

# Neuropsychological Benefits of Neuro-Exergaming for Older Adults: A Pilot Study of an Interactive Physical and Cognitive Exercise System (iPACES)

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Dementia cases are on the rise and researchers seek innovative ways to prevent or ameliorate cognitive impairment in later life. Some research has reported that combining mental and physical exercise may benefit cognition more than either alone. This randomized pilot trial examined the feasibility and cognitive benefit for older adults ( $n = 30$ ) of a single bout of neuro-exergaming (physical activity with cognitive training) using an interactive physical and cognitive exercise system (iPACES), compared with that of exergaming or neurogaming alone. Intent-to-treat and sensitivity analyses were conducted using repeated-measures ANOVA, controlling for age, sex, and education. A significant interaction effect was found for executive function (Color Trails 2), with a significant improvement in the neuro-exergaming condition. Results demonstrate feasibility for older adults to use a novel and theoretically-derived neuro-exergame, and also provide promising new evidence that neuro-exergaming can yield greater cognitive benefit than either of its component parts.

**Keywords:** aging, cognition, dementia, exergaming, cognitive training

Annual diagnoses of dementia are expected to approach one million in 2050, more than double the new cases diagnosed in 2000 (Alzheimer's Association, 2014). Lacking a cure for any of the causes of this devastating decline in cognitive function and loss of independence, researchers seek innovative ways to prevent or ameliorate impairment. Only a handful of drugs have been approved for use in dementia, but these medications only slow progression modestly (Hansen et al., 2007). Of the nonpharmacologic therapies listed by the Alzheimer's Association (2014), only cognitive training is reported to have a modest beneficial effect. There has been pervasive marketing to older adults of brain training games (e.g., Lumosity, Posit Science), and there is some significant empirical evidence (Ballesteros et al., 2014; Basak et al., 2008; Smith et al., 2009; Willis et al., 2006; Wood, 2012) and also meta-analyses (Gates et al., 2011; Huntley et al., 2015; Jean et al., 2010; Karr et al., 2014; Toril, Reales, & Ballesteros, 2014; Valenzuela & Sachdev, 2009) to support claims of effectiveness of cognitive training. However, some randomized controlled trials (RCTs) provide contrasting evidence (Redick et al., 2013; van Muijden, Band, & Hommel, 2012). In addition, there is debate concerning the transfer of skills (Boot & Kramer, 2014; Green & Bavelier, 2008; Shipstead et al., 2012) and diminished effects over time (Rebok et al., 2014; Unverzagt et al., 2012), thus dampening scientific enthusiasm and raising concern about promotion (see Cochrane review; Bahar-Fuchs et al., 2013). In contrast, research into physical activity provides robust evidence from meta-analyses and RCTs demonstrating cognitive benefit for healthy older adults (Colcombe & Kramer, 2003; Smith et al., 2010; Voss et al., 2013c), as well as for those at risk for dementia (Gates, 2013; Hess et al., 2014; Lautenschlager et al., 2008). Benefit has even been found after only brief or single bout interventions (Chang et al., 2012; Chapman et al., 2013; Hogan et al., 2013), and

significant effect sizes have been reported (see Cochrane review; Angevaren et al., 2008).

Furthermore, theoretical and empirical strides are being made to explore mechanisms of action that link the effects of exercise on the body to effects in the mind, as revealed in research demonstrating neuroplasticity (Ahlskog et al., 2011; Bherer, 2015; Cotman & Berchtold, 2002; Erickson, Hillman, & Kramer, 2015; Fissler et al., 2013; Gage, 2002; Voss et al., 2013b), even with only a single bout (Smith et al., 2014), as well as intermediate processes including fitness (Kramer et al., 1999; Nagamatsu et al., 2014), neurophysiological (Burzynska et al., 2015; Shah et al., 2014; Styliadis et al., 2015), and biomarker changes (Voss et al., 2013a). The mechanisms by which cognition is improved through either physical exercise or cognitive training are still under investigation (Bamidis et al., 2014), yet there is also increasing interest in the potential interactive effects of multiple treatments. It is posited that because multiple mechanisms may be targeted at once (e.g., vascular function as well as neuronal networks), brain health and thus cognition may be improved more by combined cognitive and physical exercise than by either intervention alone. Researchers have begun to evaluate the potentially superior cognitive advantage of combining both physical and mental exercise sometimes synchronously or in tandem (Bamidis et al., 2015; Shah et al., 2014), or as used in dual-task training for falls prevention (Bherer, 2015; Ogawa et al., 2016; Schoene et al., 2014), and also interactively as in exergaming<sup>1</sup> (Anderson-Hanley et al., 2012; Bamidis et al., 2015; Eggenberger et al., 2015; Gerling & Mandryk, 2014; Maillot, Perrot, & Hartley, 2012).

