**Abstract**

Two studies have tested the moderators between acute exercise and executive function gains. In study 1, sixty participants were assigned to two groups and performed a handgrip squeezing task at 30% of their Maximal Voluntary Contraction (MVC) or a stepping task to the cadence of a metronome. Rate of perceived exertions (RPE) and heart rate (HR) were measured at 30s intervals. Trail-making test (TMT) was administered prior to task performance, following RPE = 6 and RPE = 9. In study 2, eighty three participants were assigned to one of five groups. They performed either a handgrip squeezing task or a stepping task up to RPE = 6 or RPE = 9. Participants in the control group have not been engaged in any exercise tasks. Measures of executive function were administered at rest, immediately following exercise tasks, and after 15min delay. Results from study 1 revealed that both the handgrip squeezing and stepping tasks improved TMT scores after RPE = 9 (*p* < .001). In study 2, executive function scores improved following the handgrip and stepping tasks regardless of the exercise intensity. The control condition resulted in similar results to that of the handgrip and stepping conditions. These findings help delineate the role of moderators in the acute exercise-cognitive gains linkage. Alternative “control” conditions must be tested for broader conclusions and implications.

**Keywords**: RPE, TMT, Acute exercise, Executive function

**Effects of Acute Exercise Bouts on Executive Function: Testing the Moderators**

Evidence from research findings and meta-analytic reviews suggest some beneficial effect of acute exercise bouts on cognitive functioning (Brisswalter, Collardeau, & René, 2002; Chang, Labban, Gapin, & Etnier, 2012; Etnier et al., 1997). Specifically, acute exercise bouts seem to facilitate scores on higher-order cognitive functions, such as inhibitory control (Hillman et al., 2009), and lower-order cognitive functions, including speed of processing (Chang & Etnier, 2009), and reaction time (Pontifex, Hillman, Fernhall, Thompson, & Valentini, 2009).

Moderators between acute exercise and its cognitive effects include exercise intensity, type of cognitive task and timing of its administration (i.e., when it is administered), the study’s design, and the type of exercise (Chang et al., 2012; Lambourne & Tomporowski, 2010). Nevertheless, the effects of acute exercise on cognitive functioning and the role of moderators in this relationship remain unclear with a string of equivocal findings (Chang et al., 2012; Lambourne, Audiffren, & Tomporowski, 2010). To capture the role of these moderators in the acute exercise-cognitive effects linkage, we conducted two studies and measured the effects of several moderators on cognitive outcomes following acute bouts of exercise.

Building on the moderators, experiencing cognitive benefits following acute exercise is thought to depend on the exercise intensity. As opposed to low intensity protocols, both moderate (Barella, Etnier, & Chang, 2010) and high intensity exercise tasks (Lambourne et al., 2010) were shown to benefit some cognitive processes, but not all (Barella et al., 2010). Cognitive benefits following acute exercise also depend on the type of cognitive task performed and its timing of administration (Etnier et al., 1997; Lambourne & Tomporowski, 2010). To that end, while some suggested that acute exercise benefits cognition on the Modified Flanker task (Hillman et al., 2009), others reported no effects of exercise on the Stroop Test (Barella et al., 2010). Also, significantly larger effects were noted for executive function tasks than for alternative cognitive tasks such as information processing, reaction time, and memory (Chang et al., 2012). Meta-analysis results have also revealed that cognitive performance seems impaired when measured during exercise and improved when measured following exercise (Lambourne & Tomporowski, 2010). Cognitive gains in the first 10min, after 11-20min, and after 20min of exercise were shown to be minor, negative, and positive, respectively (Chang et al., 2012). Likewise, while some suggested that cognitive processes improve when measured following exercise (Hillman et al., 2009), others have failed to replicate these findings (Barella et al., 2010; Chang & Etnier, 2009).

The type of exercise is an additional moderator which must be taken into account when testing acute exercise effects on cognitive processes (Lambourne & Tomporowski, 2010). Smaller effects sizes were noted following treadmill running than ergometer cycling protocols (Lambourne & Tomporowski, 2010). Others have also argued that anaerobic and muscular resistance exercise result in negative effects, but have warranted for replicating these findings (Chang et al., 2012).

To that end, Chang et al. (2012) have noted the reliance on objective physiological measures, such as heart rate and/or oxygen consumption, as a major issue related to the study of exercise effect on cognitive function. Accordingly, objective measures present methodological advantages, but fail to account for the *perception* of exercise/effort intensity. It is in fact the rate of perceived exertion (RPE) that determines perceived fatigue and exertion in individuals (Robertson & Noble, 1997). Moreover, RPE increases gradually under any type of exercise, be it strength or endurance. In contrast, changes in HR or VO2 during the on-going effort fail to distinguish the effort perception between strength and endurance tasks. Thus, in the present study, we used RPE as a reliable and primary measure of exercise intensity, and HR as a secondary measure.

Last, further adding to the methodological concerns, early meta-analysis has indicated that as the rigor of the experimental methods increase, the effect sizes associated with the findings decrease (Etnier et al., 1997). Others have also suggested smaller effects for studies with control conditions and reiterated the need to systemically investigate those effects (Lambourne & Tomporowski, 2010). Similarly, randomized control trials, as well as observational studies that compare cognitive performance pre and post exercise without random assignment to exercise conditions, have yielded the largest effects (Chang et al., 2012).

