Effect of acute aerobic exercise on cognitive performance: Role of cardiovascular fitness

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Abstract:

Objectives

To determine whether fitness and cognitive task type moderate the relationship between acute exercise and cognition.

Methods

Thirty-six healthy college-aged adults completed a maximal graded exercise test and were categorized as low, moderate, or high in cardiovascular fitness. Participants then performed the Stroop Test prior to and after an acute bout of cycling exercise that consisted of a 5-min warm-up, 20 min of exercise at moderate intensity (65% VO2max), and a 5-min cool-down.

Results

Individuals of all fitness levels improved in cognitive performance following exercise. With regards to fitness, while no differences were observed on the congruent condition as a function of fitness, high fit individuals showed the longest response time on the Stroop incongruent condition.

Conclusion

The beneficial relationship between performance of an acute bout of exercise and cognitive performance were observed for both cognitive task types and for participants of all fitness levels. However, a curvilinear relationship was observed between fitness and cognitive task type performance such that participants who were moderately fit performed the best on the incongruent trials, implying that maintaining fitness at a moderate level is associated with better executive function.

Keywords: Acute exercise | Physical fitness | Executive function | Stroop test

Article:

The beneficial effects of acute exercise on cognitive performance have been well documented. Early narrative reviews suggest a beneficial relationship between acute exercise and cognition (Brisswalter et al., 2002, McMorris and Graydon, 2000 and Tomporowski, 2003) and these conclusions have been confirmed by recent meta-analyses (Chang et al., 2012 and Lambourne and Tomporowski, 2010). Notably, while these meta-analytic reviews report an overall small positive effect of acute exercise on cognitive performance (effect size = 0.10), a relatively wide range of both positive and negative effects from individual empirical studies have also been reported (effect sizes range from −0.74 to 0.49), suggesting the importance of exploring potential moderators. The purpose of this study was to explore the role of two potential moderators, cardiovascular fitness and cognitive task type, on the strength of the relationship between acute exercise and cognition.

It has been suggested that cardiovascular fitness may moderate the effect of acute exercise on cognition (Brisswalter et al., 2002 and Tomporowski, 2003). The underlying rationale for this is based upon evidence supporting that cardiovascular fitness is related to improved cognitive performance and may have an influence on brain health (Åberg et al., 2009). Longitudinal studies indicate that aerobic exercise training improves both cardiovascular fitness and cognitive function (Colcombe and Kramer, 2003 and Kramer et al., 1999). Additionally, several studies provide evidence that high fitness is associated with and exercise training results in greater brain volumes and improved functional connectivity (Chaddock, Erickson, Prakash, Kim, et al., 2010, Erickson et al., 2009 and Voss et al., 2010).

Given the improvements in cognitive performance and the beneficial changes in cerebral structure and function that have been shown to result from exercise, it is possible that people who are highly fit may receive different benefits from an acute bout of exercise as compared to people who are less fit. However, empirical studies exploring this potentially moderating effect have yielded inconsistent results. Pesce, Cereatti, Forte, Crova, and Casella (2011) provided evidence for the beneficial role of cardiovascular fitness. They reported that while favorable acute exercise effects were found in both older trained and older sedentary adults, the greatest benefits were experienced by older trained adults. In contrast, some studies have failed to demonstrate a moderating effect of cardiovascular fitness (Stroth et al., 2009 and Themanson and Hillman, 2006). Themanson and Hillman (2006) demonstrated that cardiovascular fitness affects cognitive performance such that individuals with higher fitness performed better on an action monitoring task than those with lower fitness levels, but these findings did not show a differential effect of acute exercise relative to fitness levels. A similar lack of a moderating effect was reported by Stroth et al. (2009) for cognitive processes involving response inhibition by adolescents. Recently, Chang et al. (2012) tested the effects of cardiovascular fitness as a moderator in a meta-analytic review of the acute exercise and cognitive performance literature and reported that the effects of acute exercise on cognitive performance were only statistically significant for people with moderate and high fitness. However, a limitation of this conclusion is that the majority of the studies assessed the effects in individuals with moderate fitness, and fewer studies tested the effects in those with low or high fitness. Hence, at this point, the potential moderating effects of cardiovascular fitness have not been thoroughly examined.