Early investigations of combined effects explore whether participating in both mental and physical exercise training programs (usually synchronously or in tandem, but not interactively), increased cognitive benefit more than either alone. While some studies conclude that combining mental and physical exercise does not benefit cognition more than either alone (Barnes et al., 2013; Legault et al., 2011; Shatil, 2013), others have shown added benefit of combined or tandem interventions (Fabre et al., 2012; González-Palau et al., 2014; Oswald et al., 2006; Satoh et al., 2014; Suzuki et al., 2012). Dual-task research has generally found that doing two

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things simultaneously (e.g., walking and counting backward) can diminish performance of both cognitive and physical tasks, theoretically due to increased cognitive demands and limited resources to allocate (Al-Yahya et al., 2011). However, Altmann and colleagues (2015) recently reported a contradictory observation in those with Parkinson's disease, wherein cycling speed actually increased with executive function challenges presented synchronously. They theorized an alternative Arousal and Attentional Demands (AAD) model, to explain the lack of task costs, by suggesting that the increased arousal created by the cognitive and physiological challenges might sometimes match the demands of the task. Interactivity<sup>2</sup> of cognitive and physical tasks as used herein may further enhance attainment of cognitive benefits because the tasks are intentionally arousing and yet streamlined with naturalistic integration of functions (e.g., moving through simulated space to navigate one's environment).

Exergames, a subset of a larger group of health games or "serious games" (Read & Shortell, 2011), often combine physical exercise and cognitive stimulation or challenges in an interactive fashion, as they typically use virtual reality or gaming features. In an early study of the cognitive benefits of exergaming, Maillot, Perrot, and Hartley (2012) demonstrate that exergaming improved healthy older adults' cognition compared with a no-treatment control group. Anderson-Hanley and colleagues (2012) examined whether pedaling along a virtual reality bike path ("cybercycling") would produce cognitive

benefit in older adults over and above traditional stationary cycling. Results revealed that cybercyclists received greater cognitive benefit than participants in the stationary bike condition, despite equivalent exercise effort. Anderson-Hanley and colleagues (2012) conclude that the mental stimulation of the exergame (e.g., 3D scenery and avatars) may have produced the greater cognitive benefit, perhaps in a summative or synergistic manner by simultaneous activation of various neurobiological mechanisms. More research is needed on the effects of these interactive interventions and the impact of specific components (e.g., passive stimulation vs. active cognitive training, aerobic vs. nonaerobic activity, etc.). However, recent reviews of the literature on the cognitive benefits of exergaming for older adults conclude the preliminary evidence is promising (Bamidis et al., 2014; Barry et al., 2014; Ogawa et al., 2016; Schoene et al., 2014; Smith et al., 2010).

The purpose of the present research was twofold: (1) to examine the feasibility of neuro-exergaming<sup>3</sup> using an interactive physical and cognitive exercise system (Interactive Physical and Cognitive Exercise System [iPACES<sup>4</sup>]; see Figure 1), wherein older adults were expected to engage in aerobic exercise (in this case, pedaling and steering a stationary bike along a virtual bike path to achieve their target heart rate), the action of which simultaneously and interactively controls play of a computerized game theoretically designed to train cognition (in this case, executive function, with a focus on working memory); and (2) to examine the neuropsychological effects of the iPACES



**Figure 1** — Neuro-exergame set-up showing iPACES tablet integrated with existing stationary bike (same equipment used for exergame/bike tour condition).

compared with that of: (a) exergaming (i.e., as in this case, pedaling and steering a stationary bike along a virtual bike path without a prescribed cognitive task, thus with relatively passive stimulation only) and (b) neurogaming (i.e., in this case, playing a cognitive training game in a sedentary way, seated with a game controller). Through these aims, the present research augments prior research efforts by exploring the cognitive benefits of interactive cognitive and physical training combined, rather than focusing on either alone (Anguera et al., 2013; Colcombe & Kramer, 2003; Klusmann et al., 2010), or in tandem but not interactively (Fabre et al., 2002; González-Palau et al., 2014; Oswald et al., 2006; Satoh et al., 2014; Suzuki et al., 2012).

Recently published RCTs lend additional support to the theory of interactivity, yielding greater cognitive benefit. An interactive dance game and synchronous, but noninteractive memory task while walking, both appear stronger than walking alone (Eggenberger et al., 2015), and a multifactorial physical and cognitive program (some interactive, some aerobic component) yielded significant cognitive effects over and above a passive control group (Bamidis et al., 2015). On the other hand, some research did not find added benefit of an exergame over traditional exercise (O'Leary et al., 2011), but that might be due to the fact that the exergame while entertaining may not have design features to facilitate cognitive change, or their young adult sample with normative brain functions may not have as much responsiveness. This study evaluates similar hypotheses, but with a number of advances: (1) increased focus on and control of key variables not assessed or controlled for in these recent studies (e.g., target heart rate achieved and measurable outcomes of prescribed and adaptive interactive cognitive task); (2) utilization of a theory-driven cognitive task vs. gaming for pure entertainment; (3) inclusion of comparison conditions that allow the parsing of the cognitive benefits of component parts (e.g., physical and mental exercise alone); and (4) implementation of an iPACE system that is portable and feasible for older adults to use at home.