Given the inconsistency of the findings related to moderators and their effects within the acute exercise-cognition relationship, there is a need to empirically examine these moderators and assess their influence (Chang et al., 2012; Lambourne & Tomporowski, 2010). The purpose of the present studies was to further explore the moderators of the acute exercise-cognitive processes link. The effects of acute exercise on cognitive functioning were tested across a range of exercise types and exercise intensities, cognitive tasks, and timing of administrations. Specifically, exercise type and exercise intensity were initially examined in study 1. Study 2 expanded on study 1 by adopting a different design, using additional indices of cognitive functioning, and administering alternative cognitive tasks at different times during the protocol.

**Study 1**

**Participants**

A power analysis was performed using G\* Power 3 (Faul, Erdfelder, Buchner, & Lang, 2009) to determine the study’s sample size. Previous meta-analyses revealed a small effect size

*f* = .108 (Chang et al., 2012), and a *d* = .20 (Lambourne & Tomporowski, 2010). Using *f* = .25, *α* = .05, *1- β* = .80, with two repeated measures and either one or two (gender) groups resulted in N = 65. Sixty (*M* age = 27.63, *SD* age = 9.00) male (*n =* 30) and female (*n =* 30) participated in this study. Drawing upon the General Health and Lifestyle Questionnaire (GHLQ), none of the potential participants presented a health condition (i.e., current or past injury related to the handgrip and stepping tasks, presence of hypertension, ADHD, brain injury, recent concussion) that may preclude them from taking part in the study. Using a table of random numbers, participants were assigned to one of the two conditions: (a) handgrip squeezing task (*n =* 30, *M* age = 29.33 years, *SD* age = 9.73 years), and (b) stepping task (*n* = 30, *M* age = 25.93 years, *SD* age = 8.01 years). Non-significant effects emerged for age (*p* = .26), resting HR (*p* = .47) or baseline executive function scores (*p* = .13). The institutional review board’s approval was obtained prior to any data collection in this study.

**Apparatus**

**Calibrated handgrip dynamometer.** A handgrip dynamometer was used for the handgrip squeezing task. When squeezed, the adjustable hand bar of the dynamometer moved a pointer that displayed applied force in anchors of 0-100 kilograms.

**Fitness step.** A stepping box and a digital metronome were used for the steeping task. The stepping box was 10.2cm by 30.5cm, with a non-slip stepping surface of 40.6cm by 40.6cm.

**Polar RS 100 heart rate monitor (HRM).** The HRM was used to measure HR during exercise. The device included a strap to be worn around the chest directly on the skin beneath the breastplate, and an accompanying watch that displayed the HR in beats per minute (bpm).

**Measures**

**General health and lifestyle questionnaire (**GHLQ; British Columbia Department of Health, 1975**)**. The GHLQ was used to prescreen volunteers for participation in the study. GHLQ assessed any health condition that may preclude volunteers from participating.

**Demographic form**. The form was used to gather data regarding the participant’s age, gender, sport and physical activity participation.

**Rate of perceived exertion (RPE; Borg, 1988)**. The RPE scale was used to measure perceived effort during exercise. Anchors of the scale ranged from 0 (*nothing*) to 10 (*extremely strong*). RPE has been shown to be a reliable measure of perceived effort and physical discomfort with high intra-test (*r* = .93) and test re-test (*r* = .83 - .94) reliabilities. RPE was also shown to correlate with lactic acid (LA), HR, maximal oxygen consumption (VO2max), and ventilation (VE) (Borg, 1982).

**Trail making test (TMT; Reitan & Wolfson, 1985).**  One of the most commonly used measure to assess executive function in the neuropsychological literature (Etnier & Chang, 2009), the TMT has been shown to be a valid and reliable measure of cognitive speed and agility (Spreen & Strauss, 1998). The TMT includes two parts:

**TMT part A*.*** Part A was presented on an 8.5”x11” piece of paper. Inside a rectangle were 25 circles numbered from 1-25. Using a pen the participant attempted to connect all 25 circles in ascending order (i.e., 1-2-3-4, etc.) as quickly as possible. Time started upon the researcher’s instruction “Go”, and ended the moment the participant reached the 25th circle. The test primarily measured visual scanning and mental flexibility.

**TMT part B**. Presentation of Part B was identical to Part A. Part B differed from Part A in that it included both numbers 1-12 and letters A-L. Participants were required to connect all of the circles by alternating between numerical and alphabetical order (i.e., 1-A-2-B-3-C, etc.). Time started upon the researcher’s “Go”, and ended the moment the participant reached the letter “L”. In addition to the skills measured in Part A, Part B measured inhibition and cognitive flexibility (Arbuthnott & Frank, 2000).

