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Exercise and executive functioning in older women

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ABSTRACT
Research suggests that exercise can slow the rate of decline in cognitive functioning in older adults. The effects of aerobic and resistance exercise on executive functioning was examined in 68 women over 50 years of age. Participants completed the Tower of London and Benton Controlled Oral Word Association tests. Findings indicated that individuals participating in both aerobic and resistance exercises performed significantly better than individuals not participating in exercise. Individuals who were participating in both aerobic and resistance exercises did not perform disproportionately better. Thus the form of exercise appears to be less important than engaging in some form of exercise.

KEYWORDS
Aging; card sorting test; executive functions; exercise; physical activity; verbal fluency

Introduction

In recent years there has been a rapid growth in the aged population in developed countries, with the number of people aged 65 years and over increasing by 2.5% a year in Australia (Australian Bureau of Statistics, 2010). A national health survey conducted in 2005 found that over a third of people aged 65–74 years of age and almost half of people aged 75 years and over were classified as sedentary (Australian Bureau of Statistics, 2009). These trends have increased the demands on the health care system in Australia with the federal government's expenditure on aged care increasing by 81% in the period 1997–2005 (Department of Health and Aging, 2007). However, current research provides strong support for the theory that the physiological and cognitive deterioration experienced by the aged population can be slowed or reversed through exercise, optimal nutritional intake, and the active use of cognitive resources. In particular, researchers have found that both aerobic and resistance exercises are beneficial to the improvement and maintenance of physiological and cognitive functioning (Guiney & Machado, 2013; Karr, Areshenkoff, Rast, & García-Barrera, 2014). Therefore, reducing the physiological and cognitive deterioration of the aging population through exercise and healthy lifestyle behaviors is rapidly emerging as an important public health goal (Colcombe, Erickson, Raz, Webb, Cohen, McAuley & Kramer, 2003).

Recent research has found that the rates of cognitive decline and improvements obtained through exercise are similar to those found in physiological systems, such as muscular strength and internal organ functioning. Loss of brain tissue is expected to occur from the third decade onward, which is one factor in the gradual decline in cognitive performance of older adults (Chang & Hung, 2010; Colcombe & Kramer, 2003; Farina, Rusted, & Tabet, 2014; Jedrziewski, Lee, & Trojanowski, 2007; Windle, Hughes, Linck, Russell, & Woods, 2010). Research suggests that exercise can enhance and maintain optimal cognitive functioning, slowing or reversing the rate of cognitive decline for older adults (Brownlee, 2006; Wendell et al., 2014). Both resistance training and aerobic exercise are reported as beneficial in improving and maintaining healthy functioning in the aging population (Burbank & Riebe, 2002; M. Morris & Schoo, 2004).

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Muscular strength and cardiorespiratory fitness generally begin declining in the third decade of life (American College of Sports Medicine, 1998). On average, an individual's muscular strength is expected to steadily decline after the age of 30, before declining more rapidly by approximately 15%–30% per decade after the age of 50. With regards to cardiorespiratory fitness, maximum heart rate is expected to decrease by six to 10 beats per decade after the age of 25, while maximal oxygen consumption (VO2max) decreases by 5%–15% per decade after the age of 25. Therefore, the physiological benefits of exercise are an important consideration when analyzing the cognitive benefits of exercise. These cognitive benefits are theorized to result from neurological and vascular changes in the brain, which are thought to be mediated in turn by the physiological benefits of exercising.

Numerous studies have found that both resistance training and aerobic training improve the size and strength of the heart and decrease blood pressure, thereby increasing the amount of blood that can be pumped to the brain (Baggish et al., 2008; Hagberg, Montain, Martin & Ehsani, 1989). This increased blood flow to the brain has been associated with an increase in the number of neurons and an improved structure of neurons (Kramer, Erickson, & Colcombe, 2006).

Studies on the cognitive benefits of exercise

Support for the theory that exercise can enhance and maintain cognitive functioning has been provided through numerous prospective, longitudinal, and cross-sectional studies (Colcombe & Kramer, 2003). However, initial studies failed to provide evidence to support this theory (Blumenthal et al., 1991; Hill, Storandt, & Malley, 1993; Snowden et al., 2011). It has been proposed by numerous researchers that these findings resulted from the difficulties observed in controlling for methodological problems, such as the differing nature, intensity, and length of exercise interventions, differing measurements of cognitive functioning, and individual differences occurring at baseline.

