

## The Immediate and Delayed Effects of an Acute Bout of Exercise on Cognitive Performance of Healthy Older Adults

By: Lisa A. Barella, [Jennifer L. Etnier](#), Yu-Kai Chang

\*Barella, L.A., Etnier, J.L., & \*Chang, Y.K. (2010). The immediate and delayed effects of an acute bout of exercise on cognitive performance by healthy older adults. *Journal of Aging and Physical Activity*, 18(1), 87-98.

Made available courtesy of Human Kinetics: <http://journals.humankinetics.com/japa>

© 2010 Human Kinetics, Inc. as accepted for publication.

**\*\*\*© Human Kinetics. Reprinted with permission. No further reproduction is authorized without written permission from Human Kinetics. This version of the document is not the version of record. Figures and/or pictures may be missing from this format of the document. \*\*\***

### **Abstract:**

Research on the acute effects of exercise on cognitive performance by older adults is limited by a focus on nonhealthy populations. Furthermore, the duration of cognitive improvements after exercise has not been examined. Thus, this study was designed to test the immediate and delayed effects of acute exercise on cognitive performance of healthy older adults. Cognitive performance was assessed using the Stroop task. Participants were randomly assigned to an exercise (20 min of walking) or control (sitting quietly) condition. The Stroop task was administered at baseline and at 12 time points after treatment. Acute exercise resulted in better Stroop test performance immediately postexercise; however, the effects were limited to the color test. No effects of exercise on performance were observed for the Stroop interference or inhibition tests. Findings suggest that acute exercise performed by healthy older adults has short-term benefits for speed of processing but does not affect other types of cognitive functioning.

**Keywords:** executive function | information processing | physical activity | Stroop

### **Article:**

Physical activity has been positively linked to a variety of psychological outcomes including cognitive performance. The literature addressing the impact of exercise on cognitive performance includes examinations of both chronic and acute forms of exercise. In terms of the effects of an acute bout of exercise on cognition, the results of empirical studies have not been consistent; however, when summarized using either narrative or meta-analytic techniques, a positive relationship between acute exercise and cognitive performance has been reported (Brisswalter, Collardeau, & Arcelin, 2002; Etnier et al., 1997; McMorris & Graydon, 2000; Tomporowski, 2003).

Etnier et al. (1997) conducted a meta-analytic review of the literature and reported a small positive effect (average ES = .16) of acute exercise on cognitive performance. More

recently, Tomporowski (2003) narratively reviewed this literature and concluded that acute bouts of exercise benefit various cognitive processes including response speed, response accuracy, problem solving, and inhibition. Tomporowski also examined the results relative to the specific nature of the exercise bout by categorizing the studies based on whether they tested the effects of intense anaerobic exercise, short-duration aerobic and anaerobic exercise, or steady-state aerobic exercise. With respect to steady-state exercise, he commented that there has been “relatively little systematic laboratory-based research” (Tomporowski, p. 311) in this area but that evidence supports a facilitative effect of moderate-intensity aerobic exercise performed for less than 90 min.

Although the extant literature supports a beneficial effect of steady-state acute exercise on subsequent cognitive performance, most of the research has focused on younger adults. Research on the effects of acute bouts of exercise in the older adult population has been very limited and has been dominated by a focus on nonhealthy older adults such as nursing-home patients (Stones & Dawe, 1993) and older adult participants with various health impairments including cardiovascular disease (Emery, Hsiao, Hill, & Frid, 2003), chronic obstructive pulmonary disease (Emery, Honn, Frid, Lebowitz, & Diaz, 2001), Parkinson’s disease (Molloy, Beerschoten, Borrie, Crilly, & Cape, 1988), and memory impairment (Molloy et al.). Although results of this research generally support a positive effect of an acute bout of exercise on cognitive performance in older adults (e.g., Emery et al., 2001; Molloy et al.; Stones & Dawe), the effects of acute exercise on cognitive performance in “healthy” community-dwelling older adults have not been sufficiently examined. Given that advancing age has been shown to be predictive of worse cognitive performance (Bors & Forin, 1995; Brayne et al., 1999; Salthouse, 2003; Schaie, 1994; Schonknecht, Pantel, Kruse, & Schroder, 2005) and greater risk of clinical cognitive impairment (Jorm & Jolley, 1998; Lindsay et al., 2002; Rubin et al., 1998), it is important to find ways to maintain and enhance the cognitive function of older adults. Thus, the primary purpose of this study was to examine the effects of a single bout of moderate-intensity exercise on cognitive performance in healthy older adults.