For the purpose of this study, three versions of both Part A and Part B were completed for a total of six tests (i.e., TMT A1, B1, A2, B2, A3, and B3). Two alternate forms of Part A and Part B were developed and used in addition to the original TMT Part A and B (Reitan & Wolfson, 1985). To ensure the newly developed tests were of equal difficulty to the originals, a pilot study of 71 college students aged 24-29 was conducted. The students were administered the tests with 15min intervals in a counter-balanced order. The A1, A2, A3 mean completion times (*SDs*) were 17.67s (4.19), 16.63s (4.32), and 17.1s1 (6.01), respectively. All means were similar and non-significantly (*p* > .05) different from each other. The B1, B2, and B3 mean completion times (*SDs*) were: 39.99s (9.60), 38.50s (11.10), and 38.61s (8.53), respectively. Comparable to version A, all means were similar and non-significantly different from each other (*p* > .05). The B versions were significantly (*p* < .001) harder than the A versions, and on average lasted 23.2s longer to complete. The mean values of the TMT versions A and B indicated no learning effect within 15-30min of administration. The correlations among the three A versions ranged between .43 - .64, and among the B versions between .51 - .64 revealing adequate convergent validity. The correlations between the A and B versions ranged between .12 - .38 also indicating sufficient divergent validity hence the use of the three TMT versions as indicators of executive function in the present studies.

Executive function scores were computed based on the time required to perform TMT-A and TMT-B separately. Consistent with the previously validated protocols (Arbuthnott & Frank, 2000), the difference between TMT-B and TMT-A was computed to single out the executive function requirements of the TMT-B from the general processes of perceiving and responding.

**Commitment check**. A commitment check was developed to testparticipants’ commitment to the tasks. The three items of the check included: (a) “how committed were you to the task while performing? (b) “how well do you think you tolerated the effort associated with the task?”, and (c) “how much effort did you invest in the task?”. Each item was rated on a Likert-type scale ranging from 1 (*none / not at all*) to 5 (*very much / very well*).

**Testing Procedure**

Participation in the study included one session of approximately 45min. Upon arrival at the testing site, each participant completed an informed consent form and the GHLQ to determine health status and eligibility for participation in the study. The demographic information was collected next. Then, each participant was attached to an HR monitor and wore a HR wristwatch calibrated to the signal of the HR sensor.

Once the reliability of the signal from the monitor was confirmed, participants were assigned to either the handgrip squeezing task or the stepping task. At this point, participants were presented with a description of the testing protocols and their resting/baseline HR was recorded. To guide the measurement of the resting HR, participants’ demographic information including age, height, weight, and gender was logged and programmed into the Polar RS100 monitor. Participants were allowed to relax in an upright, seated position for 1min before the Polar RS100 displayed their resting HR (see Crouter, Albright, & Bassett, 2004). Participants then took the TMT 1 to set baseline levels for executive function scores.

Consistent with the previously validated protocols (see Basevitch et al., 2011) a maximal voluntary contraction (MVC) score was computed for each participant who were assigned to the handgrip-squeezing task. For the purposes of determining MVC, participants squeezed the dynamometer at three consecutive attempts, the highest of which corresponded to their MVC. Next, for the handgrip-squeezing task, participants squeezed the dynamometer with their dominant hand, at 30% of MVC until reporting RPE = 6 or RPE = 9 (see Razon, Basevitch, Land, Thompson, & Tenenbaum, 2009). Considering that RPE is a reliable indicator of exercise intensity (Chen, Fan, & Moe, 2002), participants’ RPE was measured every 30s by means of the RPE scale placed in front of them at eye level. Handgrip squeezing task was terminated when participants reported RPE = 6 (i.e., moderate workload intensity). At this point, the researchers recorded participants’ HR and participants were administered the TMT 2.

Subsequently to a rest period of up to 10min to allow the participant’s HR to return to resting levels, the same protocol was repeated with the exception that the task was terminated when the participant reached RPE = 9 (vigorous workload intensity). At this point researchers recorded participants’ HR and participants were administered the TMT 3.

For the purposes of the stepping task, similarly to the handgrip squeezing protocol, HR was measured and TMT tests were administered at three time intervals: prior to task performance, at RPE = 6, and RPE = 9. The stepping task required participants to step up and down on a circuit step to the cadence of a metronome. At the onset of the exercise, the cadence of the metronome was set at 100 bpm, and was subsequently increased by 10 bpm every minute. An RPE scale was placed in front of the participant at eye level to report RPE every 30s. Upon reaching RPE = 6 and completing HR measurement and TMT assessment, the participant was allowed to rest for a period up to 10min to allow HR return to its resting levels. Next, the same process was repeated again with the exception that exercise was not terminated until the participant reported RPE = 9. Once the participant reported RPE = 9, his/her HR was measured one final time and they were administered the TMT 3. Upon completion of the study, participants took the commitment check and were debriefed.

