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Aerobic and Cognitive Exercise (ACE) Pilot Study for Older Adults: Executive Function Improves with Cognitive Challenge While Exergaming

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Abstract

Dementia cases are increasing worldwide; thus, investigators seek to identify interventions that might prevent or ameliorate cognitive decline in later life. Extensive research confirms the benefits of physical exercise for brain health, yet only a fraction of older adults exercise regularly. Interactive mental and physical exercise, as in aerobic exergaming, not only motivates, but has also been found to yield cognitive benefit above and beyond traditional exercise. This pilot study sought to investigate whether greater cognitive challenge while exergaming would yield differential outcomes in executive function and generalize to everyday functioning. Sixty-four community based older adults (mean age = 82) were randomly assigned to pedal a stationary bike, while interactively engaging on-screen with: (1) a low cognitive demand task (bike tour), or (2) a high cognitive demand task (video game). Executive function (indices from Trails, Stroop and Digit Span) was assessed before and after a single-bout and 3-month exercise intervention. Significant group × time interactions were found after a single-bout (Color Trails) and after 3 months of exergaming (Stroop; among 20 adherents). Those in the high cognitive demand group performed better than those in the low cognitive dose condition. Everyday function improved across both exercise conditions. Pilot data indicate that for older adults, cognitive benefit while exergaming increased concomitantly with higher doses of interactive mental challenge. (*JINS*, 2015, *21*, 768–779)

Keywords: Physical activity, Exergaming, Aging, Cognition, Executive function, Neuroplasticity

INTRODUCTION

Healthy aging has become a focus of research and clinical intervention, with emphasis on enhancing brain health and preserving cognitive function. Dementias, such as Alzheimer's disease (AD), affect one in 20 people over the age of 65 and one in five over the age of 80 (Bunn et al., 2012) and the rise in new diagnoses is concerning. While a "cure" for dementia is sought, the multiplicity of causes suggests a single intervention will likely remain elusive; thus with some urgency, research continues on interventions that could potentially delay the onset of or ameliorate the progression of decline (Brookmeyer, Johnson, Zieglr-Graham, & Arrighi, 2007). A growing base of research suggests that non-pharmacological interventions, such as exercise training, may counteract the detrimental effects of neurocognitive illnesses.

The cognitive benefits of physical exercise across the adult lifespan have been well documented (Bamidis et al., 2014; Chang, Labban, Gapin, & Etnier, 2012; Hillman et al., 2006; Etnier, Sibley, Pomeroy, & Kao, 2003). Benefits from both single-bouts of exercise (O'Leary, Pontifex, Scudder, Brown, & Hillman, 2011; Roig, Skriver, Lundbye-Jensen, Kiens, & Nielsen, 2012) and long-term fitness training have been recognized (Baker et al., 2010; Colcombe & Kramer, 2003; Prakash et al., 2015). Numerous reviews and meta-analyses of randomized controlled trials (RCTs) have established the cognitive benefits of physical exercise in normally aging adults

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(Angevaren, Aufdemkampe, Verhaar, Aleman, & Vanhees, 2008; Chang et al., 2012; Colcombe & Kramer, 2003), adults at risk for Alzheimer's disease or with mild cognitive impairment (MCI; Gates, Fiatarone Singh, Sachdev, & Valenzuela, 2013; Geda et al., 2010; Lautenschlager et al., 2008; Smith, Nielsen, Woodard, et al., 2013), and those with dementia (Hess, Dieberg, McFarlane, & Smart, 2014; Heyn, Abreau, & Ottenbacher, 2004).

The majority of neuropsychological benefits have been seen in aspects of executive function, such as planning, inhibition, and cognitive flexibility (Anderson-Hanley, Nimon, & Westen, 2010; Best, Nagamatsu, & Liu-Ambrose, 2014; Colcombe & Kramer, 2003; Etnier & Chang, 2009; Hillman, Belopolsky, Snook, Kramer, & McAuley, 2004). Furthermore, research has shown that if executive function or the semantic memory system is impaired, it will have a negative effect on everyday action (Forde & Humphreys, 2000). This is of particular importance for individuals at risk of dementia, because early symptoms of AD include impairments in episodic memory, executive function, and attention (Albert, Moss, Tanzi, & Jones, 2001; Kray & Lindenberger, 2000). The clinical implications of decline are grave, including safety concerns, decreased quality of life, and ultimately loss of independence. Yet, neuropsychological tests have been reported to have only a moderate level of generalizability or "ecological validity" when predicting everyday function (Chaytor & Schmitter-Edgecombe, 2003). The potential generalizability of measurable improvement on neuropsychological tests is somewhat elusive to specify, and could be imagined, but increasingly research aims to quantify whether a cognitive outcome also impacts everyday function.

