©Journal of Sports Science and Medicine (2015) **14,** 574-583
http://www.jssm.org

Research article

Effects of Acute Aerobic Exercise on Executive Function in Older Women

Roseann Peiffer, Lynn A. Darby ✉, Adam Fullenkamp and Amy L. Morgan
Exercise Science Program, School of Human Movement, Sport and Leisure Studies, Bowling Green State University, Bowling Green, Ohio, USA

Abstract
Acute aerobic exercise may increase cognitive processing speed among tasks demanding a substantial degree of executive function. Few studies have investigated executive function after acute exercise in older adults across various exercise intensities. Healthy females 60-75 years of age (n = 11) who were not on medications completed 20-min exercise sessions at a moderate (50%VO_2max) exercise intensity and a vigorous (75%VO_2max) exercise intensity. Modified flanker tasks (reaction times) and d2 tests of sustained and selective attention (components of executive function) were completed before, immediately after, and 30-min post-exercise. Results indicated that older adult females had improved scores on the modified flanker task reaction times (RT_T, RT_I, RT_C) and d2 tests immediately after both moderate and vigorous intensity aerobic exercise. Some of these effects were maintained 30 min post-exercise. These findings suggest that an acute bout of exercise, regardless of intensity, can improve performance on tests of executive function in older women.

Key words: Executive function, aerobic exercise, reaction time.

Introduction

There is a high prevalence of decreased cognition in the aging population (Chan et al., 2005). One of the typical characteristics of non-pathological brain aging includes some loss of cognitive function (Erickson and Kramer, 2009). Executive functions (reaction time and attention tasks) are a part of cognitive function and include tasks demanding diligence, conscious control, and the processing of new information. These executive functions typically involve the frontal, prefrontal, and parietal portions of the brain (Colcombe et al., 2004). Structural, physiological, and psychological changes in the frontal part of the brain are common in older adults (Colcombe et al., 2004).

There has been increasing evidence that regular physical activity can help prevent, or at least delay, the onset of cognitive loss (Colcombe and Kramer, 2003). Erickson and Kramer (2009), and Hillman, Snook, and Jerome (2003) have reported that cognitive function is the brain function most positively affected by cardiovascular exercise. Participation in aerobic exercise and physical activity seems to have a strong shielding effect on brain function and anatomy in many older adults as well as those who are susceptible to the development of cognitive deterioration (Churchill et al., 2002; Colcombe and Kramer, 2003). Cardiovascular exercise appears to considerably reduce the loss of brain tissue in regions controlling executive function (Colcombe and Kramer, 2003). Executive function describes attention, reaction time, and response accuracy. Executive function manipulates, controls, and organizes other aspects of cognition, and includes a wide variety of tasks, such as planning, attention, problem-solving, the initiation and directing of actions, task-switching, reasoning, and multitasking (Beilock and Carr, 2005). In older adult brains, improvements in baseline aerobic fitness can supply an amount of plasticity and resilience to neural substrates that is absent in the elderly who possess a low fitness status (Colcombe et al., 2004). It is believed that participation in exercise that improves aerobic capacity helps increase oxygen-rich blood flow to the brain, which facilitates normal physiological processes (Colcombe et al., 2004).

Implications have been made that acute aerobic exercise helps increase cognitive processing speed among tasks demanding a substantial degree of executive function (Hillman et al., 2003; Kamijo et al., 2007). Kamijo et al. (2009) reported that older adults 60-74 years of age, had elements of executive function such as reaction time, and response accuracy improved after an acute bout of “moderate” (50% of VO_2max), but not “light” (30% of VO_2max) aerobic exercise. While Kamijo et al. (2009) noted that executive function was improved after moderate exercise; it is unclear how cognition will be improved in older adults after higher intensity exercise [i.e., >60% of VO_2max; 60-84 %VO_2max – defined as “vigorous” (ACSM, 2014)], especially if they are not chronic aerobic exercisers (Pesce, 2009).

The effect of high intensity exercise on executive function has been investigated by Kamijo et al. (2004) and Budde et al. (2012) in young adults. Kamijo et al. (2004) found that executive function decreased after an acute about of high-intensity aerobic exercise (i.e., maximal cycling GXT) in young adult males. Conversely, Budde et al. (2012) reported that in young adults, only those who exercised regularly displayed improvements in executive function after high-intensity aerobic exercise (i.e., 20-m sprints for 3 min to max HR two times). In addition, Hogervorst, Riedel, Jeukendrup, and Jolles (1996) and Winter et al. (2007) reported that cognition could be increased after high-intensity exercise bouts of 75% of maximal work rate. Therefore, cognition does not always decline after high-intensity exercise, such as sprinting in young adults (Winter et al., 2007).

Because many of the studies on cognitive responses to acute exercise have been performed on younger adults, the purposes of this study were to investigate in older women who were aerobically fit: 1) whether cogni-

Received: 27 October 2014 / Accepted: 19 May 2015 / Published (online): 11 August 2015

tive function (i.e., reaction times from the flanker test, and results from a d2 test) changed after acute bouts of moderate or vigorous exercise; 2) if changes in cognitive function existed 30 minutes after exercise at each intensity; 3) whether the aerobic fitness of older women (≥ 60 years of age) was related to cognitive function after acute bouts of moderate and high-intensity exercise.

Methods

Design

The study design was a pre-test/post-test experimental study with the treatment (exercise trials at a moderate or at a vigorous intensity; Pre-Ex) performed after baseline fitness testing of the participants. After each exercise trial performed to the participant's target HR, the dependent variables were measured immediately after exercise (Imm-Ex) and at 30 minutes after exercise (Post-30). Dependent variables for the study were Total Reaction Time (RT_T), Incongruent Reaction Time (RT_I), Congruent Reaction Time (RT_C), Error rate (i.e., the relative number of all errors of confusion and elimination), GZ value (i.e., the rate at which participants mark off each d2 and the overall number of marked letters within the d2 test), and SKL value (i.e., a measure of attention; the standardized number of accurate answers minus confusion errors).

Participants

Women, 60-75 years of age (n = 11), were recruited from a midwestern university and surrounding community. Only women were chosen because few studies have been conducted investigating exercise and cognition of older women. Females may be at a greater risk for developing cognitive decline because of the decrease in estrogen levels at menopause (Spirduso et al., 2008). Any participant who was taking medications for cognitive impairment was excluded, as well as individuals who were on blood pressure medications, antidepressants, or medications for mental illness. There were 10 women who were screened out of the study because of medications; about 50% of the respondents participated in the study. A physician's consent form was obtained by each participant before involvement in the study. Participants gave their informed consent, and this study was approved by the Human Subjects Review Board at the university.