**Results**

**Commitment Check**

Analysis of commitment checks revealed that participants were highly committed in both conditions (*Mgrand*= 4.69/5). The commitment levels in the stepping task (C1: *M*= 4.76, *SD*= .43; C2: *M*= 4.83, *SD*= .46; C3: *M*= 4.52, *SD*= .57) were similar to the commitment levels in the handgrip task (C1: *M*= 4.90, *SD*= .30; C2: *M*= 4.39, *SD*= .67; C3: *M*= 4.77, *SD*= .49).​

**Manipulation Check**

**(A) Time to RPE = 6 (moderate exertion) and RPE = 9 (high exertion).** On average the handgrip squeezing task (i.e., strength-endurance) lasted *M* = 2.72min (*SD* = 1.20) until reporting moderate exertion (RPE = 6), and *M* = 3.60min (*SD* = 1.39) until reporting high exertion (RPE = 9). For the stepping task (i.e., aerobic), participants reported moderate exertion after *M* = 5.51min (*SD* =2.16) and high exertion after *M* = 7.26min (*SD* = 2.40). RM MANOVA conducted for the times to RPE = 6 and RPE = 9, revealed a time effect, *Wilk’s λ* = .48, *F*(1,55) = 60.16, *p* < .001, *η2* = .52. Time to RPE = 9 was longer than time to RPE = 6 across the two tasks by 1-2.5min. A significant task effect was also revealed, *F*(1,55) = 51.36, *p* < .001, *η2* = .48, indicating that time to moderate and high exertion took longer during the stepping task as compared to handgrip squeezing task; *M* = 6.38min, *SD* = 1.69 vs. *M* = 3.16min, *SD* = 1.70, *d* = 1.89. Time to RPE by task was also significant, *Wilk’s λ* = .89, *F*(1,55) = 6.86, *p* < .01, *η2* = .11. Time to RPE = 9 on the stepping task was *M* = 7.25, *SD* = 2.37min and *M* = 3.61, *SD* = 1.44min on the handgrip squeezing task, *d* = 1.37. Time to RPE = 6 on the stepping task was *M* = 5.65min, *SD* = 2.21, and *M* = 2.74min, *SD* = 1.29 on the handgrip squeezing task, *d* = 1.21. Finally, gender differences only tended toward significance, *F*(1,55) = 3.59, *p* < .06, *η2* = .06.

**(B) HR associated with the experimental condition and task.** RM ANOVA for HR yielded significant effect for the experimental condition, *Wilk’s λ* = .40, *F*(2,53) = 44.32, *p* < .001, *η2* = .60. On average, during the three conditions HR was *M* = 73. 83, *SD* = 11.22 at rest, *M* = 112.38, *SD* = 38.07 at RPE = 6 (*d* = 1.93), and *M* = 121, *SD* = 43.66 at RPE = 9 (*d* = 2.61). However, the task by experimental condition also resulted in significant effect, *Wilk’s λ* = .09, *F*(2,53) = 272.76, *p* < .001, *η2* = .91. At rest participants in the handgrip squeezing and stepping tasks groups reached similar HRs (*M* = 69.78, *SD* = 10.90 vs. *M* = 72.25, *SD* = 11.34, *d* = 0.22). However, at RPE = 6, HR difference between the two conditions increased to *M* = 81.75, *SD* = 21.42 vs. *M* = 145.45 *SD* = 32.34, *d* = 2.54, and further amplified to *M* = 82.55, *SD* = 13.51 vs. *M* = 162.45, *SD* = 12.42, *d* = 5.70 at RPE = 9.

**Experimental Condition and RPE Intensity Effect on Executive Function**

RM ANOVA was performed on executive function scores (TMT-B – TMT-A) using experimental condition (rest RPE = 0, moderate exertion RPE = 6, and high exertion RPE = 9) as 3 levels within repeated factor, and task (handgrip squeezing vs. stepping task) as between subjects factor. The analysis revealed a significant main effect for the experimental condition, *Wilk’s λ* = .708, *F* (2,57) = 11,76 *p* < .001, *η2* = .292. Post Hoc tests using the Bonferroni correction revealed that exercise elicited a slight decrease in executive function scores from baseline to REP = 6 (*M* = 22.26s, *SD* = 14.63 vs. *M* = 21.48, *SD* = 13.43), which was not statistically significant (*p* = .96). However, executive function scores after RPE = 9 have been reduced to *M* = 14.25s (*SD* = 7.17), which was significantly different from baseline (*p* < .001) and RPE = 6 (*p* < .001). This effect is shown in Figure 1. Neither the effects of task, *F*(1,58) = 1.38, *p* =.245, *η2* = .023, nor the time by experimental condition interaction effects were significant, *F*(2,57) = 1.60 *p* < .211, *η2* = .053.

Insert Figure 1 here

**Discussion Study 1**

The purpose of study 1 was to explore the effect of two moderators, namely type of exercise and exercise intensity on executive function gains. Specifically, we tested the comparative effects of a strength-endurance (i.e., handgrip squeezing) and aerobic (i.e., stepping) tasks performed at moderate and high intensities on the TMT. Results revealed that both types of tasks improved executive functions. Only exercising up to the higher intensity (RPE = 9) however, led to a significant positive effect for both type of tasks. These results support previous findings suggesting that higher intensity exercise results in larger effects on cognition (Knaepen, Goekint, Heyman, & Meeusen, 2010). Of importance to note within this context is that the increase in executive function after reporting RPE = 6 was not significantly different from baseline measure.

Possible limitations to study 1 included: (a) a single measure of executive function also known as mono-method bias (Shadish, Cook, & Campbell, 2002), (b) the lack of control group, and (c) the possible carry-over effect of exercise from RPE = 6 to RPE = 9. A second study was designed to address these limitations and to concurrently examine the lasting effects of exercise 15min following its completion.

