

The Effects of a Brief, Water-Based Exercise Intervention on Cognitive Function in Older Adults

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Accepted 7 January 2015

Abstract

Physical inactivity is a modifiable risk factor for accelerated cognitive decline in older adults. Water-based exercise provides the same physiological benefits as land-based exercise with reduced risk of acute injury. The current study evaluated the effects of a brief, water-based exercise intervention on cognitive functioning and cardiovascular fitness in a group of community dwelling older adults. The exercise group ($n = 27$, $M_{age} = 63.26 \pm 7.64$, 78% female) attended one moderate intensity water aerobics class per day for six consecutive days whereas the control group ($n = 33$, $M_{age} = 65.67 \pm 6.69$, 75% female) continued their typical routine. Neuropsychological and cardiovascular fitness tests were given the week before and the week after the intervention to both groups. The exercise group demonstrated significant improvements in cardiovascular fitness, as well as executive function, attention, and memory over controls. This suggests a brief exercise program can provide benefits for older adults.

Keywords: Older adults; Mild cognitive impairment; Exercise; Executive function

Introduction

By 2030, the number of adults over the age of 65 is expected to grow to 72 million, or roughly one in five Americans (Federal Interagency Forum on Aging-Related Statistics, 2012; National Center for Health Statistics, 2011). Older adults are at elevated risk for adverse neurocognitive outcomes including structural (Galluzzi, Beltramello, Filippi, & Frisoni, 2008; Raz & Rodrigue, 2006; Tisserand & Jolles, 2003) and functional (Hedden & Gabrieli, 2004; Park & Reuter-Lorenz, 2009) brain changes. These negative outcomes can range in severity from age-associated cognitive decline to dementia (Park, O'Connell, & Thomson, 2003).

A growing number of protective (i.e., education, Mediterranean diet) and risk factors (i.e., cardiovascular disease, type 2 diabetes, and obesity) for age-related cognitive decline have been identified (Biessels, ter Braak, Erkelens, & Hijman, 2001; Feart, Samieri, Alles, & Barberger-Gateau, 2013; Meng & D'Arcy, 2012; Nilsson & Nilsson, 2009; Okonkwo et al., 2010; Xingwang et al., 2013). Recent work raises the possibility that improved physical activity and exercise may ultimately reduce risk for adverse neurocognitive outcomes. Exercise is most commonly associated with improvements in multiple cognitive domains including global cognition, attention, executive functioning, and memory (Angevaren, Aufdemkampe, Verhaar, Aleman, & Vanhees, 2008; Colcombe & Kramer, 2003; Kara, Pinar, Ugur, & Oguz, 2005; Langlois et al., 2012). Older adults who are in the highest quartile of energy expenditure had a significantly lower risk of developing dementia than those in the lowest quartile (Podewils et al., 2005). Randomized control trials also suggest exercise is beneficial for those with Alzheimer's disease (Denkinger, Nikolaus, Denkinger, & Lukas, 2012; Erickson et al., 2011; Hamer & Chida, 2009; Rolland, van Kan, & Vellas, 2010; Yaguez, Shaw, Morris, & Matthews, 2011). Lower risk of developing vascular dementia (Aarsland, Sardahaec, Anderssen, & Ballard, 2010; Abbott et al., 2004; Minami et al., 1995; Podewils et al., 2005; Ravaglia et al., 2008; Verghese et al., 2003) and increased hippocampal volume (Colcombe et al., 2006) have also been demonstrated following regular exercise in this population.

Exercise interventions with older adults exhibit considerable variability in terms of length (Roma et al., 2013), exercise methodology (DiPietro, Dziura, Yeckel, & Neuffer, 2006; Forte et al., 2013; Macaluso et al., 2003), and intensity (Fukimoto et al., 2010; Malin et al., 2012; Roma et al., 2013; Yokokawa, Hongo, Urayama, Nisimura, & Kai, 2008). Despite difficulties in comparing across studies, research appears to suggest higher intensity and longer interventions produce more favorable results (DiPietro, Dziura, Yeckel, & Neuffer, 2006; Malin et al., 2012). Fortunately, a recent line of research suggests individuals do not need to engage in prolonged exercise interventions to receive benefits. Older adults with type 2 diabetes who engaged in an exercise intervention for just 7 days showed improved glycemic control (Kirwan, Solomon, Wojta, Staten, & Holloszy, 2009; Mikus, Oberlin, Libla, Boyle, & Thyfault, 2012), and insulin functioning (Kelly et al., 2012; Solomon et al., 2009), illustrating the potential benefits of short-term exercise regimens.

