An Acute Bout of Exercise Improves the Cognitive Performance of Older Adults.

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

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.

Introduction

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

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

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

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

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

Despite the emerging body of evidence comparing the immediate and delayed effects of an acute bout of aerobic or resistance exercise on cognitive performance of older adults, several questions remain unanswered. These include the time course of change, magnitude of effects and the influence and interaction of several moderator variables, such as the mode (Tomporowski, 2003), intensity and duration of the exercise session (Chang, Labban, et al., 2012; Tomporowski, 2003), the timing and type of cognitive assessment (Chang, Labban, et al., 2012; Lambourne & Tomporowski, 2010). Improving our understanding of the influence of these moderators could provide insights into the potential mechanisms of the effects observed and aid the development of exercise recommendations to optimize cognitive benefits. Furthermore, given that older adults may lack the physical conditioning to perform physical activity for 30 mins (or more) in duration, the effect of a 10-min acute bout of exercise compared to a 30-min bout of exercise on the cognitive functioning of older adults warrants investigation.

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

Method

Participants

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

Study Design

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

For each of the two experimental sessions, the participants were asked to complete the Stroop task (pre-exercise condition), and then immediately engage in their assigned exercise condition for either 10 or 30 mins (with the alternative duration completed in the second experimental session). The participants then completed the Stroop task at three time points after exercise (immediately after, 30 mins after and 60 mins after). The participants heart rates (HRs) were measured continuously using a heart rate monitor (Polar A3, Kempele, Finland) worn by the participant. The pre, immediately post-, 30 mins post- and 60 mins post-exercise HR recordings were based on a single time-point, whilst the during-exercise HR recording was an average of the participants HR during the exercise session. The Felt Arousal Scale (FAS) (Svebak & Murgatroyd, 1985) is a single-item, 6-point scale (ranging from 1 = *low arousal* to 6 = *high arousal*) measuring perceived activation (Ekkekakis, Hall, VanLanduyt, & Petruzello, 2000). The FAS has demonstrated moderate to strong correlations with other measures of arousal (Hall, Ekkekakis, & Petruzello, 2002), and has previously been used in exercise-related studies (Hall et al., 2002; Kerr & van den Wollenberg, 1997), but how it is associated with an acute bout of exercise by older adults is largely unknown. The FAS score was recorded at five time points (pre, during [the FAS was measured at the 5- and 15-min mark of the 10 and 30 minute treatment conditions respectively], immediately post-, 30 mins post-, and 60 mins post-exercise) during the experimental sessions.

Primary Outcome Measure

The Stroop task (Stroop, 1935) is a speeded task that assesses executive functions including information processing speed, short-term memory, attention, and inhibition and is sensitive to the effects of acute exercise (Barella, Etnier, & Chang, 2010; Stroop, 1935; Tomporowski, 2003). The task consisted of three computerised tests: 1) The Stroop Color (SC) test, in which a string of the letter X was written in red, blue, yellow, or green ink and participants were asked to verbally identify the color of each presentation; 2) The Stroop Word (SW) Interference test, in which a series of color names printed in an ink color that did not match the colour name are presented and participants are asked to read aloud the color of the ink; and 3) The Stroop Inhibition (SI) test (also called the 'Negative Priming' condition [Stroop, 1935]), whereby a series of color names are printed in an ink color that does not match the color name, and participants must identify the color of the ink whilst ignoring the color name. This test is the same as the SW Interference test, except that in the SI test, the color of the word for each trial is the same as the word on the previous trial. The participants are asked to complete each task as quickly and as accurately as possible, and a microphone installed on the computer transmitted the participant's response. The participants completed 5 practice trials for each Stroop condition during the initial familiarization session, and then repeated the 5 practice trials during the second familiarization session. If the participants appeared to be experiencing difficulties performing the practice trials, they were instructed to repeat the practice trials (Barella et al., 2010). The participants completed 20 trials of each Stroop condition, and the order of presentation of the Stroop conditions was randomized across the group. The dependant variable was reaction time (RT) measured in milliseconds (ms) using vocal responses. E-Prime 2.0 software (Psychology Software Tools, Pittsburgh, PA) was used to present stimuli and record verbal responses. Erroneous data was dealt with as per Barella et al. (2010). In short, prior to analyses, erroneous data, including undetected or non-relevant verbal responses, was manually identified and omitted (Barella, et al., 2010).