Although physical exercise is a valuable intervention method, it is often difficult to motivate older adults to meet minimal physical activity recommendations. One way to increase engagement has been through the use "exergames" (Read & Shortell, 2011). Exergaming refers to an activity that combines physical exercise with interactive virtual reality or gaming features. Growing in popularity, exergames (e.g., Wii or DDR) provide an interactive virtual environment that facilitates social competition and cooperation and may offer a welcome distraction from aversive aspects of exercising. In addition to likely increasing motivation and promoting exercise adherence, exergame training has been shown to improve physical function as well as executive control and processing speed in older adults (Maillot, Perrot, & Hartley, 2012).

The research on the combined effects of physical and cognitive exercise is growing, yet results are inconsistent regarding the benefits of combined interventions compared to those that target the body and brain separately. Some studies have found combined interventions (performed sequentially) to be more efficacious than individual interventions alone (Fabre, Chamari, Mucci, Massé-Biron, & Préfaut, 2002; Oswald, Gunzelmann, Rupprecht, & Hagen, 2006); whereas others have found no immediate added benefit of combined training (Barnes et al., 2013; Linde & Alfermann, 2014; Rahe et al., 2015; Shatil, 2013). Fissler, Küster, Schlee, and Kolassa (2013) postulated that the reason for these inconsistencies is due to the fact that in the majority of studies, the cognitive and physical activities were performed sequentially rather than simultaneously or interactively. Simultaneous physical and mental training may be essential to maximize synergistic benefits (Anderson-Hanley et al., 2012; Kraft, 2012).

Only a few studies have compared the benefits of simultaneous physical and cognitive interventions (such as exergames) to the benefits of the individual components. Exergames provide cognitive stimulation while requiring additional focus and divided attention, and accordingly may offer additional cognitive benefit than physical exercise alone. Furthermore, exergaming may have advantages over independent cognitive interventions. Exergames often include novelty elements and require multiple cognitive processes which may increase the transfer of cognitive benefits (Basak, Boot, Voss, & Kramer, 2008). Exergames may enhance the generalization of learning as they typically offer adaptive tasks, rewards for performance, and induce higher levels of arousal compared to stand alone cognitive interventions due to the incorporation of physical activity (Green & Bavelier, 2008).

In one RCT, Anderson-Hanley et al. (2012) compared the cognitive effects of exergaming to those of traditional physical exercise for 63 older adults. Results revealed that those pedaling along an interactive virtual bike tour had significantly better executive function performance after 3 months than those in the traditional exercise group. Additionally, among exergamers a 23% relative risk reduction was observed in clinical progression to MCI. More recently, Theill, Schumacher, Adelsberger, Martin, and Jäncke (2013) compared the effects of simultaneous (but non-interactive) working memory and cardiovascular training (n = 21) to the effects of single working memory training (n = 16) and no training (n = 26). After 10 weeks, both training groups demonstrated greater improvements in executive control compared to controls. Moreover, those in the simultaneous group exhibited larger gains on a color and shape pair-associates learning task than the working memory group. The simultaneous group also demonstrated less gait variability during a motor-cognitive dual task in which participants had to count backward by sevens while walking compared to the working memory and control groups.

These studies suggest that integrating cognitive challenges and physical exercise may have a greater chance of ameliorating cognitive decline than stand-alone physical or cognitive exercise. While cognitive training alone has some research indicating benefits to cognition (Ball et al., 2002; Ballesteros et al., 2014; Belleville et al., 2006; Brum, Forlenza, & Yassuda, 2009; Hadi Hosseini, Jramer, & Kesler, 2014; Hall et al., 2009; Karr, Areshenkoff, Rast, & Garcia-Barrera, 2014; McDougall & House, 2012; Smith et al., 2009; Stern et al., 2011; Toril, Reales, & Ballesteros, 2014), there is considerable debate in the scientific literature regarding the nature of the research, particularly as it relates to the generalizability of cognitive enhancements (Bahar-Fuchs, Clare, & Woods, 2013;

Gates, Sachdev, Sign, & Valenzuela, 2011; Jean, Bergeron, Thivierge, & Simard, 2010; Valenzuela & Sachdev, 2009).