**Study 2**

The purpose of study 2 was to investigate the role of additional moderators to the relationship between acute exercise and executive function. To that end, additional measures of cognitive functioning including reaction time and visual scanning were added. Working memory performance was also evaluated to obtain a second measure of executive functioning. All the cognitive measures were administered at three time intervals: prior to task completion, immediately following task completion, and15min after completion of exercise. We opted for 15min as a review has shown that the largest positive effects of exercise were observed following 11–20min of delay (Chang et al., 2012). Finally, in Study 2 we included a control group and adopted a between-subject design for the intensity conditions to control for the carry-over effects that may have occurred between the RPE = 6 and RPE = 9 conditions in the course of study 1.

**Method**

**Participants**

A power analysis using G\* Power 3 (Faul et al., 2009) with *f* = .30, *α* = .05, *1- β* = .80, three repeated measures and five independent groups determined a sample size of N = 88. Eighty-three (*Mage* = 22.71 years, *SD* = 4.13 years) male (*n* = 42) and female (*n* = 41) participated in this study. Drawing upon the General Health and Lifestyle Questionnaire (GHLQ), none of the potential participants presented a health condition (i.e., current or past injury related to the handgrip and stepping tasks, presence of hypertension, ADHD, brain injury, recent concussion) that may preclude them from taking part in the study. Institutional Review Board’s approval was obtained prior to any data collection for the study.

**Task Conditions**

Participants were randomly assigned to one of the five conditions that were based upon exercise modality and exercise intensity: (a) participants in the handgrip squeezing, RPE = 6 condition (*n* = 17, *M* = 21.53, *SD* = 2.83) completed a handgrip squeezing task at 30% of their MVC up to RPE = 6, (b) participants in the handgrip squeezing, RPE = 9 condition (*n* = 19, *M* = 23.74, *SD* = 4.90) completed the handgrip squeezing task at 30% of their MVC up to RPE = 9, (c) participants in the stepping task , RPE = 6 condition (*n* = 15, *M* = 23.00, *SD* = 4.09) completed a stepping task to the cadence of a metronome with 10 bpm increases every 60s and up to RPE = 6, (d) participants in the stepping, RPE = 9 condition (*n* = 16, *M* = 23.81, *SD* = 5.32) completed the stepping task at the cadence of a metronome with 10 bpm increases every 60s and up to RPE = 9, (e) participants in the control condition (*n* = 15 *M* = 22.42, *SD* = 3.82) did not perform any of the exercise tasks. Non-significant effects for age (*p* = .46), BMI (*p* =. 43), fitness level (*p* = .69), and baseline executive function scores (*p*=.409) were observed between the five conditions.

**Instrumentation**

**DynavisionD2 vision training system.** The DynavisionD2 consisted of five rings of eight clear buttons that light up red, and thereby prompting the participant to react by pressing that specific button. Additionally, a small screen (T-scope) in the middle of the board was used to present a cognitive stimulus (i.e., a math prompt such as 3+5-1). The board was adjusted (moved up or down) in order to fit to participants’ heights. For the purposes of this study, only the inner three rings of the light buttons were used. Additionally, the T-scope (placed at eye level) presented the participant with a math prompt (addition and/or subtraction) to react and verbally reply.

**Measures**

**Commitment check.** The commitment check was used to gauge the participants’ commitment to the task. For the purposes of study 2, the measure was modified to include four items. Those items included: (a) “how committed were you while performing the exercise?” (b) “how committed were you while performing the paper and pencil task?”, (c) “how committed were you while performing the reaction time (red lights) task?”, and (d) “how well do you think you tolerated the effort associated with the task?”. Each item was rated on a Likert-type scale ranging from 1 (*none/not at all*) to 5 (*very much/very well*).

**Reaction time.** Reaction time on the Dynavision task was measured to the nearest 1/100 of a second via attached computer software. For the purposes of the measure, participants completed a shortened practice trial of about 30s. The test was initiated with a five second countdown following which a single button would light up within one of the three concentric circles. Once the participant recognized the stimulus they were instructed to hit it as quickly as possible. The light remained on for one second or until it was hit. The next light appeared when the previous light was hit or after the previous light disappeared. Reaction time corresponded to the amount of time it took the participant to physically hit the lit button. Each of the three trials lasted for 60s and the software provided the average reaction time at the completion of each trial. DynavisionD2 has been previously shown to be a reliable measure of reaction time in young adults (Wells et al., 2014).

**Visual scanning.** Visual scanning was measured by the ratio number of lights that appeared by the number of lights hit. Because the lights were on for one second or until they were hit, the total number of lights per trials varied depending on how fast the participant hit them.

**Working memory.** Working memory was assessed by having the participant solve math equations while hitting the lights. The equations consisted of three one-digit numbers to add and/or or subtract (e.g., 8+5-4). Participants were instructed to maintain the numbers active in memory and compute them prior to responding to the researcher; a procedure consistent with contemporary working memory conceptualizations (Cowan et al., 2005; Shah & Miyake, 1999). The equations appeared for one second on the small screen in front of the participant and a different equation appeared every five seconds. A total of 10 equations were presented in the course of each trial. Participants’ working memory score corresponded to the sum of their errors (i.e., no response or incorrect response) and was recorded by the experimenter through the Dynavision.