It is our hypothesis that interactivity may produce greater effects due to synergistic processes that compound or magnifies the benefit in a nonlinear way, perhaps by activation and utilization of neurobiological substrate of the mind–body interface that is evolutionarily adapted for success in naturalistic tasks (in this case, moving through 3D space while learning, recalling, and manipulating key information). While research connecting cognitive processes to neurobiological pathways in humans is early in its development, there are indications of important links with various biomarkers (e.g., BDNF, IFG-1; Knaepen et al., 2010) and certain brain structures (e.g., hippocampus; Erickson et al., 2015). Animal models have more plainly linked certain compounding or synergistic cognitive benefits with neurobiological phenomenon when both physical and mental exercise are provided (e.g., in laboratory mice exposed to enriched environments with physical and/or cognitive challenges; Churchill et al., 2002; Galvan & Bredesen, 2007; Greenough, Cohen, & Juraska, 1999; Jessberger & Gage, 2014). The present research explores whether the greater mental engagement required of cognitive training will lead to even greater cognitive benefit when interactively combined with physical exercise (neuro-exergaming), compared with exergaming with some interactive mental stimulation (i.e., cybercycling) or cognitive training alone (neurogaming).

## Method

### Participants

Participants ( $n = 30$ ) were independent living older adults (average age = 68.8, range: 50–94). Nine participants were male and 21 were female and average years of education was 17; most participants

self-identified as European American (87%), with four (one each) identifying as: African American, Asian American, Hispanic, and other (nonspecified)<sup>5</sup>. Participants were randomly assigned to one of the three conditions described below ( $n = 9, 10, 11$  in each group; unequal cells due to misread of randomization chart for last enrollee). Participant characteristics were similar across the three groups, including age, retiree status, baseline cognitive function<sup>6</sup>, past experience with physical activity and computers, physical fitness estimate, etc.; only years of education were significantly different and this was incorporated as a covariate in analyses (details in Table 1). After intent-to-treat analyses with the full sample of 30 participants (using multiple imputation of averages<sup>7</sup>), sensitivity analyses were conducted after dropping the four participants with incomplete data and one participant with inadequate dose of the intervention<sup>8</sup> (resulting in  $n = 8, 9, 8$  in each group; see Table 2). Participants were provided a small gift (i.e., water bottle, pen, or magnet) as compensation for participation.

### Materials and Procedure

This research was approved by the institutional review board at Union College. Participants were recruited by fliers and emails to the college campus and nearby community over the course of 6 months. Informed consent was obtained as well as demographic information (age, education, ethnicity, marital status, familiarity with biking and video games, and exercise history). The following cognitive measures were administered pre- and postsingle bout (alternate forms were used at posttesting). All procedures were completed in a single hour-long session in the laboratory.

### Verbal Memory Measure

**Alzheimer's Disease Assessment Scale (ADAS) Word Recall (Mohs et al., 1997).** Participants read aloud 10 words presented on a card for 1–2 s, and immediate recall was subsequently solicited. The task was repeated twice more using the same list of words, but in a different order. Delayed recall was solicited after 5 min of an alternate cognitive task (herein Color Trails). Scoring per the manual is a simple tally of number of words *not* recalled; thus higher scores on this scale indicate greater impairment (range is 0–10). This measure was included as a manipulation check of the active intervention which included memory components, but was not expected to alter core memory functions; rather, the focus was to be on executive function consistent with prior literature and which would be salient to maintain for older adults aiming to remain independent (Marshall et al., 2011; Pereira, Yassuda, Oliveira, & Forlenza, 2008).

### Executive Function Measures

Color Trails (D'Elia et al., 1996), forms A and B, were preceded by a brief sample to orient the participant to the task. Form A required that participants connect numbered circles in order. Form B required connecting numbers in order, but also alternating the color of the circles, by choosing from among pink and yellow circles with the same number. A ratio was computed (time to complete Color Trails 2 divided by time to complete Color Trails 1; CT 2/1; Strauss, Sherman, & Spreen, 2006), with a lower time quotient representing better executive function.