In addition to fitness, the type of cognitive function being assessed has been recognized as another important factor in understanding the effects of acute exercise on cognition. The majority of the research has focused on basic information processing and has typically reported facilitative effects (Tomporowski, 2003). However, recent studies have begun to focus on the executive control aspect of cognition (for a detailed review, see Chang et al., 2012 and Lambourne and Tomporowski, 2010). Executive function, also known as executive control, is a higher order form of cognition which is known to involve goal-directed behavior and to control multiple aspects of basic cognitive processes (Etnier & Chang, 2009). Results regarding the effects of acute exercise on various types of cognitive performance are somewhat ambiguous. Some studies show a general improvement in cognition including both basic information processing and executive control following the cessation of exercise (Chang and Etnier, 2009, Chang et al., 2014 and Davranche et al., 2009), others demonstrate a larger effect in executive control than in basic processing (Chang et al., 2014, Davranche and McMorris, 2009 and Hillman et al., 2003), and some studies indicate that there is no facilitation of either executive control or basic processing after acute exercise (Stroth et al., 2009 and Themanson and Hillman, 2006). Challenges with interpreting these mixed findings are twofold. For example, some studies independently examine either basic information processing (for detailed review, see Tomporowski, 2003) or executive function (Chang, Chu, et al., 2011, Chang, Tsai, et al., 2011 and Chen et al., 2013), which makes the comparison across cognitive task types impossible because of differences in study design. In addition, tasks that involve multiple aspects of cognition and that have been used in previous studies associated with acute exercise and cognition (e.g., flanker task, go/no go task) are not tasks that have been widely used for assessing executive function (Etnier & Chang, 2009). Etnier and Chang (2009) indicated that it is important for future research in the area of exercise and cognitive performance to use standard neuropsychological assessments that have known characteristics with regards to the assessment of basic information processing and executive control such as the Stroop Test. The Stroop Test is ideally suited for studies exploring the potential moderating effects of cognitive task type because it includes one task that assesses basic information processing (the Stroop color condition also called the congruent condition) and another that assesses executive control (the Stroop color/word condition also called the incongruent condition) and yet both have the same instructions and procedures for performance.

In sum, the purpose of this study was to determine how cardiovascular fitness and cognitive task type impact the effects of acute exercise on cognitive performance following exercise cessation. We hypothesized that individuals categorized as having moderate and high fitness levels would experience greater improvements on the cognitive tasks after exercise compared to individuals with low fitness levels. In addition, the size of the acute exercise effect was expected to differ depending upon cognitive task type. Specifically, while acute exercise was expected to improve both types of cognitive function assessed with the Stroop Test, the incongruent condition was expected to evidence a greater effect because of its executive control requirements.

Method

Participants

Thirty-six healthy college-aged adults (n = 25 men, M = 21.60 ± 1.68 yr; n = 11 women, M = 21.09 ± 1.51 yrs) were recruited via advertisements placed around universities in Taoyuan, Taiwan. All volunteers were asked to complete a Physical Activity Readiness Questionnaire (PARQ) and a Health Screening Questionnaire (HSQ). Responses to these questionnaires were examined as inclusion criteria to ensure that it was safe for the participant to perform the cardiovascular fitness test. These initial screening processes conformed to the American College of Sports Medicine [ACSM] guidelines (American College of Sports Medicine, 2013). All participants completed a maximal exercise test and were then categorized as being in one of three groups based upon a tertiary split: low fitness group (Mean VO2max = 35.25 ml/kg/min), moderate fitness group (Mean VO2max = 45.52 ml/kg/min), and high fitness group (Mean VO2max = 56.21 ml/kg/min) (Table 1). According to ACSM guidelines, these groups would be described as having Poor, Good, and Super fitness for men and Poor, Excellent, and Superior fitness for women aged 20–29 years (American College of Sports Medicine, 2013). The sample size (n = 36) was chosen based upon a power analysis and using an effect size estimated from a previous study that tested the effects of acute exercise on Stroop Test performance (i.e., power = 0.8, partical eta square = 0.42, and alpha = 0.05 in Chang et al., 2014). All participants provided a written informed consent that was approved by the Institutional Review Board of the National Taiwan Sport University.

