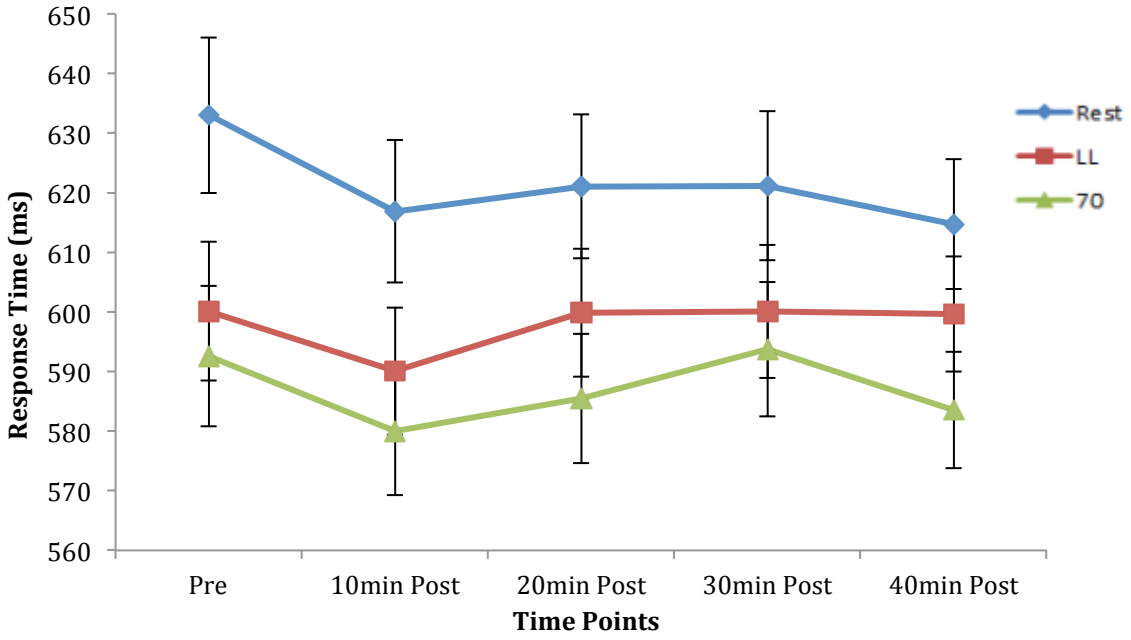

Figure 4: Stroop incongruent response times by time and session. (mean±SE) Note that pre-exercise response times were significantly different (p=0.0007) so normalized data was used in analyzes. Note also a main effect of time (p=0.026), where response times at 10min post-exercise are faster than pre-exercise and 30min post-exercise.

Congruent

There was a significant difference in Stroop response times at pre-intervention across sessions ($F_{2,42}$=10.77, p=0.0002), so data normalized to pre-intervention values were used for analyses. There was a main effect of time ($F_{3,63}$=5.07, p=0.0033). Post-hoc analyses showed that response times decreased more, relative to pre-intervention values, at 10min post-intervention (-3.93% ±0.70) compared to 30min post-intervention (-1.71% ±0.91) (p=0.0036). Effects of session and session x time did not reach statistical significance (p>0.11). Response time latency by time and session for congruent trials is displayed in **Figure 5**.

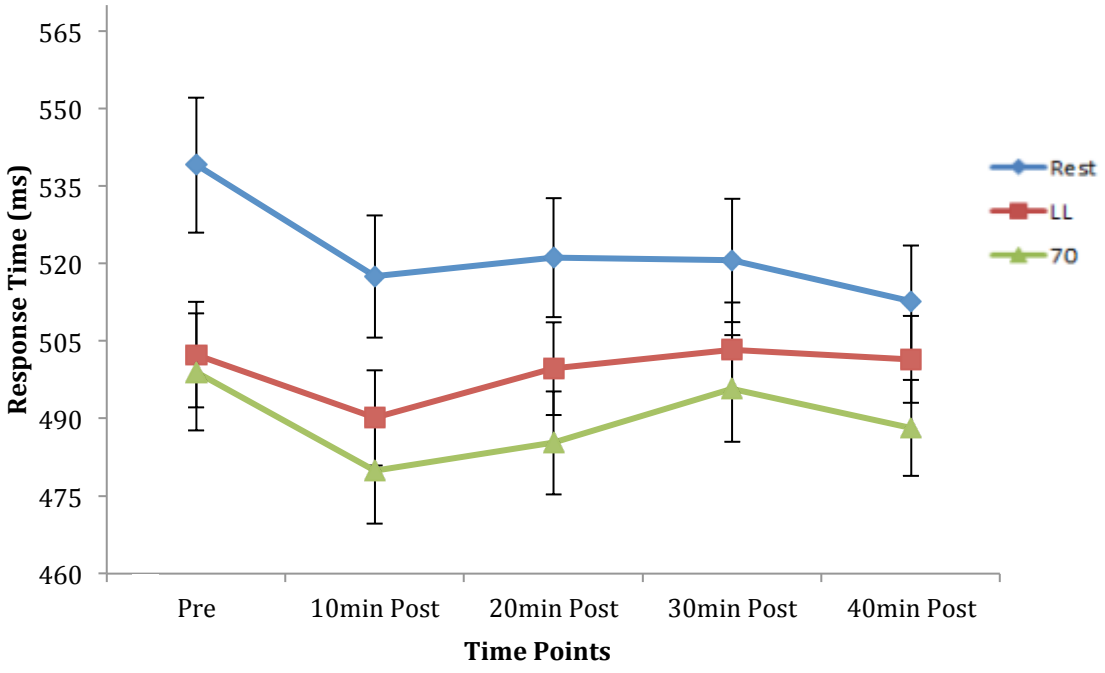

Figure 5: Stroop congruent response times by time and session. (mean±SE)
Note that pre-exercise response times were significantly different (p=0.0002) so normalized data was used for analyses. Note also a main effect of time (p=0.0033), where response times at 10min post-exercise are faster than pre-exercise and 30min post-exercise.

Stroop Accuracy

The Stroop effect was confirmed through an effect of congruency ($F_{1,20}$=71.47, p<0.0001), where incongruent trials showed a significantly lower accuracy than congruent trials. Accuracies of congruent and incongruent trials were analyzed separately. Accuracies of incongruent trials across sessions for all cognitive testing time points are displayed in **Table 7.**

Table 7: Accuracies (%) for incongruent and congruent trials by session, condition, and time.

Time	Rest	Loadless	Resistance Training
		Incongruent	
Pre	78.5 ± 2.9	84.4 ± 2.2	80.5 ± 2.7
10min Post	83.5 ± 2.4	84.0 ± 1.8	80.8 ± 2.3
20min post	81.9 ± 2.5	80.8 ± 1.9	78.6 ± 2.4
30min post	79.0 ± 2.5	79.0 ± 1.9	77.2 ± 2.4
40min post	77.8 ± 2.6	79.5 ± 2.0	78.5 ± 2.5
		Congruent	
Pre	93.6 ± 0.8	97.4 ± 0.5	96.9 ± 0.5
10min Post	96.7 ± 0.6	97.7 ± 0.4	97.2 ± 0.4
20min post	95.1 ± 0.7	96.5 ± 0.5	96.9 ± 0.4
30min post	95.5 ± 0.7	96.5 ± 0.5	97.0 ± 0.5
40min post	95.2 ± 0.7	96.7 ± 0.5	97.0 ± 0.5

Incongruent

There was no significant difference in Stroop accuracies at pre-intervention across sessions (p=0.14), so absolute data was used for analyses. Mixed effects regression analyses revealed a main effect of time ($F_{4,84}$=3.72, p=0.0078). Post-hoc analyses indicated that accuracy was significantly higher at 10min post-intervention (82.79±1.55) than at 30min (78.39±1.65) and 40min (78.63±1.70) post-intervention

(p<0.01). Effects of session and session x time were not significant (p>0.37). Accuracy by time and session for incongruent trials is displayed in **Figure 6**.