The mechanisms responsible for the cognitive benefits seen after exercise are still unclear; however, research suggests that such interventions may facilitate brain health, especially neuroplasticity, which in turn enhances cognitive function. Physical exercise has been reported to increase cerebral blood flow (Guiney, Lucas, Cotter, & Machado, 2015) and brain volume in the prefrontal cortex and hippocampus (Colcombe et al., 2006; Erickson et al., 2011). Studies using EEG have demonstrated engagement of neural structures that mediate executive functions after physical exercise (Vogt, Schneider, Brümmer, & Stüder, 2010; Yerokhin et al., 2012) and cognitive training or video game play (Anguera, Boccanfuso, Rintoul, Al-Hashimi, & Faraji, 2013; Maclin et al., 2011; Mathewson et al., 2012). Smith, Nielsen, Antuono and colleagues (2013) found decreased activation on semantic memory task-activated functional fMRIs after a 12-week walking intervention, suggesting that physical exercise improves neural efficiency. In addition to increasing peripheral concentrations of brain-derived neurotrophic factor (BDNF; Anderson-Hanley et al., 2012; Crispim Nascimento et al., 2014; Hötting & Röder, 2013; Knaepen, Goekint, Heyman, & Meeusen, 2010; Leckie et al., 2014), physical exercise has been linked to a reduction in inflammatory markers including C-reactive protein (CRP), tumor necrosis factor alpha (TNF-α), and interleukin-6 (IL-6; Crispim Nascimento et al., 2015; Loprinzi et al., 2013). Each of these biomarkers has been linked to brain plasticity and cognitive function. Indeed, even after only a single-bout of exercise, changes in neurophysiological and neuropsychological function has been documented (O'Leary et al., 2011; Roig et al., 2012), including a change in cortical inhibition that may improve the climate for brain plasticity (Smith et al., 2014), and real-time changes in biomarkers such as BDNF, VEGF, and IGF-1, that have been linked to improved consolidation of learning and memory (Skriver et al., 2014).

To address gaps in the literature, the present study examined the immediate and long-term neuropsychological effects of exergaming in a pilot sample of independent older adults. Consistent with recent literature, we focused on executive function as a primary neuropsychological outcome (Anderson-Hanley et al., 2012; Best et al., 2014; Colcombe & Kramer, 2003; Etnier & Chang, 2009; Hillman et al., 2004). Tasks that require higher cognitive demand (e.g., multitasking) have been shown to yield greater improvements in cognitive control (Anguera et al., 2013); however, it remains unclear as to what factors predict the best outcome. This pilot study aimed to clarify whether different doses of cognitive engagement, when combined interactively with physical exercise, would yield differential benefit in executive function. It was hypothesized that both single-bout and long-term interactive aerobic and cognitive exercise would result in cognitive benefit, particularly in executive functioning, and that varying the dose of mental engagement would differentially impact cognitive benefit. Furthermore, to assess the ecological validity of any findings, participants' subjective estimate of everyday thinking was measured.

METHODS

Participants

Community-dwelling older adults were recruited by fliers and information sessions (timeline: 2012–2014) at five independent living facilities in the Northeastern United States and one combination facility (adult day and outpatient physiotherapy) in Ireland. Research methods and procedures were consistent across sites as all research assistants (RAs) were trained and supervised by the principal investigator (last author). Irish participants were similar to those at the U.S. sites in that all spoke English as their primary language, but they were different in that they had to travel to the site daily to use the exercise equipment; never-the-less, adherence was similar (see Supplementary Table S1). Volunteers were screened (using a standardized check list) by phone or in person for inclusion in the study by an RA. Individuals were excluded if they had physician diagnosed neurologic disorders (e.g., AD[1], Parkinson's, or seizures) or cerebrovascular disease, or functional limitations that would restrict participation in cognitive testing or exercise (e.g., inability to pedal the recumbent stationary bike, inadequate hearing and/or vision to participate in testing procedures).

All study procedures were approved by Union College's Institutional Review Board or Galway University Hospital's Research Ethics Committee. Written informed consent and physician approval to participate was obtained from all participants.

Procedures

Participants were randomly assigned to one of two conditions for 3 months: (1) TOUR: physical exercise plus low cognitive demand (see Supplementary Figure S1 for sample screen shot); or (2) GAME: physical exercise plus high cognitive demand (see Supplementary Figure S2 for sample screen shot). A simple "flip of the coin" randomization method was used to determine the initial order of enrollment in the two conditions at each of the sites. Participants were then enrolled sequentially to help ensure equal enrollment in each group at each site.

All participants rode identical, virtual reality enhanced, recumbent stationary bikes that were located within the facilities. Individuals in the tour condition pedaled along virtual scenic bike paths. Those in the game condition pedaled through a scenic landscape where they were instructed to collect different colored coins and corresponding colored dragons. Throughout the game, participants

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[1] MCI was not a specific exclusionary criteria as we found through our previous research that those with MCI would participate successfully in an exergaming protocol (Anderson-Hanley et al., 2012), and we wished to retain generalizability to older adults living independently where MCI is often undiagnosed.

could navigate through bonus items to increase their score, all while avoiding penalties. A manipulation check using a 0–100 thermometer rating scale confirmed those in the game reported they exerted significantly more "mental effort" than those in the tour ($p = .02$; average = 70.3 *vs.* 50.9, respectively).

