

1 **An acute bout of exercise improves the cognitive performance of older adults.**

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Abstract

There is evidence that an acute bout of exercise confers cognitive benefits, but it is largely unknown what the optimal mode and duration of exercise is and how cognitive performance changes over time after exercise. We compared the cognitive performance of 31 older adults using the Stroop test before, immediately after, and at 30 and 60 minutes after a 10 and 30 minute aerobic or resistance exercise session. Heart rate and feelings of arousal were also measured before, during and after exercise. We found that independent of mode or duration of exercise, the participants improved in the Stroop Inhibition task immediately post-exercise. We did not find the exercise influenced the performance of the Stroop Color or Stroop Word Interference tasks. Our findings suggest that an acute bout of exercise can improve cognitive performance, and in particular the more complex executive functioning, of older adults.

Keywords: resistance exercise, aerobic exercise, executive function, older adults, stroop task.

1

Introduction

2 In an aging society, the age-related decline in cognitive functioning, including memory,
3 attention and processing speed, and an increase in cognitive disorders, such as dementia, have
4 become major public health issues. Significantly, the loss of one's mental abilities and
5 independence is reported to be a primary concern of older adults (Thompson & Foth, 2005). It is
6 well documented that regular exercise is associated with a range of physiological and
7 psychological benefits (Biddle, Fox, & Boutcher, 2000; Pate et al., 1995), and a meta-analysis
8 found a small positive effect for an acute bout of exercise on cognitive performance immediately
9 post-exercise and following a delay (Chang, Labban, Gapin, & Etnier, 2012), which is consistent
10 with other reviews on the cognitive effects of an acute bout of exercise (Etnier et al., 1997;
11 Lambourne & Tomporowski, 2010; Tomporowski, 2003). However, the limited capacity of
12 meta-analytical techniques to interrogate the interactions of multiple moderators simultaneously
13 suggests the current body of evidence should be cautiously interpreted. The influence of
14 moderator variables on the relationship between acute exercise and cognitive functioning is in
15 need of further examination (McMorris, Sproule, Turner & Hale, 2011).

16 A rationale for our current theoretical understanding of the acute exercise intensity-
17 cognition interaction can be traced back to Yerkes and Dodson's (1908) arousal-performance
18 interaction theory. Davey (1973) built on this by suggesting exercise intensity, and its effect on
19 arousal, influences cognitive performance in an inverted-U manner. That is, moderate intensity
20 exercise benefits cognition more than high or low intensity exercise (McMorris & Hale, 2012;
21 McMorris et al., 2011). Psychophysiological (Dietrich's reticular activation hypofrontality theory
22 [Dietrich, 2003; Dietrich & Audiffren, 2011]) and neuroendocrinological (the catecholamines
23 hypothesis [McMorris, Collard, Corbett, Dicks, & Swain, 2008]) explanations suggest that

1 moderate intensity exercise influences cognitive task performance by optimally elevating
2 arousal.

3 Meta-analytical studies have demonstrated moderate intensity acute exercise improves
4 speed of cognitive processing (McMorris & Hale, 2012; McMorris et al., 2011), but may have a
5 detrimental effect on accuracy (McMorris et al., 2011), though this relationship may be
6 dependent on the complexity of the cognitive task (McMorris & Hale, 2012; McMorris et al.,
7 2011). The effect of the mode of exercise on cognition is somewhat uncertain. Improvements in
8 executive functioning, such as planning and inhibition, have been demonstrated following acute
9 bouts of resistance (Chang, Ku, Tomporowski, Chen, & Huang, 2012; Chang, Tsai, Huang,
10 Wang, & Chu, 2014) and aerobic exercise in young (Chang et al., 2015; Weng, Pierce, Darling,
11 & Voss, 2015) and older adults (Lucas et al., 2012). Furthermore, a meta-analysis by Chang,
12 Labban et al. (2012) found studies that combined aerobic and resistance training generated the
13 largest positive effects. However, both aerobic exercise (Lambourne & Tomporowski, 2010) and
14 resistance exercise (Chang, Labban, et al., 2012) have been reported in meta-analyses to
15 negatively affect cognitive performance when performed in isolation.

16 These inconsistencies illustrate a lack of clarity regarding the influence of mode of
17 exercise on cognitive performance. Moreover, given the variability in physiological demands
18 (i.e. cardiovascular, metabolic) that characterise both types of exercise training, it is possible
19 resistance training exerts a differential effect on cognition compared to aerobic exercise. For
20 example, working memory has been shown to be improved by an acute bout of aerobic exercise
21 but not resistance exercise (Pontifex, Hillman, Fernhall, Thompson & Valentini, 2009). Whether
22 similar effects are observed for other aspects of cognition needs further exploration.

1 The timing of the cognitive task assessment following exercise is another variable that
2 may be important to consider relative to the effects of acute exercise on cognitive performance.
3 A meta-analysis by Chang, Labban et al. (2012) found small improvements in cognitive task
4 performance when assessed immediately after an acute bout of exercise and when cognitive
5 performance is assessed following a post-exercise delay (Chang, Labban, et al., 2012). The
6 largest positive effects were found between 1 to 15 mins after exercise, with these effects
7 appearing to decline thereafter (Chang, Labban, et al., 2012). When combining the effects of
8 cognition when assessed immediately post-exercise, and after a delay, the duration of the
9 exercise session has also been shown to influence cognitive performance. Exercise of less than
10 10 minutes had a negligible effect on cognitive performance, whilst exercise of 11 mins or longer
11 resulted in positive effects (Chang, Labban, et al., 2012). In a recent study, 20 mins of moderate
12 intensity cycling improved cognitive performance in young male adults, whereas 10 and 45
13 minute cycling sessions had negligible benefits (Chang et al., 2015). However, the Chang,
14 Labban et al. (2012) and Chang et al. (2015) papers are not specific to older adults, and it
15 remains possible that a shorter duration of exercise (i.e. 10 mins) benefits cognition in this group.

16 Despite the emerging body of evidence comparing the immediate and delayed effects of
17 an acute bout of aerobic or resistance exercise on cognitive performance of older adults, several
18 questions remain unanswered. These include the time course of change, magnitude of effects and
19 the influence and interaction of several moderator variables, such as the mode (Tomporowski,
20 2003), intensity and duration of the exercise session (Chang, Labban, et al., 2012; Tomporowski,
21 2003), the timing and type of cognitive assessment (Chang, Labban, et al., 2012; Lambourne &
22 Tomporowski, 2010). Improving our understanding of the influence of these moderators could
23 provide insights into the potential mechanisms of the effects observed and aid the development

1 of exercise recommendations to optimize cognitive benefits. Furthermore, given that older adults
2 may lack the physical conditioning to perform physical activity for 30 mins (or more) in
3 duration, the effect of a 10-min acute bout of exercise compared to a 30-min bout of exercise on
4 the cognitive functioning of older adults warrants investigation.