Despite benefits found from increased exercise, older adults identify numerous obstacles to exercise participation including time constraints, lack of motivation/determination, lack of familiarity with recreation facilities, fear of falling, poor physical health, osteoarthritis, and lack of knowledge about recommended type and intensity of activity (Costello, Kafchinski, Vrazel, & Sullivan, 2011; Irvine, Gelatt, Seeley, Macfarlane, & Gau, 2013; Lees, Clark, Nigg, & Newman, 2005; Matthews et al., 2010; Schutzer & Graves, 2004; Wang, Belza, Thompson, Whitney, & Bennett, 2007; Wilcox et al., 2009). One alternative approach is the use of water-based (rather than land-based) exercise programs as it places less stress on an individual's joints, as well as reduces the risk of falling (Hale, Waters, & Herbison, 2012). Water-based exercise has also been shown to increase levels of cardiovascular fitness in older adults (Bocalini, Serra, Murad, & Levy, 2008; Bocalini, Serra, Rica, & dos Santos, 2010; Campbell, D'Acquisto, D'Acquisto, & Cline, 2003; Wang et al., 2007) and by participating in water exercise, older adults are better able to meet guidelines for recommended levels of physical activity (Bocalini et al., 2008; Campbell, D'Acquisto, D'Acquisto, & Cline, 2003; Nikolai, Novotny, Bohnen, Schleis, & Dalleck, 2009).

The current study sought to examine the effects of a brief water-based exercise intervention on cardiovascular fitness and cognitive functioning in a group of healthy, community-dwelling older adults. Specifically, we hypothesized that the exercise intervention would lead to increased cardiovascular fitness and improved cognitive functioning.

Methods

Participants

A sample of 69 older adults was recruited for the study from local community recreation and wellness centers. Eligibility included older adults between the ages of 50 and 80 and native English speakers. Exclusion criteria included a lifetime history of any of the following conditions: neurological disorders (e.g., stroke, epilepsy), sleep apnea, severe mental illness (e.g., bipolar disorder, schizophrenia), brain injury with resulting loss of consciousness >5 min, unexplained recurrent chest pain, abnormal heart rhythm, narrowing of aortic valve, blood clot in the lungs, inflammation of the heart, ruptured blood vessel, acute infections, or impaired heart valve functioning.

The exercise group was composed of 33 participants, was 78.8% female, had an average age of 63.52 (± 7.33), had 14.30 (± 2.49) years of education, with an average BMI of 30.12 (± 6.1), which is classified as Obese. The control group was composed of 36 participants, was 72.2% female, had an average age of 65.78 (± 7.33), had 15.94 (± 2.91) years of education, with an average BMI of 25.81 (± 5.50), which is classified as overweight.

Measures

Neuropsychological test battery. Participants completed a brief battery of neuropsychological measures to assess function across multiple cognitive domains.

The Montreal cognitive assessment (MOCA; Nasreddine et al., 2005). This test is a brief measure of global cognitive functioning at baseline. For the current study, the total score on the MOCA was used as a screening measure to ensure intact cognitive functioning at baseline.

Adaptive rate continuous performance test (ARCPT; Cohen, 1993). The ARCPT is a computerized measure of vigilance and sustained attention. This task requires participants to respond when a specific combination of letters appears on the screen. Indices measuring accuracy (task sensitivity), reaction time (final ISI), and vigilance (vigilance decrement) were used.

Trail making test A and B (Reitan, 1958). The trail making test A (TMT-A) asks participants to connect a series of 25 numbered dots in ascending order as quickly as they can (e.g., 1-2-3, etc.). Trail making test B (TMT-B) adds a set-shifting component to Trail making test A and requires participants to alternate between numbers and letters in ascending order (e.g., 1-A-2-B, etc.). Time to completion was used for both TMT-A and TMT-B.