Table 1.

Participants' demographic and physiological characteristics for low, middle, and high fitness groups (Mean ± 1 SD).

Variable	Low fitness	Moderate fitness	High fitness	Total
Sample size	12	12	12	36
Gender (Female)	5	5	1	11
Age (yr)	21.42 ± 1.62	21.17 ± 1.34	21.75 ± 1.96	21.44 ± 1.62
Education (yrs)	13.33 ± 1.07	13.33 ± 0.98	12.50 ± 1.00	13.06 ± 1.07
Height (cm)	168.14 ± 0.10	169.42 ± 0.90	171.92 ± 0.06	169.87 ± 0.83
Weight (kg)	69.36 ± 17.47	61.50 ± 12.24	68.04 ± 13.46	66.21 ± 14.46
BMI (kg.m^{-2})	24.29 ± 4.41	21.26 ± 2.73	23.07 ± 4.87	22.83 ± 4.16
IPAQ (METs/wk)	1323 ± 824[a]	2756 ± 1579[b]	4369 ± 1778[c]	2820 ± 1910
Digit span	8.92 ± 1.62	9.00 ± 1.41	8.83 ± 1.90	8.92 ± 1.61
VO_{2peak} (mL.kg^{-1}.min^{-1}) for women	34.98 ± 5.34[a]	46.32 ± 0.54[b]	53.46 ± 4.09	41.36 ± 7.91
VO_{2peak} (mL.kg^{-1}.min^{-1}) for men	35.44 ± 4.55[a]	45.05 ± 2.26[b]	56.46 ± 4.20[c]	47.38 ± 9.73
VO_{2peak} (mL.kg^{-1}.min^{-1}) for men and women	35.25 ± 4.66[a]	45.52 ± 1.89[b]	56.21 ± 4.09[c]	45.67 ± 9.54
Exercise manipulation check				
Pre-HR	78.30 ± 13.94	73.09 ± 8.46	62.27 ± 12.38	71.00 ± 13.23
Exercise-HR	135.15 ± 8.11	145.66 ± 8.42	140.71 ± 11.55	140.67 ± 10.18
Post-HR	87.30 ± 31.33	100 ± 12.22	82.82 ± 15.64	93.06 ± 23.30
% Maximal HR	68.05%	73.5%	71.00%	70.83%
RPE	12.96 ± 2.60	13.60 ± 1.82	13.82 ± 2.43	13.45 ± 2.27

Note. BMI, body mass index; IPAQ, International Physical Activity Questionnaire; MET, Metabolic equivalent; Pre-HR and Post-HR, average HRs assessed before pre- and post-cognitive test; Exercise-HR, average HR assessed during exercise;

RPE, Ratings of Perceived Exertion assessed during exercise; means with different superscripts $^{a, b, c}$ are significantly different from one another.

Cardiovascular exercise test

Cardiovascular fitness was assessed on a treadmill (h/p/cosmos airwalk, Germany) using the Bruce protocol for a maximal graded exercise test (GXT) (Bruce, Kusumi, & Hosmer, 1973).

The GXT was conducted by a trained examiner. Participants were instructed not to eat within two hours of testing. The maximal cardiovascular capacity was determined and the GXT was terminated when the participant met at least two of the following three criteria: a) heart rate failed to increase after increasing exercise intensity; b) respiratory exchange rate (RER) ≥1.15; and c) Rating of Perceive Exertion (RPE) of original Borg scale (Pollock, Wilmore, & Fox, 1984) ≥17. During the GXT, these three indices (heart rate, RER, and RPE) were measured every one minute to monitor physiological status. All participants met at least two of the three criteria, reflecting that this was an effective assessment of maximal fitness.

Potential confounds

Age and education were assessed by self-report. Height and weight were measured in the laboratory and were used to compute body mass index (BMI). Participation in physical activity was assessed using the International Physical Activity Questionnaire (IPAQ) that was developed as an international surveillance tool for physical activity (Bauman et al., 2009).

The digit span test, derived from the Wechsler Adult Intelligence Scale-Third Edition (WAIS-III), was used to obtain a measure of working memory as an approximation of an intelligence quotient (Wechsler, 1997). This specific measure of intelligence was particularly chosen because working memory has been found to be predictive of Stroop Test performance (Kane and Engle, 2003 and Unsworth and Engle, 2007).