5 The aim of this study was to investigate the effects of an acute bout of exercise on the
6 cognitive performance of older adults. In particular, we examined the conditions at which
7 exercise benefits cognitive performance, and aim to evaluate the influence of exercise mode
8 (aerobic, resistance), exercise duration (10 mins, 30 mins) on cognitive processes (executive
9 functioning [inhibition] and speed of response) up to 60 mins post-exercise.

10 **Method**

11 **Participants**

12 Thirty-one community dwelling older adults (21 females; $M_{\text{age}} = 71.7$, $SD = 1.5$ years)
13 were recruited. Invitations to participate were sent by mail to older adults on a research volunteer
14 database held by the National Ageing Research Institute (NARI) based on their age (60 years or
15 older) and the proximity of their residence from the Victoria University Footscray Park Campus
16 testing site. Participants were also recruited via their response to advertisements placed around
17 Victoria University or in local churches newsletters. Participants were excluded from the study if
18 they had 1) uncorrected visual deficits; 2) color blindness; 3) an inability to read and/or speak
19 English; and 4) been deemed unsuitable to participate by their General Practitioner. All
20 participants completed a health history questionnaire and provided written informed consent.
21 This study was approved by the Victoria University Human Research Ethics Committee.

22 **Study Design**

1 Participants attended the exercise science testing laboratory at Victoria University one
2 day per week for four consecutive weeks (same day and time on each occasion). They completed
3 two familiarization sessions and two experimental sessions. The study protocol is illustrated in
4 Figure 1. The participants were randomly assigned into one of two exercise condition groups:
5 aerobic exercise (AE) or resistance exercise (RE). The participants were then familiarized with
6 the Stroop task (Stroop, 1935) by being provided with instructions on how to complete the task
7 and completed 5 practice trials for each condition. The participants were also familiarized with
8 the Borg Rating of Perceived Exertion (RPE) scale (6 to 20) (Borg, 1970), which was used to
9 monitor the exercise intensity of the participants during the exercise sessions, and their assigned
10 exercise condition. The RE group also completed one-repetition maximum (1-RM = the
11 maximum weight that can be lifted through a full range of motion with proper form) testing
12 (Phillips, Betterham, Valenzuela, & Burkett, 2004) for each resistance exercise to be performed
13 during the acute RE sessions. The Mini Mental State Examination (MMSE) (Folstein, Folstein,
14 & McHugh, 1975) and Seven-Day Physical Activity Recall (7-d PAR) (Sallis et al., 1985) was
15 also completed during the first familiarization session. During the second familiarization session,
16 all participants completed a graded, submaximal cardiorespiratory fitness (CRF) test with 12-
17 lead electrocardiogram (ECG), and were further familiarized with the computerised Stroop task
18 and their assigned exercise condition.

19 For each of the two experimental sessions, the participants were asked to complete the
20 Stroop task (pre-exercise condition), and then immediately engage in their assigned exercise
21 condition for either 10 or 30 mins (with the alternative duration completed in the second
22 experimental session). The participants then completed the Stroop task at three time points after
23 exercise (immediately after, 30 mins after and 60 mins after). The participants heart rates (HRs)

1 were measured continuously using a heart rate monitor (Polar A3, Kempele, Finland) worn by
2 the participant. The pre, immediately post-, 30 mins post- and 60 mins post-exercise HR
3 recordings were based on a single time-point, whilst the during-exercise HR recording was an
4 average of the participants HR during the exercise session. The Felt Arousal Scale (FAS)
5 (Svebak & Murgatroyd, 1985) is a single-item, 6-point scale (ranging from 1 = *low arousal* to 6
6 = *high arousal*) measuring perceived activation (Ekkekakis, Hall, VanLanduyt, & Petruzello,
7 2000). The FAS has demonstrated moderate to strong correlations with other measures of arousal
8 (Hall, Ekkekakis, & Petruzello, 2002), and has previously been used in exercise-related studies
9 (Hall et al., 2002; Kerr & van den Wollenberg, 1997), but how it is associated with an acute bout
10 of exercise by older adults is largely unknown. The FAS score was recorded at five time points
11 (pre, during [the FAS was measured at the 5- and 15-min mark of the 10 and 30 minute treatment
12 conditions respectively], immediately post-, 30 mins post-, and 60 mins post-exercise) during the
13 experimental sessions.

14 **Primary Outcome Measure**

15 The Stroop task (Stroop, 1935) is a speeded task that assesses executive functions
16 including information processing speed, short-term memory, attention, and inhibition and is
17 sensitive to the effects of acute exercise (Barella, Etnier, & Chang, 2010; Stroop, 1935;
18 Tomporowski, 2003). The task consisted of three computerised tests: 1) The Stroop Color (SC)
19 test, in which a string of the letter X was written in red, blue, yellow, or green ink and
20 participants were asked to verbally identify the color of each presentation; 2) The Stroop Word
21 (SW) Interference test, in which a series of color names printed in an ink color that did not match
22 the colour name are presented and participants are asked to read aloud the color of the ink; and 3)
23 The Stroop Inhibition (SI) test (also called the 'Negative Priming' condition [Stroop, 1935]),

1 whereby a series of color names are printed in an ink color that does not match the color name,
2 and participants must identify the color of the ink whilst ignoring the color name. This test is the
3 same as the SW Interference test, except that in the SI test, the color of the word for each trial is
4 the same as the word on the previous trial. The participants are asked to complete each task as
5 quickly and as accurately as possible, and a microphone installed on the computer transmitted
6 the participant's response. The participants completed 5 practice trials for each Stroop condition
7 during the initial familiarization session, and then repeated the 5 practice trials during the second
8 familiarization session. If the participants appeared to be experiencing difficulties performing the
9 practice trials, they were instructed to repeat the practice trials (Barella et al., 2010). The
10 participants completed 20 trials of each Stroop condition, and the order of presentation of the
11 Stroop conditions was randomized across the group. The dependant variable was reaction time
12 (RT) measured in milliseconds (ms) using vocal responses. E-Prime 2.0 software (Psychology
13 Software Tools, Pittsburgh, PA) was used to present stimuli and record verbal responses.
14 Erroneous data was dealt with as per Barella et al. (2010). In short, prior to analyses, erroneous
15 data, including undetected or non-relevant verbal responses, was manually identified and omitted
16 (Barella, et al., 2010).

17 **Exercise Condition**

18 Prior to exercising, resting HR was assessed and all participants completed the FS, FAS
19 and Stroop task (including 10 practice trials). The AE group participants were then asked to ride
20 a cycle ergometer (Monark Exercise AB, Sweden) at a comfortably intense workload (RPE 13 =
21 *somewhat hard* to 14 = *sweating, still able to talk, but don't want to*) and to adjust the speed
22 and/or resistance during the exercise bout if necessary to maintain this workload. An RPE of 13
23 to 14 was selected to ensure that participants exercised at a comfortable level below the

1 ventilatory threshold (Ekkekakis, 2009). The participants were frequently reminded during their
2 exercise session about the required exercise intensity (after approximately 2, 4, 6 and 8 minutes
3 in the 10 minute condition and after 5, 10, 15, 20 and 25 minutes in the 30 minute condition).