Congruent

There was a significant difference in Stroop accuracies at pre-intervention across sessions ($F_{2,42}$=11.67, p<0.0001), so normalized data was used for analyses. Mixed effects regression analyses of normalized data indicated a main effect of session ($F_{2,42}$=3.88, p=0.028). Post-hoc analyses revealed that participant accuracies increased more relative to pre-intervention after the rest intervention (2.4% ±1.0) compared to the LL intervention (-0.5% ±0.6) (p=0.02). There was also a main effect

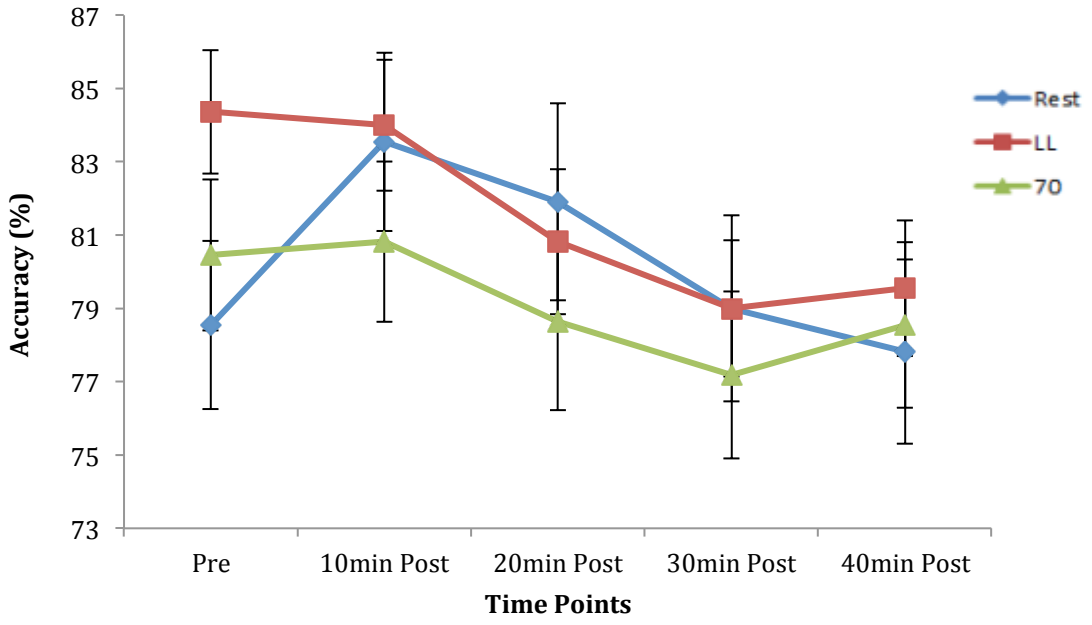

Figure 6: Stroop incongruent accuracies by time and session. (mean±SE)
Note a main effect of time (p=0.0078), where accuracies at 10min post-exercise are higher than 30 and 40min post-exercise for all sessions.

of time ($F_{3,63}$=3.16, p=0.031). Post-hoc analyses revealed that participant accuracies improved relative to pre-intervention values at 10min post-intervention (1.4% ±0.4) when compared to 40min post-intervention (0.5% ±0.5) (p=0.04). Effects of session x time were not statistically significant (p=0.84).

Simple Response Time Task Responses Times

There was no significant difference in simple response time at pre-intervention across sessions so absolute data was used for analyses. Mixed regression analyses revealed no effects of session, time, or session x time (p>0.15).

Section 9. Discussion

This study examined the effects of RT on executive function relative to LL movement or rest. Our data did not support the hypothesis that executive function, as characterized by P3 and response time during a modified Stroop task, is augmented after RT compared to after LL movement or rest. The reason for the lack of effects in contrast to some prior studies may be a shorter rest time, a simpler cognitive task, age of participants, fitness, RT experience of participants, and/or lack of randomization of the rest session.

In this study, there was no significant improvement in Stroop task performance after RT, through EEG or behavioural measures, in contrast with our hypotheses. Our results were also in contrast with most prior studies that observed significant improvements in various executive function tasks after RT compared to after rest (Chang et al., 2014; Chang & Etnier, 2009a, 2009b; Chang et al., 2011; Chang et al., 2012; Harveson et al., 2016; Tsai et al., 2014). Only one other study showed no effect of RT on cognitive function, similar to the present study (Pontifex et al., 2009).

Evidence suggests that the greatest effects of RT on cognitive function occur after moderate intensity exercise, as employed in this study (Tsai et al., 2014b; Chang & Etnier, 2009b; Chang et al 2011, 2012, 2014). It is possible, however, that rest time between sessions may alter the relationship between intensity of RT and cognitive effects and that exertion required for this study was too intense to elicit positive effects. In this study, participants had 60s of rest between sets and 90s between exercises, in contrast to 90s and 120s in the only prior study of acute RT on executive

function and the P3 waveform (Tsai et al., 2014b). It is possible that the decreased recovery time resulted in more stress for a given exercise intensity, resulting in null effects on cognitive function as observed after high intensity RT in some prior studies (Chang & Etnier 2009b; Chang et al 2011). Higher stress could lead sufficient cortisol or catecholamine release to induce neural noise, leading to no change of cognitive function. Our results are also consistent with one other study that used the same rest scheme with moderate intensity RT (Pontifex et al., 2009). It should be noted, however, that what they refer to as moderate RT could be deemed as high intensity RT by most definitions (80% 1-RM). Even if decreased rest may have increased the intensity of the RT bout, the low number of sets and the recorded RPE range of 12-15 give evidence that the 70% 10-RM RT intervention was in fact moderate intensity, and did not elicit positive results.

Positive results after acute RT have been observed using a number of different executive function tasks, including Stroop, Tower of London, and Flanker (Chang & Etnier 2009; Chang et al., 2011; Tsai et al., 2014b). Several previous studies have found that performance in the Stroop task improves after moderate intensity RT (Chang & Etnier 2009; Chang et al., 2014). However, the computerized modified Stroop task used in the present study might be a simpler, less challenging task than the traditional Stroop task. In our modified Stroop task, participants only had to identify whether the task was congruent or incongruent and respond with a button push, rather than say the colour that the word is printed in for the standard version. A previous study found no effects for simpler tasks compared to more challenging inhibitory tasks (Chang & Etnier, 2009b). The Stroop task in the present study may

be more similar to an oddball inhibitory task than to the standard Stroop task, choosing a button appropriate to two congruency options instead of saying the word appropriate to one of four ink colours. Where the effects of RT seem to be greater for more challenging executive function tasks, the modified Stroop task in the current study might have been too simple to be sensitive to the effects of RT, in either EEG or behavioural measures. Although, the concept of the modified Stroop task seems simpler in theory, it should be noted that response times for this study were longer than traditional Stroop task by about 150-200ms (Chang et al., 2014) and were nearly double the length of the Flanker task (Tsai et al., 2014b). The longer response times and the fact that accuracies were not close to ceiling suggests that the modified Stroop was indeed challenging enough, and the lack of difference between RT and its controls is true.