Another relevant issue in the acute-exercise literature is that the time course of the benefits of exercise for cognitive performance is not known. This is an important issue as we strive to further our understanding of potential mechanisms underlying the relationship and to develop our ability to prescribe acute exercise as a means of benefiting cognitive performance. It has been hypothesized that the increases in cognitive performance are driven by changes in state processes, rather than changes in computational processes (Sergeant, 2000; Sergeant, Oosterlaan, & van der Meere, 1999; Tomporowski, 2003). Thus, it is expected that the changes that occur after an acute bout of exercise are transitory and, therefore, that the cognitive benefits would not be long lasting. Although empirical studies demonstrate a positive effect of acute exercise on cognitive performance, the extant literature has focused exclusively on the effects immediately after the acute exercise bout, and studies have not been conducted to test the duration of the observed effects. Therefore, a secondary purpose of this study was to test the time course of the effects of an acute bout of exercise on cognitive performance.

## **Methods**

### **Participants**

Older community-dwelling adults age 60–90 years were recruited through oncampus newspapers, physical activity programs, newspaper advertisements, and the YMCA and at an older adult apartment community. To qualify for the study, participants had to be community dwelling and healthy enough to perform a moderate-intensity exercise bout. Participants were screened according to the guidelines of the American College of Sports Medicine (2006) and using the Physical Activity Readiness Questionnaire (PARQ) and a medical health history questionnaire. In addition, self-reported clinical cognitive impairments, uncorrected visual problems, color blindness, and inability to speak English precluded participation. A total of 32 women and 8 men participated in the study, and their mean age was 69.48 years ( $SD = 8.32$ ).

Participants were asked to avoid consumption of caffeine and exposure to second-hand cigarette smoke for 2 hr before their laboratory visit. They were also asked to not exercise on the day of their testing; however, at times, this would have precluded the involvement of participants who regularly exercised, because they wanted to maintain their normal exercise schedules. Therefore, participants with regular exercise schedules were allowed to come to the laboratory for testing on days when they had only participated in low-intensity exercise (e.g., walking at a low intensity for 30 min, playing golf using a golf cart for transportation). However, regularly active participants who participated in low-intensity exercise on Day 1 were required to participate in this same low-intensity exercise on Day 2 so that their level of physical activity before testing was equivalent on both days.

## Materials

The PARQ, a medical health history form, and a pretest questionnaire were used to assess whether participants met the inclusion criteria and to ascertain compliance with the requirements for participation.

## The Stroop Task

The Stroop task (Jensen & Rohwer, 1966; Stroop, 1935) is a speeded task that requires short-term memory, attention, task switching, and inhibition and is considered to be a measure of executive function. This particular task was chosen as the measure of cognitive performance because of evidence that measures of inhibition (and the Stroop task in particular) are sensitive to the effects of acute exercise (Tomprowski, 2003). The Stroop task consists of three different tests, with each test consisting of 20 trials.

The stimuli for the color test were a series of four colored circles (Os) that appeared in one of four colors (red, green, yellow, or blue). Participants were asked to orally identify the color of the circles as quickly and as accurately as possible. The color test is primarily a measure of information-processing speed.

The stimuli for the interference test were a series of color names printed in an ink color that did not match the color name. Participants were instructed to identify the color of the ink and to ignore the color name. For example, if the word was yellow printed in green ink, the participant was asked to ignore the word yellow and say “green.” The interference test is a measure of executive function.

The inhibition test was exactly the same as the interference test except that the stimuli were related to one another in a fashion designed to cause negative priming. That is, the color of the word for each trial (with the exception of the first trial) was the same as the word on the

previous trial. For example, after a trial in which *green* was written in blue ink (so that participants had to inhibit their desire to say “green” and instead were to say “blue”), the next trial would be red written in green ink, and the participant would have to say “green” (the word that had just previously been inhibited). The inhibition test is a measure of executive function.

The Stroop task was programmed using DirectRT, and the images were displayed on a 19-in. computer monitor. A microphone installed on the computer transmitted the participant’s response. DirectRT records sound waves in real time, and reaction time is recorded at the first detection of sound, with a detection accuracy of  $\pm 10$  ms. The dependent variable was the average reaction time for the block of trials.

To lessen the likelihood of the participants’ remembering the test structure from the repeated test exposure and to minimize order effects, two steps were taken. First, the order in which the Stroop tests was administered at a given time point was randomized. Second, the order of presentation of the individual stimuli in the color test and the interference test was randomized. The 20 inhibition trials could not be randomized because of the requirement regarding the relationship between the individual trials; therefore, 13 versions with different stimuli were created and the particular version a participant performed at a given time was selected at random.