Upon enrollment participants completed demographic and fitness history questionnaires and were administered a brief neuropsychological battery. Individuals were trained in the use of the bike and underwent a 20-min single bout of exercise in their assigned condition. Throughout the exercise, participants were asked to maintain a target heart rate (HR), which was calculated using the Karvonen equation (McAuley et al., 2011). Post-testing was conducted following the single bout of exercise.

Following the initial visit, individuals were invited to exercise at least 20 min, twice a week and to gradually increase exercise frequency to 45 min, three to five times per week for 3 months. They were asked to maintain their target HR throughout the intervention period and this was confirmed by sampling ride data among adherents[2]. Heart rate was displayed on the bike's screen to allow individuals to monitor and maintain their target heart rate while exercising. Participants were also asked to document their exercise sessions in a paper log (frequency, intensity, duration). A final evaluation was conducted after 3 months.

Outcome Measures

Cognitive function (executive function)

Cognitive testing was done at baseline, after single-bout, and after the 3-month intervention. Three tests were administered to measure different aspects of executive function. Alternate forms were used for each test to minimize practice effects.

Stroop (van der Elst, van Boxtel, van Breukelen, & Jolles, 2006)

A 40-item version of Stroop was administered. Colored squares were presented first (Stroop A), followed by black words (Stroop B), and then incongruent color words (Stroop C; in which participants were asked to name the color of the ink while ignoring the written word). Lansbergen, Kenemans, and van Engeland (2007) recommend using a ratio score (Stroop A/C) which does not pose the sensitivity problems seen when using difference scores. We report results using the Stroop A/C ratio formula with higher ratio scores indicating better executive function.

Color Trails 1 and 2 (D'Elia, Satz, Uchiyama, & White, 1996)

In Color Trails 1, participants are asked to connect numbered circles in ascending order. In Color Trails 2, individuals are asked to connect numbered circles in consecutive order while also alternating the color of the circle. The time quotient (time to complete Color Trails 2 divided by time to complete Color Trails 1; CT 2/1) was used as a measure of executive function, with a decrease in time quotient representing a positive outcome (Strauss, Sherman, & Spreen, 2006).

Digit Span (Strauss et al., 2006)

In Digit Span, participants first repeated a series of numbers in order, followed by repeating a series of numbers in reverse order. The sum of correct trials on Digit Span Backward divided by the sum of correct trials on Digit Span Forward (Digits B/F) was used in analyses; thus an increase in score was the desired outcome.

Montreal Cognitive Assessment (MoCA; Nasreddine et al., 2005)

As a secondary cognitive measure, the MoCA was administered at baseline to characterize the samples at baseline. The MoCA consists of eight different subtests to assess overall cognitive impairment. For characterization purposes scores below 22 out of 30 were used to categorize MCI (Freitas, Simões, Alves, & Santana, 2013).

Ecological Validity

In the latter half of the pilot study, a measure was added of the ecological validity of possible neuropsychological benefits. To assess participants' self-ratings of their everyday functioning in regards to memory and concentration, the Ecological Validity Questionnaire (Klusmann, Evers, Schwarzer, & Heuser, 2011) was administered at baseline and after 3 months. This measure consists of 11 statements that ask about participants perceptions of their behavior across three domains: (1) metacognition (self-report of memory skills), (2) metaconcentration (self-report of concentration skills), and (3) everyday function. Using a 5-point Likert scale (1 = absolutely wrong/bad to 5 = absolutely true/good), participants rated how much of the statements described their behavior in the past 2 weeks. Answers were summed to produce individual domain scores as well as a total score, ranging from 11 to 55, with higher scores representing perceptions of better functioning.

Statistical Analyses

Data were analyzed using SPSS version 19 for Windows (IBM Corporation). To evaluate equivalency between groups (e.g., randomly assigned conditions, community sites, ride frequency) and potential for some variables to serve as covariates (e.g., age, education, MoCA), correlation, analysis of covariance (ANCOVA) and paired t tests were used (p was set at .05 for these comparisons as we wanted to err on the side of detecting and correcting for potential covariates). Repeated measure ANCOVAs were used to explore possibly different patterns of change in group (tour *vs.* game) by time (baseline *vs.*

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[2] 97.6% of the time (over a sampling of 351 rides), participants stayed within 80% of their target HR.