4 The participants in the RE group engaged in a circuit of 5 exercises using machines
5 (bench press, leg curls, seated row exercise, squat rack and bicep curls). The resistance exercises
6 began at an intensity of 60% of 1-RM. Participants performed each exercise for two minutes, and
7 passively rested for 30 seconds between exercises. Participants were asked to exercise at a
8 comfortably intense workload (RPE 13 = *somewhat hard* to 14 = *sweating, still able to talk, but*
9 *don't want to*) and were able to adjust the weight lifted during each set to maintain this workload.
10 The order of exercise condition (aerobic or resistance exercise) completion was counterbalanced
11 across the group.

12 **Initial Fitness Assessments**

13 **Graded, submaximal CRF test with 12-lead ECG.** The graded, submaximal CRF test
14 was performed on an electronically braked cycle ergometer (Lode, Groningen, Netherlands). The
15 test began with an initial workload of 20 watts (W), which then increased by 20 W every minute.
16 The test was terminated when a participant's RPE reached level 17, or prior if clinical signs or
17 symptoms of cardiorespiratory abnormalities appeared (American College of Sports Medicine,
18 2013). Expired respiratory gases were collected through a breath-by-breath (BxB) pneumotach
19 system connected to gas analysers (AEI Moxus Metabolic Cart 2010, AEI Technologies Inc.
20 Pittsburgh Pennsylvania). The BxB data was integrated for each 15-second interval, and the
21 mean values for oxygen consumption volume (VO_2), carbon dioxide expulsion volume (VCO_2)
22 and ventilatory rate (VE) were used for that interval. The gas analyser was calibrated
23 immediately before each test using gases that had been calibrated at alpha standard.

1 **Self-reported Physical Activity.** The 7-d PAR (Sallis et al., 1985) was also administered
2 to provide information about the participant's recent physical activity (PA). The 7-d PAR
3 assesses work and non-work related PA by asking participants to report how many hours they
4 spend in moderate, hard or very hard activity during the last week. The 7-d PAR has shown good
5 reliability and validity (Dishman & Steinhardt, 1988).

6 **Statistical analysis**

7 We conducted 2 (exercise mode: RE vs. AE) by 2 (duration: 10 mins [short] vs. 30 mins
8 [long]) by 4 (time: pre-exercise; immediate post-exercise; 30 mins post-exercise; 60 mins post-
9 exercise) mixed-model analysis of variance (ANOVA), with exercise mode as between-
10 participants factor and duration and time as within-participants factors, for RT in the SC test, SW
11 test, and SI test. Additionally, we conducted 2 (exercise mode: RE vs. AE) by 2 (duration: 10
12 mins [short] vs. 30 mins [long]) by 5 (time: pre-exercise; during exercise; immediate post-
13 exercise; 30 mins post-exercise; 60 mins post-exercise) mixed model ANOVA with repeated
14 measures on the last two factors for the dependent variables HR (beats per minute⁻¹ [bpm]), and
15 the FAS. In the instance of a significant time main effect, we conducted post-hoc comparisons
16 using Sidak. Paired sample *t*-tests were used to explore simple main effects. Two-tailed
17 independent samples *t*-tests were used to compare participant characteristics, aerobic fitness, and
18 physical activity levels between AE and RE. Data are presented as Mean (SD). Results were
19 considered significant at $p < 0.05$, and statistical analyses were performed using IBM SPSS
20 Statistics 21.0 (IBM, Somers, NY).

21 **Results**

22 **Participant Characteristics and Initial Assessments**

1 Participants' characteristics, their aerobic fitness, and 7-d PAR levels are summarised in
2 Table 1. There was no significant difference ($p > 0.05$) between the AE and RE groups in any of
3 these measures pre-exercise.

4 **Stroop Task**

5 Erroneous data accounted for $< 1\%$ of the total number of trials. This data was removed
6 prior to analyses. Stroop task data are summarised in Table 2.

7 **Stroop Color (SC) Task.** A significant time by exercise duration effect was observed in
8 the SC task ($F(3,87) = 6.29, p = .001, \eta_p^2 = .18$) (see Fig. 2A). Follow-up paired sample t-tests
9 for each measurement point showed that the short duration exercise bout resulted in significantly
10 faster RTs at 60 mins post-exercise compared to the long duration exercise bout ($t = 2.36, p =$
11 $.03$), whereas the long duration exercise bout was faster pre-exercise ($t = -2.12, p = .04$). Whilst
12 both groups improved from pre-exercise to immediately post-exercise (4% and 2% for the 10 and
13 30 min exercise bouts respectively) ($p < .05$), the participants in the short exercise bout condition
14 showed a RT reduction over time post-exercise that was marginally significant at 30 mins ($p =$
15 $.06$) and significant at 60 mins ($p = .01$) compared to pre-exercise levels. The participants in the
16 long exercise bout condition returned to pre-exercise levels 30 mins after the exercise bout and
17 performed worst at 60 mins post-exercise (+4%) compared to pre-exercise ($p = .14$). There were
18 no other main or interaction effects for the SC task ($p > .05$).

19 **Stroop Word (SW) Interference Task.** No main or interaction effects were found for
20 the SW task (see Table 2). The participants responded similarly across the 4 measurement points
21 independent of exercise mode or duration.

22 **Stroop Inhibition (SI) Task.** A significant time main effect was observed in the SI test
23 ($F(3,87) = 6.56, p < .001, \eta_p^2 = .18$) (see Fig. 2B). Post-hoc comparisons revealed that RT was

1 significantly shorter immediately post-exercise compared to pre-exercise. Independent of mode
2 or duration of exercise, the participants performed 5% faster post-exercise compared to pre-
3 exercise. Although not significantly different, performance was 3% and 2% faster after 30 and 60
4 mins post-exercise respectively compared to pre-exercise. RT increased 30 mins after exercise
5 when compared to immediately post-exercise ($p = .07$), and remained higher 60 mins after
6 exercise when compared to immediately post-exercise ($p = .05$). There was no significant
7 difference in RT between 30 and 60 mins after exercise. There were no other main or interaction
8 effects for the SI task ($p > .05$).