Measures

Baseline Physiological and Fitness Tests

Determination of predicted VO_2max: A measure of each participant's fitness level was assessed by having each participant complete a submaximal graded exercise test (GXT) (Balke Protocol) walking on a motorized treadmill. A submaximal graded exercise test was given instead of a maximal graded exercise test because submaximal tests of cardiovascular fitness do not require a physician's presence, provide lower risks than exercising at maximal intensity, and are fairly precise in predicting VO_2max (ACSM, 2014). Participants walked on the treadmill until their heart rate reached 85% of their age-predicted maximal HR calculated from 206.9 - (.67*age) (ACSM, 2014). The protocol included a 3-minute warm-up period at 2.0 mph before the first stage (ACSM, 2014). Blood pressure via auscultation, and heart rate via electrocardiograph (EKG) were measured before the test, as well as during each stage of the GXT (ACSM, 2014). Ratings of perceived exertion (RPE) using the 15-point (6-20) Borg (1973) scale were recorded at the end of each stage of the GXT.

Waist and hip circumferences: Waist and hip circumferences (cm) were used to determine distribution of body fat and health risk. A Gulick tape was used to measure these circumferences according to standard procedures (ACSM, 2014). The waist-to-hip ratio (WHR) was calculated from these values.

International Physical Activity Questionnaire (IPAQ) (Hagströmer et al., 2006): The *IPAQ* is a popular and valid physical activity questionnaire used internationally to assess physical activity levels (Hagströmer et al., 2005). The *IPAQ* has three ratings. A 3 designates those who are highly active and participate in 30 minutes of high-intensity exercise, or an hour or more of moderate-intensity exercise above the basal level of physical activity (approximately 5,000 steps per day) (IPAQ, 2005). Individuals who are highly active are also classified by completing 12,500 or more steps per day (IPAQ, 2005). Those who are rated at a moderate physical activity score of a 2 are active for 30 minutes on most days of the week at a moderate-intensity (IPAQ, 2005). Individuals who score a 1 are considered low active and do not meet any of the criteria for moderate or high active (IPAQ, 2005). The IPAQ also classifies individuals into a low, moderate, or high category as a sum of MET-minutes/week (IPAQ, 2005). Those who are high active, or category 3, score at least 3000 MET-minutes/week from total physical activity levels (walking, moderate, or high-intensity exercise), or 1500 MET-minutes/week from high-intensity exercise (IPAQ, 2005). Individuals who are categorized as a 2, or are moderately active, attain at least 600 MET-minutes/week (IPAQ, 2005). Those who are categorized as a 1, or are low active, do not meet the criteria for categories 2 or 3 (IPAQ, 2005).

Executive Function Tests - Modified flanker task and d2 test (Budde et al., 2012; Kamijo et al., 2009): The modified flanker task measures reaction time and response accuracy, which are aspects of inhibitory control and executive function (Kamijo et al., 2007; Kamijo et al., 2009). The test was administered on a computer screen, where 5 arrows were shown per situation. There were 80 situations, 40 congruent and 40 incongruent. In the congruent situation, arrows are displayed that point in the same direction as the middle arrow, the arrow of reference, allowing quicker reaction time (e.g., ⇒ ⇒ ⇒ ⇒ ⇒). In the incongruent condition, the arrow can point in the same or opposite direction as the arrow of reference, which can increase reaction time (e.g., ⇒ ⇒ ⇐ ⇒ ⇒). This reaction time condition demands a larger extent of executive function, which is attributable to stimulation of the inaccurate answer before the assessment is finished (Kamijo et al., 2009). The participant pressed either the right or left "control" button, depending on the direction the middle arrow was pointing. The modified flanker task takes about 8.5 minutes to complete (Kamijo et al., 2009).

The d2 test of sustained and selective attention, components of executive function (Bates and Lemay, 2004; Budde et al., 2012), includes 14 lines of 47 arbitrarily assorted letters ("p" or "d") per line, where one line is shown at a time (Budde et al., 2012). There are one to four dashes over and under each letter. The participant only chooses the letter "d" with two dashes above or below the letter. With a click of a mouse, an "x" will be marked at the top of the chosen letter on a computer screen. Each line is shown for only 20 seconds before a new line is revealed. The total time allowed for the d2 test was approximately 5 minutes. The d2 test has been shown to be valid, and reliable in measuring some components of executive function, such as sustained and selective attention (Budde et al., 2012). There are three variables measured within the d2 test to assess attention. Each variable was normalized into a ratio according to the total number of d2's within the test. The error rate measures precision and thoroughness, and is the number of all errors (marking off the wrong letter, a "d" with more or less than 2 dashes, or not marking off a d2 when there was one present). The GZ value measures working speed, and is the overall number of marked letters within the test. The SKL value is an indicator of attention span, and is the standardized number of accurate answers minus confusion errors (Budde et al., 2012).

Procedure

Each participant reported to the exercise physiology laboratory three times at the same time of day, 4-7 days apart. When arriving for the first visit (i.e., baseline fitness testing), each participant was given an informed consent form, a medical history questionnaire, and the long version of the *International Physical Activity Questionnaire (IPAQ)* (Hagströmer et al., 2006). After completing all of these forms, participants had their height and body mass measured, and body mass index (BMI) was calculated. Waist and hip circumferences (cm) were measured with a Gulick tape and WHR was calculated (ACSM, 2014). Demographic data are shown in Table 1.

For the baseline fitness testing and the exercise trials, the modified flanker task and d2 test were given before exercise to assess executive function. In order to reduce the effects of learning (Davranche et al., 2009; Kamijo et al., 2009), 32 practice trials of the modified flanker task and 3 lines of the d2 test were permitted before the protocol for the VO_2max test and exercise trials. After practice, either 80 real trials (40 congruent and 40 incongruent situations) of the modified flanker test and the d2 test were completed first with the order of the tests alternated.

After these cognitive tasks were completed prior to (Pre-Ex) the baseline fitness testing or exercise trials, the GXT or exercise trials were completed. Less than two minutes after exercise (Imm-Ex), participants again completed 80 trials of the modified flanker task (Kamjio et al., 2009) followed by 14 lines of the d2 test. The modified flanker task and d2 test were taken again 30 minutes post-exercise (Post-30). During the waiting period, participants were given magazines to read, as well as water. For the d2 test of selective and sustained attention, each dependent variable of the d2 test was normalized into a ratio because the total number of d2's in each test was not the same. The number of d2's in each test was randomized because if the total number of d2's were identical in each test, participants might start to recognize a pattern.