### Acute Exercise Bout

The intensity of the exercise bout was individualized based on participant age and using heart-rate reserve (HRR; American College of Sports Medicine, 2006). During the first 5 min of exercise (warm-up), the speed and grade of the treadmill were determined based on the modified Naughton protocol. The goal was to get the participant to the target heart-rate range ( $60\% \pm 3\%$  of HRR) gradually, but within approximately 5 min. Participants who reported being physically active started the exercise at Stage 2, whereas participants who reported being sedentary started at Stage 1. This was done to ensure that participants started at an intensity level that was manageable for them, but also to ensure that the more active participants got to their target heart rate in approximately the same amount of time as the less active participants. Once the target heart rate was reached, participants exercised for 20 more minutes.

### Design and Procedures

Participants came to the sport and exercise psychology laboratory on either 1 or 2 days, and each session was approximately 3 hr in duration. To maximize statistical power (Hopkins, 1997), a crossover design was initially used whereby participants completed either the control condition or the exercise condition on the first day of testing and then completed the other condition on the second day of testing. However, when using a crossover design, one must consider the possibility of carryover effects, and these effects were discovered midway through data collection. Because it is not possible to discern the specific cause of carryover effects, Dallal (2000) recommends that when they occur, the “usual practice is to set aside the results of the second time period and analyze the first only” (p. 4). This was done for the first 20 participants in the study. The second 20 participants were tested on only 1 day and were randomly assigned to the exercise or control condition for that day.

On arrival on the first day, each participant was provided with a consent form approved by the university’s institutional review board. After completion of the consent form, the heart-

rate monitor and watch (Polar Electro, Inc., Lake Success, NY, Model #A3) were described, and the participant was instructed on how to wear the devices. After the heart-rate monitor and watch were secured, the participant was seated in the chair directly facing the testing computer and completed the PARQ, the medical health history form, and the pretest questionnaire (total time was approximately 10 min).

Resting heart rate was then recorded, and the Stroop task was explained. Each participant then completed practice trials (5 color trials, 10 interference trials, and 10 inhibition trials). If the investigator noticed that the participant was having difficulty during the practice trials, the participant was prompted to take the practice trials a second time. This occurred on nine occasions.

On completion of the practice tests, participants were informed as to whether they would be exercising or not exercising on that day. They then performed the Stroop task for a baseline measure. Participants completed their assigned treatment condition and performed the Stroop task 12 times after the treatment condition. The 12 time intervals were as follows: immediately and 5, 10, 15, 20, 30, 45, 60, 75, 90, 105, and 120 min posttreatment.

If randomized into the exercise session, a participant completed a 20-min bout of treadmill exercise at moderate intensity ( $60\% \pm 3\%$  of HRR) after a 5-min warmup period. Heart rate was continuously monitored, and the experimenter ensured that the participant remained at the appropriate heart rate for 20 min by adjusting the speed or incline of the treadmill as necessary.

If randomized to the control condition, the participant was asked to sit quietly at the end of the treadmill. The treadmill was running at a speed of 2.0 miles/hr and set at an incline of  $7.5^\circ$ . During the 25 min of sitting quietly, the experimenter remained with the participant for part of the time and carried on a general conversation. This was done to minimize participant boredom and to make this condition as similar as possible to the exercise session, during which the experimenter had to converse with the participant regarding the exercise protocol. The experimenter spoke about three topics (general information about the research study—no information regarding hypotheses was shared, information about the Kinesiology Program at the University of North Carolina at Greensboro, and information on the background of the principal investigator) and allowed the participant to ask questions and talk minimally.

After completing the treatment condition, the participant moved quickly to the cognitive-testing computer and started the “immediate” Stroop cognitive test (within 30–90 s of completing the exercise bout). The participant then completed the remaining Stroop tests at the required time points. The experimenter was present in the room during the breaks between Tests 1 (immediate) and 6 (30 min). After the 30-min test, participants were allowed to read their own reading materials or magazines provided by the experimenter during the time between tests.

## Statistical Analyses

Before statistical analyses, erroneous data were identified and omitted. Erroneous data were defined as a verbal response that was not detected by the software; a verbal response, such as a giggle, laugh, or cough, that was detected by the software but not a relevant response; verbal responses that indicated an inability to distinguish the colors of yellow and green as displayed on the computer terminal; or reaction time that was less than 300 ms or more than 3,000 ms.

To test for differences at baseline between the first 20 participants and the second 20 participants, independent-sample t tests were used to compare means for each Stroop test (color,

interference, and inhibition) and age, and a chi-square test was used to test for gender differences.