The Stroop Test (40-item format; Van der Elst et al., 2006) required participants to verbally respond to three similar sets of stimuli. First, participants stated the name of each colored block (i.e., red, blue, and green). Second, participants read these three color names as typed in black ink. Finally, participants were presented with the same three typed color names, but printed in a contrasting

**Table 1 Demographics for All Enrolled Older Adults (n = 30)**

Demographics <sup>a</sup>	Neurogame (n = 9)		Neuro-Exergame (iPACES) (n = 10)		Exergame (n = 11)		Total Enrolled (n = 30)	
	X	SD	X	SD	X	SD	X	SD
Age	67.0	15.3	66.3	10.8	72.6	12.3	68.8	12.7
Education (years) <sup>b</sup>	16.0	3.3	19.2	3.2	17.6	2.6	17.6	3.2
Sex (% female)	89%		60%		64%		70%	
Ethnicity (% European American)	89%		90%		90%		87%	
Retiree status (% retired) <sup>c</sup>	56%		50%		64%		57%	
Marital status (% married)	33%		70%		27%		43%	
Self-rated physical activity <sup>d</sup>	3.0	1.5	3.6	1.4	3.1	1.5	3.2	1.3
Past experience <sup>e</sup>								
Cycling	2.0	.71	2.4	.71	2.6	.60	2.4	.85
Computers	3.2	.71	3.6	.87	3.0	.97	3.3	.91
Videogames	1.0	.60	1.0	.71	0.5	.60	0.8	.71
Motivations to exercise <sup>f</sup>								
Increase fitness	4.9	.33	4.9	.32	4.9	.30	4.9	.31
Think more clearly	4.8	.44	4.8	.42	4.2	1.08	4.6	.77
Improve mood	4.7	.71	4.8	.42	4.3	1.10	4.6	.82
Increase alertness	4.7	.71	4.5	.85	4.3	.90	4.5	.82
Because of social support	4.3	1.66	4.6	.70	4.3	1.27	4.4	1.22

Abbreviation: iPACES = Interactive Physical and Cognitive Exercise System.

<sup>a</sup> Medical status not assessed formally, but unsolicited, one participant in each group noted medical info: legs unable to rotate pedaler; legally blind, yet able; familial resting tremor.

<sup>b</sup> Of those not retired, current occupations included: nurse, secretary, engineer, business owner, researcher, professor, administrator, college employee, manager.

<sup>c</sup> Significant difference between groups, used as covariate.

<sup>d</sup> Scale: 1–5 (inactive to vigorous 3+ days/week) Jurca et al., 2005.

<sup>e</sup> Scale: 0–4 (none to lots).

<sup>f</sup> Scale: 0–5 (disagree to agree).

**Table 2 Results with “Completers” and Covariates: Age, Education, and Sex (n = 25)**

Measure	Group (n = 8, 9, 8)	Pre		Post		Group × Time [F (2,19)]	p	es
		X <sup>a</sup>	SD	X <sup>ab</sup>	SD			
Executive function								
Stroop A/C	Neurogame	.44	.08	.47	.08	.65	.53	.06
	Neuro-exergame (iPACES)	.49	.08	.47	.09			
	Exergame	.44	.08	.45	.08			
Color Trails 1/2	Neurogame	.49	.15	<b>.37</b>	.14	3.68	.04	.28
	Neuro-exergame (iPACES)	.36	.15	<b>.45</b>	.14			
	Exergame	.40	.14	.45	.13			
Digits B/F	Neurogame	.56	.17	.73	.20	1.89	.18	.17
	Neuro-exergame (iPACES)	.65	.17	.69	.20			
	Exergame	.66	.16	.62	.19			
Verbal memory								
ADAS delayed recall <sup>c</sup>	Neurogame	7.34	1.38	7.06	1.81	.49	.62	.05
	Neuro-exergame (iPACES)	7.02	1.39	7.64	1.82			
	Exergame	6.64	1.33	7.10	1.74			

Abbreviation: ADAS = Alzheimer’s Disease Assessment Scale; iPACES = Interactive Physical and Cognitive Exercise System.

<sup>a</sup> Marginal means with covariates evaluated at the following values: age = 68.8, sex = .70, education = 17.6.

<sup>b</sup> Bolded values indicate pre to post change within group was significant ( $p < .05$ ).

<sup>c</sup> ADAS delayed recall is “reverse scored” (i.e., tally of number of items *not* recalled; range: 0–10); baseline performance across groups is comparable to reported normal controls (mean = 3.19; SD = 1.33; Graham et al., 2004).

ink (e.g., “red” typed in blue ink); participants stated the color of the ink. Time to complete was recorded, and a ratio (Stroop A/C) was computed (Lansbergen, Kenemans, & van Engeland, 2007), with higher ratio scores indicating better executive function.

**Digit Span (Strauss, Sherman, & Spreen, 2006).** Participants first listened to a string of numbers and repeated the string in forward order (Digit Span Forward). String length was increased if at least one of two strings of a given length was recalled correctly. Participants then listened to a string of numbers and repeated them in reverse order, with the same discontinuation rule (Digit Span Backward). A ratio was computed (correct trials backward divided by the correct trials forward; Digits B/F), with higher ratios indicating better function.

### Heart Rate

Resting heart rate (HR) was measured before the intervention and used to compute target HR (i.e., Karvonen & Vuorimaa, 1988).

### Experimental Conditions

All participants were seated upon a virtual-reality-enhanced recumbent stationary bike. In the two gaming conditions (neuro-exergaming and neurogaming), a tablet was hung in front of the bike’s built-in screen to display a theoretically-derived cognitive training game designed to further enhance executive function beyond that typical of physical exercise alone. In the two aerobic conditions (neuro-exergaming and exergaming), the participant was instructed to maintain their target HR as computed at the start of the session. Participants were randomly assigned to one of the following 20-min single bout conditions.