Recent research has provided some support for the physical activity-cognitive functioning relationship. Yaffe, Barnes, Nevitt, Lui and Covinsky (2001) conducted a 6–8-year prospective study on 5,925 women over 65 years of age, measuring the effects of physical activity on cognitive functioning. After adjusting for confounding variables determined at baseline (i.e., age, education, alcohol use, and gait speed), they found that women with the highest activity and energy expenditure levels had the least decline in cognitive functioning. Furthermore, it was determined that the participants in the lowest quartile of physical activity and energy expenditure were 37% more likely to be affected by cognitive decline than participants in the highest quartile.

Similarly, a prospective study measured the effects of physical activity on the cognitive functioning of 16,466 female nurses over 70 years of age (Weuve et al., 2004). Weuve et al. (2004) found that after controlling for confounding factors, women in the highest quintile of physical activity and energy expenditure had a 20% less chance of cognitive decline than women in the lowest quintile. The cognitive benefits of physical activity and energy expended were assessed as preventing cognitive decline by 2 to 3 years, within the age parameters of the participants.

Colcombe et al. (2004) conducted a longitudinal and a cross-sectional study to assess the cognitive functioning and brain activity of people over 50 years of age. fMRI scans indicated that the group with high cardiovascular fitness levels demonstrated significantly greater activation in a number of cortical regions associated with executive functioning. (Etnier, Nowell, Landers, & Sibley, 2006), however, concluded that the literature did not support cardiovascular fitness and cognitive functioning.

Executive functioning processes

Executive functions are controlled by three neural circuits in the frontal lobes: the dorsolateral prefrontal circuit, the lateral orbitofrontal circuit, and the anterior cingulate circuit (Royall et al., 2002). The dorsolateral prefrontal circuit is implicated in a variety of higher cognitive functions, including the planning, scheduling, and monitoring of goal-directed behavior. The lateral orbitofrontal circuit is involved in the initiation of social and internal behavior, as well as the inhibition of inappropriate behaviors. The anterior cingulate circuit is involved in monitoring behavior and correcting errors. Recent research has found that age-related declines in dopamine D2 receptors in the anterior cingulate and prefrontal cortices are associated with lower scores on the Wisconsin Card Sorting Test and the Stroop Colour-Word Test (Volkow et al., 2000). The Wisconsin Card Sorting Test consistently activates regions of the dorsolateral prefrontal circuit, and the Stroop Colour-Word test, as shown in fMRI scans, activates regions of the anterior cingulate circuit.

Effects of resistance exercise on executive functioning

Numerous studies have found that aerobic exercise slows the rate of decline in executive functioning for aged populations (Colcombe & Kramer, 2003; Colcombe et al., 2004; Van Boxtel et al., 1997). However, little research has examined the effects of resistance exercise on executive functioning (Cassilhas, Viana, Grassmann, Santos, Santos, Tufik & Mello, 2007).

A number of other factors have been found to slow cognitive declines in the aged population. Cognitively stimulating activities, including reading, interacting with friends and family members, playing card or mind games (i.e., crosswords), and engaging in productive activities (i.e., housework, gardening etc.), have been found to slow decline in reasoning, speed, and memory processes (Salthouse, 2006; Schooler & Mulatu, 2001; Studenski et al., 2006). Education has been associated (Lee, Anderson, Dennerstein, Henderson, & Szoeke, 2013) with activation of prefrontal, premotor, parietal, and temporal regions of the brain (Alexander et al., 1997; Stern, 2002). Conversely, excessive alcohol consumption and a history of smoking have also been associated with a decreased performance on working memory tasks (Bryan & Ward, 2002). These factors have been consistently controlled for in recent studies examining the effects of exercise on cognition.

Aims and hypotheses

The aim of this study was to use cross-sectional data to investigate the types of exercise that are most associated with executive functioning in an older sample of women. It was hypothesized that women participating in aerobic exercise would perform better on tests of executive function than individuals not participating in aerobic exercise. It was hypothesized that women participating in resistance exercise would perform better on tests of executive function than individuals not participating in resistance exercise. Given the different physiological and cognitive effects of aerobic and resistance exercise reviewed, it was also hypothesized that a combination of aerobic and resistance exercise would result in disproportionately better performance on tests of executive function.

Method

Participants

A total of 68 women between 50 and 85 years old participated. The participants were categorized into four exercise groups (aerobic, resistance, combined, and control) based on their exercise behaviors. All participants were placed in a draw to win a $50 gift voucher as remuneration for their participation. The aerobic group contained 21 participants, the resistance group contained five participants, the combined group contained 22 participants, and the control group contained 20 participants. In the 8 weeks prior to testing, eight (12%) of the participants reported that they smoked cigarettes, and 48 (71%) of the participants reported that they consumed alcohol. Fifty-four (79%) of the participants considered themselves to be postmenopausal.