To test for immediate and delayed effects of the acute bout of exercise on cognitive function, linear mixed models with time (baseline, immediate) or times (all 13 time points) as within-subject variables and condition (exercise, control) as a between-subjects variable were conducted. Separate analyses were conducted for each Stroop test (color, interference, and inhibition). An alpha value of .05 was used for all statistical tests. Pairwise comparisons were conducted when there was a significant main effect for time.

## Results

There were no significant differences between the first 20 participants and the second 20 participants for baseline performance on any of the Stroop tests (color, interference, and inhibition), age, or gender,  $p > .05$ . Participant demographics are presented in Table 1. Means and standard deviations for Stroop test performance as a function of time for each treatment condition and for the entire sample are presented in Table 2.

### Immediate Effects

In the color test, a significant main effect was found for time,  $F(1, 38) = 5.47$ ,  $p = .03$ , partial  $\eta^2 = .13$ , which indicated that performance improved from baseline ( $M = 672.01$ ,  $SD = 86.46$ ) to immediately posttreatment ( $M = 645.38$ ,  $SD = 98.54$ ) regardless of the treatment condition. However, this main effect was superseded by a significant time-by-condition interaction,  $F(1, 38) = 4.88$ ,  $p = .03$ , partial  $\eta^2 = .11$ , which indicated that performance improved from baseline to posttreatment for those in the exercise condition but remained stable for those in the control condition (see Figure 1). The main effect for condition was not significant,  $F(1, 38) = 0.42$ ,  $p = .52$ .

**Table 1** Descriptive Statistics for the Sample

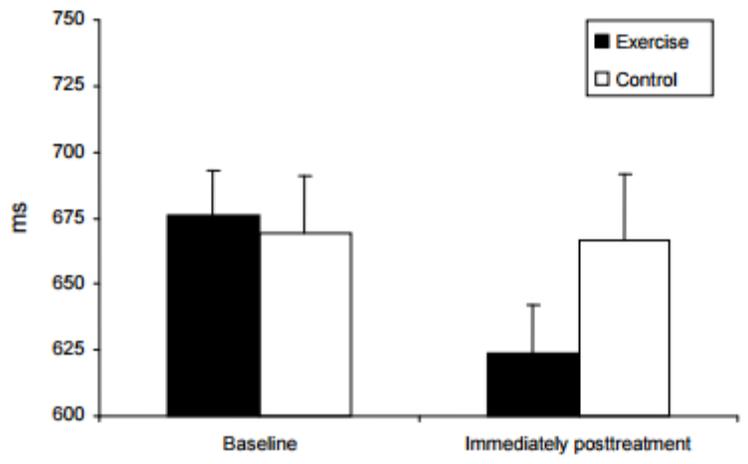
	Condition	
	Exercise, $n = 20$	Control, $n = 20$
Female, %	42.5%	40.0%
60–75 years, $n$	15	15
>75 years, $n$	5	5
Age, $M (SD)$	70.05 (8.53)	68.47 (8.28)

**Table 2 Performance on the Stroop Tests for the Treatment Conditions and the Total Sample as a Function of Time, *M* (*SD*)**