**Neuro-Exergaming.** The iPACES was set up such that a tablet (10.1-in. high-resolution 1280 × 800 IPS Screen) was hung on the bike’s existing screen and the game was interactively operated by the pedaling of the stationary bike (a hardwired cadence monitor and joystick connected the player’s movements on the bike with the game; Figure 1). In this instance, as noted above, the theoretically- and empirically-derived focus was on training executive function via a working memory task wherein the participant was instructed to learn a list of neighborhood errand locations (e.g., doctor, pharmacy, grocer), pedal along a scenic pathway (reaching their target HR range), choose the correct location at each fork in the road, and then retrace the same path, choosing correctly at each decision point. The task is adaptive in that it gradually increases the length of the errand list, but only after a player successfully completes two lists of the same length. This prototype iPACES neuro-exergame provided simple feedback, such as “correct” or “incorrect” with redirection to try again. While a score could be computed from the data collected (e.g., length of errand list completed and number of trials to learn the list), such feedback was not yet available on-screen for this single bout pilot trial<sup>9</sup>. Participants in the two physically active conditions were directed to maintain their target HR and could monitor their HR, minutes lapsed, and rotations per minute on the bike’s screen. This iPACES neuro-exergame differs from traditional exergames by targeting a particular cognitive function, in this case executive function, and integrating controlled, measurable, and adaptive mental exercise, with the goal of maximizing benefit.

**Exergaming.** Participants completed their single bout using a traditional “off-the-shelf” exergame, designed with some mental stimulation for exercise enhancement and entertainment purposes, not specific cognitive benefit. In this case, participants rode a “cybercycle” (as described above). The cybercycle simulates riding a bike

along a scenic trail and offers a lesser degree of cognitive challenge than that of the iPACES.

**Neurogaming.** Participants completed the game developed for the iPACES (described above), but in a sedentary mode (without pedaling), wherein forward motion was controlled only by the joystick. This condition served as a control condition, to isolate the relative contribution of the cognitive training component of the interactive neuro-exergaming intervention above.

### Final Measures and Procedures

After their 20-min single bout experimental intervention, participants completed behavioral measures<sup>10</sup> to allow HR to decrease before cognitive reevaluation. Verbal memory and executive function measures, as described above, were repeated (alternate forms) and participants were debriefed and compensated.

### Statistical Analyses

Data were analyzed using SPSS version 19 for Windows (IBM Corporation, Armonk, NY). Repeated measure ANOVAs were used to examine group (neuro-exergame vs. exergame vs. neurogame) by time (baseline vs. postsingle bout) interaction effects. Age, sex, and education were included as covariates in statistical analyses given their potential impact on neuropsychological test performance reported in the theoretical and empirical literature (Hannay, & Lezak, 2004; Lam et al., 2013). To further evaluate a significant interaction, post hoc analyses (ANOVA) were conducted to clarify between which of the three conditions significant differences in change over time occurred; Bonferroni correction was applied to these analyses to control for escalating error rate given multiple comparisons. Follow-up analyses were conducted using paired *t* tests (2-tailed) to examine change over time within each group.

## Results

### Intent-to-Treat Analyses

For these analyses, all 30 enrolled participants were retrained regardless of missing data or incomplete participation. Imputation of averages was used for four participants with missing data (per above). A significant interaction effect for condition (neuro-exergaming, exergaming, neurogaming) by time (pre- and postsingle bout), controlling for age, sex, and education, was found for one of the three tests of executive function (Color Trails: [ $F(2,24) = 3.54; p = .045; es = .23$ ]; see Table 3 for details).

### Sensitivity Analyses

For these analyses, participants were retained who were “completers” (i.e., per above had completed both pre- and posttesting and received an adequate dose of their assigned intervention; sample sizes for each group, respectively: 8, 9, 8). A significant interaction effect for condition (neuro-exergaming, exergaming, neurogaming) by time (pre- and postsingle bout), controlling for age, sex, and education, was found for one of the three tests of executive function (Color Trails: [ $F(2,19) = 3.68; p = .045; es = .28$ ]; see Figure 2). Post hoc analyses (ANOVA using change scores), with Bonferroni adjustment for multiple group comparisons, were conducted to determine which of the three groups differed significantly in their magnitude and direction of change from pre- to postbout, and these analyses revealed that change in neuro-exergaming differed significantly from neurogaming ( $p = .03$ ), but not from exergaming