Measures of control variables

Participants were asked to provide personal information on a sociodemographic questionnaire. Participants responded to questions relating to their age, gender, smoking and alcohol behaviors, and years of formal education. Physical, social, and cognitive activities were then measured by asking participants to complete the lifestyle activities interview. Participants were asked to provide information about their physical activity by responding to questions relating to the type, length, and intensity of physical activities in which they participated. These activities included exercise, gardening, housework, etc. Participants also provided information relating to their cognitive activity by responding to questions relating to the amount of time spent reading; watching television; and playing mind games, board games, or card games. In particular, social behaviors were measured by asking participants to respond to questions relating to the length of communicative interactions with family, friends, and members of the community.

Measures of executive functioning

The Tower of London test was used to measure the participants' planning and problem-solving abilities (Debelak, Egle, Kostering, & Kaller, 2015; R. Morris, Ahmed, Syed, & Toone, 1993). It was administered to participants via a laptop computer using the CATS software (Davis & Keller, 2002). During the test, the participants were required to rearrange a "working window" (on the left of the screen) of colored beads placed on pegs. The aim of the test was to achieve the same structure as displayed in the goal window (on the right of the screen) in as few moves and as quickly as possible. The test consisted of 21 trials that were preceded by one practice trial. This was almost twice as many trials as used by the Lee et al. (2013) normative study that used a physical pegs and discs version of the Tower test. The test trials consisted of arrangements containing three, four, and five pegs with three, four, or five beads. The number of moves made was recorded for subsequent analysis. It was decided that the time taken to complete the task would not be considered in the final analysis, as a number of participants had no previous computer experience and were considerably slower at manipulating the beads than more experienced computer users.

Version A of the Benton Controlled Oral Word Association Test was designed as a measure of the verbal deficits that are associated with deterioration of the left dorsolateral prefrontal cortex (Benton, 1968; Warkentin, Risberg, Nilsson, Karlson, & Graae, 1991). During this test, participants were instructed to state as many words as possible in 1 minute, starting with the letter provided (Ruff, Light, & Parker, 1996). The three letters provided separately for testing over a 1-minute period were C, P, and L. Included in the instructions to the participants were the standard rules applying to the words they were required to state, such as not using names and plurals.

Measures of physical activity

Participants were categorized into one of four exercise groups based on the activities in which they participated. These four categories were aerobic, resistance, combined, and control. The aerobic category consisted of participants who reported participating in only aerobic-based activities (i.e., walking, jogging, etc.). The resistance category consisted of participants who reported participating in only resistance-based activities (i.e., weight lifting, body weight exercises, etc.). The combined category consisted of participants who reported participating in a combination of aerobic and resistance-based activities (i.e., circuit training), and the control group consisted of participants who reported not participating in any form of exercise.

Physical activity levels were measured by identifying the type, length, and intensity of the physical activities in which participants reported taking part. One prerequisite of these activities was that the participant was required to have participated in the activity for at least 2 months prior to the testing. The information gained from the questionnaire regarding physical activity was then used to calculate a metabolic equivalent (MET) score for each activity, indicating the amount of oxygen used by the body during each activity (Ainsworth et al., 1993; U.S. Department of Health and Human Services, Center for Disease Control and Prevention, 2016). The ratio for MET levels has been previously calculated by measuring the oxygen intake per kilogram of body weight per minute for each physical activity in comparison to the average oxygen intake for an adult sitting quietly (approximately 3.5 ml of oxygen per kilogram per minute). It is also assumed that the personal intensity level each individual perceives is relatively accurate to the individual's actual intensity level (percentage of maximum heart rate).

Procedure

Participants were recruited from posters placed on notice boards at exercise centers, University of the Third Age, and other associated seniors community clubs. Participants were tested at their place of residence as the procedural requirements were suitable. The procedural requirements included administering the questionnaires and tests in a quiet and comfortable location, free of distractions and stressors. The study was approved by the James Cook University Human Research Ethics Committee.

After formally consenting to take part, participants were asked to complete the sociodemographic questionnaire and the lifestyle activities interview, followed by the Benton Controlled Oral Word Association Test and the Tower of London Test. All participants completed the tasks in this order.