Table 1. Baseline demographics, neuropsychological variables and single-bout outcomes

	Single Bout Intervention										*t*-test repeated measures ANCOVA	
	Combined			Tour			Game					
	ave	*SD*	*n*	ave	*SD*	*n*	ave	*SD*	*n*	*P*		
Demographics												
age	82.2	9.7	64	80.6	8.6	34	84.1	10.6	30	.15		
education (yrs)	13.9	2.4	59	13.5	2.4	30	14.3	2.4	29	.24		
sex (% female)	60%		57	67%		30	52%		27	.13		
physical activity level	2.5	1.3	53	2.3	1.2	26	2.6	1.3	27	.30		
MoCA	21.0	5.0	60	20.6	5.6	33	21.6	4.3	27	.47		
Began 3-mo intervention	75%		48/64	68%		23/34	83%		25/30			
Adherent (%)	42%		20/48	43%		10/23	40%		10/25	.86		
Baseline Executive function[a]												
Color trails 2/1	.50	.15	61	1.97	.51	26	2.27	.64	24	.07		
Stroop A/C[a]	.45	.21	61	.44	.13	27	.46	.30	24	.73		
Digits B/F		.21	64	.60	.18	29	.61	.22	26	.22		
Post-Single Bout Executive Function											(group × time)[c] effect size[d]	*p*
Color trails 2/1				2.21	.67	26	1.96	.52	24	.15	.12	.02*
Stroop A/C[b]				.45	.14	27	.46	.08	24	.84	.00	.90
Digits B/F				.57	.16	29	.54	.17	26	.54	.00	.66

[a] baseline by-group data reported for only those subjects in pie-post
[b] used a ratio score formula consistent with Lansbergen et al. (2007)
[c] controlling for age, educ, MoCA
[d] partial eta^2 ($\eta_p{}^2$)
*$p < .05$

post single-bout and 3-month outcomes) interaction effects. Baseline performance on neuropsychological variables was automatically accounted for statistically as part of the repeated measures procedure (Tabachnick & Fidell, 2001); furthermore, there were no significant differences between groups at baseline on the neuropsychological variables (see details in notes on Table 1, and Figures 1 and 2). Covariates entered into the repeated measures analyses included: age, education, and MoCA (due to variability in subgroups reported below, correlation with baseline cognitive measures, as well as theoretical and empirical literature; Hannay & Lezak, 2004; Lam et al., 2013). Due to the use of multiple statistical tests in the outcome analyses and concern about escalation of family-wise error rates, the Holm-Bonferroni correction was applied (Blakesley et al., 2009; Eichstaedt, Kovatch, & Maroff, 2013).

RESULTS

Effect on Executive Function

Single-bout

Sixty-four individuals from six community sites were physically able to proceed with randomization[3] (average age was 82; variability existed across sites and between groups, despite random assignment, leading to the use of covariates in analyses; see Table 1 for details and characterization of the overall sample and tour/game conditions; see Supplementary Table S1 for sites).

Repeated measures ANCOVAs were conducted for each of three measures of executive function (i.e., ratio indices of Trails, Stroop, and Digit Span), controlling for age, education, and MoCA (per above). Group by time interactions revealed a significant effect for Color Trails 2/1 after a single bout, with those in the game condition showing more improved performance than those in the tour [$F(1,45) = 5.86; p = .020; \eta_p{}^2 = .12$; Figure 1]. There were no significant effects for Stroop A/C or Digits B/F indices after a single-bout of exercise.

Three-month intervention

Participants who completed the above single-bout were invited to continue using the exergaming equipment for 3 months. Of the 64 that participated in single-bout testing, 25% ($n = 16$) decided not to participate in the longer-term intervention (citing various issues such as lack of time, health problems, or lack of interest). Of the 48 that began the 3-month intervention, 68% ($n = 28$) were partially adherent, while 42% ($n = 20$) fully adhered to the minimum dose of their assigned exergaming condition during the 3-month

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[3] A total of 69 provided informed consent to participate, but five individuals had difficulty pedaling the cycle ergometer due to pre-existing health conditions (e.g., arthritis) and thus were not able to participate in this initial, single bout, phase.

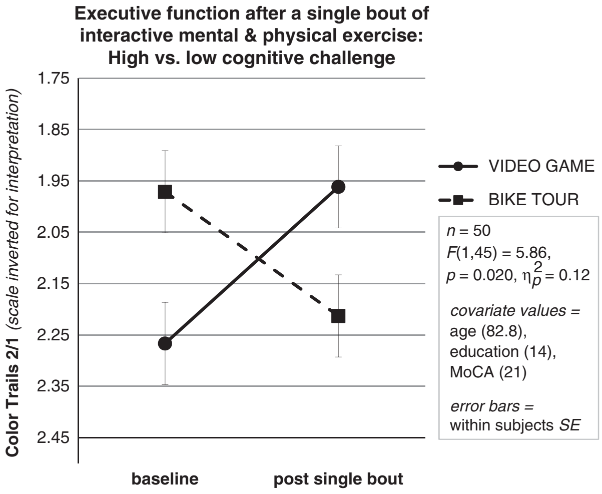

Fig. 1. Single-bout tour *versus* game intervention and Color Trails 2/1 ratio. *Note.* Between group comparison of baseline performance was not significantly different between the two groups ($p = .07$); however, variability in baseline performance was automatically, statistically controlled for in the repeated measures analysis. Thus, the significant interaction effect confirms a between-group difference in the direction of change (slope of lines), perhaps indicating the added cognitive challenge of playing a videogame while exercising, may not be as immediately beneficial as the exercising while engaged with the less challenging, but more naturalistic scenic bike tour.