One novel aspect of the current study was the investigation of cognitive effects over time, up to 40min post-intervention. Few studies of aerobic exercise and no studies of RT have examined cognitive performance over the course of time (Heckler & Croce, 1992; Joyce, Graydon, McMorris, & Davranche, 2009; Joyce, Smyth, Donnelly, & Davranche, 2014; Pontifex et al., 2009). In this study, there was an effect of time for most outcomes but few differences by session. P3 amplitude improved over time whereas response times improved at 10min after interventions and then returned to baseline values by 40min post-intervention. Improvements across sessions, as seen through time effects, could be due to practice effects, where participants became more familiar with the task and attend to stimuli more efficiently (Hillman et al., 2003; Pontifex, Hillman, & Polich, 2009).

Though the timeline of effects remains important to capitalizing on the acute improvements after RT, it may be that the implementation of so many trials meant that participants were more likely to be less motivated or focused in earlier trials and to be fatigued in later trials. Evidence of possible boredom or fatigue may be the cause of the significant decline in Stroop accuracy over time. The confounding effects of practice and fatigue may reduce our ability to detect any real RT effects.

In this study, our participants were young healthy adults. This is in contrast to the majority of RT studies that used middle-aged and older adults (Chang & Etnier, 2009a; Chang et al., 2011, 2012, 2014). Studies suggest that age modifies the acute effect of aerobic exercise on cognitive function (Chang et al. 2012; Kamijo et al., 2009), and the same may be true for RT. Given potential mechanisms, it is not unreasonable to think that acute RT may have greater cognitive effects among older adults. There is evidence that some neuroendocrine responses vary with age through exercise, which may be the case with for RT though it has not been well studied thus far (de Vries et al., 2004; Kraemer & Ratamess, 2005; Traustadottir, Bosch, & Matt, 2005).

It is also possible that fitness or RT experience may modify the cognitive effects of RT, again not examined to date. Previous studies of youth or young adults used untrained samples and demonstrated positive changes in cognitive function after a session of RT (Harveson et al., 2016; Pontifex et al., 2009; Tsai et al., 2014). In contrast, 68% of the sample in the current study had high fitness according to the IPAQ and 80% currently participated in RT, as shown through weekly training response in the RT questionnaire. It may be that young adults who are less fit and/or

have less RT experience, have a greater arousal response to RT (through cortisol or catecholamines) due to higher novelty and, thus, experience greater improvements in executive functioning.

The research design of the study could have also influenced the results. Of prior studies, 5 of 8 used repeated measure designs (Chang et al, 2011, 2012, 2014; Harveson et al., 2016; Pontifex et al 2009). The greatest disadvantages of a repeated measures design are practice effects due to repeated testing. The influence of these effects by session can be counteracted by randomization and greater time between sessions. However, in the present study, only the two active sessions (RT and LL) were randomized but not the rest session, which always occurred first. While this reduced the number of sessions required of participants, this may have confounded our results. All participants performed the rest session first and may have experienced greater practice effects during this session compared to the RT or LL sessions. This would increase the improvement experienced pre- to post-rest, especially between pre- and 10min post-rest. Any improvement due to practice effects in the rest session would make it difficult to detect intervention effects for the other sessions.

Another disadvantage of the lack of randomization of the rest session is that participants knew that they would be exercising (whether LL or RT) in the latter sessions. This may lead to different arousal pre-intervention as compared to the rest session. Studies of catecholamine release in RT identified significant increases in E and NE prior to exercise, demonstrating a preparatory arousal effect (Kraemer et al., 1991; Kraemer et al., 1999). This increased arousal before the intervention may lead

to better performance pre-intervention than would occur for a blinded participant (Lambourne & Tomporowski, 2010; McMorris et al., 2008; Pineda et al., 1997), which would reduce pre- to post-intervention differences during the RT and LL sessions.

If we compare only the two randomized sessions, which would be more similar in terms of practice effects and pre-intervention arousal, there are some intriguing observations. There were no differences in cognitive effects between the RT and LL sessions for behavioural and EEG measures. Based on the current results, the exertion required for RT seemed to have little additional effect on cognitive function over the movement required for the LL session. This evidence suggests that the lack of randomization of the rest session may have not truly impacted the lack of differences. The lack of difference between the two randomized exercise sessions advocates for the present results that RT does not have a significant effect on cognitive function after a single session. There was even little difference for RT when looked within session. This was the first time the relative effects of RT versus LL, or any exercise versus LL, have been identified. Future research should further investigate the influence of movement versus exertion on cognitive function.

Given effect sizes in the one prior acute RT study and acute aerobic exercise studies, P3 amplitudes and latencies were expected to be more sensitive to the effects of RT than behavioural responses (Hillman et al., 2003; Kamijo et al., 2004; Tsai et al., 2014b). Effect sizes for P3 amplitude were approximately double effect sizes for a Flanker size in the one prior acute RT study (Tsai et al., 2014b). In contrast, neither the P3 nor the Stroop task behavioural measures showed significant changes after exercise compared to rest or LL in this study. In addition to possible

explanations for lack of effects discussed above, when performing P3 analysis, epochs with ocular artifacts were completely rejected in the prior study whereas a reduction method was used in the current study, which allowed for retention of more trials but may have included more variable epochs.

Section 10. Limitations

This study was the first to measure the cognitive response to acute RT over an extended period after exercise to better understand the time course of effects. It was also the first to include a LL condition to control for the effects of movement. However, the study has limitations. The most significant limitation was the lack of randomization of the rest session, as the rest session was always first. As a result, practice effects were likely accentuated in the rest session compared to other sessions. This may have artificially inflated the improvement in cognitive function observed over the course of the rest session, hiding any potential RT or LL effects. In addition, day-to-day variability of participants could not be completely controlled. Participants always performed the sessions at the same time of day and were asked not to partake in exercise, consume medication, or caffeine prior to the study. However, there was likely variability in what participants ate, the amount of sleep they got, and outside stressors. These factors may have impacted the pre-intervention state of the participants and their reaction to the interventions. Furthermore, the sample was primarily recruited from the University of Waterloo Kinesiology building. As a consequence, the young healthy sample is likely more fit, performs RT more often, and is less diverse than a general population of healthy

young adults. Finally, we did not measure growth factors, catecholamines, or cortisol responses to interventions. As a result, we can only hypothesize possible mechanisms or reasons for our results.