9 **Heart Rate**

10 There was a significant duration by exercise mode interaction ($F(1,25) = 4.56, p = .04, \eta_p^2$
11 $= .15$) and a significant time main effect ($F(4,216) = 199.4, p < .002, \eta_p^2 = .79$) (see Fig. 3). Post-
12 hoc comparisons did not show any differences for the interaction effect. However, post-hoc
13 comparisons for the time main effect showed that all time points were different from each other
14 ($p < .001$) for HR except pre-exercise with 30 mins post-exercise. No other main or interaction
15 effects for HR were found ($p > .05$). The average heart rate during exercise was between 106.5
16 and 111.1. Using the Karvonen formula we calculated the heart rate reserve (HRR) (mean age =
17 71 years; HR maximum = ± 150 bpm; resting HR = 65 bpm) for working at about 50 to 60% of
18 maximum HR. This indicates a HR between 107 and 116 bpm. Together with the use of RPE
19 scale (Level 13 – 14) to regulate exercise, this suggests that the participants exercised at a
20 moderate intensity.

21 **Felt Arousal Scale**

22 A significant time main effect was observed for arousal ($F(4,92) = 14.74, p < .001, \eta_p^2 =$
23 $.39$) (see Fig. 4). Post-hoc comparisons revealed that arousal was significantly higher during and

1 immediately post-exercise compared to all other measurement points (all $p < .05$). Arousal
2 returned to near-pre-exercise levels by 30 mins post-exercise. Arousal at 30 and 60 mins post-
3 exercise were not different. No other main or interaction effects for arousal were found ($p > .05$).

4 **Discussion**

5 Our study has shown the cognitive performance of older adults, including executive
6 functioning, can be improved with an acute bout of exercise. Our findings might indicate the
7 benefits generated from an acute bout of exercise are greatest for more complex cognitive tasks
8 than basic information processing tasks, as has previously been suggested (Hillman, Snook &
9 Jerome, 2003; McMorris et al., 2008; McMorris et al., 2011). This study extends the current
10 understanding of the influence of multiple moderator variables, namely mode of exercise,
11 duration of exercise, and timing of cognitive task, on cognitive performance following an acute
12 bout of exercise.

13 Improved executive functioning (SI task) was observed independent of the mode or
14 duration of exercise, with the greatest benefits (i.e. lowest reaction times) observed immediately
15 post-exercise. Chang, Labban et al. (2012) demonstrated executive function was improved when
16 measured during, immediately after and following a delay after exercise. The improved
17 performance of the Stroop Inhibition task immediately post-exercise demonstrated in our study
18 adds to a body of evidence supporting the positive influence of acute exercise on executive
19 function (Chang et al., 2011; Sibley, Etnier, & Le Masurier, 2006; Tomporowski, 2003). Despite
20 our findings, we consider the influence an acute bout of exercise has on executive function
21 remains equivocal. Given Barella et al. (2010) found only speed of processing was improved by
22 acute aerobic exercise, and Coles and Tomporowski (2008) demonstrated improvements only in

1 delayed long-term memory after an acute bout of exercise, we suggest that further clarification is
2 necessary.

3 Joyce, Graydon, McMorris & Davranche (2009) provided some evidence that exercise
4 can enhance executive functioning up to 52 minutes post cessation of a 30 min bout of moderate
5 intensity aerobic exercise. Although our study showed enhanced performance of the Stroop
6 Inhibition task of a similar magnitude at 30 and 60 mins, this was not significant. A possible
7 explanation for this was the high variability found in our study. This is, however, an important
8 issue which can have significant implications for the promotion of exercise guidelines for older
9 adults. In particular for older adults who may be physically deconditioned and have a limited
10 exercise capacity, regular, acute bouts of resistance training or aerobic exercise may be an
11 appropriate prescription not only for improved health and fitness, but also cognition. However,
12 this warrants further study.

13 The results of the present study supports the suggestion that exercise can equally benefit
14 basic information processing as well as more complex executive function tasks (Lambourne &
15 Tomporowski, 2010). Whilst we did not find a significant change in the performance of the
16 Word Interference tasks after exercise, we did find that exercise benefited executive functioning
17 (i.e. Stroop Inhibition test) and information processing speed (i.e. Stroop Color test).

18 Stroop Color task performance after the short exercise condition was better (lower
19 reaction times) at 60 mins post-exercise compared to the long exercise condition. Following a
20 meta-analysis including 2072 individuals ($M_{\text{age}} = 28.51$ years) across 79 studies (only 61 studies
21 reported mean age), it was reported that 11 to 20 mins of exercise resulted in the largest
22 cognitive benefits when cognitive performance was measured post-exercise (Chang, Labban, et
23 al., 2012). Our findings suggest as little as 10 mins of exercise is sufficient enough to improve

1 cognitive performance in older adults. The participants included in the aforementioned meta-
2 analyses were substantially younger than those in this study, and it is possible that the older
3 adults in our study presented with a reduced level of conditioning and might have required less
4 time exercising to elicit cognitive improvements.

5 Chang, Labban et al. (2012) reported significant cognitive benefits immediately after
6 very light, to moderate intensity exercise, but not after hard to maximal intensity exercise, and
7 further found exercise at all intensities except very light, resulted in improved cognition
8 following a post-exercise delay. Our results appear to support such reports, with the older adults
9 in this study exercising at a comfortably intense workload (13 to 14 on the rating of perceived
10 exertion scale) and were able to self-adjust the workload so as to maintain a consistent level of
11 exercise intensity. Our study also suggests that self-regulation of exercise intensity results in
12 similar cognitive benefits (5% improvement) as experimenter-defined exercise intensity
13 (Edwards & Polman, 2013).

14 It is beyond the scope of this study to explain the possible bio-physiological mechanisms
15 underlying the improved cognitive performance following an acute bout of moderate intensity
16 exercise. However, exercise and/or arousal-induced alterations in lateral prefrontal cortex neural
17 activity (Yanagisawa et al., 2010), biochemical release (Chang et al., 2014; Hillman et al., 2009)
18 and cerebral blood flow (MacIntosh et al., 2014) may be posited. Our findings are consistent
19 with proposed neuroendocrinological explanations of the relationship between exercise and
20 cognitive functioning (see McMorris & Hale, 2012 and McMorris et al., 2011). That is, moderate
21 intensity exercise is said to stimulate stimulates levels of arousal and activation that result in the
22 optimal release of catecholamines, such as dopamine and norepinephrine, and enhance cognition
23 (the catecholamines hypothesis [McMorris et al., 2008]). The influence, and interactive effect, of

1 other moderators, such as exercise intensity, nutritional status, individual and group
2 characteristics, and other measures of cognitive performance remain unclear and require
3 examination. Furthermore, the potential interactive effects of the moderators involved in this
4 study suggest a cautious approach should be taken when interpreting our results. However, our
5 findings are congruent with previous work in this area and supports previous suggestions that
6 moderate intensity exercise is most beneficial for executive function (Chang & Etnier, 2009).

7 We are mindful that the small sample size included in this study, the between-subject
8 design of our study, and the variability of outcomes found, limit the conclusions that can be
9 drawn from this work. Finally, the absence of a control condition makes it difficult to distinguish
10 the change in cognitive performance from learning effects, though the inclusion of
11 familiarization sessions with the cognitive assessment was intended to minimize any effects of
12 learning.