**Procedure**

Participation to this study took one session of approximately 45min. Prior to the onset of the study, participants were instructed to read and sign the informed consent form and complete the General Health and Life Type Questionnaire (GHLQ). Next, the anthropometric data were collected. Participants were then instructed to wear a HR monitor. Once the HR monitor was properly placed, a three-minute resting HR was recorded. At this point, participants completed TMT1 and first round of the Dynavision tasks in order to set their executive function and visual scanning/reaction time baselines. Next, participants completed the YMCA fitness test that consisted of stepping on a 12-inch high circuit step for 3min at 96 bpm. At the completion of the three-minute stepping task, participants were instructed to sit while a radial pulse was recorded for one minute by one of the researchers. The fitness level was then computed according to the age-adjusted standards based on guidelines published by the YMCA (Golding, 2000). Finally, the researcher explained the procedure to the participants for their respective condition.

Prior to the handgrip squeezing task, to establish their MVC, participants squeezed the dynamometer for three independent attempts with one-minute resting interval. The highest of the three attempts corresponded to the participant’s MVC (see Basevitch et al., 2011). The researcher then computed 30% of the participant’s MVC. Next, the participants were instructed to squeeze the dynamometer with their dominant hand at 30% of their MVC. At 30s intervals participants rated their perceived exertion on the RPE scale placed in front of them at eye level. HR was also recorded at 30s intervals. Depending on the condition the participant was assigned, either following the report of RPE = 6 (moderate exertion) or RPE = 9 (high exertion), the researcher terminated the task. Next, HR was measured and participants were administered TMT2 and the Dynavision tests for a second round.

For the stepping task, participants were instructed to step up and down on a circuit step at the cadence of a metronome. The metronome was set at 100 bpm; the cadence increased at 60s intervals by 10 bpm up to RRP = 6 or RPE = 9. Similarly to the handgrip squeezing task, RPE was verbally reported and HR was measured at 30s intervals. Depending on the participants’ conditions, following the report of RPE = 6 or RPE = 9, the session was terminated. Participants’ HR was measured, TMT2 and Dynavision tests were administered for a second round.

For the control group, the TMT and Dynavision tasks were similarly administered at baseline. However, instead of completing exercise tasks, a 5min break was allocated to emulate the time taken to complete the exercise tasks. Following the break, participants completed TMT2 and Dynavision tests for a second round. Identical data collection protocols to the experimental conditions applied to control however, the YMCA fitness test was completed last in order to prevent any effects of exercise on the TMT and Dynavision tests.

Following the administration of TMT2 and Dynavision tests, participants in all five conditions took a 15min rest period. During the rest period, participants watched a video and their HR was recorded every 60s. The video presented the benefits of exercise on physical health. At the end of the 15min rest period, TMT3 and Dynavision tests were administered for a third and last round. Next, participants completed the commitment check. Finally, the researcher debriefed participants.

**Results**

**Commitment Check**

Analysis of the commitment check indicated that (a) all groups were highly effortful and committed while performing the exercise and executive function tasks (*Mgrand*= 4.70/5), and (b) participants in the four exercise conditions did not differ in respect to their commitment and effort levels, *Wilk’s λ* = .732, *F*(3,77) = 1.42, *p* =.13, *η2* = .07.

**Manipulation Checks**

**(A) Time to RPE = 6 (moderate exertion) and RPE = 9 (high exertion)**. On average the handgrip squeezing task (i.e., strength-endurance) lasted *M* = 2.76min (*SD* = 1.15) until the report of moderate exertion (RPE = 6), and *M* = 4.41min (*SD* = 1.57) until the report of high exertion (RPE = 9). Similarly, on average the stepping task (i.e., aerobic) lasted *M* = 5.21min (*SD* =1.91) until the report of moderate exertion, and *M* = 7.43min (*SD* = 1.92) until the report of high exertion (RPE = 9). ANOVA performed for the total times up to RPE = 6 and RPE = 9 revealed a RPE effect, *F* (1, 57) = 20.91, *p* <.001, *η2* =.27. Time to RPE = 9 was longer than time to RPE = 6 across the two tasks by about 2min. A significant task effect was also revealed, *F* (1, 57) = 42.10, *p* < .001, *η2* =.43. Time to RPE = 6 and RPE = 9 for the stepping task were longer than the time to RPE =6 and RPE = 9 for the handgrip squeezing task by almost 3min (6.3min vs. 3.6min). The task by RPE condition interaction was not significant, *F* (1, 57) =.461, *p* =.5, *η2* = .008.

**(B) HR associated with the experimental condition and task.** ANOVA performed for HR at RPE = 6 and RPE = 9 for both the handgrip squeezing and stepping tasks revealed a significant task effect, *F* (1,57) = 207.24, *p* < .001, *η2*=.784. HR for the stepping task was higher than HR for the handgrip squeezing task across both RPE conditions by 71bpm. RPE condition was also significant, *F* (1,57) = 8.158, *p* =.006, *η2*= .125. Across both task conditions, HR at RPE = 9 was higher than HR at RPE = 6 by 14bpm. The interaction task by RPE condition was not significant, *F* (1,57) = .002, *p* =.966, *η2*<.001.