During the exercise trials, the participants were alternately assigned to a moderate exercise session at 50% of their estimated VO_2max for 20 minutes, following a 5-minute warm-up period of walking, or a vigorous intensity exercise session at 75% of their estimated VO_2max for the same duration. The duration of 20 minutes was chosen because previous studies with exercise of 15 to 20 minutes had an impact on cognitive functioning (Davranche et al., 2005, 2006; Davranche and Audiffren, 2004; Kamijo et al., 2009). Budde et al. (2010) noted previously that exercise intensity is more important than exercise duration when investigating the endocrine response and cognition. In this study, cognition was measured before and after moderate and high intensity aerobic exercise of the same duration. The exercise intensity at a percentage of VO_2max was estimated using metabolic equations (ACSM, 2014). The speed was set at 3.0 mph while the grade was manipulated by the researcher to ensure each participant reached the specified intensity after the warm-up period. Each participant completed both intensities of exercise on separate days. HR, blood pressure, and RPE were recorded every 5 minutes during each 20-min exercise session (Kamjio et al., 2009). The modified flanker and d-2 tests were administered similarly to the baseline fitness testing session.

Table 1. Descriptive characteristics of participants (n = 11).

Variable	Mean ± SD	Minumum	Maximum
Age (years)	65.8 ± 3.8	60	72
Height (m)	1.64 ± .07	1.55	1.73
Body Mass (kg)	65.1 ± 8.0	50.5	77.7
BMI ($kg \cdot m^{-2}$)	24.2 ± 2.3	19.7	25.7
Waist (cm)	74.8 ± 6.5	65	89.7
Hip (cm)	98.9 ± 5.4	88.6	109.5
WHR	0.75 ± 0.05	0.69	0.86
VO_2max ($ml \cdot kg^{-1} min^{-1}$)	36.8 ± 14.5	14.93	56.8
IPAQ Total Physical Activity Score (MET-minutes)	6857 ± 6298	657	22,947
IPAQ Rating	2.6 ± 0.51	2	3

VO_2 max = maximal oxygen consumption; BMI = Body Mass Index; WHR = Waist-to-Hip Ratio; IPAQ = International Physical Activity Questionnaire; IPAQ rating: 1 = low active, 2 = moderately active, 3 = high active.

Table 2. Means and standard deviations for Total Reaction Time (RT_T), Incongruent Reaction Time (RT_I), and Congruent Reaction Time (RT_C) by time regardless of exercise intensity (N = 10).

	Pre-Ex	Imm-Ex	Post-30	p	η_p^2	$1\text{-}\beta$
RT_T	529.6 ± 109.8	494.8 ± 89.5	511.2 ± 100.3	.010*	.403	.825
RT_I	566.3 ± 134.7	516.6 ± 88.8	526.8 ± 101.1	.005*	.447	.890
RT_C	492.8 ± 91.4	473.0 ± 92.7	485.2 ± 97.9	.035*	.310	.644

Pre-Ex=pre-exercise; Imm-Ex=immediately after exercise; Post-30=post-exercise 30-min * $p \le 0.05$= significant main effect for Time; η_p^2 = partial eta^2; 1-β = power

Table 3. Means and standard deviations for Error rate (normalized number of errors), GZ value, and SKL value by time regardless of exercise intensity (N = 11).

	Pre-Ex	Imm-Ex	Post-30	p	η_p^2	$1\text{-}\beta$
Error Rate	.179 ± .840	.165 ± .774	.142 ± .666	.003*	.435	.912
GZ Value	.826 ± .192	.848 ± .188	.861 ± .159	.005*	.414	.886
SKL Value	.817 ± .188	.835 ± .178	.863 ± .164	.001*	.482	.956

* $p \le 0.05$ = significant main effect for Time; Error rate, GZ value, and SKL value were each normalized into a ratio divided by the total number of possible d2's per line in each test. Pre-Ex=pre-exercise; Imm-Ex=immediately after exercise; Post-30=post-exercise 30-min; η_p^2 = partial eta^2; 1–β = power

Statistical analysis

Means and standard deviations were calculated for all variables. Appropriate two-way repeated measures (2 × 3; Exercise Intensity × Time) ANOVAs were used to determine if there were significant differences between means for the various levels of the independent variables. Level of significance was set at $p \le 0.05$. Appropriate *post hoc* tests were calculated to determine where the differences occurred, if applicable. Pearson correlations for VO_2max with each dependent variable at each time, and for VO_2max with the difference scores for Pre-Ex to Imm-Ex were calculated.

Results

Descriptive characteristics of the participants

Demographic data for the participants are shown in Table 1. The mean BMI for the women was 24.2 and was in the "normal" range (ACSM, 2014), and the mean WHR of 0.75 was in the "low" risk category (ACSM, 2014). The mean estimated VO_2max value for participants was 36.8 $ml \cdot kg^{-1} \cdot min^{-1}$; for this age group this is rated as superior (ACSM, 2014). Results from the IPAQ indicated that 7 women were highly active, while 4 were moderately active. The average Total IPAQ Physical Activity Score for participants was 6857 MET-minutes, while their mean IPAQ rating was 2.6. Those who had the highest VO_2max values in this study scored a 3 for high physical activity levels, while those who scored a 2 for moderate physical activity levels had lower VO_2max values. This indicates the participants from this study were moderate to highly active, generally of low risk for cardiovascular disease, and not on any medications.

Reaction time scores from the Modified Flanker Task – Effects of exercise intensity and time

Total Reaction Time (RT_T): Results of the two-way repeated measures ANOVA for RT_T indicated no significant difference due to Exercise Intensity (F = 0.138; df = 1; p = 0.719; η_p^2 = 0.015; 1-β = 0.063). However, there was a main effect for Time [see Table 2 and Figure 1a]. There was no Time × Intensity interaction. Two-tailed, *post hoc* dependent *t-tests* for each combination of RT_T means (i.e., Pre-Ex to Imm-Ex, Pre-Ex to Post-30, and Imm-Ex to Post-30) were calculated. The mean Pre-Ex RT_T was significantly greater than the mean Imm-Ex RT_T (t = 3.053; df = 19; p = 0.007; Cohen's d = 0.46; 1-β = 0.20). Other means were not significantly different.

Incongruent Reaction Time (RT_I): There was not a significant effect for Exercise Intensity (F = 1.658; df = 1; p = 0.230; η_p^2 = 0.156; 1-β = 0.211) for RT_I. However, there was a significant main effect for Time (see Table 2 and Figure 1b). There was no significant interaction. There was a significant difference from Pre-Ex to Imm-Ex (t = 3.018; df = 19; p = 0.007; Cohen's d = 0.56; 1-β = 0.33), and Pre-Ex to Post-30 (t = 2.217; df = 19; p = 0.039; Cohen's d = 0.43; 1-β = 0.40). The Imm-Ex to Post-30 mean was not significantly different.