13 **Conclusion**

14 Cognitive vitality is central for independent living and health-related quality of life.
15 Declining cognitive ability is of concern for older adults. Regular physical activity can moderate
16 this age-related decline, and our research builds on an emerging body of evidence that suggests a
17 short, single bout of moderate-intensity aerobic or resistance exercise has immediate benefits on
18 cognition. Our findings lend support to the current exercise prescription guidelines for older
19 adults and enhance the evidence for exercise to promote cognition. Future studies should
20 examine the influence of exercise frequency, and cognitive task complexity on cognitive
21 performance.

22 **Conflicts of interest**

23 The authors report no conflicts of interest.

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6 **References**

- 7 American College of Sports Medicine (ACSM). (2013). *ACSM's guidelines for exercise testing
 8 and prescription* (9th ed.). Lippincott Williams & Wilkins: Philadelphia.
- 9 Barella, L.A., Etnier, J.L., & Chang, Y.K. (2010). The immediate and delayed effects of an acute
 10 bout of exercise on cognitive performance of healthy older adults. *Journal of Aging and
 11 Physical Activity*, *18*(1), 87-98.
- 12 Biddle, S.J.H., Fox, K.R., & Boutcher S.H. (2000). *Physical activity and psychological well
 13 -being*. London: Routledge.
- 14 Borg, G. (1970). Perceived exertion as an indicator of somatic stress. *Scandinavian Journal of
 15 Rehabilitation Medicine*, *2*(2), 92-98.
- 16 Chang, Y.K., Chu, C.H., Wang, C.C., Wang, Y.C., Song, T.F., Tsai, C.L., & Etnier, J.L. (2015).
 17 Dose-response relation between exercise duration and cognition. *Medicine and Science in
 18 Sports and Exercise*, *47*(1), 159-165. doi:10.1249/MSS.0000000000000383.
- 19 Chang, Y.K., & Etnier, J.L. (2009). Exploring the dose-response relationship between resistance
 20 exercise intensity and cognitive function. *Journal of Sport and Exercise Psychology*,
 21 *31*(5), 640-656.

- 1 Chang, Y.K., Ku, P.W., Tomporowski, P.D., Chen, F.T., & Huang, C.C. (2012). Effects of acute
2 resistance exercise on late-middle-age adults' goal planning. *Medicine and Science in*
3 *Sports and Exercise, 44*(9), 1773-1779. doi:10.1249/MSS.0b013e3182574e0b.
- 4 Chang, Y.K., Labban, J.D., Gapin, J.I., & Etnier, J.L. (2012). The effects of acute exercise on
5 cognitive performance: a meta-analysis. *Brain Research, 1453*, 87-101.
6 doi:10.1016/j.brainres.2012.02.068.
- 7 Chang, Y.K., Tsai, C.L., Hung, T.M., So, E.C., Chen, F.T., & Etnier, J.L. (2011). Effects of
8 acute exercise on executive function: a study with a tower of London task. *Journal of*
9 *Sport and Exercise Psychology, 33*(6):847-865.
- 10 Chang, Y.K., Tsai, C.L., Huang, C.C., Wang, C.C., & Chu, I.H. (2014). Effects of acute
11 resistance exercise on cognition in late middle-aged adults: general or specific cognitive
12 improvement? *Journal of Science and Medicine in Sports, 17*(1), 51-55.
13 doi:10.1016/j.jsams.2013.02.007.
- 14 Coles, K., & Tomporowski, P.D. (2008). Effects of acute exercise on executive processing,
15 short-term and long-term memory. *Journal of Sports Sciences, 26*(3):333-344.
16 doi:10.1080/02640410701591417
- 17 Davey, C.P. (1973). Physical exertion and mental performance. *Ergonomics, 16*(5), 595-599.
- 18 Dietrich, A. (2003). Functional neuroanatomy of altered states of consciousness: the transient
19 hypofrontality hypothesis. *Consciousness and Cognition, 12*(2), 231-256.
20 doi:10.1016/S1053-8100(02)00046-6
- 21 Dietrich, A., & Audiffren, M. (2011). The reticular-activating hypofrontality (RAH) model of
22 acute exercise. *Neuroscience and Biobehavioral Reviews, 35*(6), 1305-1325.
23 doi:10.1016/j.neubiorev.2011.02.001.

- 1 Dishman, R.K., & Steinhardt, M. (1988). Reliability and concurrent validity for a 7-d re-call of
2 physical activity in college students. *Medicine and Science in Sports and Exercise*, 20(1),
3 14-25.
- 4 Edwards, A.M., & Polman, R.C.J. (2013). Pacing and awareness: brain regulation of physical
5 activity. *Sports Medicine*, 43(11), 1057-1064. doi:10.1007/s40279-013-0091-4.
- 6 Ekkekakis, P. (2009). Let them roam free? physiological and psychological evidence for the
7 potential of self-selected exercise intensity in public health. *Sports Medicine*, 39(10),
8 857-888. doi:10.2165/11315210-000000000-00000.
- 9 Ekkekakis, P., Hall, E.E., VanLanduyt, L.M., & Petruzzello, S.J. (2000). Walking in (affective)
10 circles: can short walks enhance affect? *Journal of Behavioral Medicine*, 23(3), 245-275.
11 doi:10.1023/A:1005558025163.
- 12 Etnier, J.L., Salazar, W., Landers, D.M., Petruzzello, S.J., Han, M., & Nowell, P. (1997). The
13 influence of physical fitness and exercise upon cognitive functioning: a meta-analysis.
14 *Journal of Sport and Exercise Psychology*, 19, 249-277.
- 15 Folstein, M.F., Folstein, S.E., & McHugh, P.R. (1975). "Mini mental state". a practical method
16 for grading the cognitive state of patients for the clinician. *Journal of Psychiatric*
17 *Research*, 12(3), 189-198. doi:10.1016/0022-3956(75)90026-6.
- 18 Hall, E.E., Ekkekakis, P., & Petruzzello, S.J. (2002). The affective beneficence of vigorous
19 exercise revisited. *British Journal of Health Psychology*, 7(1):47-66.
20 doi:10.1348/135910702169358.
- 21 Hillman, C.H., Pontifex, M.B., Raine, L.B., Castelli, D.M., Hall, E.E., & Kramer, A.F. (2009).