Exercise Condition

Prior to exercising, resting HR was assessed and all participants completed the FS, FAS and Stroop task (including 10 practice trials). The AE group participants were then asked to ride a cycle ergometer (Monark Exercise AB, Sweden) at a comfortably intense workload (RPE 13 = *somewhat hard* to 14 = *sweating, still able to talk, but don't want to*) and to adjust the speed and/or resistance during the exercise bout if necessary to maintain this workload. An RPE of 13 to 14 was selected to ensure that participants exercised at a comfortable level below the ventilatory threshold (Ekkekakis, 2009). The participants were frequently reminded during their exercise session about the required exercise intensity (after approximately 2, 4, 6 and 8 minutes in the 10 minute condition and after 5, 10, 15, 20 and 25 minutes in the 30 minute condition).

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

Initial Fitness Assessments

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

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

Statistical analysis

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

Results

Participant Characteristics and Initial Assessments

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

Stroop Task

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

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

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

Stroop Inhibition (SI) Task. A significant time main effect was observed in the SI test ($F(3,87) = 6.56$, $p < .001$, $\eta_p^2 = .18$) (see Fig. 2B). Post-hoc comparisons revealed that RT was significantly shorter immediately post-exercise compared to pre-exercise. Independent of mode or duration of exercise, the participants performed 5% faster post-exercise compared to pre-exercise. Although not significantly different, performance was 3% and 2% faster after 30 and 60 mins post-exercise respectively compared to pre-exercise. RT increased 30 mins after exercise when compared to immediately post-exercise (p = .07), and remained higher 60 mins after exercise when compared to immediately post-exercise (p = .05). There was no significant difference in RT between 30 and 60 mins after exercise. There were no other main or interaction effects for the SI task (p > .05).

Heart Rate

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

Felt Arousal Scale

A significant time main effect was observed for arousal ($F(4,92) = 14.74$, $p < .001$, $\eta_p^2 = .39$) (see Fig. 4). Post-hoc comparisons revealed that arousal was significantly higher during and immediately post-exercise compared to all other measurement points (all $p < .05$). Arousal returned to near-pre-exercise levels by 30 mins post-exercise. Arousal at 30 and 60 mins post-exercise were not different. No other main or interaction effects for arousal were found ($p > .05$).

Discussion

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

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

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

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

Stroop Color task performance after the short exercise condition was better (lower reaction times) at 60 mins post-exercise compared to the long exercise condition. Following a meta-analysis including 2072 individuals (M_{age} = 28.51 years) across 79 studies (only 61 studies reported mean age), it was reported that 11 to 20 mins of exercise resulted in the largest cognitive benefits when cognitive performance was measured post-exercise (Chang, Labban, et al., 2012). Our findings suggest as little as 10 mins of exercise is sufficient enough to improve cognitive performance in older adults. The participants included in the aforementioned meta-analyses were substantially younger than those in this study, and it is possible that the older adults in our study presented with a reduced level of conditioning and might have required less time exercising to elicit cognitive improvements.

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

It is beyond the scope of this study to explain the possible bio-physiological mechanisms underlying the improved cognitive performance following an acute bout of moderate intensity exercise. However, exercise and/or arousal-induced alterations in lateral prefrontal cortex neural activity (Yanagisawa et al., 2010), biochemical release (Chang et al., 2014; Hillman et al., 2009) and cerebral blood flow (MacIntosh et al., 2014) may be posited. Our findings are consistent with proposed neuroendocronological explanations of the relationship between exercise and cognitive functioning (see McMorris & Hale, 2012 and McMorris et al., 2011). That is, moderate intensity exercise is said to stimulate stimulates levels of arousal and activation that result in the optimal release of catecholamines, such as dopamine and norepinephrine, and enhance cognition (the catecholamines hypothesis [McMorris et al., 2008]). The influence, and interactive effect, of other moderators, such as exercise intensity, nutritional status, individual and group characteristics, and other measures of cognitive performance remain unclear and require examination. Furthermore, the potential interactive effects of the moderators involved in this study suggest a cautious approach should be taken when interpreting our results. However, our findings are congruent with previous work in this area and supports previous suggestions that moderate intensity exercise is most beneficial for executive function (Chang & Etnier, 2009).

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

Conclusion

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

Conflicts of interest

The authors report no conflicts of interest.

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

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

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

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

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