Frontal assessment battery (FAB; Dubois, Slachevsky, Litvan, & Pillon, 2000). This test employs several short tasks to provide a broad measure of executive function. More specifically, participants are asked to identify similarities among two words (e.g., table, chair), name as many words as they can that start with a target letter (e.g., words that begin with 'S'), complete frontal-motor hand movements, and tap patterns with their dominant hand. The total score on the FAB was used.

Stroop test (Golden, 1978). This test measures selective attention and mental flexibility. Participants are asked to first read columns of words spelling out colors (word subtest), then asked to identify the color a series of Xs is printed in different colors (color subtest), and finally to indicate the color of the ink a word (which spells out a color) is printed in, regardless of the verbal content (color-word subtest). An interference score (predicted color word vs. actual color word) was used.

Hopkins verbal learning test revised (HVLTR; Brandt, 1991). This test asks participants to learn and remember a list of 12 words. Approximately 20 min after the three learning trials, participants are administered a delayed recall, and a recognition trial. An alternate version of the HVLTR was administered during follow-up testing to minimize potential practice effects. Total number of words learned, and number of words recalled after a delay were used.

Rey–Osterrieth complex figure test (Osterrieth, 1944; Rey, 1941). This test asks participants to copy a complex geometric figure. Immediately after completion of this learning trial participants are asked to draw as much of the figure from memory (immediate recall). Following a delay, participants are again asked to draw the figure from memory (delayed recall). The Taylor complex figure was administered as an alternate form to eliminate potential practice effects. The total scores from the immediate and delayed recall trials were used in analyses.

Cardiovascular fitness. In order to assess cardiovascular fitness, each participant completed the 2 minute step test (2MST; Rikli & Jones, 1999). During this test, participants are asked to march in place for 2 min raising the knee to a predetermined height. The required height for the knee raise was measured to be the midpoint between the individual's hip and knee. The number of times the right knee is raised to the required height was used. The 2MST has been demonstrated to be a feasible and accurate option for assessing cardiovascular fitness in older adults (Garcia et al., 2011; Rikli & Jones, 2002).

Self-reported physical activity. Participants were also asked about self-reported levels of physical activity through the rapid assessment of physical activity (RAPA; Topolski et al., 2006). This is a 9-item questionnaire designed to assess level of physical activity in older adults. Total score, ranging from 0 to 10 was used, with higher scores indicating greater levels of physical activity. The RAPA has a positive predictive power of 0.77 and a negative predictive power of 0.75 when compared with other measures of physical activity (Topolski et al., 2006).

Exercise intervention. The exercise intervention consisted of participants attending one moderate intensity water aerobics class per day for six consecutive days. This intensity was chosen as research has demonstrated higher levels of intensity to be effective in producing changes in physical functioning (DiPietro, Dziura, Yeckel, & Neuffer, 2006; Malin et al., 2012). Water aerobics classes were conducted by certified trainers and monitored by lifeguards certified in first aid.

A subset (42%) of those in the exercise group were randomly selected to wear heart rate monitors (Polar FT1; Polar Electro Inc., Lake Success, NY, USA) to ensure that they were reaching the desired 60%–70% of their maximum heart rate indicating moderate-to-high-intensity activity level (Malin et al., 2012). Participants were able to achieve a moderate level of exercise intensity, as evidenced by an average of 66% of their maximum heart rate during those sessions. The average maximum heart rate achieved was 113 (± 21.60). The intervention appeared to be well tolerated by participants as they reported attending an average of 5.85 (± 0.36) exercise classes during the week.

Procedures

All procedures were approved by the Kent State University Institutional Review Board and all participants provided written informed consent prior to study enrollment. At the baseline session, participants in the exercise group completed self-report questionnaires, the neuropsychological test battery, and the 2MST. Individuals were then instructed to participate in one water aerobics class per day for six consecutive days. Water aerobics were designated as moderate-to-high intensity, and designed as to allow participants to safely reach 60%–70% maximum heart rate. Following the intervention, participants completed follow-up testing which included the neuropsychological test battery and the 2MST. Baseline and follow-up testing sessions were conducted ~2 weeks apart.