Congruent Reaction Time (RT_C): There was not a significant main effect for Exercise Intensity (F = 0.550; df = 1; p = 0.477; η_p^2 = 0.058; 1-β = 0.102) for RT_C. However, there was a significant main effect for Time (F = 4.044; df = 2; p = 0.035; η_p^2 = 0.310; 1-β = 0.644) (see Table 2 and Figure 1c). There was no significant Time × Intensity interaction. There was a significant difference from Pre-Ex to Imm-Ex (t = 2.297; df = 19; p = 0.033; Cohen's d = 0.29; 1-β = 0.18). The other means were not significantly different.

Effects of exercise intensity and time on attention

Error rate: For Error Rate (relative number of errors) there was not a significant main effect for Exercise Intensity (F = 1.067; df = 1; p = 0.326; η_p^2 = 0.096; 1-β = 0.155). However, there was a significant main effect for Time (see Table 3 and Figure 2a). There was no significant interaction. For each combination of Error Rate means *t-tests* indicated there a significant difference from Pre-Ex to Post-30 (*t value* = 2.795; df = 21; p = 0.011; Cohen's d = 0.29; 1-β = 0.10). Other means were not significantly different.

There was no significant difference due to Exercise Intensity for the GZ value (F = 3.686; df = 1; p = 0.084; η_p^2 = 0.269; 1-β = 0.411). However, there was a significant main effect for Time (see Table 3 and Figure 2b). There was no interaction. For each combination of GZ value means *t-tests* indicated there was a significant difference from Pre-Ex to Imm-Ex (t = -2.373; df = 21; p

= 0.027; Cohen's d = -0.16; 1-β = 0.70), and Pre-Ex to Post-30 (t = -2.864; df = 21; p = 0.009; Cohen's d = -0.28; 1-β = 0.08). Other means were not different.

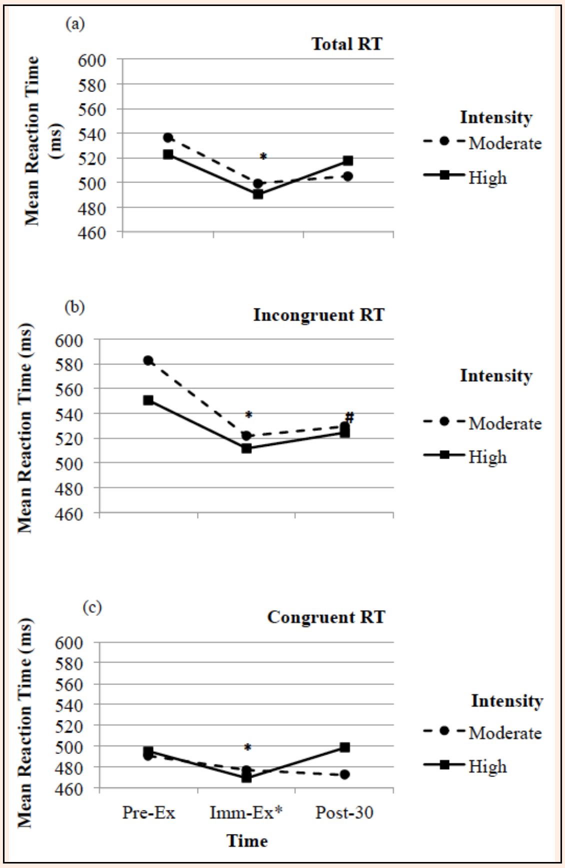

Figure 1. Total Reaction Time (a), Incongruent Reaction Time (b), and Congruent Reaction Time (c) by time and exercise intensity. (Pre-Ex = pre-exercise; Imm-Ex = immediately after exercise; Post-30 = post-exercise 30-minutes) (N = 10). *, # p ≤ 0.05, significantly different from Pre-Ex

SKL: There was not a significant effect for Exercise Intensity (F = 1.002; df = 1; p = 0.340; η_p^2 = 0.091; 1-β = 0.148) for the SKL value. However, there was a significant main effect for Time (see Table 3 and Figure 2c). There was no interaction. Dependent, two-tailed *t-tests* for each combination of SKL value indicated there was a significant difference from Pre-Ex to Post-30 (t = -3.271; df = 21; p = 0.004; Cohen's d = -0.35; 1-β = 0.08), and Imm-Ex to Post-30 (t = -2.176; df = 21; p = 0.041; Cohen's d = -0.22; 1-β = 0.15). The other means were not significantly different.

Relationship of VO_2max to cognitive function

Correlations were calculated between VO_2max and the dependent variables at Pre-Ex, Imm-Ex, or Post-30 by exercise intensity and are shown in Table 4. VO_2max was correlated with three of the dependent variables, RT_T Pre-Ex and RT_T Post-30 for both intensities, RT_T at all time periods except RT_I Imm-Ex vigorous intensity, and for RT_C for moderate Intensity exercise at Pre-Ex and Post-30 but not for vigorous intensity exercise (see Table 4). Only two correlations of VO_2max with change scores (i.e., Pre-Ex minus Imm-Ex values) for RT_T Moderate Intensity, r = 0.619, p = 0.028 and RT_C Moderate Intensity, r = .619, p = 0.028 were significant. No other correlations were significant.

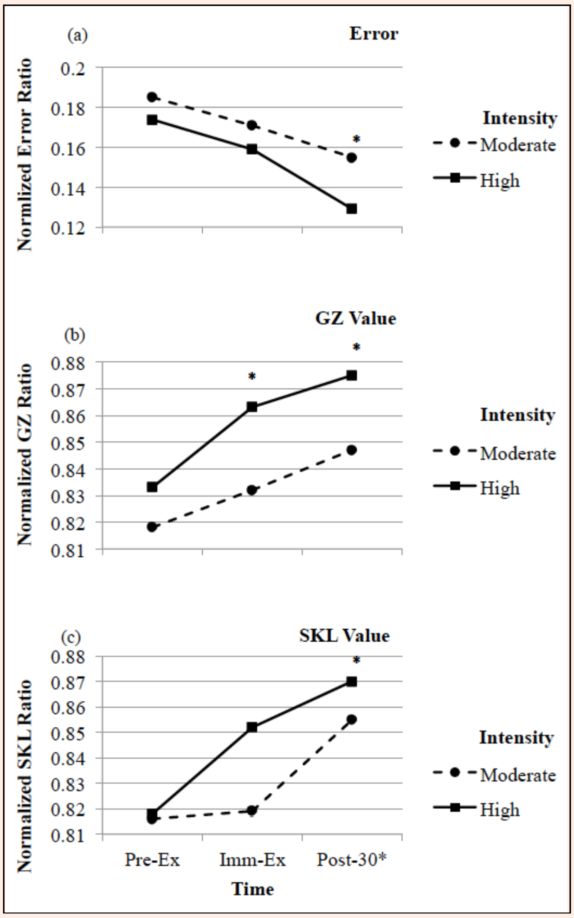

Figure 2. Error Rate (a), GZ value (b), and SKL value (c) by Time and Intensity Levels. (N = 11) (Pre-Ex = pre-exercise; Imm-Ex = immediately after exercise; Post-30 = post-exercise 30-min). *p ≤ 0.05, significantly different from Pre-Ex