All participants used the same laptop, computer mouse, and mouse pad. Participants were asked if they had ever used a computer before. Any participants that had little or no previous experience with computers were provided with brief instructions on how to use the computer mouse and were then given a brief period of time to navigate around the screen until they felt comfortable controlling the cursor.

Results

The normality of the distributions of scores obtained on the Tower of London (TOL) and Benton Controlled Oral Word Association (BCOWA) tasks was checked. The TOL score was moderately skewed (.74, Kolmogorov = .13, p = .01). Normality within the four exercise groups was deemed acceptable.

The mean age of the sample was 64.2 years (SD = 8.35) with a mean of 12.7 years of education (SD = 3.62). Mean estimated MET score was 1311.2 (SD = 1152.30).

Correlations were used to explore the relationship between TOL and BCOWA scores and all extraneous variables to assist in determining the variables to be used as covariates in a multivariate analysis of covariance between exercise groups and TOL and BCOWA scores. MET scores correlated .56 with TOL scores and .60 with BCOWA scores. Linearity and homoscedasticity were tested, and no serious violations were noted. Based on the differences observed in the data and the correlations of MET scores, age (.28 with TOL scores), education (.32 with BCOWA scores), and mind games (.32 with BCOWA) were used as covariates in the following analyses of covariance.

A two-way between-groups multivariate analysis of covariance (MANCOVA) was performed to investigate exercise differences in executive functioning. Two dependent variables were used: TOL and BCOWA scores. Two independent variables were used: Aerobic (levels: yes and no) and resistance (levels: yes and no). Estimated MET scores, age, education, and playing mind games were included as covariates in the analysis. There was no significant interaction effect between resistance and aerobic exercise on the combined TOL and BCOWA variables: $F(2, 59\ df) = 2.2$, $p = .12$; Wilks' Lambda = .93; partial $\eta^2 = .07$. Significant main effects were found for aerobic exercise: $F(2, 59\ df) = 6.22$, $p < .01$; Wilks' Lambda = .83; partial $\eta^2 = .17$; and resistance exercise: $F(2, 59\ df) = 3.74$, $p = .03$; Wilks' Lambda = .88; partial $\eta^2 = .11$. The results of the TOL and BCOWA were considered separately using a Bonferroni adjusted alpha level of .025. A significant effect was found for TOL scores for the aerobic group: $F(1, 67\ df) = 7.98$, $p < .01$, partial $\eta^2 = .12$; and resistance group: $F(1,67\ df) = 7.59$, $p = .01$, partial $\eta^2 = .12$. A significant effect was found for BCOWA scores

Table 1. Estimated marginal means for aerobic and resistance exercise across TOL and BCOWA scores.

Dependent variable	Independent variable		Mean	*SD*	Mean difference	*SD*	Sig.
TOL	Aerobic	No	11.46	1.29	4.86*	1.72	.01
TOL	Aerobic	Yes	6.60	.88	−4.86*	1.72	.01
TOL	Resistance	No	11.41	.88	4.77*	1.73	.01
TOL	Resistance	Yes	6.65	1.30	−4.77*	1.73	.01
BCOWA	Aerobic	No	38.37	1.70	−6.46*	2.27	.01
BCOWA	Aerobic	Yes	44.83	1.16	6.46*	2.27	.01
BCOWA	Resistance	No	40.66	1.16	−1.88	2.28	.41
BCOWA	Resistance	Yes	42.54	1.71	1.88	2.28	.41

Note. *$p \leq .01$.

for the aerobic group: $F(1, 67\ df) = 8.08$, $p < .01$, partial $\eta^2 = .12$; but not for the resistance group: $F(1,67\ df) = .68$, $p = .41$, partial $\eta^2 = .01$. Estimated marginal means for these effects are shown in Table 1.

Discussion

In support of the first hypothesis, individuals participating in aerobic exercises performed significantly better on both tests of executive functioning than individuals not participating in aerobic exercise. Significantly better scores were found on both the Tower of London test and the Benton Controlled Oral Word Association test for those active in aerobic exercise. The second hypothesis that individuals participating in resistance exercises would perform significantly better on tests of executive functioning than individuals not participating in resistance exercise was also supported. Significantly better scores were found on the Tower of London test. In contrast, individuals participating in resistance exercises performed better on the Benton Controlled Oral Word Association task than individuals not participating in resistance exercise; however, these differences were not found to be significant. Furthermore, the expectation that individuals participating in both aerobic and resistance exercises would perform disproportionately better on tests of executive functioning when examining the impact of aerobic and resistance exercise in conjunction with each other was not supported. It is important to note that the limited sample size, particularly the small sample of participants who were categorized as only participating in resistance exercises, could have led to Type 1 and Type 2 errors in examining differences between these groups.