Section 11. Conclusions

RT is a type of physical activity that should be implemented in exercise regimes for all ages due to the numerous physical and health benefits. However, in contrast to most prior studies, this study does not support the hypothesis that a single session of RT benefits cognitive function. There were no improvements observed up to 40min after RT compared to rest. Lack of effects may be due to the use of a modified (and simplified) Stroop task, the lack of randomization of the rest session, or the highly fit and experienced sample. Alternatively, it may be that the lack of effects was not due to study design but was a true effect, where the RT intervention does not promote an appropriate arousal response to improve cognitive function in comparison to controls. Interestingly, there were no differences between the randomized RT and LL movement control conditions, indicating that the additional exertion required by RT may not positively affect cognitive function. Future research should further investigate the relative effects of RT, LL movement, and rest on cognitive function to better understand movement and exertion influences, as well as explore underlying mechanisms for any observed differences.

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Appendix A

Recruitment Poster

University of Waterloo

Department of Kinesiology
University of Waterloo

PARTICIPANTS NEEDED FOR A RESEARCH STUDY:

Physical Activity (weight training) and Cognitive Function

We are looking for volunteers to take part in a study of the impact a single session of resistance training can have on brain (cognitive) function. As a participant in this study, you would be asked to:

- Perform exercise that will test your fitness but is not exhaustive
- Perform basic tests of your decision-making ability and have your brain activity monitored during these tasks.
- Wear non-invasive equipment to measure electrical brain activity
- Inform us of your normal physical activity levels.
- Perform three 30 minute sessions of: rest, weight training exercises performed under no resistance, and weight training exercise performed under somewhat heavy (moderate) resistance.

Your participation would involve *THREE* sessions, each about 2 weeks apart. The first session will be approximately 3.5 hours in length and the second and third will be approximately 2.5 hours.

All experiences with resistance training accepted!

You are ineligible for the study if you have medical conditions that could worsen with exercise, have unstable cardiovascular disease, or have any neurological condition such as epilepsy, recent concussion or stroke.

All participants will receive $10 for each day, for a total of $30 after all three sessions have been performed.

For more information or to volunteer for this study, please contact:

Matt Vonk
mvonk@uwaterloo.ca
519-588-5644

This study has been reviewed by, and received ethics clearance through a University of Waterloo Research Ethics Committee

Appendix B

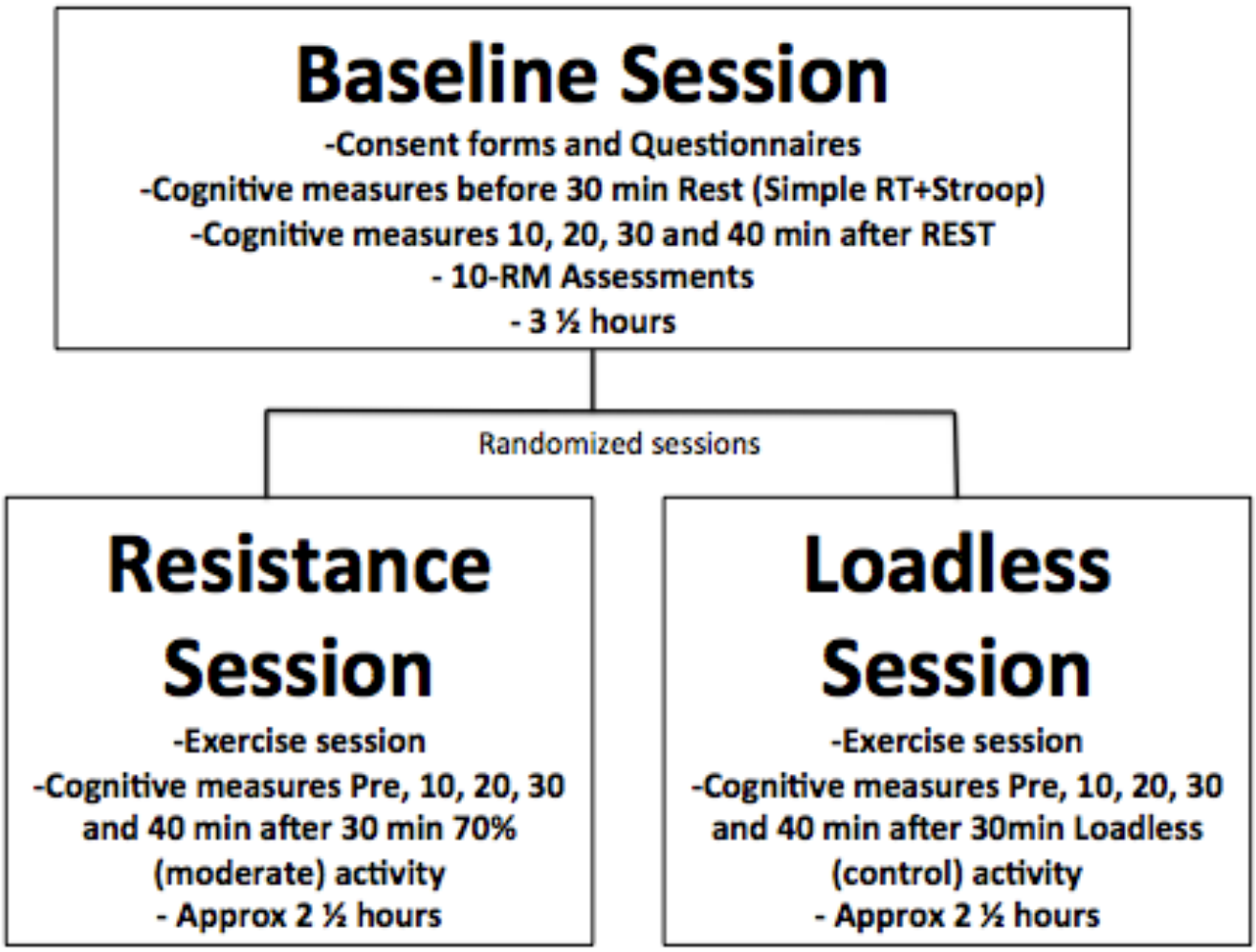
Inclusion and Exclusion Criteria

Inclusion Exclusion Criteria

Inclusion	Exclusion
• Healthy • Young adult (20-30 years) • Willingness to exercise	• History of heart disease • Uncontrolled diabetes • Uncontrolled hypertension • Drop in blood pressure when you rise from a seated position (symptoms include dizziness and feeling like you will faint) • Neurological conditions including stroke, epilepsy, Parkinson's disease, or dementia • Taking medications that influence heart rate such as beta blockers, anticoagulants, or anticholinergics • Have chronic obstructive pulmonary disease • You have a history of allergies to electrode gel or adhesive • Any musculoskeletal injuries/impairments of the upper or lower body that will prevent from performing the specific exercises or cause undue pain including pulled muscles, contusions, sprained ligaments, and broken bones • A strong history of concussions or have had a concussion less than 6 month previous • Visual impairment • Communication disorder that would prevent the participant from expressing discomfort, concern or a desire to withdrawal from the study.