Acute exercise intensity manipulation check

Heart rate (HR)

HR was monitored by Polar heart rate monitor (Sport Tester PE 3000, Polar Electro Oy, Kempele, Finland). Three HR measures were recorded and these were: pre-HR (HR assessed immediately before conducting the cognitive tasks at the pre-test), exercise-HR (the average HR assessed during exercise), and post-HR (HR assessed immediately after treatment and before conducting the cognitive tasks at the post-test).

Rating of perceived exertion (RPE)

The RPE scale ranged from 6 to 20 and was used to provide a subjective rating of each individual's perception of effort during the exercise (Borg, 1982). RPE was recorded at 2-min intervals during the exercise.

The Stroop Test

Cognitive performance was assessed using the Stroop Test. The Stroop Test, also referred to as the Color Naming Task, is the one of the most commonly used neuropsychological assessments used to measure multiple cognitive processes including information processing speed, executive control, selective attention, and the ability to inhibit habitual responses (Pachana, Thompson, Marcopulos, & Yoash-Gantz, 2004). The Stroop Test is also recognized as one of the top three most commonly used neuropsychological tests of executive function (Etnier & Chang, 2009).

The typical administration of the Stroop Test includes the measurement of verbal responses of participants to a list of color names or a series of color patches and response time for performance of the entire Stroop condition is assessed by a stop watch (i.e., total time to completion). However, in order to more precisely assess Stroop performance, participants in this study completed a computerized version of the Stroop Test using Neuroscan system (Stim2 software, Neurosoft labs, Inc. Sterling VA, USA) which allows for the precise assessment of response time. The computerized Stroop Test consisted of two types of trials: congruent and incongruent.

In the congruent trials, stimuli consisted of one of three Chinese color words (i.e., “紅”: red, “藍”: blue, and “綠”: green) in which the name of the word was the same as the color of ink. In the incongruent trials, the stimuli consisted of one of the same three color words; however, the words were written in different colors of ink. In other words, the color of the word's ink did not match the word meaning. In both conditions, the participant was asked to identify the color of the ink.

The size of the Chinese characters was two centimeters square and each was displayed in the center of a 21-inch screen. Each block of 90 trials had two types of stimuli (53 congruent and 37 incongruent) and trials were presented in the same order for each trial block at both testing sessions. A trial started with a fixation point (a cross displayed in the center of the monitor) and was followed by a stimulus shown for 500 ms. The interval between the fixation point and the stimulus presentation was 383, 583 or 783 ms (randomly selected) and the interstimulus interval (ISI) was 1700 ms.

The response panel is a 10 cm × 8 cm × 2 cm box with colored buttons which represent red, blue, and green respectively. The participant was instructed to respond to the stimulus by pressing the color button that matched the color of ink of the stimulus as quickly as possible with minimal error. The participant was requested to complete five blocks of trials with a 2-min rest interval between each block. Times for correct response on the Stroop Test for incongruent and congruent conditions were averaged separately for further analysis. The duration of the Stroop Test was approximately 30 min.

Experimental procedures

Participants individually attended the laboratory for two testing sessions with a 3-day interval between sessions. At the first session, each participant was given a brief introduction of the experimental process, was given an informed consent form, and was asked to complete the PAR-

Q, HSQ, a demographic questionnaire, and the IPAQ. Participants meeting the inclusion criteria then completed the GXT.

At the second session, the participant was given instructions, demonstrations, and practice on the Stroop Test. Practice trial blocks consisted of 24 trials (congruent and incongruent), and each participant had to reach 90% accuracy in a practice trial block before being allowed to move on to the pre-test. Then, the participant was asked to perform 5 blocks of 90 trials of the Stroop Test as a pre-test. An acute exercise session was then performed on a bicycle ergometer (Ergomedic 839E, Monark, Sweden). Participants warmed up for 5 min, exercised at 65% VO2max for 20 min, and cooled down for 5 min. Participants were asked to maintain their pedaling rate at 70 rpm and the workload was increased by 15 Watts for each two minutes during the warm up. Watts were then adjusted further to reach the resistance level identified as equivalent to 65% VO2max for that individual. During the exercise period, participants were instructed to maintain their cadence at 70 rpm, and the experimenter alerted him/her if their speed decreased below 67 rpm or was faster than 73 rpm. If the participant could not maintain the 70 rpm cadence, the resistance level was adjusted by the experimenter to keep participants at their target HR while maintaining a speed of 70 rpm. Lastly, the participant performed the Stroop Test again as a post-test within five minutes after exercise termination. The total duration for both sessions was approximately three hours. Participants were given $50 US dollars for compensation and briefed on the purpose of the experiment after completing the entire process.