- 1 The effect of acute treadmill walking on cognitive control and academic achievement in
2 preadolescent children. *Neuroscience*, 159(3), 1044-1054.
3 doi:10.1016/j.neuroscience.2009.01.057.
- 4 Hillman, C.H., Snook, E.M., & Jerome, G.J. (2003). Acute cardiovascular exercise and executive
5 control function. *International Journal of Psychophysiology*, 48(3), 307-314.
- 6 Joyce, J., Graydon, J., McMorris, T., & Davranche, K. (2009). The time course effect of
7 moderate intensity exercise on response execution and response inhibition. *Brain and*
8 *Cognition*, 71(1), 14-19. doi:10.1016/j.bandc.2009.03.004.
- 9 Kerr, J.H., & van den Wollenberg, A. (1997). High and low intensity exercise and psychological
10 mood states. *Psychology and Health*, 12(5), 603-618. doi:10.1080/08870449708407409.
- 11 Lambourne, K., & Tomporowski, P. (2010). The effect of exercise-induced arousal on cognitive
12 task performance: a meta-regression analysis. *Brain Research*, 1341, 12-24.
13 doi:10.1016/j.brainres.2010.03.091.
- 14 Lucas, S.J.E., Ainslie, P.N., Murrell, C.J., Thomas, K.N., Franz, E.A., & Cotter, J.D. (2012).
15 Effect of age on exercise-induced alterations in cognitive executive function: relationship
16 to cerebral perfusion. *Experimental Gerontology*, 47(8), 541-551.
17 doi:10.1016/j.exger.2011.12.002.
- 18 MacIntosh, B.J., Crane, D.E., Sage, M.D., Rajab, A.S., Donahue, M.J., McIlroy, W.E., &
19 Middleton, L.E. (2014). Impact of a single bout of aerobic exercise on regional brain
20 perfusion and activation responses in healthy young adults. *PLoS One*, 9(1), e85163.
21 doi:10.1371/journal.pone.0085163.

- 1 McMorris, T., Collard, K., Corbett, J., Dicks, M., & Swain, J.P. (2008). A test of the
2 catecholamines hypothesis for an acute exercise-cognition interaction. *Pharmacology,*
3 *Biochemistry and Behavior*, 89(1), 106-115. doi:10.1016/j.pbb.2007.11.007.
- 4 McMorris, T., & Hale, B.J. (2012). Differential effects of differing intensities of acute exercise
5 on speed and accuracy of cognition: a meta-analytical investigation. *Brain and Cognition*,
6 80(3), 338-351. doi:10.1016/j.bandc.2012.09.001.
- 7 McMorris, T., Sproule, J., Turner, A., & Hale, B.J. (2011). Acute, intermediate intensity
8 exercise, and speed and accuracy in working memory tasks: a meta-analytical comparison
9 of effects. *Physiology and Behavior*, 102(3-4), 421-428.
10 doi:10.1016/j.physbeh.2010.12.007.
- 11 Pate, R.R., Pratt, M., Blair, S.N., Haskell, W.L., Macera, C.A., Bouchard, C., ... Wilmore, J.H.
12 (1995). Physical activity and public health - a recommendation from the centers for
13 disease control and prevention and the American college of sports medicine. *The Journal*
14 *of the American Medical Association*, 273(5), 402-407.
15 doi:10.1001/jama.1995.03520290054029.
- 16 Phillips, W.T., Betterham, A.M., Valenzuela, J.E., & Burkett, L.N. (2004). Reliability of maximal
17 strength testing in older adults. *Archives of Physical Medicine and Rehabilitation*, 85(2),
18 329-334. doi:10.1016/j.apmr.2003.05.010.
- 19 Pontifex, M.B., Hillman, C.H., Fernhall, B., Thompson, K.M., & Valentini, T.A. (2009). The
20 effect of acute aerobic and resistance exercise on working memory. *Medicine and*
21 *Science in Sports and Exercise*, 41(4), 927-934. doi:10.1249/MSS.0b013e3181907d69.
- 22 Sallis, J.F., Haskell, W.L., Wood, P.D., Fortmann, S.P., Rodgers, T., Blair, S.N., & Paffenbarger,

- 1 R.S. Jr. (1985). Physical activity assessment methodology in the five-city project.
2 *American Journal of Epidemiology*, 121(1), 91-106.
- 3 Sibley, B.A., Etnier, J.L., & Le Masurier, G.C. (2006). Effects of an acute bout of exercise on
4 cognitive aspects of stroop performance. *Journal of Sport and Exercise Psychology*,
5 28:285-299.
- 6 Stroop, J.R. (1935). Studies of interference in serial verbal reactions. *Journal of Experimental*
7 *Psychology*, 18, 643-662.
- 8 Svebak, S., & Murgatroyd, S. (1985). Metamotivational dominance - a multimethod validation of
9 reversal theory constructs. *Journal of Personality and Social Psychology*, 48(1), 107-116.
- 10 Thompson, G., & Foth D. (2005). Cognitive-training programs for older adults: what are they
11 and can they enhance mental fitness? *Educational Gerontology*, 31(8), 603-626.
12 doi:10.1080/03601270591003364.
- 13 Tomporowski, P.D. (2003). Effects of acute bouts of exercise on cognition. *Acta Psychologica*,
14 112(3), 297-324. doi:10.1016/S0001-6918(02)00134-8
- 15 Weng, T.B., Pierce, G.L., Darling, W.G., & Voss, M.W. (2015). Differential effects of acute
16 exercise on distincts aspects of executive function. *Medicine and Science in Sports and*
17 *Exercise*, 47(7), 1460-1469. doi:10.1249/MSS.0000000000000542.
- 18 Yanagisawa, H., Dan, I., Tsuzuki, D., Kato, M., Okamoto, M., Kyutoku, Y., & Soya, H. (2010).
19 Acute moderate exercise elicits increased dorsolateral prefrontal activation and improves
20 cognitive performance with stroop test. *NeuroImage*, 50(4):1702-1710.
21 doi:10.1016/j.neuroimage.2009.12.023.
- 22 Yerkes, R.M., & Dodson, J.D. (1908). The relation of strength of stimulus to the rapidity of
23 habitat formation. *Journal of Comparative Neurology and Psychology*, 18, 459-482.

1 **Figure 1** - Study Protocol. *Note:* RPE = rating of Perceived Exertion; RM = Repetition
2 Maximum; MMSE = Mini Mental State Examination; 7-d PAR = 7-day Physical Activity Recall;
3 HR = Heart rate; FS = Feeling Scale; FAS = Felt Arousal Scale.

4 **Figure 2A** - Average completion time (ms) for the two exercise durations (dark is 10 mins
5 [short]; light is 30 mins [long]) independent of exercise mode for the Stroop Color (SC) task at
6 pre-exercise, immediately post-exercise, and at 30 and 60 mins post-exercise (PE). All values are
7 displayed as Mean (SD). (α) indicates between exercise-duration group significance of $p < 0.05$.

8 **Figure 2B** - Average completion time (in milliseconds [ms]) independent of exercise mode or
9 duration for the Stroop Inhibition task at pre-exercise, immediately post-exercise, and at 30 and
10 60 mins post-exercise (PE). All values are displayed as Mean (SD). (*) indicates between-time-
11 point significance of $p < 0.05$ relative to pre-exercise.

12 **Figure 3** - Average heart rate (bpm) of the participants for each exercise mode and duration at
13 pre-exercise, during exercise, immediately post-exercise, and 30 and 60 mins post-exercise (PE).
14 All values are displayed as Mean (SD). Note, there were only measurement point differences
15 with all being significantly different except pre-exercise and 30 mins post-exercise.