Participants in the control group completed the same self-report questionnaires, neuropsychological test battery, and the 2MST as the exercise group. However, these participants were instructed to continue their typical daily routine until follow-up testing. Similarly, baseline and follow-up testing sessions were conducted ~2 weeks apart.

Data Analysis

A series of analyses examined differences between participants in the exercise and control groups. First, *t* tests were conducted to examine differences between the two groups at baseline. Results of these analyses were used as subsequent covariates. Repeated measures analysis of covariance (ANCOVA) was used to examine differences between the exercise and control group on cardiovascular fitness from baseline to post-testing. This procedure was repeated for examination of cognitive functioning from baseline to post-testing.

Data Screening

In order to facilitate interpretation of data, all raw cognitive test scores were converted into *T*-scores (a distribution with a mean of 50 and a standard deviation of 10) using normative data based on age, and when possible, gender and education. Composite scores were created for the domains of attention (ARCPT-accuracy, ARCPT-reaction time, ARCPT-vigilance, and TMT-A) executive functioning (TMT-B, FAB, and stroop interference) and memory (HVLt-learning, HVLt-delayed recall, CFT-immediate recall, CFT-delayed recall) by using the mean of the *T*-scores for the selected indices within each domain. In keeping with convention of many clinical settings, impairment in domains for the current study was defined as *T*-score < 35 (i.e., <1.5 deviations below the mean) (Alosco et al., 2012).

Outliers and subsequent violations of univariate normality were identified through histograms and examination of *z*-scores for cognitive domains and physical fitness. Any *z*-score that was ± 3 *SD* from the mean was considered to be an outlier. Analyses of baseline data revealed one case with a *z*-score >3 on the 2MST (raw score = 200), thus this case was removed from further analyses. No violations of normality or outliers were present in the domains of attention, executive function, or memory.

Results

Participant Screening

Participants were screened for clinical levels of cognitive impairment using their baseline MOCA score. Consistent with established cutoffs, any participant with a baseline MOCA score <23 was removed from analyses (Luis, Keegan, & Mullan, 2009; Tsai et al., 2012). Analyses identified eight cases that met criteria for removal. These cases were removed from primary analyses in an effort to detect improvements in functioning in a cognitive healthy older adult population. Participants excluded from analyses had a significantly lower estimated intelligence than those retained ($t(67) = -2.74, p \leq .01$), but no other demographic differences emerged.

Baseline Comparisons of Exercise and Control Groups

The final sample consisted of 60 older adults: 27 in the exercise group and 33 in the control group. No between group differences emerged in terms of age ($t(58) = -1.28, p = .21$), gender ($\chi^2 = 0.03, p = .85$), education ($t(58) = -1.95, p = .06$), or estimated intelligence ($t(58) = -0.86, p = .40$). The groups differed in self-reported baseline physical activity ($t(58) = -3.11, p = .003$) with the control group reporting more activity on the RAPA. The groups were also significantly different in terms of the 2MST ($t(58) = -2.22, p = .03$) with the control group demonstrating higher step count (see Table 1).

Table 1. Demographic characteristics of exercise and control groups

	Exercise group (<i>N</i> = 27) Mean (<i>SD</i>)	Control group (<i>N</i> = 33) Mean (<i>SD</i>)	Statistic (<i>t</i> or χ^2)	<i>p</i> -Value
Age	63.26 (7.64)	65.67 (6.96)	-1.28	.20
Gender (M/F)	6/21	8/25	0.03	.85
Years of education	14.63 (2.39)	16.00 (2.94)	-1.95	.06
Estimated intelligence (standard score)	9.78 (3.61)	10.52 (3.05)	-0.86	.40
Self-RAPA	7.44 (1.81)	8.70 (1.31)	-3.11	<.01
Fitness (2MST)	94.74 (30.15)	110.24 (24.05)	-2.22	.03

Note: Bold indicates significant difference.

Short-term Exercise Results in Improved Cardiovascular Fitness

In order to examine possible changes in cardiovascular fitness (2MST) from baseline to post-testing, a repeated measures ANCOVA was conducted in both the exercise and control groups adjusting for baseline levels of the RAPA. Overall, a significant group by fitness interaction was observed ($F(1, 57) = 7.97, p = .007$). Analyses revealed the exercise group improved from baseline to post-testing on the 2MST ($F(1, 26) = 6.22, p = .019, d = 0.39$), exhibiting a 12.3% increase in cardiovascular fitness. Interestingly, the control group demonstrated a decrease in performance on the 2MST ($F(1, 32) = 4.07, p = .05, d = 0.35$) (see Table 2).