Time point	Color Stroop Test			Interference Stroop Test			Inhibition Stroop Test		
	Exercise	Control	Total	Exercise	Control	Total	Exercise	Control	Total
Baseline (T0)	675.80 (76.48)	668.21 (97.28)	672.01 (86.46)	832.27 (122.27)	874.32 (166.10)	853.30 (145.53)	874.68 (137.83)	917.81 (211.36)	896.24 (177.47)
Immediate (T1)	624.02 (81.60)	666.73 (110.96)	645.38 <sup>aa</sup> (98.54)	783.92 (117.13)	845.37 (145.84)	814.65 <sup>aa</sup> (134.21)	789.93 (103.12)	877.63 (151.76)	833.78 <sup>aa</sup> (135.55)
5 min (T2)	634.72 (69.21)	645.71 (77.10)	640.22 <sup>ad</sup> (72.53)	786.73 (102.34)	802.74 (120.74)	794.73 <sup>ab</sup> (110.98)	799.83 (95.25)	853.37 (128.41)	826.60 <sup>*</sup> (114.84)
10 min (T3)	632.82 (76.09)	643.94 (87.35)	638.38 <sup>*</sup> (81.05)	774.56 (104.76)	798.23 (99.40)	786.39 <sup>aac</sup> (111.51)	808.59 (114.31)	831.04 (146.46)	819.82 <sup>*</sup> (130.17)
15 min (T4)	636.43 (78.04)	638.15 (64.63)	637.29 <sup>ac</sup> (70.73)	794.12 (105.81)	804.72 (104.41)	799.42 <sup>ad</sup> (103.89)	811.44 (140.15)	823.40 (142.09)	817.42 <sup>*</sup> (139.44)
20 min (T5)	634.68 (75.99)	638.81 (70.41)	636.74 <sup>*</sup> (72.34)	799.64 (98.63)	808.43 (93.99)	804.03 <sup>*</sup> (95.20)	795.56 (102.70)	812.04 (121.76)	803.80 <sup>ab</sup> (111.49)
30 min (T6)	635.45 (90.56)	643.97 (64.32)	639.71 <sup>*</sup> (77.65)	787.25 (103.61)	802.84 (69.71)	795.04 <sup>ac</sup> (87.52)	791.59 (106.77)	823.34 (101.97)	807.47 <sup>*</sup> (104.30)
45 min (T7)	648.25 (98.12)	654.77 (82.89)	651.51 <sup>*</sup> (89.71)	788.23 (107.15)	819.90 (95.57)	803.06 <sup>*</sup> (101.66)	812.80 (119.95)	820.77 (110.85)	816.78 <sup>*</sup> (114.07)
60 min (T8)	637.80 (84.46)	644.64 (67.57)	641.22 <sup>ac</sup> (75.57)	801.83 (125.34)	803.60 (78.87)	802.72 <sup>*</sup> (103.37)	814.74 (122.14)	830.55 (88.01)	822.64 <sup>*</sup> (105.38)
75 min (T9)	662.41 (94.13)	648.91 (64.13)	655.66 <sup>d</sup> (83.92)	796.85 (119.68)	809.76 (100.51)	803.31 <sup>*</sup> (109.28)	818.46 (115.01)	837.61 (109.43)	828.04 <sup>*</sup> (111.23)
90 min (T10)	656.78 (97.98)	658.92 (70.43)	657.85 <sup>abcd</sup> (84.23)	792.72 (103.36)	829.31 (77.79)	811.01 <sup>ac</sup> (92.17)	813.73 (110.48)	833.94 (92.81)	823.83 <sup>*</sup> (101.23)
105 min (T11)	653.02 (96.70)	669.17 (72.92)	661.09 <sup>abcde</sup> (84.93)	808.16 (161.33)	811.99 (89.03)	810.08 <sup>ac</sup> (128.63)	800.92 (108.13)	833.30 (111.69)	817.11 <sup>*</sup> (109.74)
120 min (T12)	654.23 (87.25)	654.87 (59.23)	654.55 (73.60)	812.51 (115.14)	834.61 (103.87)	823.56 <sup>abcde</sup> (108.81)	826.46 (137.67)	834.59 (129.30)	830.53 <sup>ab</sup> (131.89)

Note. There was a significant main effect for time for all Stroop tests. Superscripts are used to show results of pairwise comparisons. Means identified with the same superscript are significantly different from one another.

<sup>ab</sup>Significantly different from baseline (T0).



**Figure 1** — Mean (and standard error) performance on the Stroop color test from baseline to immediately posttreatment as a function of treatment condition.

For the interference test, a significant main effect was found for time,  $F(1, 38) = 13.98$ ,  $p = .001$ ,  $\eta^2 = .27$ , indicating that performance improved from baseline ( $M = 853.30$ ,  $SD = 145.53$ ) to immediately posttreatment ( $M = 814.65$ ,  $SD = 134.21$ ) regardless of the treatment condition. No significant effects were found for condition,  $F(1, 38) = 1.46$ ,  $p = .23$ , or the time-by-condition interaction,  $F(1, 38) = 0.88$ ,  $p = .35$ .

For the inhibition test, a significant main effect was found for time,  $F(1, 38) = 22.10$ ,  $p < .001$ ,  $\eta^2 = .37$ . Examination of the means showed that irrespective of treatment condition, performance improved from baseline ( $M = 896.24$ ,  $SD = 177.47$ ) to immediately posttreatment ( $M = 833.78$ ,  $SD = 135.55$ ). No significant effects were found for condition,  $F(1, 38) = 1.90$ ,  $p = .18$ , or the time-by-condition interaction,  $F(1, 38) = 2.81$ ,  $p = .10$ .

### Delayed Effects

For the color test, there was a significant main effect for time,  $F(12, 456) = 2.67$ ,  $p = .002$ ,  $\eta^2 = .07$ ; however, there were no significant effects for condition,  $F(1, 12) = 0.10$ ,  $p = .76$ , or the time-by-condition interaction,  $F(12, 456) = 0.97$ ,  $p = .48$ . In general, the pairwise comparisons indicated that participants improved (were quicker) after baseline and maintained this improved performance for up to 60 min, at which point performance began to slow (see Table 2).