Appendix C

Study Design Diagram


Baseline Session
-Consent forms and Questionnaires
-Cognitive measures before 30 min Rest (Simple RT+Stroop)
-Cognitive measures 10, 20, 30 and 40 min after REST
- 10-RM Assessments
- 3 ½ hours
Randomized sessions
Resistance Session
-Exercise session
-Cognitive measures Pre, 10, 20, 30 and 40 min after 30 min 70% (moderate) activity
- Approx 2 ½ hours
Loadless Session
-Exercise session
-Cognitive measures Pre, 10, 20, 30 and 40 min after 30min Loadless (control) activity
- Approx 2 ½ hours

Appendix D

Study Consent Form

UNIVERSITY OF WATERLOO

INFORMATION CONSENT FORM

Physical Activity (Weight Training) and Cognitive Function

Faculty Supervisor
Laura Middleton, PhD, University of Waterloo, Department of Kinesiology, 519-888-4567 Ext. 33045
Student Investigator
Matthew Vonk, BSc, University of Waterloo, Department of Kinesiology, 519-588-5644

INTRODUCTION

You are being invited to take part in Matthew Vonk's Master's Thesis research study. Before agreeing to participate in this study, it is important that you read the study procedures. The following information describes the purpose, procedures, benefits, discomforts, risks, and precautions associated with this study. It also describes your right to refuse to participate or withdraw from the study at any time. In order to decide whether you wish to participate in this research study, you should be aware of its risks and benefits to be able to make an informed decision. This is known as the informed consent process. Please ask the study staff to explain any details that are unclear before signing this consent form. Make sure all your questions have been answered to your satisfaction before signing this form.

WHAT IS THE PURPOSE OF THIS STUDY?

Physical activity is recommended as an important portion of physical health. Growing research suggests that physical activity is not only associated with physical health but also thinking abilities. The purpose of this study is to determine how physical activity affects your thinking abilities and brain health and to hopefully look towards reducing/preventing dementia later in life by using exercise.

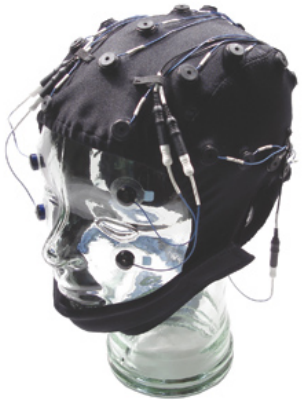
ELIGIBILITY

You are eligible for this study if you are a healthy young adult (18-30 years). You are ineligible if you have an unstable medical condition that could make exercise unsafe or have a condition that would interfere with the study procedures. These include:

- History of heart disease (heart attack or operation, heart murmur, coronary artery disease, congenital heart disease, pacemaker)
- Uncontrolled diabetes (your blood sugar levels are not well regulated by medicine, diet or exercise)
- Uncontrolled hypertension (your blood pressure is not well regulated with or without medicine)
- Drop in blood pressure when you rise from a seated position (symptoms include dizziness and feeling like you will faint)
- Neurological conditions including stroke, epilepsy, Parkinson's disease, or dementia
- Are taking medications that influence heart rate such as beta blockers, anticoagulants, or anticholinergics
- Have chronic obstructive pulmonary disease
- You have a history of allergies to electrode gel or adhesive

- Any musculoskeletal injuries/impairments of the upper or lower body that will prevent from performing the specific exercises or cause undue pain including pulled muscles, contusions, sprained ligaments, and broken bones
- A strong history of concussions or have had a concussion in the last year
- Have a visual impairment that prevents the viewing of the computer monitor
- Have a communication disorder that would prevent the participant from expressing discomfort, concern or a desire to withdrawal from the study.

- **Cap used to monitor your brain function.**



WHAT WILL YOU BE ASKED TO DO?

If you agree to participate, you will be asked to attend 3 sessions in a kinesiology lab at the University of Waterloo. These visits will be approximately 3 hours in duration. These visits will take place approximately 2 weeks apart. You will be carefully monitored during each session.

Prior to or on the first visit, you will sign this consent form. Exercise and health screening forms will be asked to fill out as well for the purposes of establishing your eligibility for the study.

Please note, you will not allowed to take any Caffeine or Ephedrine based products prior to attending the study sessions.

At the first visit, you will complete a health screening form (PAR-Q), a baseline screening form, and a physical activity questionnaire (IPAQ). The PAR-Q and IPAQ questionnaires will ask you about your regular physical activity where the baseline form will ask basic information such as age, number of years of education, and handedness. Resting heart rate and blood pressure will then be taken using an automatic blood pressure cuff to complete the medical screening aspect.
We will then monitor your brain activity while you perform a decision-making task. Decision-making refers to choice of pressing one button over another, where your reaction time (the time it takes to press the button after the stimulus is presented) will be measured. The “Stroop” task will require you to act appropriately to words presented on a monitor by responding whether the colour of the word presented is the same as what the word represents. Errors are normal on these tests and should not be taken as a reflection of your cognitive abilities. You will wear a cap (EEG cap) with electrodes that will monitor your

brain function during this test. A picture of the cap is shown above. The cap contains many disks that sit on the surface of your scalp. A few electrodes will also be placed on your face to measure eye-blinks throughout the test.

Prior to testing, we need to clean the sites underneath each of the disks and move the hair out of the way. This is done using a disposable blunt syringe, which is not sharp and is about as wide as a pen tip. This blunt syringe is also used to squirt a small amount of gel onto your scalp to improve the signal from your brain activity. Please note the EEG cap contains wires; all wires will be bundled up. The bundle of wires will be plugged into an electronic device behind you during computer tasks to stay out of the way. During exercise tasks, the bundle will be placed and taped down your back to ensure that it will not impede movement or cause discomfort during the performance of the exercise movements required.

You will then be performing the six exercises (leg press, hamstring curls, pull-downs, chest press, bicep curls, tricep extensions) to assess your 10-repetition maximum. The 10-repetition maximum will be used to determine appropriate weight in the subsequent session. A CPR and first aid certified instructor (the researcher himself) will guide you through the appropriate technique for each exercise to optimize performance and prevent injury. The instructor will be present the entire time in case of any emergency. You will then perform 3-4 sets of each exercise with increasing weight until you are able to complete only 10 repetitions at that weight. Your heart rate will be measured with a chest strap throughout. The chest strap is a commercial device that is cleaned with alcohol before and after use. The participant will be able to put the chest piece on himself or herself. Blood pressure will NOT be taken at any other point besides after the initial medical screening. If you feel any unusual discomfort or pain or if you feel dizzy, faint, or light headed during this test, inform the researcher immediately and the test will be stopped. This first session will take about 3 1/2 hours. You will be provided a towel and shampoo to wash your hair, if you wish, at the end of this study session.

In the second and third sessions, you will perform 30 minutes of exercise (under the supervision of the CPR certified instructor) repeating the same six exercises as in the first visit. Exercise session 1 will consist of performing the movements without any resistance for 2 sets of 10 reps for each exercise. There will be 1 minute of rest between each set and exercise, respectively. Exercise session 2 will involve moderate intensity of the same exercises (70% of the 10-RM) with similar rest. How hard you exercise in this session will be carefully set and monitored. You will be free to stop at any time. After you complete the exercise, you will then perform the same decision making tasks that were performed in the first visit while your brain activity is monitored, immediately after exercise. The same cognitive tasks will be performed 20 and 40 minutes post exercise. The second and third sessions will take approximately 2 1/2 hours.

All study sessions will be performed in the Brain and Body Lab which is in the B.C. Matthews Hall, Room 1015 at the University of Waterloo.

HOW MUCH TIME WILL IT TAKE?

Your first visit will be approximately 3 1/2 hours.
Your second and third visits will be approximately 2 1/2 hours each.

PAYMENT/REMUNERATION

The participant will receive payment of $10 for each session for a total of $30 after the whole experiment (the three sessions) has been completed. The amount received is taxable. It is your responsibility to report this amount for income tax purposes.