**Exercise Condition and RPE Intensity Effect on Executive Function**

RM ANOVA was performed for executive function scores (i.e., TMT-B – TMT-A) using time (prior to exercise task, immediately after task completion, and 15min delay) as three levels of within repeated measures, and five experimental conditions as a between subject factor: (a) moderate RPE = 6 - squeezing, (b) moderate RPE = 6 – stepping, (c) high RPE = 9 – squeezing, (d) high RPE = 9 stepping, and (e) control. The analysis revealed significant main effect for time, *Wilk’s λ* = .769, *F*(2,71) = 10,67 *p* < .001, *η2* = .23, indicating that executive function scores changed among the three time points. Post Hoc analysis with Bonferroni correction revealed that exercise elicited a decrease in executive function scores from baseline to immediately after task completion (*M* = 21.90s, *SD* = 12.98 vs. *M* = 15.31, *SD* = 6.90; *d* = 0.66), which was statistically significant (*p* <.001). Executive function scores remained stable 15min following task completion (*M* = 16.99s, *SD* = 10.87), which was significantly different from baseline (*p* < .025, *d* = 0.41), but not statically different from immediately after exercise (*p* < .726). This effect is shown in Figure 2. Neither the effects of experimental condition, *F*(4,72) = .76, *p* <.56, *η2* = .040, nor the time by experimental condition effects were significant, *F*(8,142) = .74, *p* <.66, *η2* = .040.

Insert Figure 2 here

**Experimental Condition and RPE Intensity Effect on Reaction Time**

The RM ANOVA performed on reaction time (RT) scores indicated a significant effect for time, *Wilk’s λ* = .43, *F*(2,71) = 46.25, *p* <.001, *η2* = .57. Post Hoc analysis revealed that RT did not change from baseline to immediately after task completion (*M* = .66s, *SD* = .05 vs. *M* = .66s, *SD* = .04; *p* < .200). However, RT was significantly faster 15min following task completion (*M* = .63s, *SD* = .04), which was significantly different from baseline and immediately after exercise (*p* < .001, *d* = 0.75). This effect is displayed in Figure 3. Neither the experimental condition, *F*(4,72) = .224, *p* =.924, *η2* = .012, nor the time by experimental condition interaction, *F*(8,142) = 1.36, *p* =.219, *η2* = .07, were significant.

Insert Figure 3 here

**Experimental Condition and RPE Intensity Effect on Working Memory**

The RM ANOVA on working memory results revealed a significant effect for time, *Wilk’s λ* = .84, *F*(2,71) = 6.77, *p* =.002, *η2* = .16. Similar to RT scores, Post Hoc analysis revealed that the number of computation errors did not change from baseline to immediately after task completion (*M* = 2.23, *SD* = 1.85 vs. *M* = 1.90, *SD* = 1.58; *p* = .089). However, participants committed less errors 15min following task completion (*M* = 1.53, *SD* = 1.27), which was significantly different from baseline (*p* < .001, *d* = 0.45) and immediately after exercise (*p* =.027, *d* = 0.19). Working memory scores are presented in Figure 4. Neither the experimental condition, *F*(4,72) = .404, *p* < .805, *η2* = .02, nor the experimental condition by time interaction *F*(8,142) = 1.08, *p* <.381, *η2* = .06 were significant.

Insert Figure 4 here

**Experimental Condition and RPE Intensity Effect on Visual Scanning**

RM ANOVA performed for visual scanning revealed a significant main effect for time, *Wilk’s λ* = .61, *F*(2,71) = 22.44, *p* <.001, *η2* = .39. Post Hoc analysis revealed that the hit/total number of lights ratio was significantly (*p* < .001) higher immediately following task completion compared to baseline (*M* =.88, *SD* =.07 vs. *M* =.86, *SD* = .08; *d* = 0.27). Visual scanning scores also improved following the 15min delay (*M* =.91, *SD* =.06), which was significantly higher than baseline (*p* <.001, *d* = 0.71), and higher than immediately following exercise (*p* < .001, *d* = 0.46). These results are shown in Figure 5. Neither the experimental condition, *F*(4,72) = .95, *p* =.442, *η2* = .05, nor the time by experimental condition effects, *F*(8,142) = .710, *p* =.682, *η2* = .04, were significant.

Insert Figure 5 here

**Discussion Study 2**

Study 2 results revealed that throughout the three time periods (i.e., prior to task completion, immediately following task completion, 15min delay) executive function scores as measured by the TMT improved from baseline to immediately after exercise, and the effects were maintained after a delay of 15min. Working memory scores did not improve immediately following exercise but only after a delay of 15min. However, a similar pattern was also present for the participants in the control group and this is important to note. An initial plausible explanation to these findings is the limited sample size. Additionally, in contrast to study 1, in study 2, executive function gains occurred following both the stepping (aerobic) and handgrip squeezing (strength-endurance) tasks, and exercise intensity did not affect executive function. Present improvements for both the experimental and control conditions stand in contrast with other studies using comparable experimental designs. To that end, some studies had participants in the control group sat quiet and complete reading assignments (Chang & Etnier, 2009; Pontifex at al., 2009). Others had participants sat by the treadmill or on the cycle ergometer and discuss general topics with the researcher (Barella et al., 2010; Coles & Tomporowski, 2008). In contrast to the present findings, these studies have reported significant differences between the exercise and control conditions. Given that the control participants in the current study had similar conditions to that of Barella et al. and Coles and Tomporowski, the lack of significant results likely cannot be attributed to the operationalization of the control group per se, but rather to alternative dynamics which are considered in the general discussion.