Discussion

The purpose of this study was to investigate the acute effects of 20 minutes of moderate (50% of VO_2max) and 20 minutes of vigorous (75% of VO_2max) aerobic exercise for older adult females (60-75 years of age) on cognitive function as measured by executive functions (reaction time and attention tasks), immediately after exercise and post-exercise 30-minutes. In addition, the relationship of VO_2max with the cognitive variables was investigated.

Acute effects of exercise on reaction time

Reaction time results from the modified flanker task (i.e., RT_T, RT_I, and RT_C) improved after acute exercise (i.e., Imm-Ex) regardless of exercise intensity (i.e., moderate intensity and vigorous intensity). RT_T and RT_C did not stay improved after 30 min of recovery. However, the effects of acute exercise remained for RT_I as improvement was sustained after 30 minutes of recovery (see Figure 2). These results are comparable to the findings by

Table 4. Correlations (r values) between VO_2max and Dependent Variables at Pre-Ex, Imm-Ex and Post-30 Minutes Exercise for Moderate and High Intensities.

Moderate Intensity	Pre-Ex	Imm-Ex	Post-30
RT_T	.633*	.523	.618*
RT_I	.608*	.572*	.611*
RT_C	.626*	.474	.642*
Error rate	-.164	-.316	-.474
GZ	.183	.299	.462
SKL	.173	.318	.396
High Intensity	**Pre-Ex**	**Imm-Ex**	**Post-30**
RT_T	.585*	.483	.651*
RT_I	.622*	.478	.626*
RT_C	.496	.464	.485
Error rate	-.324	-.369	-.055
GZ	.395	.539*	.122
SKL	.411	.468	.098

Pre-Ex = pre-exercise, Imm-Ex = immediately after exercise, Post-30=post-exercise 30-min *$p \leq 0.05$; one-tailed. RT_T = total reaction time; RT_I = incongruent reaction time; RT_C = congruent reaction time. Error rate = the relative number of all errors of confusion and elimination. GZ value = measures the rate at which participants mark off each d2; the overall number of marked letters within the d2 test. SKL value measures attention; the standardized number of accurate answers minus confusion errors.

Kamijo et al. (2009), who reported that reaction time was improved immediately after moderate-intensity (i.e., 50% VO_2max) exercise for older males (60-74 years) and younger males (19-25 years). They had participants complete a modified flanker task before and less than 2 minutes after both a light (30% VO_2max) and moderate (50% VO_2max) 20-min cycling session. After exercising at 50% VO_2max, reaction time significantly decreased for both age groups. However, the exercise session at 30% VO_2max resulted in no significant decrease in reaction time as compared to baseline. Davranche et al. (2009) also used a modified version of the Eriksen flanker task, which measures executive function, and found that during 20 minutes of cycling at a moderate intensity of 50% of maximal aerobic power, congruent and incongruent reaction times were improved in university students and staff compared to baseline. Immediately after aerobic exercise at both moderate and vigorous intensities (50% VO_2max and 75% VO_2max) in this study, older adult females (60-75 years) significantly decreased their reaction times (i.e., RT_T, RT_I, and RT_C) as well. Therefore, reaction time improved regardless of the intensity of exercise.

In this study, the changes in incongruent RT were greater than in the congruent condition. This may be because incongruent RT uses a larger portion of executive function processing (Hillman et al., 2003; Kamijo et al., 2007) than the congruent condition. The incongruent arrows cause a slower reaction time due to the stimulation of an inaccurate answer before the task is finished (Hillman et al., 2003). This is because the surrounding arrows point in opposite directions as compared to the middle arrow, the arrow that participants are expected to react to (Kamijo et al., 2009). The accurate answer brought out by the target stimulus is challenged in the incongruent condition (Hillman et al., 2003; Kamijo et al., 2009). Older adult females had faster reaction times in incongruent condition immediately after exercise, as well as 30 minutes after exercise for both exercise intensities. In contrast, for the congruent condition, reaction time was only significantly improved from immediately after exercise. It appears that the incongruent condition elicited greater reaction time changes. The incongruent condition of a flanker task requires a larger extent of executive function than the congruent condition (Colcombe et al., 2004).

The findings from this study of the reaction time effect for the incongruent condition also are important because acute aerobic exercise of moderate and vigorous intensities can improve executive function processes in older women who possess a high level of fitness (i.e., mean VO_2max was 36.8 $ml \cdot kg^{-1} \cdot min^{-1}$ in this study). The VO_2max of the participants was considered superior for females 60-79 years of age (ACSM, 2014), and was between the 90-95 percentiles. This supports the results of Colcombe et al. (2004) who assessed fitness levels of older adults using the Rockport 1-mile walk test. They reported that older adults with higher fitness levels displayed a greater reduction in reaction time during the incongruent condition of a flanker task as compared to those with lower fitness levels. Because of a small sample size, participants in the present study could not be stratified by fitness level, and served as their own controls. Future studies may include a control group and fitness stratification of older women not taking medications to further delineate whether aerobic fitness levels effects on RT changes after acute exercise in aerobically fit older adults are comparable to their less fit counterparts.

In older adults, executive function may be responsible for controlling how they walk, particularly during more difficult predicaments such as walking up stairs or walking outside in icy conditions (Mirelman et al., 2012). Because of this, the risk of a fall may increase due to declining executive functioning (i.e., reaction time and attention). At rest, participants in this study of high and moderate fitness possessed similar reaction time scores, however, those who had a higher fitness level displayed a greater reduction in the incongruent condition of a flanker task, which requires a larger extent of executive function than the congruent condition (Colcombe et al., 2004). If executive function can be improved through increases in aerobic fitness, then this knowledge may help motivate some older adults to participate in regular aerobic exercise.