PARTICIPATION

If you choose to participate, we recommend wearing light, comfortable clothing and running shoes to the study sessions.

Participation in this study is entirely voluntary and you may refuse to participate or withdraw at any time by informing the researcher or research assistants. You may also decline to answer question(s) or stop taking part in the study tasks at any time by notifying the researcher. Likewise, the researchers may also stop participation of anyone in the study at any time. If we learn any new information that might affect your desire to participate or decision to remain in the study you will be told of this.

RISKS

You may experience temporary muscle fatigue or soreness from the exercise. Exercise intensities will be low to moderate, reducing the risk of fatigue.

During exercise, there is a small chance that chest pain (cardiac ischemia) or heart beat irregularity (arrhythmia) will occur. You will only be included in the study if you are considered to be at low risk for such events. In addition, we will stop the exercise if you report chest pain, shortness of breath, drowsiness, feeling faint, dizziness, or lightheadedness. Monitoring heart rate will be done regularly to detect any abnormal changes. The chest strap is the commercially produced heart rate monitor throughout the exercise. Blood pressure will only be taken on the first session for the baseline collection form using an automatic blood pressure cuff. You will be under direct supervision for the entire study to ensure your safety.

You may experience mild pain or discomfort when we clean the skin on your face around your eyes using abrasive gel (similar to a skin exfoliating cream) and when adding the conductive gel to your scalp so that we can monitor your brain activity. If you have sensitive skin, you may develop a slight reddening from the adhesive used to affix some electrodes to the skin. Your head may also be slightly sore from wearing the EEG cap. Electrode gel will get into your hair as a result of the EEG cap, but soap, shampoo, conditioner and towels will be provided if you wish to wash your hair in a nearby changing facility. Any person with allergies or sensitivities to alcohol will be excluded from this study. The researcher will ask you if you have any known allergies or sensitivities before beginning the procedures. The chest strap will be cleaned with alcohol before and after each use. The EEG cap will be thoroughly cleaned with soap and hot water after each session in preparation for the next session. Blunt syringes will be thrown out into proper receptacles immediately after use.

BENEFITS

By participating in this study, you will benefit by furthering your knowledge and understanding of experimental procedures commonly used in neuroscience research. Your help will contribute to our knowledge on the benefits that weight training may have on brain health. This study may provide insight for future research on stroke rehabilitation and prevention of cognitive impairment, particularly research on neuroplasticity (the brain's ability to adapt).

CONFIDENTIALITY AND SECURITY OF INFORMATION

Your identity will be kept confidential and will not be passed to a third party. Only the researchers associated with the study (Dr. Middleton and Matthew Vonk) will have access to the data. The collected data will be coded with participant numbers (not names) and will be kept in a locked file cabinet in Burt Matthews Hall room 1114 or on a password-protected computer for seven years after publication. After this time, all paper copies will be shredded and computer disks erased.

QUESTIONS

Any questions with regard to this research should be directed to Dr. Laura Middleton, 519-888-4567 Ext. 33045.

ETHICS CLEARANCE

This study was reviewed and received ethics clearance through a University of Waterloo Research Ethics Committee. However, the final decision about participation is yours. If you have any comments or concerns resulting from your participation in this study, you may contact the Office of Research Ethics, 519-888-4567 Ext. 36005.

UNIVERSITY OF WATERLOO

Faculty Supervisor
Laura Middleton, PhD
Student Investigator
Matthew Vonk, BSc

CONSENT FORM

Physical Activity (Weight Training) and Cognitive Function

I have been informed of the aim of this study, and have read the INFORMATION AND CONSENT FORM. I am aware that I am under no obligation to take part and may withdraw from the study at any time.

I am aware that the researchers will be asking me questions concerning my health. This information will remain confidential and I will be free to refuse to reply to any question that I am prefer not to answer.

I am aware that I am free to ask questions and to withdraw from this study at any time. I am also aware that, if I feel uncomfortable during exercise, I may ask the researcher to stop it immediately.

I am aware that by signing this consent form, I am not waiving my legal rights, nor does it relieve the investigators or involved institution from their legal and professional responsibilities.

I agree to take part in the study. I will receive a copy of the signed consent form.

_____ WITNESS
PARTICIPANT NAME

_____
PARTICIPANT SIGNATURE

_____
LOCATION

_____
DATE

_____

Appendix E

Physical Activity Readiness Questionnaire (PAR-Q)

PAR-Q+

The Physical Activity Readiness Questionnaire for Everyone

Regular physical activity is fun and healthy, and more people should become more physically active every day of the week. Being more physically active 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.

SECTION 1 - GENERAL HEALTH

	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)?	☐	☐
5.	Are you currently taking prescribed medications for a chronic medical condition?	☐	☐
6.	Do you have a bone or joint problem that could be made worse by becoming more physically active? Please answer NO if you had a joint problem in the past, but it does not limit your current ability to be physically active. For example, knee, ankle, shoulder or other.	☐	☐
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.

Go to Section 3 to sign the form. You do not need to complete Section 2.

- Start becoming much more physically active – start slowly and build up gradually.
- Follow the Canadian Physical Activity Guidelines for your age (www.csep.ca/guidelines).
- You may take part in a health and fitness appraisal.
- If you have any further questions, contact a qualified exercise professional such as a CSEP Certified Exercise Physiologist® (CSEP-CEP) or CSEP Certified Personal Trainer® (CSEP-CPT).
- If you are over the age of 45 yrs. and NOT accustomed to regular vigorous physical activity, please consult a qualified exercise professional (CSEP-CEP) before engaging in maximal effort exercise.

If you answered YES to one or more of the questions above, please GO TO SECTION 2.

Delay becoming more active if:

- You are not feeling well because of a temporary illness such as a cold or fever – wait until you feel better
- You are pregnant – talk to your health care practitioner, your physician, a qualified exercise professional, and/or complete the PARmed-X for Pregnancy before becoming more physically active OR
- Your health changes – please answer the questions on Section 2 of this document and/or talk to your doctor or qualified exercise professional (CSEP-CEP or CSEP-CPT) before continuing with any physical activity programme.

SECTION 2 - CHRONIC MEDICAL CONDITIONS

Please read the questions below carefully and answer each one honestly: check YES or NO.			YES	NO
1.	Do you have Arthritis, Osteoporosis, or Back Problems?		☐ If yes, 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)	☐	☐
	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)?	☐	☐
	1c.	Have you had steroid injections or taken steroid tablets regularly for more than 3 months?	☐	☐
2.	Do you have Cancer of any kind?		☐ If yes, 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 neck?	☐	☐
	2b.	Are you currently receiving cancer therapy (such as chemotherapy or radiotherapy)?	☐	☐
3.	Do you have Heart Disease or Cardiovascular Disease? This includes Coronary Artery Disease, High Blood Pressure, Heart Failure, Diagnosed Abnormality of Heart Rhythm		☐ If yes, answer questions 3a-3e	☐ 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)	☐	☐
	3b.	Do you have an irregular heart beat that requires medical management? (e.g. atrial brillation, premature ventricular contraction)	☐	☐
	3c.	Do you have chronic heart failure?	☐	☐
	3d.	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)	☐	☐
	3e.	Do you have diagnosed coronary artery (cardiovascular) disease and have not participated in regular physical activity in the last 2 months?	☐	☐
4.	Do you have any Metabolic Conditions? This includes Type 1 Diabetes, Type 2 Diabetes, Pre-Diabetes		☐ If yes, answer questions 4a-4c	☐ If no, go to question 5
	4a.	Is your blood sugar often above 13.0 mmol/L? (Answer YES if you are not sure)	☐	☐
	4b.	Do you have any signs or symptoms of diabetes complications such as heart or vascular disease and/or complications affecting your eyes, kidneys, and the sensation in your toes and feet?	☐	☐
	4c.	Do you have other metabolic conditions (such as thyroid disorders, pregnancy-related diabetes, chronic kidney disease, liver problems)?	☐	☐
5.	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 yes, answer questions 5a-5b	☐ If no, go to question 6
	5a.	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)	☐	☐
	5b.	Do you also have back problems affecting nerves or muscles?	☐	☐