**Table 3 Results with “Intent-to-Treat” Sample, Imputation, and Covariates: Age, Sex, and Education ( $n = 30$ )**

Measure	Group ( $n = 9,10,11$ )	Pre		Post		Group $\times$ Time [ $F(2,24)$ ]	$p$	es
		$X^a$	$SD$	$X^a$	$SD$			
Executive function								
Stroop A/C	Neurogame	.44	.09	.48	.09	.94	.40	.07
	Neuro-exergame (iPACES)	.49	.08	.48	.09			
	Exergame	.46	.08	.45	.08			
Color Trails 1/2	Neurogame	.49	.14	.36	.13	3.54	.04	.23
	Neuro-exergame (iPACES)	.36	.14	.44	.13			
	Exergame	.42	.13	.44	.12			
Digits B/F	Neurogame	.56	.17	.73	.18	3.21	.06	.21
	Neuro-exergame (iPACES)	.67	.16	.69	.18			
	Exergame	.69	.16	.61	.17			
Verbal memory								
ADAS delayed recall	Neurogame	6.75	1.80	7.22	1.68	.04	.96	.003
	Neuro-exergame (iPACES)	6.85	1.77	7.62	1.66			
	Exergame	6.61	1.71	7.19	1.60			

Abbreviation: ADAS = Alzheimer’s Disease Assessment Scale; iPACES = Interactive Physical and Cognitive Exercise System.

<sup>a</sup> Marginal means with covariates evaluated at the following values: age = 68.8, sex = .70, education = 17.6.

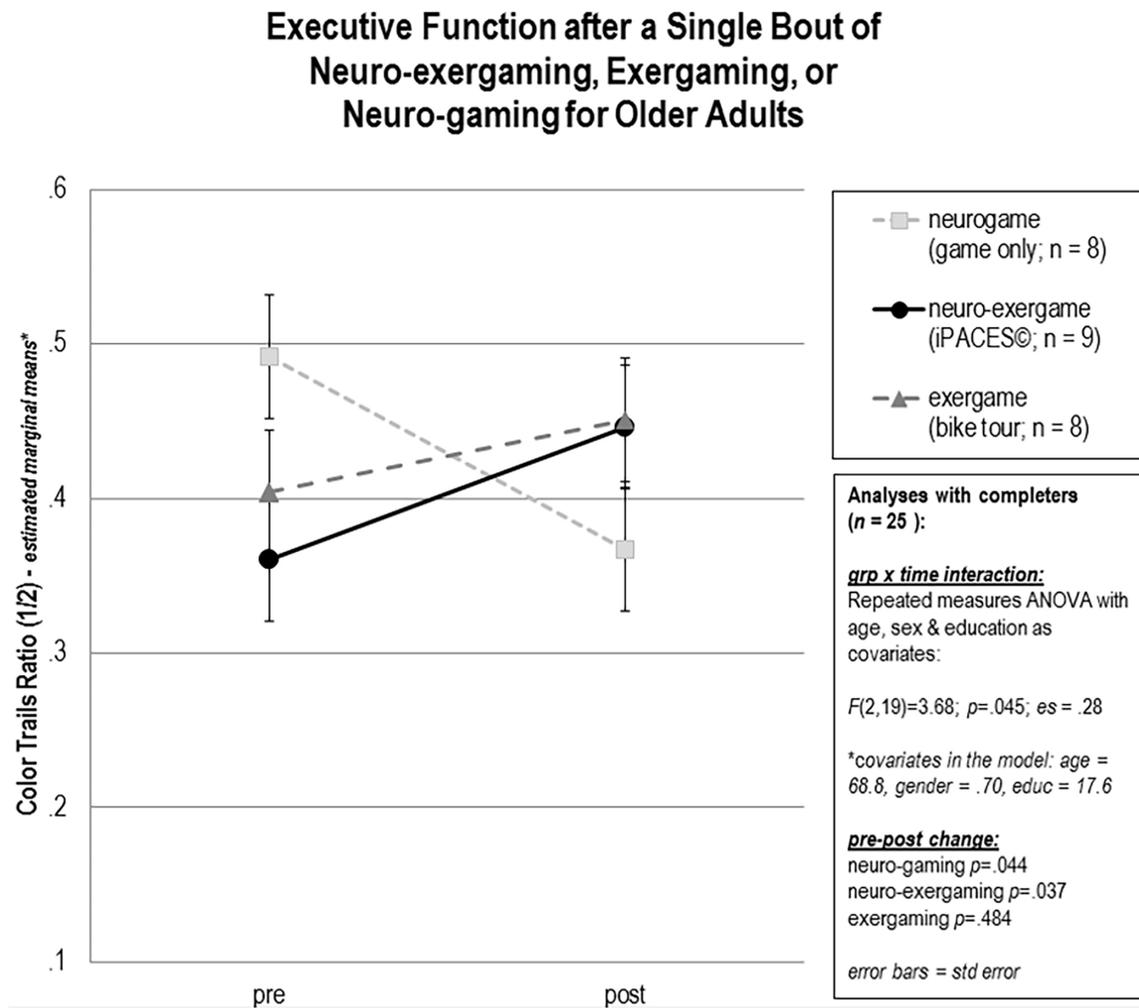
( $p = .09$ ); and additionally, neurogaming and exergaming did not differ significantly ( $p = 1.0$ ). Follow-up analyses examined the magnitude of change within each group (paired  $t$  tests; 2-tailed) and indicated significant improvement in executive function from pre- to postsingle bout for neuro-exergaming ( $p = .037$ ), no significant change for exergaming ( $p = .484$ ), and a significant decrease for neurogaming ( $p = .044$ ). As expected, there was no significant interaction for verbal memory.