Acute effects of exercise on attention

Each d2 test variable that was measured (i.e., error rate, GZ score, and SKL score) improved after exercise, and all were significantly different from baseline at 30 minutes after the completion of exercise, regardless of exercise intensity. The number of total errors (both errors of elimination and confusion), as well as measures of precision and thoroughness, significantly decreased from Pre-Ex to Post-30. This means that aerobic exercise reduces error through 30-minutes post-exercise. The GZ value is the overall number of marked letters (“d” or “p”), whether the marked letter is right or wrong, within the d2 test (Budde et al., 2012). This value corresponds to working speed (how fast one responds in marking off a letter), and significantly increased from Pre-Ex to Imm-Ex, as well as from Pre-Ex to Post-30, meaning that working speed increased after exercise, and persisted 30-minutes post-exercise. The SKL value measures attention span, and is the standardized number of accurate answers minus confusion errors. The SKL value significantly improved from Pre-Ex to Post-30, and from Imm-Ex to Post-30. This means that almost all marked letters were accurately marked as d2’s, therefore, attention span increased across time (Budde et al., 2012). Together, the d2 test variables of Error Rate, GZ, and SKL measure selective and sustained attention, aspects of executive function (Budde et al., 2012) and were improved after acute exercise for these older women.

Stroth et al. (2009) believed that the d2 test of attention requires less concentration, can become automatic, and may not be a reliable task to use in assessing the effects of exercise on attention. In this study participants practiced the d2 test during their baseline session, where fitness status was assessed. They first had a chance to practice 3 lines of the d2 test, and then real trials (14 lines) were taken before their submaximal exercise test. Immediately and 30 minutes after the exercise test, real trials (14 lines) were taken of the d2 test. When participants arrived for their second and third sessions to assess the effects of acute aerobic exercise of moderate and high-intensity on executive function (i.e., attention and reaction time), they had a chance to practice 3 lines of the d2 test, and then took the real trials, 14 lines of the test Pre-Ex, Imm-Ex, and Post-30. Even though the participants had many chances to practice, the results were still improved for the d2 test of attention following aerobic exercise of moderate and high-intensity. It is unlikely participants’ scores changed due to a practice effect, because the number of d2’s in each test was randomized.

Aerobic capacity (VO_2max) and performance on executive function tests

Recent evidence proposes that increases in aerobic fitness through regular physical activity are essential to sustain cognition (Hötting and Röder, 2013). In this study, reaction time was significantly lower following both a moderate and high-intensity exercise session for older adult females 60-75 years of age who possessed a superior VO_2max for their age group. This supports results from previous studies. Barnes et al. (2003) reported that higher fitness levels of older adults (68.7 yrs) resulted in improved cognition in their investigation in which they compared high (maxVO_2 = 22.8 to 36.1 ml·kg^{-1}·min^{-1}) and low fit (maxVO_2 = 12.3 to 18.6 ml·kg^{-1}·min^{-1}) women. Colcombe et al. (2004) also reported that individuals with a higher level of fitness show greater improvements in attention and reaction time after exercise. In addition, Albert et al. (1995) suggested that in adults 70-79 years of age, those who regularly incorporated high-intensity exercise showed less of a decline in cognition. Budde et al. (2012) also studied active and inactive young adults (19-29 years of age) and had them complete the d2 test of attention after intermittent maximal exercise session and a seated control session. Those who were more active were able to improve their attention on the d2 test after the exercise condition, while those who were inactive did not benefit from the exercise session. This finding is similar to results in this study, because older adult females 60-75 years of age who possessed a higher level of aerobic fitness and physical activity participation were able to improve their attention on the d2 test following an acute bout of moderate and high-intensity aerobic exercise. In addition, in the present study, maximal oxygen consumption was not correlated with cognitive variables. However, because of the small sample size these results should be interpreted carefully. There was difficulty in recruiting older females not on medications (a selected criterion for the study), and therefore a comparison between older females with high and low fitness levels was not completed.

Since older adults of a high fitness level participated in this study, this could have significant implications because if older adult women could exercise before they start their day, they might be better able to pay attention to surrounding stimuli, such as during driving. However, according to Kamijo et al. (2007), individuals should first increase their fitness level to gain cognitive benefits. It is believed that decreased blood flow to the frontal lobe in the brain is due to a reduced ability to maintain attention during challenging endeavors in older adults (Mahoney et al. 2010). Because the act of driving a car, planning out business meetings, or balancing a checkbook requires executive function, if a decline in this type of cognition occurs in older adults, they are going to have a more difficult time carrying out these tasks. Since aerobic exercise is known to increase blood flow to the brain (Colcombe et al., 2004), it is important that older adults increase the amount of time they spend participating in aerobic exercise to enhance their fitness so that they can maintain good levels of executive functioning.

Effects of recovery time on cognition

Dependent variables were measured immediately after exercise and post-30-minutes to determine the time course for improvement in cognition, if present. Pontifex et al. (2009) tested 21 younger adults (Means: 20.2 years,

VO_2max = 54.6 ml·kg^{-1}·min^{-1}) to determine whether acute aerobic exercise, resistance exercise, or both affected cognition after exercise. Participants completed a modified Sternberg task (Sternberg, 1996) that assessed reaction time and response accuracy (i.e., executive function) by displaying a series of letter sequences involving uppercase consonants or lowercase consonants. Participants had to press a key with their right or left thumbs, depending on which sequence was present. Participants completed the Sternberg task before, immediately after, and 30-minutes following 30 minutes of aerobic exercise on a treadmill at 60-70% of VO_2max, 30 minutes of strength training, or a rest condition of 30 minutes. Reaction time decreased immediately after exercise and 30-minutes post-exercise for the aerobic exercise condition only (Pontifex et al., 2009). Hogervorst et al. (1996) found that in trained individuals (18-42 years of age), reaction time and working speed was improved immediately after a bout of cycling at 70% of their VO_2max, a workload that mimicked what they would cycle at for a one-hour all-out effort. Lambourne et al. (2006) found that in young adults (Means: 21.1 ± 1.7 years, VO_2max 37.33 ± 5.15 ml·kg^{-1}·min^{-1}) who cycled for 40 minutes at a moderate intensity, cognition returned to baseline measurements 30-minutes post-exercise.

If attention is elevated after exercise, this may help an individual identify a stimulus, and then react. For example, if attention and reaction time are improved after exercise, this may help an individual be more alert during driving. If individuals, especially older adults, can pay more attention to events "on the road", (e.g., deer suddenly crosses the road), they may more readily react and step on the brakes. Executive function, especially selective attention, is very important during driving; deterioration in selective attention results in an increased risk for crashes and decreases in driving ability (Adrian et al., 2011). More research is needed to determine the effects of differences in exercise intensities on cognition 30-minutes post-exercise in older adults.