For the interference test, there was a significant main effect for time,  $F(12, 456) = 3.90$ ,  $p < .001$ ,  $\eta^2 = .09$ ; however, there were no significant effects for condition,  $F(1, 12) = 0.50$ ,  $p = .48$ , or the time-by-condition interaction,  $F(12, 456) = 1.03$ ,  $p = .42$ . Overall, the pairwise comparisons indicated that performance was quicker at all times after the baseline measure (see Table 2).

For the inhibition test, there was a significant main effect for time,  $F(12, 456) = 5.38$ ,  $p < .001$ ,  $\eta^2 = .12$ ; however, there were no significant effects for condition,  $F(1, 12) = 0.69$ ,  $p = .41$ , or the time-by-condition interaction,  $F(12, 456) = 1.31$ ,  $p = .21$ . Generally, the pairwise comparisons indicated that performance improved after the baseline measure (see Table 2).

### Discussion

Significant main effects for time were observed for all three of the Stroop tests whether examining the immediate effects (baseline to immediately posttreatment) or the delayed effects (baseline to the 12 time points posttreatment). For the immediate effects, these results indicated that performance improved from baseline to immediately posttreatment irrespective of whether participants had exercised or been in the control condition. Similarly, for the delayed effects, the results showed that regardless of treatment condition, participants experienced initial improvements in performance, which plateaued by some of the later time points. Thus, these results suggest that participants improved on the Stroop tests as a function of having the opportunity to perform the tests repeatedly.

The hypothesized interaction of condition by time was observed for the immediate effects on the Stroop color test. This interaction showed that exercise resulted in greater performance improvements from baseline to immediately posttreatment than were observed in the control condition (see Figure 1). This effect is consistent with past literature describing a beneficial effect of acute exercise on cognitive performance (Brisswalter et al., 2002; Etnier et al., 1997; McMorris & Graydon, 2000; Tomporowski, 2003) and supports Tomporowski's conclusion that exercise should affect response speed. Furthermore, because the results were only observed when looking at the immediate effects and were not evident when examining the delayed effects, the results support the hypothesis that the effects are relatively transitory (Sergeant, 2000; Sergeant et al., 1999; Tomporowski). Thus, this finding is consistent with our expectations and suggests that acute exercise has transitory benefits for speed of processing in healthy older adults.

However, based on past studies (Hogervorst, Riedel, Jeukendrup, & Jolles, 1996; Lichtman & Poser, 1983; Sibley, Etnier, & Le Masurier, 2006) and on Tomporowski's (2003) conclusions that acute exercise affects response accuracy, problem solving, and inhibition, we expected that there would be effects for all three of the Stroop tests. Furthermore, because past research has shown that effortful tasks are more sensitive to the effects of physical activity than automatic tasks or those that require little attention, we actually expected the effects of exercise to be larger for the interference and inhibition tests (Chodzko-Zajko, 1991; ChodzkoZajko, Schuler, Soloman, Heini, & Ellis, 1992). Clearly, these expectations were not supported by our findings. The failure to produce beneficial effects for the other Stroop tests (which assess higher levels of cognitive functioning such as short-term memory, attention, task switching, and inhibition) is perplexing, and the reasons for this lack of a significant effect should be considered.

First, given our interest in understanding the time course of the effects of the exercise on cognitive performance, we tested cognitive performance repeatedly for 120 min (baseline and 12 posttreatment times) after the acute bout of exercise. Considering the repeated exposure to the test and the length of time that participants were required to stay in the laboratory, it is possible that fatigue or an effort–reward imbalance may have affected participants' motivation to continue task performance. That is, if a participant felt that the perceived effort was greater than the reward, he or she might have lacked the motivation to perform the tests, experienced fatigue, and perhaps not given full effort at every testing period (Boksem, Meijman, & Lorist, 2006). It is unclear how early in the testing process fatigue or motivational issues would have been experienced by the participant, and these issues might have contributed to the lack of an effect of acute exercise on performance of the Stroop interference and inhibition tests in this study.

Second, the specifics of the exercise bout in combination with the sample characteristics might be important for influencing cognitive performance. In this study, participants performed a 25-min acute bout of exercise that included a 5-min warmup and 20 min at 60% of HRR.

Aerobic exercise of similar duration and performed at moderate intensity has typically been found to benefit cognitive performance (Gondola, 1987; Heckler & Croce, 1992; Sibley et al., 2006; Tomporowski, 2003). However, very few studies have tested the effects of acute exercise on the cognitive performance of older adults, and the research to date has focused on participants who were not considered healthy. Therefore, it is possible that the duration and intensity of the exercise may not have been the most appropriate for eliciting cognitive performance benefits in healthy community-dwelling older adults.