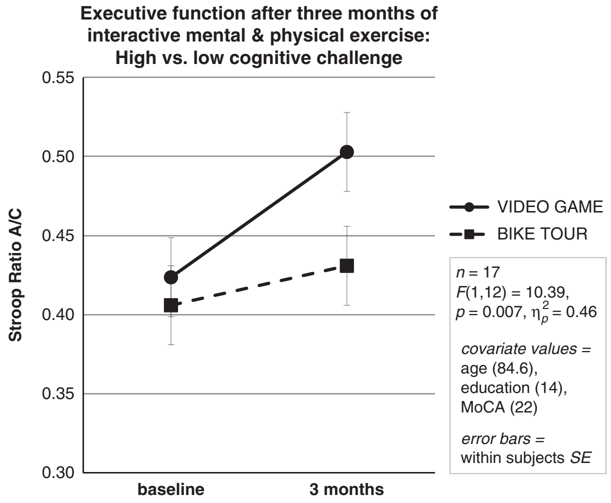

Fig. 2. Three-month intervention: Tour vs. Game and Stroop A/C Ratio.

intervention[4]. These rates of adherence are similar to or exceed those reported in the literature on self-directed (unsupervised) exercise (e.g., 19% per Kravitz et al., 1993; 35% per Sluijs, Kok, & van der Zee, 1993). There were no significant differences in adherence to the randomly assigned game *versus* tour conditions. Characteristics of those adherent to the 3-month intervention, by tour and game groups, can be found in Table 2.

The impact of the tour *versus* the game among full dose adherents ($n = 20$) was evaluated with repeated measures ANCOVAs conducted for each of the three measures of executive function (i.e., ratio indices of Trails, Stroop, and Digit Span), controlling for age, education, and MoCA (per above). Group by time interactions revealed a significant effect for Stroop A/C after 3 months of exercise, with those in the interactive game condition showing more improved performance than those in the tour [$F(1,12) = 10.39$; $p = .007$; $\eta_p{}^2 = .46$; Figure 2]. There were no significant effects for Trails 2/1 or Digits B/F indices after 3 months.

Post hoc analyses were conducted to explore possible differential effects of the interventions in the normative and MCI subsamples. Repeated measures ANCOVA were repeated as above (dropping MoCA as a covariate due to redundancy/collinearity with MCI coding), with just those with MCI after a single bout, and revealed the group × time interaction for Trails 2/1 trended toward significance with an effect size similar to that of the combined sample analysis ($p = .07$; $\eta_p{}^2 = .15$). When examining only the normative subsample of adherents to the 3-month intervention, the group × time interaction for Stroop A/C revealed a statistically significant and somewhat larger effect than the combined sample ($p = .006$; $\eta_p{}^2 = .69$).

Effect on Ecological Validity

Repeated measures ANCOVA was conducted for the measure of ecological validity that had been implemented part way through the study and was thus available on a subsample of adherents ($n = 10$), controlling for age, education, and MoCA (per above). Group by time interaction was non-significant, but there was a significant main effect of time, such that collapsing across exergaming conditions allowed detection of a significant improvement in ecological validity [$F(1,5) = 17.16$; $p = .009$; $\eta_p{}^2 = .77$]. Adherent exercisers (bike tour and videogame conditions combined) reported an increase in their everyday functions from baseline ($X = 40.7$; $SD = 9.4$) to post-exercise, after 3 months ($X = 45.9$; $SD = 5.7$).

DISCUSSION

This study aimed to build upon prior research which found that interactive physical and cognitive exercise (exergaming) led to enhanced neuropsychological and neurobiological benefits (Anderson-Hanley et al., 2012). This pilot study varied the degree of cognitive challenge combined with exercise to explore whether cognitive benefit could be

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[4] To be consistent with Maillot, Perrot, & Hartley (2012), adherence was defined as a minimum of two sessions per week, allowing for one week off due to vacation/illness. Reasons for non-adherence included: inability to ride on the bike due to a change in health not caused by the bike (e.g. heart attack, stroke), time limitations, task difficulty, and participant unavailability (e.g., moving away).