Please read the questions below carefully and answer each one honestly: check YES or NO.			YES	NO
6.	Do you have a Respiratory Disease? This includes Chronic Obstructive Pulmonary Disease, Asthma, Pulmonary High Blood Pressure		☐ If yes, answer questions 6a-6d	☐ 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)	☐	☐
	6b.	Has your doctor ever said your blood oxygen level is low at rest or during exercise and/or that you require supplemental oxygen therapy?	☐	☐
	6c.	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?	☐	☐
	6d.	Has your doctor ever said you have high blood pressure in the blood vessels of your lungs?	☐	☐
7.	Do you have a Spinal Cord Injury? This includes Tetraplegia and Paraplegia		☐ If yes, answer questions 7a-7c	☐ 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)	☐	☐
	7b.	Do you commonly exhibit low resting blood pressure significant enough to cause dizziness, light-headedness, and/or fainting?	☐	☐
	7c.	Has your physician indicated that you exhibit sudden bouts of high blood pressure (known as Autonomic Dysreflexia)?	☐	☐
8.	Have you had a Stroke? This includes Transient Ischemic Attack (TIA) or Cerebrovascular Event		☐ If yes, answer questions 8a-c	☐ 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)	☐	☐
	8b.	Do you have any impairment in walking or mobility?	☐	☐
	8c.	Have you experienced a stroke or impairment in nerves or muscles in the past 6 months?	☐	☐
9.	Do you have any other medical condition not listed above or do you live with two chronic conditions?		☐ If yes, answer questions 9a-c	☐ If no, read the advice on page 4
	9a.	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?	☐	☐
	9b.	Do you have a medical condition that is not listed (such as epilepsy, neurological conditions, kidney problems)?	☐	☐
	9c.	Do you currently live with two chronic conditions?	☐	☐

Please proceed to Page 4 for recommendations for your current medical condition and sign this document.

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:

- It is advised that you consult a qualified exercise professional (e.g., a CSEP-CEP or CSEP-CPT) 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 – 20-60 min. 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 yrs. and NOT accustomed to regular vigorous physical activity, please consult a qualified exercise professional (CSEP-CEP) before engaging in maximal effort exercise.

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

- You should seek further information from a licensed health care professional before becoming more physically active or engaging in a fitness appraisal and/or visit a or qualified exercise professional (CSEP-CEP) for further information.

Delay becoming more active if:

- You are not feeling well because of a temporary illness such as a cold or fever – wait until you feel better
- You are pregnant - talk to your health care practitioner, your physician, a qualified exercise profesional, and/or complete the PARmed-X for Pregnancy before becoming more physically active OR
- Your health changes - please talk to your doctor or qualified exercise professional (CSEP-CEP) before continuing with any physical activity programme.

SECTION 3 - DECLARATION

- You are encouraged to photocopy the PAR-Q+. You must use the entire questionnaire and NO changes are permitted.
- The Canadian Society for Exercise Physiology, the PAR-Q+ Collaboration, and their agents assume no liability for persons who undertake physical activity. If in doubt after completing the questionnaire, consult your doctor prior to physical activity.
- If you are less than the legal age required for consent or require the assent of a care provider, your parent, guardian or care provider must also sign this form.
- Please read and sign the declaration below:

I, the undersigned, have read, understood to my full satisfaction and completed this questionnaire. I acknowledge that this physical activity clearance is valid for a maximum of 12 months from the date it is completed and becomes invalid if my condition changes. I also acknowledge that a Trustee (such as my employer, community/fitness centre, health care provider, or other designate) may retain a copy of this form for their records. In these instances, the Trustee will be required to adhere to local, national, and international guidelines regarding the storage of personal health information ensuring that they maintain the privacy of the information and do not misuse or wrongfully disclose such information.

NAME _____ DATE _____

SIGNATURE _____WITNESS _____

SIGNATURE OF PARENT/GUARDIAN/CARE PROVIDER _____

For more information, please contact:
Canadian Society for Exercise Physiology
www.csep.ca

KEY REFERENCES
1. Jamnik VJ, Warburton DER, Makarski J, McKenzie DC, Shephard RJ, Stone J, and Gledhill N. Enhancing the eectiveness 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.

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 BC Ministry of Health Services.

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CSEP approved Sept 12 2011 version

Appendix F

Baseline Information Collection

PARTICIPANT #_____

BASELINE HEALTH COLLECTION

Personal Info		Notes: (Anything that researcher should be aware of)
Age		
Sex		
Years of Education		
Height (cm)	**inches to cm→ multiply by 2.54	
Weight (kg)	**lbs to kg→ divide by 2.2	
Resting HR		
Resting BP		

Have you had any source of caffeine in the last 4 hours? YES NO

Have you had any source of ephedrine in the last 4 hours? YES NO

Have you ingested any form of recreational drug (ie. THC) in the last 4 hours? YES NO

Have you performed any type of exercise today? YES NO

Health Info

Vision Impairment: Yes No

Colour Blindness: Yes No

Diabetes: Yes No

Hypertension: Yes No

High Cholesterol: Yes No

Musculoskeletal injuries: Yes No

Other:

Handedness: L R

→See Other Side

Medications that may affect HR and BP:

1. _____
2. _____
3. _____
4. _____
5. _____

Effect of Medication:

1. _____
2. _____
3. _____
4. _____
5. _____

Age-Predicted HRmax:

220-age=_____

Concussions Yes No

If **Yes**, how many?

How long ago was your last concussion? _____

Will Stop Assessments and Exercise Sessions If:

- Complaints of chest pain
- Volitional fatigue/requests to stop
- Unable to perform 70%10RM for 2 sets
- Musculoskeletal complaints

Appendix G

International Physical Activity Questionnaire (IPAQ)

INTERNATIONAL PHYSICAL ACTIVITY QUESTIONNAIRE (October 2002)

LONG LAST 7 DAYS SELF-ADMINISTERED FORMAT

FOR USE WITH YOUNG AND MIDDLE-AGED ADULTS (15-69 years)

The International Physical Activity Questionnaires (IPAQ) comprises a set of 4 questionnaires. Long (5 activity domains asked independently) and short (4 generic items) versions for use by either telephone or self-administered methods are available. The purpose of the questionnaires is to provide common instruments that can be used to obtain internationally comparable data on health–related physical activity.