One limitation that should be considered when interpreting the results of the current study is that VO_2max was estimated. This estimation may introduce a ±10% error and could possibly mask differences between the moderate and high exercise intensities (Heyward, 2010). However, in the present study, cognition was improved regardless of exercise intensity in older women. More research needs to be completed with older adults to determine at what intensities increases in cognition might be elicited and what mechanisms (e.g., blood flow, neural activity, etc.) may contribute to these changes in reaction time and attention (Tsujii et al., 2013). Subsequent investigations may directly measure VO_2max and use indirect calorimetry to directly set varied exercise intensities. This is important because it is unknown whether the positive cognitive benefits after acute aerobic exercise in highly fit older adults are the same regardless of exercise intensity (Kamijo, 2009; Zervas et al., 1991). In addition, further research could be done to examine various recovery times (i.e., 15, 30, 60, or 120 minutes) and cognition after each of these intensities in older adults. In order to increase sample sizes, individuals on some medications may need to be included in future research designs.

This study was completed with older adult females because females may be at the greatest risk of developing cognitive decline because of the decrease in estrogen levels at menopause (Spirduso et al., 2008). It is believed that estrogen may have a protective effect on cognitive function in women. However, taking supplemental estrogen is not recommended because of the increased health risks (Asthana, 2004). All of the participants in this study were post-menopausal, but were moderately to highly active. Further research needs to be completed on older adult females to determine what other beneficial effects that aerobic exercise might have on cognition after exercise.

Conclusion

Following acute aerobic exercise of moderate and high-intensities, older adult females, 60-75 years of age, significantly reduced their reaction time and improved their attention. Reaction time and attention are aspects of executive function. Executive function is typically part of age-related cognitive decline, and if older adults are able to increase executive function after aerobic exercise, this could improve older adults completion of tasks requiring immediate attention and reaction. Also, in order to gain the most in terms of cognition it may be important for older adult females to increase their fitness levels by participating in aerobic exercise more often and for longer periods of time. Additional studies need to be completed on older adults to delineate the mechanisms of how acute exercise influences cognitive abilities.

Acknowledgements
The authors would like to thank Yu Zhang for assistance with data collection.

References

Adrian, J., Postal, V., Moessinger, M., Rascle, N. and Charles, A. (2011) Personality traits and executive functions related to on-road driving performance among older drivers. *Accident Analysis and Prevention* **43**, 1652-1659.

Albert, M.S., Jones, K., Savage, C.R., Berman, L., Seeman, T., Blazer, D. and Rowe, J.W. (1995) Predictors of cognitive change in older persons: MacArthur studies of successful aging. *Psychology & Aging* **10**, 578-589.

American College of Sports Medicine. (2014) *ACSM's Guidelines for Exercise Testing and Prescription*. 9th edition. Lippincott, Williams & Wilkins, Philadelphia, PA.

Asthana, S. (2004) Estrogen and cognition: A true relationship? *Journal of the American Geriatrics Society* **52**, 316-318.

Barnes, D.E., Yaffe, K., Satariano, W., A. and Tager, I.B. (2003) A longitudinal study of cardiorespiratory fitness and cognitive function in healthy older adults. *American Geriatrics Society* **51**, 459-465.

Bates, M.E. and Lemay, E.P. (2004) The d2 test of attention: Construct validity and extensions in scoring techniques. *Journal of the International Neuropsychological Society* **10**, 392-400.

Beilock, S.L. and Carr, T.H. (2005) When high-powered people fail: Working memory and "choking under pressure" in math. *Psychological Science*, **16**, 101-105.

Borg, G.A. (1973) Perceived exertion: A note on "history" and methods. *Medicine and Science in Sports* **5**, 90-93.

Budde, H., Brunelli, A., Machado, S., Velasques, B., Ribeiro, P., Arias-Carrion, O. and Voelcker-Rehage, C. (2012) Intermittent maximal exercise improves attentional performance only in physically active students. *Archives of Medical Research* **43**, 125-131.

Budde, H., Voelcker-Rehage, C., Pietrassyk-Kendziorra, S., Machado, S., Ribeiro, P. and Arafat, A.M. (2010) Steroid hormones in the saliva of adolescents after different exercise intensities and their influence on working memory in a school setting. *Psychoneuroendocrinology 35*, 382-391.

Chan, A.S., Ho, Y., Cheung, M., Albert, M.S., Chiu, H.F.K. and Lam, L.C.W. (2005) Association between mind-body and cardiovascular exercises and memory in older adults. *Journal of the American Geriatrics Society* **53**, 1754-1760.

Churchill, J.D., Galvez, R., Colcombe, S., Swain, R.A., Kramer, A.F. and Greenough, W.T. (2002) Exercise, experience, and the aging brain. *Neurobiology of Aging* **23**, 941-955.

Colcombe, S.J., and Kramer, A.F. (2003) Fitness effects on the cognitive function of older adults: A meta-analytic study. *Psychological Science* **14**, 125-130.

Colcombe, S.J., Kramer, A.F., Erickson, K.I., Scalf, P., McAuley, E., Cohen, N.J.,, Webb, A., Jerome, G.J., Marquez, D.X., and Elavsky, S. (2004) Cardiovascular fitness, cortical plasticity, and aging. *Proceedings of the National Academy of Sciences* **101**, 3316-3321.

Colcombe, S.J., Erickson, K.I., Scalf, P.E., Kim, J.S., Prakash, R., McAuley, E., Elavsky, S., Marquez, D.W., Hu, L. and Kramer, A.F. (2006). Aerobic exercise training increases brain volume in aging humans. *The Journal of Gerontology: Biological Sciences and Medical Sciences* **61,** 1166-1170.

Davranche, K. and Audiffren, M. (2004) Facilitating effects of exercise on information processing. *Journal of Sports Sciences* **22**, 419-428.

Davranche, K., Burle, B., Audiffren, M. and Hasbroucq, T. (2005) Information processing during physical exercise: A chronometric and electromyographic study. *Experimental Brain Research* **165**, 532-540.

Davranche, K., Burle, B., Audiffren, M., & Hasbroucq, T. (2006) Physical exercise facilitates motor processes in simple reaction time performance: An electromyographic analysis. *Neuroscience Letters* **396**, 54-56.

Davranche, K., Hall, B., and McNorris, T. (2009) Effect of acute exercise on cognitive control required during an Eriksen flanker task. *Journal of Sport and Exercise Psychology* **31**, 628-639.

Erickson, K.I., Colcombe, S.J., Elavsky, S., McAuley, E., Korol, D.L., Scalf, P.E. and Kramer, A. F. (2007) Interactive effects of fitness and hormone treatment on brain health in postmenopausal women. *Neurobiology of Aging* **28**, 179-185.