16 **Figure 4** - Average arousal of the participants independent of exercise mode or duration at pre-
17 exercise, during exercise, immediately post-exercise, and 30 and 60 mins post-exercise (PE). All
18 values are displayed as Mean (SD). (*) indicates measurement point differences of $p < 0.05$
19 relative to pre-exercise; (^) indicates measurement point differences of $p < 0.05$ relative to 30
20 Min PE; (#) indicates measurement point differences of $p < 0.05$ relative to 60 Min PE.

Table 1 Participant characteristics, fitness and physical activity levels

	Exercise condition		<i>t</i> ₂₉	<i>p</i>
	Aerobic (<i>n</i> = 17; 11 F, 6 M)	Resistance (<i>n</i> = 14; 10 F, 4 M)		
Age (years)	72.3 (7.4)	71.0 (9.6)	0.43	.67
MMSE	29.1 (1.4)	29.4 (0.7)	-0.72	.48
VO ₂ peak (ml·kg ⁻¹ ·min ⁻¹)	20.7 (6.0)	17.5 (6.5)	0.73	.48
Moderate PA (hours·week ⁻¹)	7.8 (3.9)	8.5 (9.2)	0.30	.77
Hard PA (hours·week ⁻¹)	2.1 (2.4)	4.1 (6.0)	1.22	.23
Very hard PA (hours·week ⁻¹)	0.5 (1.3)	0.3 (0.8)	0.64	.35

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2 *Note.* Data presented as Mean (SD); F = Females; M = Males; MMSE = Mini Mental State
3 Examination; PA = Physical Activity.

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1 **Table 2**

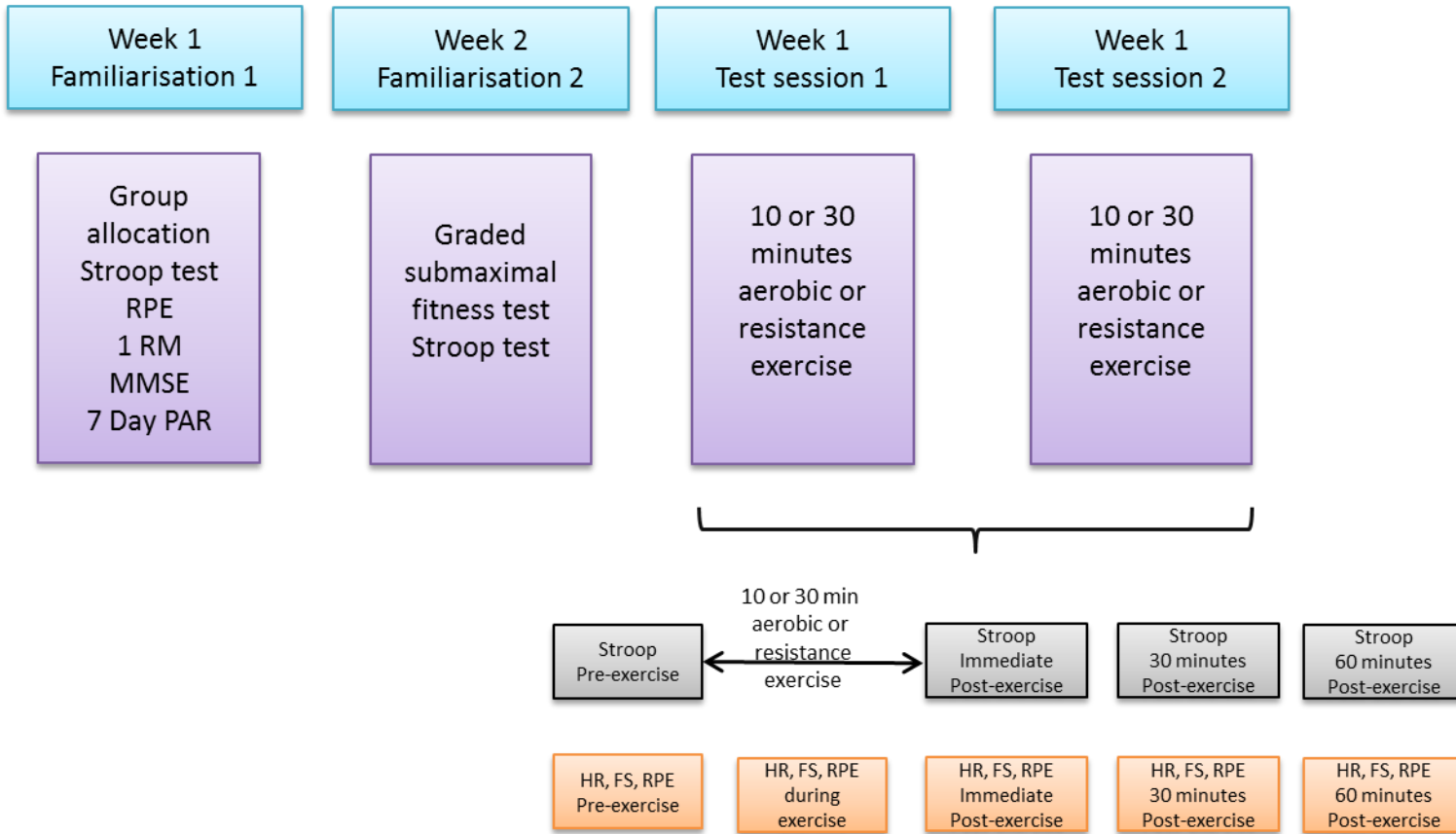
		Reaction time (ms)			
Test	Exercise condition	Baseline	Immediately PE	30 mins PE	60 mins PE
Stroop Color	Aerobic 10	646.29 (125.14)	605.74 (69.57)	604.84 (92.83)	594.08 (67.67)
	Resistance 10	640.38 (105.64)	625.98 (68.77)	631.15 (71.16)	610.51 (78.07)
	Aerobic 30	616.47 (83.99)	596.86 (75.42)	600.01 (98.51)	627.86 (109.63)
	Resistance 30	611.74 (77.77)	611.42 (86.86)	625.75 (88.94)	650.11 (115.69)
Stroop Word Interference	Aerobic 10	625.03 (171.11)*	594.33 (143.57)	583.80 (73.02)	572.67 (91.20)*
	Resistance 10	650.61 (84.70)*	625.22 (90.45)	631.16 (92.71)	591.49 (88.47)*
	Aerobic 30	575.33 (91.28)*	585.57 (104.01)	626.53 (123.38)	593.47 (102.76)*
	Resistance 30	607.84 (115.18)*	620.57 (105.56)	598.89 (93.54)	614.06 (112.14)*
Stroop Inhibition	Aerobic 10	817.22 (129.26) [¥]	768.46 (117.19) [¥]	807.41 (130.88)	794.69 (125.22)
	Resistance 10	805.26 (121.88) [¥]	774.25 (82.91) [¥]	791.66 (120.73)	779.44 (99.43)
	Aerobic 30	815.36 (152.10) [¥]	764.80 (119.48) [¥]	784.68 (124.81)	793.59 (138.28)
	Resistance 30	846.99 (152.78) [¥]	810.18 (124.60) [¥]	813.60 (93.86)	840.52 (115.60)