## Discussion

This pilot study demonstrated feasibility for older adults to use a novel and theoretically-derived aerobic neuro-exergame that was implemented using an interactive physical and cognitive exercise system (iPACES). Furthermore, preliminary evidence from 30 older adults randomly assigned to a single bout of neuro-exergaming, exergaming, or neurogaming, demonstrated significant improvement in cognition from neuro-exergaming (exercise with specified interactive cognitive training) over and above either exergaming (relatively passive cognitive stimulation) or neurogaming (sedentary cognitive training alone). Neurogaming alone unexpectedly yielded a significant decline in cognitive function, which may have been due in part to some regression to the mean, but perhaps also due to a lack of activation from a relatively mundane cognitive training task of trying to learn and retain a list of errand locations. The present research is the first experiment with older adults to attempt to tease apart the neuropsychological effects of interactive physical exercise (aerobic) and theoretically-derived cognitive training, from its component parts (exercise alone or cognitive training alone). While prior research has examined the cognitive effects of interactively combining aerobic exercise with some cognitive

stimulation (Anderson-Hanley et al., 2012; Bamidis et al., 2015) or cognitive training with nonaerobic movement (Eggenberger et al., 2015), no prior research has examined interactive aerobic exercise and theoretically-driven cognitive training together. These are arguably the two most potent forms of intervention when taken individually, with the greatest potential for synergistic impact given past research, suggesting component neurobiological activation, as well as evolutionary and theoretical links.

A notable strength of the present research is that the cognitive intervention has aimed for ecological validity (i.e., the task mimics real-life scenario key for maintaining independence of completing a list of errands and returning home) and as such, perhaps also greater propensity for generalizability of cognitive benefit beyond the training realm (i.e., future research could assess whether long-term use increases length of time one remains independent vs. requiring institutionalization). As previously mentioned, there is considerable debate about whether training in one area of cognition will transfer to other areas, benefit global cognition, or translate into improvements in tasks of daily living. Prior studies have been limited by their cognitive interventions, because often they involve training on tasks that are unrelated to daily living. The present research overcomes this methodological limitation, as participants were asked to remember a list of errand locations, proceed accordingly, and then retrace their path back home, mirroring what many older adults actually do in their daily lives. Although the present research was limited to a single-bout analysis, ideally, future research will examine the long-term effects of training with the neuro-exergame. It may be, for example, that long-term intervention using the game introduced in the current research would also improve participants’ performance on activities of daily living by virtue of training in this related domain.



**Figure 2** — Executive function after a single bout of neuro-exergaming, exergaming, or neurogaming for older adults.

Another strength of the present research lies in the benefit of the iPACES technology used in implementation of this neuro-exergame, since a portable tablet-based game can be paired with existing exercise equipment (e.g., home-use stationary bike or elliptical, or even an under-desk pedaler), and thus have wider application than many older or unwieldy exergaming systems (e.g., the expensive commercial grade Espresso or BrainBike, the now defunct Wii Cyberbike, or equipment that interacted with game systems that are phasing out such as the PS2). This research provides preliminary evidence that an easily transportable, cost-effective tablet with a theoretically-driven sophisticated neuro-exergame can be used as a feasible interactive physical and cognitive exercise intervention for older adults. While prior research (Anderson-Hanley et al., 2012) has indicated the cognitive benefit of mental stimulation and physical exercise (i.e., cybercycling), the ultimate applicability of these findings to designing a long-term intervention that may aid in the treatment of cognitive declines (i.e., for those with mild cognitive impairment [MCI]) is limited by the costliness and inconvenience of the equipment required. A made-for-tablet cognitive training neuro-exergame that could easily be adapted to various exercise equipment is promising in terms of the eventual widespread distribution of a physical and cognitive exercise training program for the treatment of cognitive decline.

One limitation of this study is that the generalizability of findings is unknown, in that participants were primarily European American, with relatively high socioeconomic status inferred based on high educational attainment and ability to volunteer to participate in an uncompensated study. A replication and extension of this study with a more diverse sample would be useful to clarify that this type of intervention is both feasible and effective across a broader array of individuals, especially since exercise seems to play an important mediating role (Masel, Raji & Peek, 2010). There were also a disproportionate number of women ( $n = 21$ ) compared with men ( $n = 9$ ) that enrolled in the study; no significant differences were found for sex across pre or post measures, other than for education which was used as a covariate in analyses. In addition, a similar imbalance has been noted in the general population (58% of older adults are women; Older Americans report, 2012). Furthermore, adaptations of iPACES may be warranted to suit individual needs (e.g., one participant could not activate the pedaler due to drop foot) and some may not be able to participate in a virtual reality intervention (e.g., one participant had to cease play due to motion sickness). Overall, the completion rate of the single bout was good, but future research will need to examine applicability or adaptation to particular subgroups.