Table 2. Three-month adherents by group: baseline and neuropsychological outcomes

	Non-Adherent			Adherents to Full Dose of Three-Month Intervention: Combined Adherents			Tour			Game			t-test	repeated measures ANCOVA	
	ave	*SD*	*n*	ave	*SD*	*n*	ave	*SD*	*n*	ave	*SD*	*n*	*p*		
Demographics															
age	80.6	10.2	28	85.1	9.1	20	85.3	6.9	10	84.8	11.3	10	.91		
education (yrs)	13.9	2.5	27	14.3	2.6	19	13.9	2.4	10	14.7	3.0	9	.54		
sex (% female)	56%		25	56%		18	80%		10	25%		8	.02*		
physical activity level	2.2	1.3	25	2.7	1.1	18	2.9	1.1	10	2.5	1.2	8	.47		
MoCA	20.8	4.9	26	22.6	4.2	18	22.0	5.3	9	23.1	3.1	9	.59		
Group (% game)	54%		15/28	50%		20									
Baseline Executive Function[a]															
Color trails 2/1	2.12	.62	26				2.10	.45	8	2.16	.39	8	.96		
Stroop A/C[b]	.53	.28	25										.29		
Digits B/F	.59	.19	28										.006**		
3-month Executive Function														(group × time)[c] effect size[d]	*p*
Color trails 2/1							2.92	1.62	8	2.05	.41	8		.19	.14
Stroop A/C[a]							.43	.09	9	.50	.10	8		.46	.007**
Digits B/F							.15	.17	9	.60	.13	8		.27	.06
Exercise Outcome															
Ride frequency	7.8	5.5	28	51.9	25.4	20	46.2	20.5	10	57.5	29.6	10			.33
Miles	13.6	21.1	27	162.5	143.3	20	124.3	107.3	10	200.6	169.2	10			.24

[a] baseline by-group data reported for only those subjects in pre-post analyses
[b] used a ratio score formula consistent with Lansbergen et al. (2007)
[c] controlling for age, educ, MoCA
[d] partial eta^2 ($\eta_p{}^2$)
*$p < .05$, **$p < .01$

differentially improved for independent older adults. Sixty-four participants were randomly assigned to either a low or high dose of cognitive challenge with interactive physical exercise. Significant benefits to executive function were found for the high cognitive challenge condition, over and above the lesser cognitive engagement after a single bout (Color Trails ratio) and also after 3 months (Stroop ratio). Ecological validity data was also obtained from a subset of the overall sample and both exergaming conditions perceived improvement in everyday functioning from baseline to 3 months. The current findings demonstrate neuropsychological benefit of exergaming interventions, and suggest that engaging in a higher dose of cognitive challenge may yield greater improvement in some aspects of executive functioning.

Improved executive functioning following interactive exercise is consistent with findings of other RCTs of exergaming (Anderson-Hanley et al., 2012; Maillot et al., 2012; Oswald et al., 2006; Shatil, 2013). An interesting finding was that a single-bout of exercise resulted in different cognitive changes compared to long-term exercise. Specifically, after a single-bout, a significant interaction effect was seen on Color Trails, while at 3 months the effect was on Stroop in both cases, with those in the game condition exhibiting greater benefit than those in the tour. This is inconsistent with findings reported by Anderson-Hanley et al. (2012) and Maillot et al. (2012) who found improvement on both Stroop and Color Trails after 3 months of exergaming. It may be that there are different underlying mechanisms responsible for neurocognitive benefit of short *versus* long-term interactive exercise and high *versus* low cognitive demand.

The immediate improvement on Color Trails may represent a transfer of training effects after a single-bout of exercise. The Color Trails task is a measure of visual processing speed, divided attention, and task switching. Participants in the game condition were asked to switch back and forth from collecting coins and catching dragons all the while navigating through the interactive playing field, whereas those in the tour condition only had to navigate through a pathway. A limitation of the data are the non-equivalent groups at baseline for Color Trails (trending at $p = .07$), despite random assignment, and although repeated measures analyses compensate by accounting for pre-test scores and focusing on the relative change in the two groups over time, there is the possibility that both groups demonstrated some degree of regression to the mean.

The significant Stroop results indicate an improvement in flexibility and inhibition after 3 months. It may be that inhibitory control and working memory need to collaborate with brain processes other than task switching. Further investigation is needed to clarify the neurobiological mechanisms responsible for differential cognitive benefit seen after short-term and long-term interactive training. It is interesting to note that the effect on Stroop performance remained strong even when only considering the normative subgroup (roughly half of the sample not categorized with MCI). Additional research is needed to clarify whether the effect is different with MCI patients or if the reduced sample size and loss of power, combined with a smaller effect explains the lack of significance among just the MCI subgroup.

Contrary to expectations, the dose of cognitive demand did not appear to impact ecological validity. Regardless of condition, adherent exercisers reported subjective improvements in their thinking and functioning skills after 3 months. Additionally, improvements in executive functioning did not appear to translate into improved everyday functioning (*via* self-report). The absence of unique translation into everyday functioning is not surprising given our small sample and the use of a self-report measure. The participants were independent older adults; therefore, they are likely to demonstrate competence in independent activities of daily living and may be less inclined to report poor everyday functioning at baseline. Furthermore, it may be that 3 months was not long enough to achieve transfer of benefits.