Third, it is possible that the use of a relatively broad age range of participants affected our ability to observe significant effects. Of concern was the possibility that age was systematically different between the two treatment conditions. However, examination of the distribution of participants indicated that young old (60–75) and old old (>75) participants were equally represented across the treatment conditions (see Table 1). It is also possible that observance of exercise effects in this sample of older adults was hindered by the increased variability in their performance. Although it is limited, there is evidence to suggest that advancing age is predictive of greater variability in Stroop task performance (Bunce, Tzur, Ramchurn, Gain, & Bond, 2008) and that increased reaction time typically seen with advancing age is associated with greater variability of performance (Hale, Myerson, Smith, & Poon, 1988). Thus, the variability in performance inherent in the speeded aspects of the Stroop tests might have minimized the likelihood of observing significant results. Future studies designed to assess the effects of acute exercise on cognitive performance might benefit from using a smaller age range of older participants and by using tasks that do not include such a large speeded component.

In summary, this study was designed to provide an important extension to the literature by testing the effects of acute exercise on the cognitive performance of healthy older adults and by examining the relative duration of any observed effects. The findings of this study suggest that an acute bout of exercise of 20 min of walking at 60% of age-predicted HRR, after a 5-min warm-up, at moderate intensity in healthy community-dwelling older adults has a short-term positive effect on speed of processing but does not affect higher order cognitive functions as measured by the Stroop task. Given the literature supporting the beneficial effects of acute exercise on cognitive performance (Brisswalter et al., 2002; Etnier et al., 1997; McMorris & Graydon, 2000; Tomporowski, 2003) and the fact that our findings demonstrate the benefits of acute exercise for healthy older adults, future research in this area is warranted. In particular, given the somewhat limited scope of the beneficial effects observed here, future research is needed to enhance our understanding of the precise dose of acute exercise needed to optimally benefit cognitive performance, the populations that can attain these benefits, the particular types of cognitive tasks that are likely to be affected, and the duration of the observed effects.

#### Acknowledgments

Dr. Yu Kai Chang is now at the Institute of Coaching Science at the National Taiwan Sport University. This study was supported by the 2005 University of North Carolina Graduate Summer Assistantship Award.

#### References

American College of Sports Medicine. (2006). ACSM's guidelines for exercise testing and

- prescription (7th ed.). Champaign, IL: Human Kinetics.
- Boksem, M.A., Meijman, T.F., & Lorist, M.M. (2006). Mental fatigue, motivation, and action monitoring. *Biological Psychology*, 72(2), 123–132.
- Bors, D.A., & Forin, B. (1995). Age, speed of information processing, recall, and fluid intelligence. *Intelligence*, 20(3), 229–248.
- Brayne, C., Spiegelhalter, D.J., Dufouil, C., Chi, L.Y., Dening, T.R., Paykel, E.S., et al. (1999). Estimating the true extent of cognitive decline in the old old. *Journal of the American Geriatrics Society*, 47(11), 1283–1288.
- Brisswalter, J., Collardeau, M., & Arcelin, R. (2002). Effects of acute physical exercise characteristics on cognitive performance. *Sports Medicine (Auckland, N.Z.)*, 32(9), 555–566.
- Bunce, D., Tzur, M., Ramchurn, A., Gain, F., & Bond, F.W. (2008). Mental health and cognitive function in adults aged 18 to 92 years. *The Journals of Gerontology. Series B, Psychological Sciences and Social Sciences*, 63(2), 67–74.
- Chodzko-Zajko, W.J. (1991). Physical fitness, cognitive performance, and aging. *Medicine and Science in Sports and Exercise*, 23(7), 868–872.
- Chodzko-Zajko, W.J., Schuler, P., Soloman, J., Heini, B., & Ellis, N.R. (1992). The influence of physical fitness on automatic and effortful memory changes in aging. *International Journal of Aging & Human Development*, 35(4), 265–285.
- Dallal, G.E. (2000). The computer-aided analysis of crossover studies [electronic version]. Retrieved May 18, 2006, from [www.jerrydallal.com/LHSP/crossovr.htm](http://www.jerrydallal.com/LHSP/crossovr.htm)
- Emery, C.F., Honn, V.J., Frid, D.J., Lebowitz, K.R., & Diaz, P.T. (2001). Acute effects of exercise on cognition in patients with chronic obstructive pulmonary disease. *American Journal of Respiratory and Critical Care Medicine*, 164(9), 1624–1627.
- Emery, C.F., Hsiao, E.T., Hill, S.M., & Frid, D.J. (2003). Short-term effects of exercise and music on cognitive performance among participants in a cardiac rehabilitation program. *Heart & Lung*, 32(6), 368–373.
- Etnier, J.L., Salazar, W., Landers, D.M., Petruzzello, S.J., Han, M., & Nowell, P. (1997). The influence of physical fitness and exercise upon cognitive functioning: A meta-analysis. *Journal of Sport & Exercise Psychology*, 19, 249–277.
- Gondola, J.C. (1987). The effects of a single bout of aerobic dancing on selected tests of creativity. *Journal of Social Behavior and Personality*, 2, 275–278.
- Hale, S., Myerson, J., Smith, G.A., & Poon, L.W. (1988). Age, variability, and speed: Between-subjects diversity. *Psychology and Aging*, 3(4), 407–410.
- Heckler, B., & Croce, R. (1992). Effects of time on posttest after two durations of exercise on speed and accuracy of addition and subtraction by fit and less-fit women. *Perceptual and Motor Skills*, 75, 1059–1065.
- Hogervorst, E., Riedel, W., Jeukendrup, A., & Jolles, J. (1996). Cognitive performance after strenuous physical exercise. *Perceptual and Motor Skills*, 83, 479–488.
- Hopkins, W.G. (1997). A new view of statistics: Repeated-measures ANOVA with two trials plus a between-subjects effect. [electronic version]. Retrieved May 18, 2006, from <http://sportsci.org/resource/stats/twotrials.html>
- Jensen, A.R., & Rohwer, W.D. (1966). The Stroop Color Word Test: A review. *Acta Psychologica*, 25, 36–93.
- Jorm, A.F., & Jolley, D. (1998). The incidence of dementia: A meta-analysis. *Neurology*, 51(3), 728–733.