Statistical analysis

All values are expressed as means ± SD. Because of the cross-sectional nature of cardiovascular fitness in this study, participants' descriptive characteristics (age, education, height, weight, BMI, digit span) were initially compared between low, moderate, and high fitness groups using between-subjects one-way analysis of variance (ANOVA) (SPSS 17.0, SPSS Inc, Chicago, USA) so that significant variables could be included as covariates. Differences in physical activity as assessed with the IPAQ were also examined using ANOVA to compare between the fitness groups. To test the exercise intensity manipulation, a mixed 3 (fitness group: low, moderate, high) × 3 (time: pre-HR, exercise-HR, post-HR) ANOVA was conducted for HR. The effects of acute exercise, fitness, and type of cognitive performance on the Stroop condition were analyzed with a mixed 3 (fitness group: low, moderate, high) × 2 (time: pre-test, post-test) × 2 (Stroop condition congruent vs. incongruent) ANOVA. For significant interactions and main effects, multiple comparisons with Bonferroni post-hoc analysis were used. Effect sizes (ESs) of Cohen's d and partial eta-square (partial η^2) were reported for significant effects. An alpha of 0.05 was used as the level of statistical significance for all analyses.

Results

Participant characteristics

Table 1 summarizes the basic descriptive characteristics for the three fitness groups. ANOVA indicated that there were no significant differences among the fitness groups on the demographic variables of age, height, weight, BMI, digit span, or education (p's = 0.20–0.69). Regarding amount of physical activity, IPAQ differed significantly between the groups, $F(2,33) = 13.35$, p

< .001, and post-hoc analyses revealed that all three group were significantly different from each other, such that the high fitness group showed the highest Metabolic equivalent (MET) value, the moderate fitness group followed, and the low fitness group had the lowest MET value. As expected, fitness levels differed significantly between the groups, F(2,33) = 91.81, p < .001, and post-hoc analyses revealed that all three groups were significantly different from each other, such that the high fitness group showed the highest VO2max value, the moderate fitness group followed, and the low fitness group had the lowest value.

Exercise intensity manipulation

The 3 × 3 mixed ANOVA for HR revealed main effects for fitness group (F(2, 29) = 4.97, p = .01, partial η2 = 0.26) and time (F(2, 58) = 175.00, p < .001, partial η2 = 0.86), but not the interaction of fitness group by time (p > .15). Follow-up post-hoc analysis revealed that across time, the high fitness group had a significantly lower HR compared to the moderate and low fitness groups (p = .01). Regarding the main effect for time, post-hoc analyses revealed that HR was the highest during exercise, followed by HR post-exercise and then HR pre-exercise (p's < 0.001).

During exercise, percentages of aged-predicted maximal HR ranged from 68.05% to 73.50% in all three fitness groups and were not significantly different from one another (p = .08), reflecting that for all participants, the acute exercise session was at moderate intensity. Non-significant differences were found in RPE among the three fitness groups (p = .65). RPE during exercise ranged from 12.96 to 13.82, which equates to an effort that is perceived as somewhat hard. Table 1 presents detailed descriptive statistics for the exercise manipulation check.

Stroop Test performance

Table 2 presents performances of Stroop Test between pre- and post-test for the three groups. Results of the three-way mixed ANOVA revealed that there were significant main effects for time (F(1, 33) = 4.26, p = .047, partial η2 = 0.11) and Stroop condition (F(1, 33) = 156.48, p < .001, partial η2 = 0.83), and the interaction of Stroop condition by fitness group (F(2, 33) = 5.84, p < .001, partial η2 = 0.26) was also statistically significant.

Table 2.