Taking into account the limitations of the findings made from this study, both aerobic and resistance exercise are considered effective methods in maintaining executive functioning in older women. These results are consistent with the large literature relating aerobic exercise with executive functioning and the growing body of literature relating the effects of resistance exercise on executive functioning. Although no disproportionate benefits were found for individuals participating in both aerobic and resistance exercise for this study, research indicates that disproportionate benefits may exist when aerobic and resistance exercises are combined (Colcombe & Kramer, 2003). It is a possibility that the lack of significant differences related to this finding may be a result of a small sample size.

Given that similar differences were observed for aerobic and resistance exercise, and aerobic exercise is reported to have the greatest effect on heart and lung functioning, it appears that resistance exercise may have the greatest effect on the release of these neurochemicals and the amount of blood required by frontal regions of the brain to sustain resistance exercises (Baggish et al., 2008; Burbank & Riebe, 2002; Morris & Schoo, 2004). It is possible that this could be a result of the greater variety of movements required in executing resistance exercises. If this is the case, then a combination of aerobic and resistance exercise would provide disproportionate benefits in slowing the rate of decline in executive functioning.

There are a number of limitations of this study. One problem with using a cross-sectional design for this study is that preexisting differences between participants' performances on measures of executive functioning were not accounted for. Furthermore, longitudinal measures of actual exercise levels prior to 2 months before participation in the study were not obtained. The measures used also provided problems in standardizing the design of the study. The measure used to determine if participants' physical activities were categorized as aerobic or resistance exercise created difficulties in providing a standardized measure. Due to the cross-sectional design of the study, some difficulties were observed in classifying the types of exercise participated in. Therefore, participants were recruited from standardized aerobic, resistance, or combined exercise classes conducted by qualified fitness instructors. However, a number of participants were also involved in physical activities outside the programs from which they were recruited. In these cases many of the participants were already categorized in the combination of aerobic and resistance group, but in the few cases in which this was not the case, the guidelines mentioned in the methodology were applied. These guidelines were effective in categorizing the few cases in which they were required in this study. However, these guidelines may be problematic in determining particular activities that do not fit neatly into these guidelines. Therefore, these guidelines are not recommended for use in replication of this design if these problems are expected to occur.

The CATS computer-based version of the Tower of London task requires the participants to maneuver objects on a computer screen via a mouse. Participant differences in facility in using a computer led to the removal of the time variable from the measures of executive functioning used in the final analyses. Participants with visual impairments also reported difficulties in discriminating between the different colored beads used in the program, which may have also had an effect on the number of moves variable used in the final analysis. Another problem with the Tower of London program was the compounding effect it had on the participants' confidence levels throughout the task. The program displays the number of moves made by the participant and the optimal number of moves required to solve the problem. Participants' reactions to the display of their results for each individual trial may have affected future trials, as their confidence levels may have increased or decreased depending on the result of each trial. This may have in turn affected their performance in the following trials, as confidence levels have been found to affect performance (Stankov & Crawford, 1997). It is also important to note that the different administration formats used different numbers of trials, which can make comparisons across studies more difficult.

Future directions

This study has provided results consistent with the current literature relating to the effects of aerobic and resistance exercise on executive functioning. Future research aiming at acquiring a greater depth of knowledge into the type, length, and intensity of exercise programs required to gain the greatest physical and cognitive benefits is recommended. This would involve analyzing short (0–20 minutes), medium (20–40 minutes), and long (40+ minutes) programs of low, medium, and high intensity for aerobic, resistance, and combined exercises. It is recommended that experimental designs in which inactive participants are provided the opportunity to participate in standardized exercise programs be used.

Research focused on analyzing the active neurotransmitters and blood flow relating to specific regions of the brain, as well as postural and gait analyses in relation to the previously mentioned designs, would also provide a greater insight into the effects of exercise on cognition. Finally, research focused on the relationship between the effects of exercise and related physical and mental activities (i.e., crosswords, socializing, and nutrition) on cognition would also prove useful in providing effective health programs designed to improve the quality of life in the aged population and to decrease the pressure placed on the health care system.

The findings presented in this study add to the growing body of literature supporting the role of aerobic and resistance exercise in slowing the rate of decline in executive functioning for aged women. Although insignificant differences were found in determining if a combination of aerobic and resistance exercise was the most effective method in preventing the rate of decline in executive functioning, the direction of the findings are consistent with the current literature in this area.

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