Background on IPAQ

The development of an international measure for physical activity commenced in Geneva in 1998 and was followed by extensive reliability and validity testing undertaken across 12 countries (14 sites) during 2000. The final results suggest that these measures have acceptable measurement properties for use in many settings and in different languages, and are suitable for national population-based prevalence studies of participation in physical activity.

Using IPAQ

Use of the IPAQ instruments for monitoring and research purposes is encouraged. It is recommended that no changes be made to the order or wording of the questions as this will affect the psychometric properties of the instruments.

Translation from English and Cultural Adaptation

Translation from English is encouraged to facilitate worldwide use of IPAQ. Information on the availability of IPAQ in different languages can be obtained at www.ipaq.ki.se. If a new translation is undertaken we highly recommend using the prescribed back translation methods available on the IPAQ website. If possible please consider making your translated version of IPAQ available to others by contributing it to the IPAQ website. Further details on translation and cultural adaptation can be downloaded from the website.

Further Developments of IPAQ

International collaboration on IPAQ is on-going and an ***International Physical Activity Prevalence Study*** is in progress. For further information see the IPAQ website.

More Information

More detailed information on the IPAQ process and the research methods used in the development of IPAQ instruments is available at www.ipaq.ki.se and Booth, M.L. (2000). *Assessment of Physical Activity: An International Perspective.* Research Quarterly for Exercise and Sport, 71 (2): s114-20. Other scientific publications and presentations on the use of IPAQ are summarized on the website.

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***

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***

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.

Appendix H

Resistance Training History Questionnaire

Participant Name_____

Resistance Training Questionnaire

NOTE: All questions are specific to resistance training (also known as weight training or strength training). Resistance training is a series of simple or complex movements designed to work a muscle or muscle group against external resistance to improve muscular fitness and promote development. Please do not include other types of physical activity such as aerobic exercise (biking, running, etc.) or stretching in your responses. Metabolic conditioning exercise, such as CrossFit (WODs), will be accepted as resistance training.

1. Have you ever performed resistance training?
   - □ Yes
   - □ No

2. When have you most recently done resistance training?
   - □ This week
   - □ The past month
   - □ The past 6 months
   - □ The past year
   - □ Other

3. When you last did resistance training regularly, how many times a week (on average) did you perform resistance training?
   _____times/wk OR □ n/a

4. When you last did resistance training regularly, what was the average the duration of your resistance training workouts?
   - □ <15 minutes
   - □ 15-30 minutes
   - □ 30-60 minutes
   - □ 60-90 minutes
   - □ 90+ minutes
   - □ N/A

5. When you last did resistance training, what was the average number of exercises you performed in a single workout?
   _____exercises OR □ n/a

6. When you last performed resistance training regularly, on average, how many sets did you perform for each exercise?
   _____sets OR □ n/a

Participant Name_____

7. When you last did resistance training regularly, on average, how many repetitions were you aiming to achieve for each set?
   - 15+
   - 8-10
   - 3-5
   - 1-2
   - N/A

8. When you last did resistance training regularly, on a scale of 1 to 10, how intense were your workouts on average?
   - 1 Very Light (no more difficult than normal daily activities)
   - 2
   - 3
   - 4
   - 5
   - 6
   - 7
   - 8
   - 9
   - 10 Maximal effort (failure by the last repetition)

Appendix I

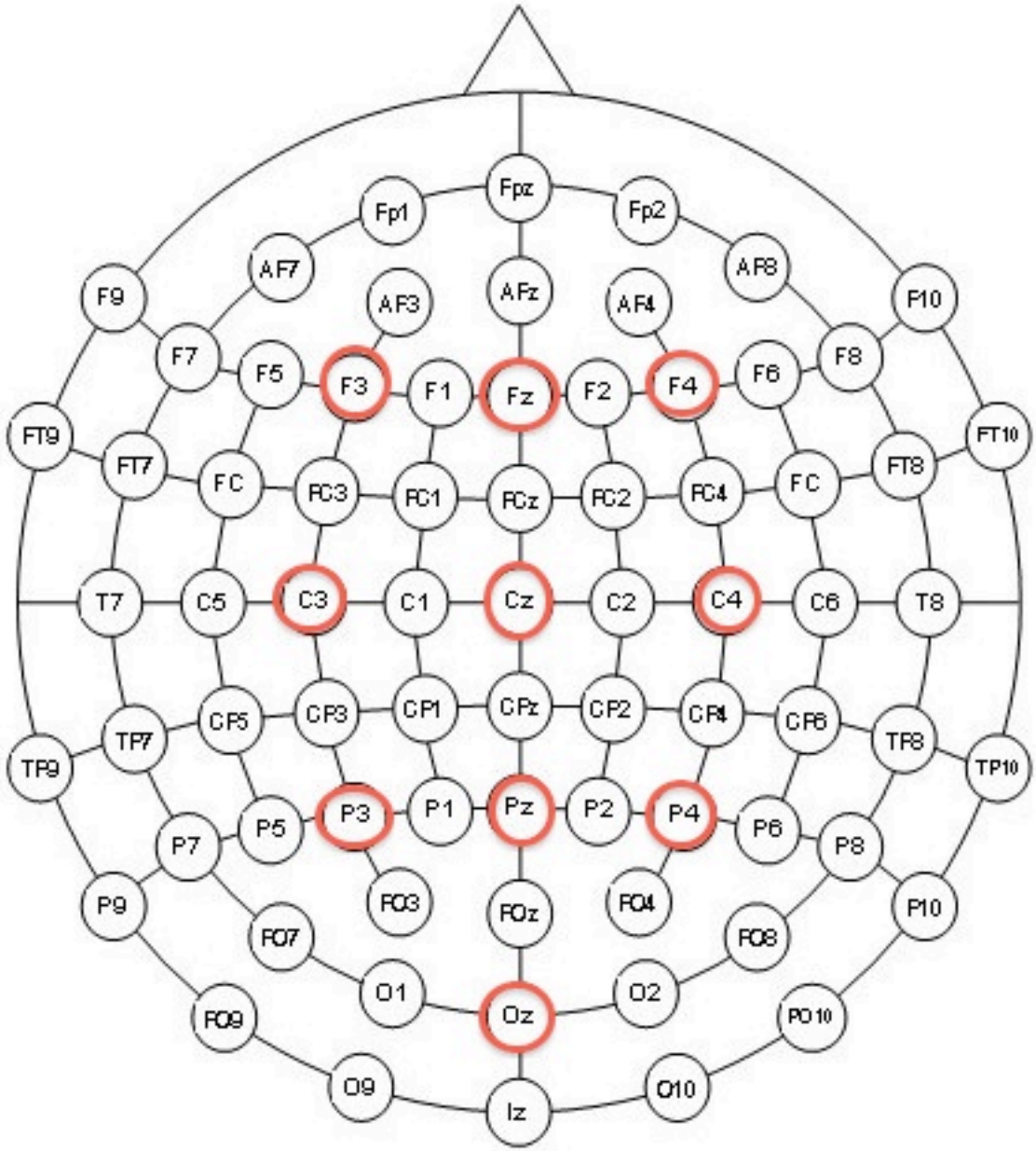
Stroop Incongruent and Congruent Examples

Congruent

Incongruent

Appendix J

EEG Electrode Schematic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AF7
AF8
F9
AF3
AFz
AF4
P10
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F3
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F4
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