Means (msec), Standard Deviation, and Effect Sizes of Stroop Test for Low, Moderate, and High Fitness Groups.

Variables	Low fitness			Moderate fitness			High fitness		
	Pre-test	Post-test	ES	Pre-test	Post-test	ES	Pre-test	Post-test	ES
Stroop Congruent	516.77 ± 69.23	486.63 ± 59.02	−0.23	488.13 ± 61.56	465.10 ± 55.55	−0.19	526.54 ± 71.20	513.70 ± 94.88	−0.08
Stroop Incongruent	570.10 ± 95.68	531.49 ± 84.83	−0.21	533.86 ± 82.29	506.61 ± 65.26	−0.18	597.81 ± 81.97	600.91 ± 110.62	0.02

Note. Effect size (ES) is calculated by Cohen' *d*. More negative value represents better performance.

Specifically, the main effect for time illustrates that participants demonstrated significantly shorter response times on the Stroop Test at the post-test (517.41 ± 13.11 ms) as compared to the pre-test (538.87 ± 12.71 ms). Additionally, the main effect of Stroop condition indicates a longer response time during the Stroop incongruent trials (556.80 ± 84.16 ms) as compared to the Stroop congruent trials (499.48 ± 64.58 ms). Regarding the interaction of Stroop condition by fitness group, follow-up analyses indicated that there were non-significant differences in performance during the Stroop congruent condition among the three fitness groups, however in the Stroop incongruent condition, the moderate and low fitness groups demonstrated significantly shorter response times than the high fitness group ($p < .02$) (Fig. 1). A follow-up trend analysis revealed that in the Stroop incongruent condition, the linear trend was non-significant, but there was a marginally significant curvilinear trend between fitness and performance ($p = .06$). In the Stroop congruent condition, no significant trends were observed between fitness and performance.

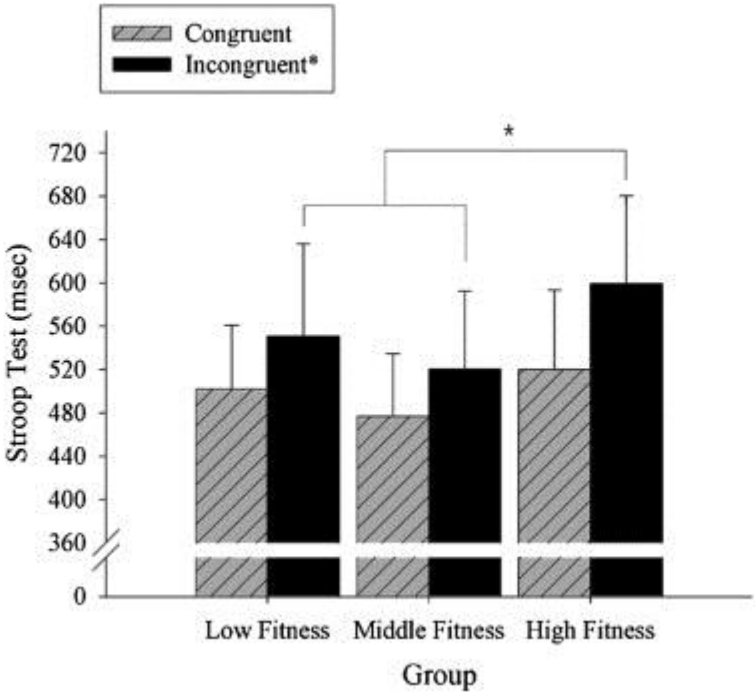

Fig. 1.

Interaction of fitness group and Stroop condition. Shorter response times represent better performance. Data are presented as means ± 1 SD.

Discussion

Past research has shown that fitness influences cognitive performance and that an acute bout of exercise may benefit various types of cognitive performance differently; however, very few studies have explored the potential for a combined interactive effect of fitness and cognitive task type on the effects of acute exercise on cognitive performance. The purpose of this study, therefore, was to examine whether fitness and cognitive task type moderate the relationship between acute exercise and cognition.