This pilot study is not without limitations, especially the homogeneity of the sample, the small adherent sample size and high attrition. All of the participants were Caucasian and the majority were women, thus limiting the generalizability of our findings. Unlike some studies which reported high levels of exercise adherence when using exergames (Anderson-Hanley et al., 2012; Maillot et al., 2012; Shatil, 2013), only approximately half of participants who started the 3-month intervention were adherent in the current study. However, these rates were consistent with prior research on self-directed exercise (see above). As a largely unfunded pilot study, with part-time RAs, the lack of periodic phone check-ins may have diminished motivation, whereas our prior exergaming study was funded, with regular RA contact and also recruitment *en masse* at each site may have led to greater cohesion and adherence. Small sample sizes minimize the effect of all implications, decrease the generalizability of the results, and produce lower statistical power. Also, Toril et al. (2014) suggest that decreases in task novelty may decrease motivation. Personalization of training may enhance adherence and additional research on the barriers and motivations to exercise is warranted.

The present study did not evaluate premorbid status (again due to limited resources) and as an unfunded pilot, raters were not able to be blinded; such variables could be important and should be accounted for in future research. Additionally, future research should examine if benefits persisted once the training regime stopped. Current literature reveals mixed results on sustained benefit. Long-term follow-up after separate and combined interventions is encouraged to help answer this question. Although the ecological validity measure used has been deemed valid (Klusmann et al., 2011), it may not fully reflect cognitive function in real life. Thus, it is recommended that future research incorporate multiple measures of ecological validity to analyze the various aspects of generalizability.

Although those in the game condition were instructed to strive for high scores, the tactics used were highly variable. Some participants caught only a few dragons that were worth a large number of points, whereas others caught many dragons worth fewer points. Also, targets appear randomly, so quantification of opportunity taken/lost is difficult. The game overall is thought to require higher cognitive engagement than the tour (requires more planning, multi-tasking, and strategizing); however, there is little control over how much cognitive effort the participant actually puts forth (although as noted above a manipulation check did confirm that game participants reported exerting more mental effort than those in the tour). Future research could create an exergame that has less variability, ready quantification, and allows the researcher more control of degree of mental effort. This would help quantify the degree of cognitive stimulation participants engage to further clarify the impact of level and type of cognitive demand.

While much of the empirical literature focuses on cardiovascular health as the primary reason for cognitive vitality (Colcombe et al., 2006), there may be additional mechanisms that produce cognitive benefit (Angevaren et al., 2008; Colcombe & Kramer, 2003; Maillot et al., 2012). Researchers have postulated that an adequately intense bout of exercise can have immediate effects on cognitive processing, and can facilitate allocation of mental resources, among various other benefits. Additional research on the relationship between neurobiological, neuropsychological, and functional effects of interactive exercise is needed. Future research should strive to assess other potential mediating or moderating factors, such as psychological (mood) status, and physical fitness (e.g., using techniques such as VO2max, which was beyond the scope of this pilot study). This may further shed light onto what aspects of training produce the greatest benefit, in addition to clarifying how individual differences may contribute to differential effects. The use of functional neuroimaging and biomarkers may provide further insight regarding biological mechanisms of training and transfer effects.

To determine the optimal combination of engagement to maximize benefits to cognition and subsequent quality of life, it would be beneficial to explore benefits when varying the strenuousness of the aerobic exercise while keeping the cognitive exercise constant and to include solely aerobic and cognitive groups for comparison. Additionally, alternative combinations of interactive interventions, beyond exergaming, might be further evaluated. For example, older adults learning to dance are simultaneously engaged in cognitive and physical exercise (Alpert et al., 2009; Merom et al., 2013).

Overall, the current findings suggest neuropsychological benefits differ as a function of the combination of physical exercise and various doses of interactive cognitive challenge. This study also provides some insight into the real-world benefits of exercise. As the prevalence of dementia is on the rise, early intervention is paramount. If behavioral interventions such as exergaming are proven efficacious in ameliorating cognitive deficits, it would be of significance for individuals at risk of dementia or with MCI. Older adults want to stave off cognitive decline and remain independent and are seeking opportunity to avoid or ameliorate MCI. Despite the limitations of the current investigation, a combination of prior research and the present study provide evidence that engaging in physically and mentally stimulating interactive activities may have significant cognitive benefit that can be measured and observed. This preliminary evidence could perhaps serve as ample motivation for those anticipating longevity to "move it and use it" and carry on a journey toward healthy aging, aiming to use interactive cognitive and physical exercise as one tool in an effort to preserve brain health and function.

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Supplementary material

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