**General Discussion**

The role of several moderators involved in the acute exercise-executive function link was tested in two studies. In study 1, we investigated the comparative effects of a strength-endurance and aerobic task performed at moderate and high perceived intensities using a single cognitive task administered prior and following exercise. Identical exercise tasks were used in study 2 with the addition of (a) a classical control group and a between-subject design for exercise task and intensity, (b) multiple types of cognitive measures, and (c) an additional timing of test administration.

Drawing upon the results from study 1, pertaining to the type of exercise, both the aerobic and strength endurance tasks seemed to help improve executive functions. The improvements were similar for both tasks. Consistent with these results, others have also reported that both aerobic and strength-endurance tasks help improve speed of processing (Barella et al., 2010; Chang & Etnier, 2009). The results from study 1 also revealed that, pertaining to the perceived intensity of exercise, exercising at higher intensity (i.e., RPE = 9) results in greater cognitive gains for both type of exercise, which could be due to larger increases in circulating brain-derived neurotrophic factors (BDNF) (Chang et al., 2012; Knaepen et al., 2010).

Results from study 2 revealed unexpectedly that participants in the control group performed similarly to those exercising regardless of the type of exercise or the cognitive task administered. The inclusion of a control group in study 2 aimed at monitoring any learning effect inherent in repeated measures. However, results from study 2 suggest that exercise did not improve cognitive performance above the learning effects observed under the control condition. Other researchers (Tomporowski & Ganio, 2006) have also indicated similar improvements in a switch-task performance for both the exercise and no-exercise (rest) periods. Those results were explicated from a distributed-learning perspective (Pelligrini & Bjorklund, 1997). Distributed-learning hypothesis is based on the notion of attentional resources. According to the hypothesis, the non-exercise (rest) period could help participants to replenish their attentional resources and thereby help improve their cognitive performance. Given that a similar traditional non-exercise (rest) condition was present in study 2, it could be plausible that those participants replenished their attentional resources and thus improved their cognitive performance.

The task duration may further explain the apparent lack of benefits of acute exercise on executive function beyond a rest effect. It has been suggested that exercise tasks that are longer than 20min result in positive effects on cognitive performance (Chang et al., 2012), while exercise tasks lasting 11-20min result in a negative effect. Earlier findings (Brisswalter et al., 2002) have also suggested that 20min of exercise was necessary for cognitive benefits. In study 2, the average duration of exercise was 5min across conditions which may explain the similar performances between the exercise and control groups. Specifically, 5min of exercise may not be sufficient to benefit executive function beyond the learning and resting effects. In study 1, participants exercised until reporting moderate and high RPEs with a resting period in between, which resulted in a total exercise duration of 10min.This difference in exercise duration between the two studies might account for the benefits observed in study 1 for the RPE = 9 condition. Nevertheless, the lack of a control condition in study 1 makes this assertion speculative at best and requires further investigation.

**Limitations and Future Research Directions**

There were two limitations to Study 2: (a) the short duration of the exercise protocols, and (b) the inclusion of a single control condition. To best circumvent these shortcomings, future studies would benefit from using exercise protocols of at least 20min in length, and testing for possible cognitive gains within diverse control conditions (Brisswalter et al., 2002; Chang et al., 2012). Additionally, accounting for a possible distributed-learning effect remains important. To that end, Coles and Tomporowski (2008) have used two control conditions: a traditional rest control condition with participants sitting in an isolated area and watching an educational video, and a non-exercise control condition with participants sitting on a cycle ergometer and completing all the experimental procedures except for the exercise task. No differences were observed between the two control conditions, but these conditions nonetheless have differed from the exercise condition, which facilitated the consolidation of information into the long-term memory. For more robust conclusions on the exercise-executive function relationship and the moderators of this relationship, additional research needs to replicate these research paradigms.

All in all, the present studies emphasize the need for considering the moderators when interpreting cognitive gains associated with acute bouts of exercise. As such, similarly to this study, both subjective (i.e., RPE) and objective (i.e., VO2max, HRmax or VT) markers of exercise intensity must be considered (Ekkekakis & Petruzello, 1999). Additionally, going beyond the present framework, research should include diverse types of control conditions in order to best tease out learning and transfer effects. Finally, to critically evaluate and delineate the effects of acute exercise on cognition, further empirical research needs to explore the weight of the presently explored moderators and ponder on the possible role of others (i.e., fitness levels, education levels, SES etc.)

From a practical perspective, these results present further evidence to support the benefits of exercise for improving cognitive gains. From an evidence- based practice standpoint, implementation of the knowledge on how to use acute exercise for cognitive gains would improve exercise prescription to maximize these gains. Ultimately, this may present particular relevance for all exercisers who may need to maintain optimal levels of cognitive functioning against cognitive aging or for individuals with compromised cognitive function for whom exercise would prevent further decline (Ma, Ma, Wang, Liu, Chen, & Yang, 2017).

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