The primary findings of the present study were that individuals at all three levels of fitness demonstrated improved cognitive performance following the cessation of exercise. Importantly, these improvements were found in both conditions of the Stroop Test indicating that general improvements in cognition were associated with participation in the exercise session. Because our main purpose was to examine the role of fitness within the relationship between acute exercise and cognition, our experimental design did not contain a control condition. Therefore, it is impossible to isolate the effect of acute exercise from effects of learning or familiarity. However, participants were given practice in the Stroop Test until they obtained more than 90% accuracy prior to performing the pre-test, thus, minimizing the potential effects of learning or familiarity. In addition, the acute exercise protocol used in this study was similar to that used in our previous research (Chang, Tsai, et al., 2011) and in other empirical studies (Audiffren et al., 2009, Davranche and McMorris, 2009 and Yanagisawa et al., 2010), and these previous studies have consistently shown improved cognitive performance after acute exercise as compared to a control condition. Thus it is reasonable to conclude that participants in this study received benefits to cognitive performance that were associated with performance of a single bout of moderate intensity aerobic exercise.

It is widely accepted that increased physiological arousal induced by acute exercise is responsible for observed changes in cognitive performance. According to the inverted-U hypothesis, moderate arousal is linked to optimal cognitive performance, while arousal levels that are below or above the optimal level would decrease the beneficial effects (Kashihara, Maruyama, Murota, & Nakahara, 2009). This hypothesis is supported by the findings of Kamijo and colleagues in two empirical studies (Kamijo, Nishihira, Hatta, Kaneda, Kida, et al., 2004 and Kamijo, Nishihira, Hatta, Kaneda, Wasaka, et al., 2004). Compared to low and high intensity conditions, Kamijo and colleagues indicated that acute moderate intensity exercise elicited evidence of superior neuroelectrical activation suggesting that acute moderate intensity exercise provides the optimal level of arousal and hence has the most beneficial effect on attentional resources necessary for cognitive performance.

Several biological hypotheses have also been raised to interpret the phenomenon of facilitative cognitive performance following the cessation of an acute bout of moderate intensity exercise. Griffin et al. (2011) reported that both acute and five-week exercise interventions improved cognitive performance as assessed by the Stroop Test and altered serum levels of brain-derived neurotrophic factor (BDNF). Similar improvements in Stroop performance following acute exercise were also found by Yanagisawa et al. (2010) who also reported that the increased performance corresponded with increased activation in the left dorsolateral prefrontal cortex. It should be noted that increased BDNF, neuroelectrical, and brain activation following acute exercise were found in participants who ranged in fitness from sedentary to highly trained adults (Griffin et al., 2011, Rojas Vega et al., 2006 and Yanagisawa et al., 2010). Therefore, findings from these studies which have focused on potential underlying mechanisms are consistent with the finding in this study that fitness level did not impact the positive relationship between acute moderate exercise and cognition.

The present study also indicated a main effect for Stroop condition, which is in accordance with previous studies (Buck et al., 2008, Chang et al., 2014, Larson et al., 2009 and Yanagisawa et al., 2010). Specifically, our results showed that there is a longer response time in the Stroop incongruent condition than in the Stroop congruent condition regardless of the acute exercise intervention and fitness level. This finding is not surprising as during the Stroop incongruent trials that involved different colors and words, participants were required to use more cognitive resources to inhibit the automatic response (to read the word), thus interference, inhibition, and selective attention are required, resulting in a longer time necessary to complete the task (Pachana et al., 2004).

A third finding was that while performance did not differ as a function of the three fitness levels in the congruent condition, there was a marginally significant curvilinear relationship between performance in the Stroop incongruent condition and fitness level ($p = .06$), with the moderate fitness group having the shortest reaction time, suggesting that moderate fitness might play a role in executive control. This result is partially consistent with findings from previous studies which have shown that the fitness effect is particularly evident in executive control aspects of cognitive function, and others have attributed this finding to the positive relationship between fitness and brain volume in the basal ganglia (Chaddock, Erickson, Prakash, VanPatter, et al., 2010) and hippocampus (Chaddock, Hillma, et al., 2010 and Erickson et al., 2009) as well as increased neural functional activation during cognitive performance (Voss et al., 2010), which are brain areas thought to be important for executive function.