Short-Term Exercise Results in Improved Cognitive Functioning

To investigate possible changes in cognitive functioning composite scores from baseline to post-testing, a series of repeated measures ANCOVA were conducted in both the exercise and control groups adjusting for baseline RAPA and 2MST. When examining changes on executive functioning, a significant interaction was observed between executive function and group ($F(1, 53) = 10.64, p = .002$). The exercise group demonstrated an increase from baseline to post-testing ($F(1, 24) = 58.46, p < .001, d = 0.92$). Conversely, the control group did not change from baseline to post-testing ($F(1, 31) = 1.63, p = 0.21, d = 0.11$).

Similar to executive function, the exercise group demonstrated an increase from baseline to post-testing on the attention composite score ($F(1, 24) = 12.82, p = .002, d = 0.53$). The control group did not change ($F(1, 32) = 2.65, p = .11, d = 0.25$) and no interaction was observed ($F(1, 54) = 0.36, p = .55$).

The exercise group demonstrated a significant increase in performance on the memory composite score from baseline to follow-up testing ($F(1, 24) = 9.27, p = .005, d = 0.41$) and a significant interaction was observed ($F(1, 54) = 4.34, p = .04$). The control group did not change from baseline to follow-up testing ($F(1, 31) = 0.01, p = .92, d = 0.01$) (see Table 2).

To further characterize the amount of change in the exercise group, a change score was calculated for each of the cognitive measures. The exercise group demonstrated a significant overall average increase in performance ($t(1, 58) = 3.63, p = .001$). Regarding change in each cognitive domain, the exercise group demonstrated significant change in the domains of executive functioning ($t(1, 58) = 3.77, p \leq .001$) and memory ($t(1, 57) = 2.26, p \leq .05$). No such change was observed for attention ($t(1, 57) = 1.18, p = .24$).

Discussion

The results of the current study show that a short exercise program provides numerous benefits for an older adult population. Building from previous literature, it was hypothesized that 1 week of water aerobics would lead to improvements in cardiovascular fitness and cognitive functioning. Consistent with these expectations, the exercise intervention produced significant increases in both cardiovascular fitness and cognitive functioning across multiple domains. Several aspects of the study warrant further discussion.

The current study found that 1 week of water aerobics produced a significant increase in cardiovascular fitness. Few studies have examined the effects of water aerobics on cardiovascular fitness (Meredith-Jones, Waters, Legge, & Jones, 2011), though most suggest equivalent or even greater benefits relative to land-based interventions. When placed in water, the body is subjected to forces (i.e., hydrostatic pressure) which are not found during land-based exercise (Meredith-Jones et al., 2011). During water immersion, the lower body is subject to increased pressure, causing blood to be diverted to the thoracic area placing the heart under an increased workload (Chu, Rhodes, Taunton, & Martin, 2002). Additionally, the pressure of the water inhibits

Table 2. Comparison of performance on fitness testing, and cognitive functioning composites from pre- to post-intervention between groups

	Exercise group		F-value	Sig	Control group		F-value	Sig
	Pre-testing mean T-score (SD)	Post-testing mean T-score (SD)			Pre-testing mean T-score (SD)	Post-testing mean T-score (SD)		
Fitness (2MST) (raw score)	94.74 (30.15)	106.37 (29.04)	6.22	.01	110.24 (24.05)	102.24 (20.57)	4.07	.05
Executive function composite	45.00 (7.01)	50.91 (5.66)	58.46	<.001	48.46 (6.01)	49.15 (6.11)	1.63	.21
Attention composite	52.44 (7.21)	56.36 (7.33)	12.83	<.01	56.68 (8.62)	58.65 (6.76)	2.65	.11
Memory composite	43.24 (9.53)	46.98 (8.48)	9.27	<.01	47.74 (8.66)	47.86 (5.69)	0.01	.92

Note: Bold indicates significant difference.

the body's ability to fully expand the lungs during an inhalation, increasing the workload of the lungs by as much as 60% (Agostoni, Gurtner, Torri, & Rahn, 1966). These physiological changes effectively challenge the cardiovascular system during water-based exercise and may help account for the rapid improvement in fitness found in the current study. Future studies are needed to confirm these effects and further clarify the possible advantages of water-based exercise in older adult populations.