- Lichtman, S., & Poser, E.G. (1983). The effects of exercise on mood and cognitive functioning. *Journal of Psychosomatic Research*, 27, 43–52.
- Lindsay, J., Laurin, D., Verreault, R., Hebert, R., Helliwell, B., Hill, G.B., et al. (2002). Risk factors for Alzheimer's disease: A prospective analysis from the Canadian Study of Health and Aging. *American Journal of Epidemiology*, 156(5), 445–453.
- McMorris, T., & Graydon, J. (2000). The effect of incremental exercise on cognitive performance. *International Journal of Sport Psychology*, 31, 66–81.
- Molloy, D.W., Beerschoten, D.A., Borrie, M.J., Crilly, R.G., & Cape, R.D.T. (1988). Acute effects of exercise on neuropsychological function in elderly subjects. *Journal of the American Geriatrics Society*, 36(1), 29–33.
- Rubin, E.H., Storandt, M., Miller, J.P., Kinscherf, D.A., Grant, E.A., Morris, J.C., et al. (1998). A prospective study of cognitive function and onset of dementia in cognitively healthy elders. *Archives of Neurology*, 55(3), 395–401.
- Salthouse, T.A. (2003). Memory aging from 18 to 80. *Alzheimer Disease and Associated Disorders*, 17(3), 162–167.
- Schaie, K.W. (1994). The course of adult intellectual development. *The American Psychologist*, 49(4), 304–313.
- Schonknecht, P., Pantel, J., Kruse, A., & Schroder, J. (2005). Prevalence and natural course of aging-associated cognitive decline in a population-based sample of young-old subjects. *The American Journal of Psychiatry*, 162(11), 2071–2077.
- Sergeant, J. (2000). The cognitive-energetic model: An empirical approach to attention-deficit hyperactivity disorder. *Neuroscience and Biobehavioral Reviews*, 24, 7–12.
- Sergeant, J.A., Oosterlaan, J., & van der Meere, J.J. (1999). Information processing and energetic factors in attention-deficit hyperactivity disorder. In H.C. Quay & A.E. Hogan (Eds.), *Handbook of disruptive behavior disorders* (pp. 75–104). New York: Cambridge University Press.
- Sibley, B.A., Etnier, J.A., & Le Masurier, G.C. (2006). Effects of an acute bout of exercise on cognitive aspects of Stroop performance. *Journal of Sport & Exercise Psychology*, 28, 285–299.
- Stones, M.J., & Dawe, D. (1993). Acute exercise facilitates semantically cued memory in nursing home residents. *Journal of the American Geriatrics Society*, 41, 531–534.
- Stroop, J.R. (1935). Studies of interference in serial verbal reactions. *Journal of Experimental Psychology*, 18, 643–662.
- Tomprowski, P.D. (2003). Effects of acute bouts of exercise on cognition. *Acta Psychologica*, 112(3), 297–324.