2 *Note.* Data presented as Mean (SD); ms = milliseconds; PE = post-exercise; mins = minutes * Duration main effect (short vs. long);
3 time main effect

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1 **Figure 1: Study design**

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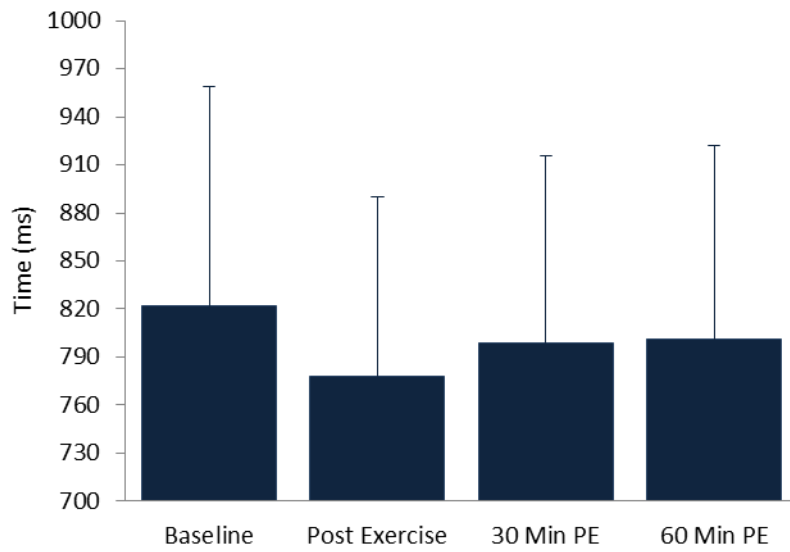


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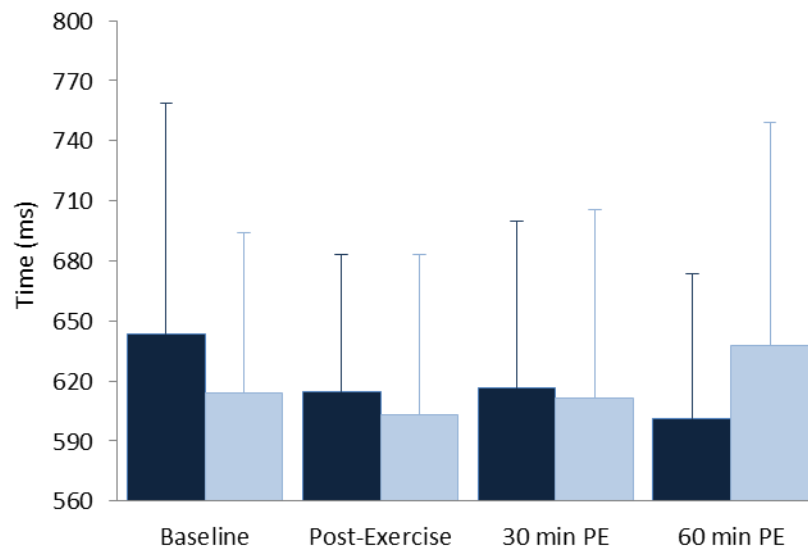
1 **Figure 2a: Completion time SC task.**



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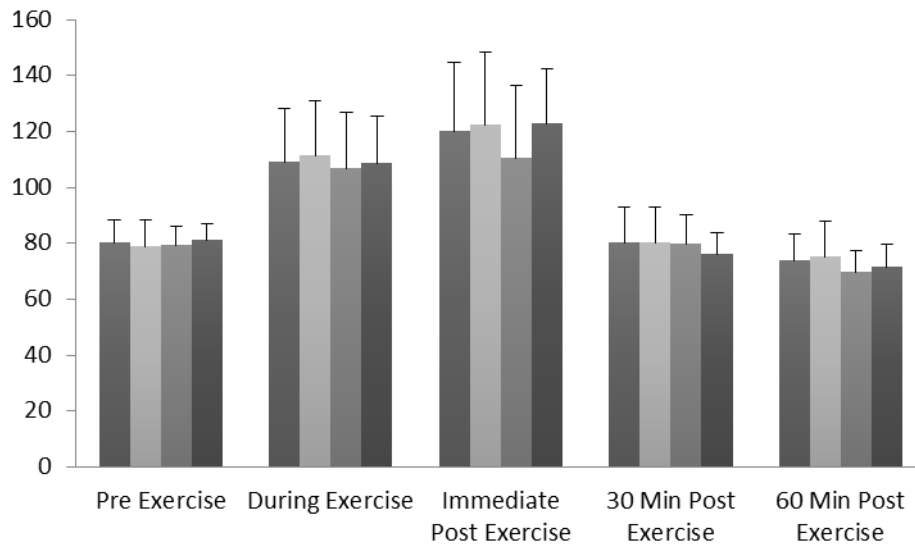
4 **Figure 2b: Completion time Inhibition task**



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1 **Figure 3: Average Heart Rate**

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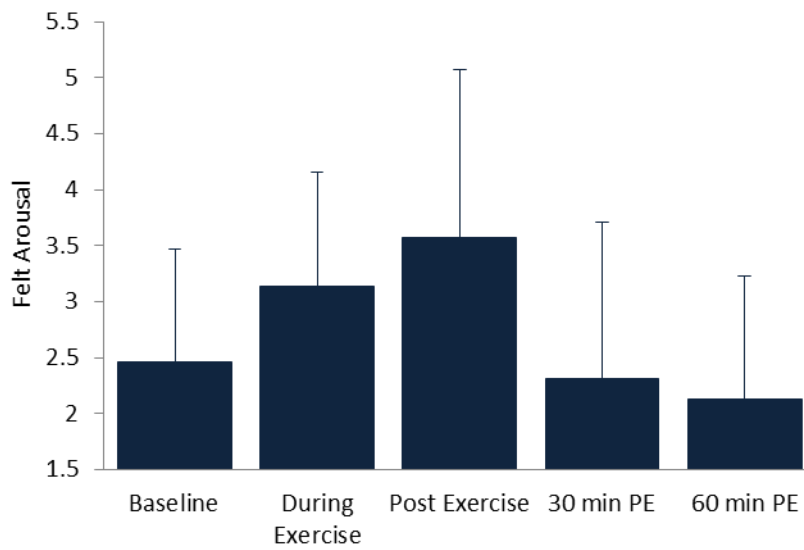


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5 **Figure 4: Average Arousal**

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