One interesting and unexpected finding was the control group decreasing in cardiovascular fitness at the follow-up time point. While the exact explanation for this remains unclear several possibilities exist. Participants in the control group were aware of their group membership and may have modified behavior similar to the Hawthorne effect. Additionally, participants may have put forth reduced effort during the follow-up testing session due to misconceptions about their role within the study. As this finding was unexpected and future research is needed to elucidate other possible explanations.

Consistent with expectations, the current study also found 1 week of water aerobics produced significant increases in executive function, attention, and memory performance. The cognitive benefits of land-based exercise for older adults are well established and can improve executive function, attention, and memory (Angevaeren et al., 2008; Colcombe & Kramer, 2003; Kara, Pinar, Ugur, & Oguz, 2005; Langlois et al., 2012). Fewer studies have examined the potential benefits of water aerobics on cognitive functioning (Cancela Carral & Ayan Perez, 2007; Hawkins, Kramer, & Capaldi, 1992; Munguia-Izquierdo & Legaz-Arrese, 2007). However, the exercise program may have differentially affected participants depending on their level of baseline cognitive impairment. For example, prior research indicates those with cognitive impairment at baseline show different levels of improvement following an exercise intervention (Tanne et al., 2005).

Improvement in physiological indices known to influence cognitive functioning may also be contributing to the current results. For example, 15.2% of those in the exercise group reported a diagnosis of T2DM and such persons are at risk for cognitive impairments (Tiehuis et al., 2010; Yeung, Fischer, & Dixon, 2009). Prior research has suggested those with T2DM can achieve better control of blood glucose levels following 7 days of high-intensity exercise (i.e., 70% of maximum heart rate) (Kirwan et al., 2009). Thus, gains in blood glucose control in the exercise group may be implicated in the observed improvement in cognitive functioning. The current findings not only support brief exercise interventions as a method for improving cognition, but suggest that water aerobics is a safe and effective alternative to land-based exercise regimens.

Several limitations of the current study require further discussion. A primary limitation is the lack of randomization to study condition as participants selected to be in either the exercise or control group. This is important as past work has identified poor health as a reason older adults chose not to join an exercise program (Biedenweg et al., 2014). Future studies utilizing random assignment of participants are needed to resolve any possible confounds due to selection bias. Another limitation is found in the modest sample size of the current study, as excluding of participants for impaired cognition at baseline resulted in a smaller than expected sample available for analysis, ultimately limiting statistical power. By using a lower than recommended cut-off score on the MOCA (i.e., 23 vs. 26), the possibility exists that some participants may have been in the early stages of a degenerative condition, even if they did not currently meet criteria for these disorders. It is possible this methodological approach may have influenced study findings. Finally, this preliminary study collected relatively little information about possible mechanisms for improved cognitive function after a brief exercise intervention and future studies are needed to clarify possible metabolic, cardiorespiratory, and neural changes that underlie these benefits.

Despite these limitations, the current results of the study may have meaningful implications for future work. Past research (Middleton et al., 2011) suggests older adults need to engage in long-term physical activity and exercise to prevent cognitive decline. However, the current results suggest the same improvements in cognitive function can be achieved in a shorter duration when performed at a higher intensity level. The short duration is essential, given the many barriers which prevent older adults from regular exercise (Mcphate, Simek, & Haines, 2013). Another important feature of the current study is the use of water-based exercise over traditional land-based exercise. Moving exercise into the water eliminates many concerns related to falling and lower extremity arthritis (Lees et al., 2005; Wang et al., 2007).

In summary, the current study shows that older adults exhibit improved cardiovascular fitness and cognitive function after a brief, water-based exercise program. While future research is needed to confirm these effects, the current study raises the possibility that even brief exercise interventions can provide meaningful benefits in a high-risk population.

Funding

This work was supported by the Kent State University Graduate Student Senate, and the Kent State University Applied Psychology Center.

Conflict of Interest

None declared.

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