Erickson, K. I., and Kramer, A. F. (2009) Aerobic exercise effects on cognitive and neural plasticity in older adults. *British Journal of Sports Medicine* **43**, 22-24.

Hagströmer, M., Oja, P. and Sjöström, M. (2006) The International Physical Activity Questionnaire (IPAQ): A study of concurrent and construct validity. *Public Health Nutrition* **9**, 755-62.

Heyward, V.H. (2010) *Advanced Fitness Assessment and Exercise Prescription.* Human Kinetics, Champaign, Illinois.

Hillman, C.H., Snook, E.M., and Jerome, G.J. (2003) Acute cardiovascular exercise and executive control function. *International Journal of Psychophysiology* **48**, 307-314.

Hogervorst, E., Riedel, W., Jeukendrup, A., Jolles, J. (1996) Cognitive performance after strenuous physical exercise. *Perceptual and Motor Skills* **83,** 479-488.

Hötting, K. and Röder, B. (2013) Beneficial effects of physical exercise on neuroplasticity and cognition. *Neuroscience and Behavioral Review* **13,** S0149-7634.

International Physical Activity Questionnaire (IPAQ). (2005) *Guidelines for data processing and analysis of the international physical activity questionnaire (IPAQ).* Available from URL: http://www.ipaq.ki.se

Kamijo, K., Hayashi, Y., Sakai, T., Yahiro, T., Tanaka, K. and Nishihira, Y. (2009) Acute effects of aerobic exercise on cognitive function in older adults. *Journal of Gerontology: Psychological Sciences* **64B**, 356-363.

Kamijo, K., Nishihira, Y., Hatta, A., Kaneda, T., Wasaka, T., Kida, T. and Kuroiwa, K. (2004) Differential influences of exercise intensity on information processing in the central nervous system. *European Journal of Applied Physiology* **92**, 305-311.

Kamijo, K., Nishihira, Y., Higashiura, T. and Kuroiwa, K. (2007) The interactive effect of exercise intensity and task difficulty on human cognitive processing. *International Journal of Psychophysiology* **65**, 114-121.

Lambourne, K., Audiffren, M. and Tomporowski, P.D. (2006) Effects of acute exercise on sensory and executive processing tasks. *Medicine and Science in Sports and Exercise* **42**, 1396-1402.

Mahoney, J.R., Verghese, J., Goldin, Y., Lipton, R. and Holtzer, R. (2010) Alerting, orienting, and executive attention in older adults. *Journal of the International Neuropsychological Society* **16**, 877-889.

Mirelman, A., Herman, T., Brozgol, M., Dorfman, M., Sprecher, E., Schweiger, A., Giladi, N., and Hausdorff, J.M. (2012) Executive function and falls in older adults: New findings from a five-year prospective study link fall risk to cognition. *PLoS One* **7**, e40297.

Pesce, C. (2009) An integrated approach to the effect of acute and chronic exercise on cognition: the linked role of individual and task constraints. In : *Exercise and Cognitive Function.* Ed: T. McMorris, T., Tomporowski, P.D. and Audiffren, M. Hoboken, NJ. Wiley-Heinrich. 213-226.

Pontifex, M.B., Hillman, C.H., Fernhall, B., Thompson, K.M. and Valentini, T.A. (2009) The effect of acute aerobic and resistance exercise on working memory. *Medicine and Science in Sports and Exercise* **41**, 927-934.

Spirduso, W.W., Poon, L.W. and Chodzko-Zajko, W. (2008) *Exercise and Its Mediating Effects on Cognition.* Champaign, Illinois: Human Kinetics.

Sternberg, S. (1996) High-speed scanning in human memory. *Science* **153,** 652-654.

Stroth, S., Hille, K., Spitzer, M. and Reinhardt, R. (2009) Aerobic endurance exercise benefits memory and affect in young adults. *Neuropsychological Rehabilitation* **19,** 223-243.

Tsujii, T., Komatsu, K. and Sakatani, K. (2013) Acute effects of physical exercise on prefrontal cortex activity in older adults: A functional near-infrared spectroscopy study. In: *Oxygen transport to tissue XXXIV.* Ed: Welch, W.J., Palm, Bruley, F.D.F. and D. K. Harrison, D.K. Springer, New York. 293-298.

Winter, B., Breitenstein, C., Mooren, F.C., Voelker, K., Fobker, M., Lechtermann, A., Krueger, K., Fromme, A., Korsukewitz, C., Floel, A. and Knecht, S. (2007) High impact running improves learning. *Neurobiology of Learning and Memory* **87**, 597-609.

Zervas, Y., Danis, A. and Klissouras, V. (1991) Influence of physical exertion on mental performance with reference to training. *Perceptual and Motor Skills* **72,** 1215-1221.

Key points

- Few studies have investigated the effects of the intensity of exercise on executive function in older women
- Executive function improved after 20-min of aerobic exercise regardless of exercise intensity in older women
- Findings from the study were not confounded by prescribed medications; all participants who were older women were not taking any medications

AUTHOR BIOGRAPHY

Roseann PEIFFER

Employment

School of Human Movement, Sport and Leisure Studies, Bowling Green State University, Bowling Green, OH, USA

Degree

MEd

Research interests

Aerobic exercise, cognition, and older adult females.

E-mail: rperchi@bgsu.edu

Lynn A. DARBY
Employment
Professor, Exercise Science Program, School of Human Movement, Sport and Leisure Studies Bowling Green State University, Bowling Green, Ohio, USA
Degree
PhD
Research interests
Responses of obese clients to exercise, and functional fitness assessments and training for golf.
E-mail: ldarby@bgsu.edu

Adam M. FULLENKAMP
Employment
Asst. Professor, Exercise Science Program, School of Human Movement, Sport and Leisure Studies Bowling Green State University, Bowling Green, Ohio, USA
Degree
PhD
Research interests
Human 3D Kinematic Analysis for Gait Recognition, Sport Performance, and Clinical Applications.
E-mail: fullena@bgsu.edu

Amy L. MORGAN
Employment
Professor, Exercise Science Program, School of Human Movement, Sport and Leisure Studies Bowling Green State University, Bowling Green, Ohio, USA
Degree
PhD
Research interests
The impact of changes in body composition on the functional ability of older individuals.
E-mail: amorgan@bgsu.edu

✉ **Lynn A. Darby, PhD**
218 Eppler South, Exercise Science Program, School of Human Movement, Sport and Leisure Studies, Bowling Green State University, Bowling Green, OH 43403, USA