However, we also observed that people with high fitness levels showed the longest response time in the Stroop incongruent condition, suggesting that high fitness was associated with poor performance for this measure of executive control. This finding is in contrast to findings of past research. One possible explanation relates to the differences in fitness levels used in studies testing this research question. In particular, in previous studies that found positive associations between fitness and cognition, people were categorized as being in the high fit group with VO2max levels that ranged from 36.5 to 52.5 ml/kg/min (Chaddock, Erickson, Prakash, Kim, et al., 2010, Chaddock, Erickson, Prakash, VanPatter, et al., 2010, Erickson et al., 2009 and Griffin et al., 2011). This range of fitness levels is actually similar to our moderate fitness group. Closer examination of the results of this study indicates that people in the moderate fitness group tend to perform better than those with low fitness, thus this finding is somewhat consistent with past research. The results of this study add to the literature because they indicate that there are not additional cognitive benefits when people have extremely high fitness (VO2max = 56.21 ± 4.09). Although not an a priori hypothesis, based upon the results observed in this study, it is speculated that there is an inverted-U dose–response relationship between fitness and cognition such that moderate fitness levels (as judged relative to ACSM norms) are associated with better cognitive performance than are low or high fitness levels. Clearly, future research is necessary to further explore how and why higher levels of fitness might be related to poorer performance on executive function tasks. In summary, we propose that moderate fitness may relate positively to cognition, but high fitness is not necessary to obtain further advantages.

One limitation of this study is the cross-sectional nature of the fitness variable which limits the ability to draw causal conclusions regarding this independent variable. However, given the potential moderating role of fitness in the effects of acute exercise on cognition, it will be important for future studies to use causal designs to further our understanding of the role of fitness. A second limitation is that a control condition was not used to allow for statements regarding the effect of acute exercise on Stroop Test performance. This a prioriri decision not to use a control condition was made because there is substantial evidence showing that acute exercise benefits performance on the Stroop Test (Chang and Etnier, 2009, Chang et al., 2014, Sibley et al., 2006 and Yanagisawa et al., 2010) and because the primary purpose of this study was to determine if those benefits differ dependent upon fitness level and cognitive task type. Importantly, however, this limitation means that the results of this particular study do not directly add to the evidence of an effect of acute exercise on cognitive task performance. A third limitation of the study is that the percentage of congruent (59%) and incongruent (41%) trials was not equivalent in the trial blocks which may limit the extent to which the findings in this study generalize to tasks in which congruent and incongruent trials are equiprobable. Nevertheless, reaction time for the incongruent trials was significantly slower than for the congruent trials suggesting that the ratio of congruent to incongruent trials did not significantly influence our ability to observe the typical Stroop effect. Lastly, the present study might also be limited because the proportion of men and women in each fitness group was heterogeneous and the VO2max within each fitness group between men and women were not categorized identically. Although the differing distributions did not reach statistical significance and VO2max values within the three fitness group still can reflect the level of fitness categorization by gender, these issues may limit the generalizability of the findings. Clearly, future research should be conducted using designs that allow for a determination of causation. Further study is also encouraged to examine the extent to which acute exercise and physical fitness influence the conflict adaptation effect which is evidenced in tasks like the Stroop test. The conflict adaptation effect refers to the observation that reaction time on a given trial is influenced by the previous trial. Specifically, Larson et al. (2009) demonstrated that faster reaction times were observed on cC (congruent trials preceded by a congruent trial) as compared to iC (congruent trials preceded by an incongruent trial) and on iI (incongruent trials preceded by an incongruent trial) trials compared to cI (incongruent trials preceded by a congruent trial) trials. Kamijo and Takeda (2013) have shown that fitness moderates this effect such that a conflict adaptation is observed for inactive participants on incongruent trials, but is not evident for active participants. Thus, it will be important for future research to consider the possible moderating role of fitness and/or acute exercise on the conflict adaptation response.

In conclusion, our results confirm the findings of past literature in demonstrating the beneficial relationship between acute exercise and cognition performance for both a measure of basic information processing and a measure of executive control. Importantly, findings indicate that this relationship can be observed regardless of different fitness levels. Furthermore, while the moderate level of fitness was associated with the best performance on the executive control aspect of cognition, extremely high fitness was not associated with greater benefits. From a practical point of view, this information highlights the importance of conducting single bouts of exercise on a regular basis as well as maintaining a moderate fitness level.

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