Another limitation of the study is that the cognitive benefit of this single-bout intervention needs to be established as resilient versus transient. Fleeting effects have been observed in other single-bout exercise interventions. An alternate explanation for these findings is that a particular brain network may have been activated by interactive physical and cognitive exercise (e.g., Smith et al., 2014), which facilitated cognitive function in a certain domain, but that benefit may diminish as one's physiology returns to baseline after a period of time. Some research shows benefits can last at least 2 hr following an acute bout (e.g., Basso et al., 2015). Additional research would be needed to clarify the duration of benefit and whether gains persist after either a single bout or a period of regular, long-term use.

The findings of this pilot study favored neuro-exergaming over sedentary game-only play and exergaming, which appears consistent with the findings of prior research, which found that exergaming was not as impactful as physical exercise alone (O'Leary et al., 2011). It may be that exergaming that is not specifically tailored to improve a specific cognitive function, while entertaining, stimulating, and perhaps motivating, may not yield specific cognitive benefit as might a theoretically-derived neuro-exergame as tested in prototype form herein.

Future research should examine the cognitive benefits of iPACES as a longer-term (i.e., 3–6 months) intervention. The current research provides preliminary evidence for the benefits of an interactive intervention through single-bout data, but a long-term intervention and follow-up is necessary to examine longstanding cognitive improvements or slowing of cognitive decline, as well as possible transfer and generalizability. Further refinement of the prototype would be beneficial to enhance feedback, score keeping, visual arts, and other features that have been shown to facilitate enjoyment and promote repeated use (Lyons, 2015). As previously mentioned, long-term studies examining the potential benefits of the working memory game proposed in the present research should, especially, examine whether participants' independent activities of daily living improve because these are being trained by way of the cognitive training. In addition to a long-term intervention study, future research should also explore the feasibility of an interactive intervention for individuals with cognitive impairment (i.e., those with MCI or Alzheimer's disease [AD]). Scant research has examined the impact of interactive interventions for these populations, although prior research indicating that physical activity or cognitive training alone may be especially powerful for individuals at greater risk for dementia makes this exploration salient (Gates et al., 2013 and Jean et al., 2010, respectively).

In this pilot study, the feasibility of iPACES for older adults was demonstrated and promising new evidence was presented for a theoretically-derived neuro-exergame to have greater cognitive benefit than either of its component parts administered separately (e.g., as an exergame found effective in Anderson-Hanley et al., 2012, or a neurogame found potent in Angavaren et al., 2013). More innovation and research is needed to explore the scientific outcomes and underpinnings of these types of interventions, to tailor neuro-exergames to address specific cognitive domains, and to create opportunities to move promising findings from bench to bedside in the fight against cognitive decline.

## Endnotes

1 Exergaming has been defined as "technology-driven physical activities, such as video game play, that requires participants to be physically active or exercise to play the game" (American College of Sports Medicine [ACSM],

2014, p. 1) and has also been referred to as active gaming or motion-based videogames (Gerling & Mandryk, 2014).

2 Interactivity herein indicates the two-way communication between the exerciser and the equipment, such that physical and cognitive actions of the exerciser are seamlessly interwoven and actions (e.g., steering or pedaling faster) register and affect operations of the equipment, with corresponding feedback from the technology provided to the exerciser (e.g., change in virtual scenery, score displayed, etc.); thus, iPACES functions in contrast to either synchronous, dual-task, or tandem physical and cognitive activities.

3 Neuro-exergaming 2015 Anderson-Hanley, is an adaptation of existing terms and used herein to indicate the integration of neurogaming with exergaming for the express purpose of benefiting brain health and fostering improved cognitive function.

4 iPACES 2013–present Anderson-Hanley, patent pending.

5 These proportions are consistent with recent census data for this region.

6 No significant differences were found between groups on baseline cognitive function (e.g., ADAS delayed recall which can be used as a proxy screen for MCI/dementia) and, furthermore, participants were comparable to normative controls (see Table 2; Graham et al., 2004).

7 Reasons for missing data: Stroop data/color blindness; no posttest data/refused game-only condition; no posttest data/unable to pedal due to drop-foot; no posttest data/partial dose from ceasing midway due to motion sickness.

8 Reason for inadequate dose of intervention: game froze in middle of bout/incomplete dose of mental exercise.

9 The score display feature has since been implemented (following completion of this pilot trial), specifically for use in a longer-term interventions where feedback regarding accomplishment is more salient to promote continued use.

10 Results of these behavioral measures are not reported herein given the brevity of this report and use of these data for characterization purposes not central to primary hypothesis testing.

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