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Effects of Interactive Physical-Activity Video-Game Training on Physical and Cognitive Function in Older Adults

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The purpose of the present study was to assess the potential of exergame training based on physically simulated sport play as a mode of physical activity that could have cognitive benefits for older adults. If exergame play has the cognitive benefits of conventional physical activity and also has the intrinsic attractiveness of video games, then it might be a very effective way to induce desirable lifestyle changes in older adults. To examine this issue, the authors developed an active video game training program using a pretest-training-posttest design comparing an experimental group (24 × 1 hr of training) with a control group without treatment. Participants completed a battery of neuropsychological tests, assessing executive control, visuospatial functions, and processing speed, to measure the cognitive impact of the program. They were also given a battery of functional fitness tests to measure the physical impact of the program. The trainees improved significantly in measures of game performance. They also improved significantly more than the control participants in measures of physical function and cognitive measures of executive control and processing speed, but not on visuospatial measures. It was encouraging to observe that, engagement in physically simulated sport games yielded benefits to cognitive and physical skills that are directly involved in functional abilities older adults need in everyday living (e.g., Hultsch, Hertzog, Small, & Dixon, 1999).

Keywords: physical activity, aging, video game, cognition, exergames

A ubiquitous observation in studies of human aging is that cognitive abilities differ between young and elderly adults in a number of neurocognitive domains such as reasoning, attention, memory, and processing speed (e.g., Craik & Salthouse, 1999; Hoyer & Verhaeghen, 2006; Park & Gutchess, 2002; Salthouse, 2004). Nevertheless, epidemiological work suggests that in old age, a lifestyle rich in mental, physical, and social stimulation could have beneficial influences on the level of cognitive performance (e.g., Hultsch et al., 1999; Kramer, Bherer, Colcombe, Dong, & Greenough, 2004). Generalized transfer is relatively rare in studies of learning, but there is clear evidence that regimens involving physical-activity training or video-game playing can result in improved cognitive function in older adults (e.g., Green & Bavelier, 2008; Green, Li, & Bavelier, 2010; Spence & Feng, 2010). Exercise adherence is a particular challenge with older adults (Chao, Capri, & Farmer, 2000), but video-game playing is increasingly popular among middle-aged and older adults (e.g., Flew & Humphreys, 2005). Products that have recently become available support entertaining video games that combine game play with significant physical exercise by using physical input devices (e.g., Nintendo Wii and Microsoft Xbox 360 Kinect). We will call these “exergames.” There has been a rapid growth of the popularity of exergames, including among the elderly (e.g., Vance, McNees, & Meneses, 2009). The purpose of the present study was to assess the potential of exergame training based on physically simulated sport play as a mode of physical activity that could have cognitive benefits for older adults. If exergame play has the cognitive benefits of conventional physical activity, and also has the intrinsic attractiveness of video games, then it might be a very effective way to induce desirable lifestyle changes in older adults.

Physical Activity and Cognition

The relationship between physical activity and cognition has been examined empirically with cross-sectional designs (e.g., Clarkson-Smith & Hartley, 1989; Hillman et al., 2006; Perrot, Gagnon, & Bertsch, 2009; Shay & Roth, 1992), and with physical training interventions (e.g., Dustman et al., 1984; Hawkins, Kramer & Capaldi, 1992; Kramer et al., 1999). It has also been approached from neuroscience perspectives (Colcombe, Kramer, McAuley, Erikson, & Scalf, 2004; Erickson & Kramer, 2009). The results of meta-analytic reviews have established that the beneficial effects of participation in physical activity on cognitive performance in older adults are reliable, with one review reporting an effect size (*ES*; Cohen, 1988) that was moderate ($ES = 0.48$ using Hedges’ formula; Hedges, 1982; Colcombe & Kramer, 2003) and another reporting a small to large effect using the Weighted Mean Difference and Standardized Mean Difference ($ES = 0.10$ to 1.17; Angeraven, Aufdemkampe, Verhaar, Aleman, & Vanhees, 2008). Additionally, Colcombe and Kramer indicated that aerobic exercises ($ES = 0.41$) and combined training (e.g., aerobic with strength exercises; $ES = 0.59$) yielded larger effects in executive

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function tasks (*ES* = 0.68) than inprocessing-speed tasks (*ES* = 0.27), visuospatial-awareness tasks (*ES* = 0.43), or controlled cognitive tasks (*ES* = 0.46). Empirical studies have largely focused on aerobic exercise, based on the presumed role of cardiovascular fitness as a potential mechanism, in the relationship between cognitive decline and physical activity (e.g., Chodzko-Zajko, 1991; Colcombe et al., 2004; Kramer et al., 1999). However, findings from the meta-analytic reviews suggest that cardiovascular fitness is not the only mechanism of the effect (Angeraven et al., 2008; Colcombe & Kramer, 2003; Etnier, Nowell, Landers, & Sibley, 2006). This, then, allows for the possibility that increases in cardiovascular fitness are not necessary for cognitive benefits, and, consequently other forms of physical activity that do not particularly emphasize improvements in cardiovascular fitness should be explored for their possible cognitive benefits. As we noted, there is also an underlying issue. Although the effects of physical activity on cognitive vitality are widely recognized in popular culture, resistance to exercise among the elderly remains very high (U.S. Department of Health and Human Services, 1996). This is presumed to be due to the unattractiveness and inaccessibility of physical activity as well as to functional restrictions (i.e., reduced cardiorespiratory endurance, reduced resistance strength, weight gain) related to advancing age (e.g., Hughes, Seymour, Campbell, Whitelaw, & Bazarre, 2009; Schutzer & Graves, 2004).

Video Games and Cognition

Training regimens based on sedentary video games can improve cognitive skills (e.g., Achtman, Green, & Bavelier, 2008; Green & Bavelier, 2008; Green et al., 2010). The benefits of video games for cognitive performance have been demonstrated in younger adults primarily in cross-sectional studies comparing game players with nongame players on visuospatial attentional functions (for a review, see Green & Bavelier, 2006), and on attention, memory, and executive control functions (Boot, Kramer, Simons, Fabiani, & Gratton, 2008). In older adults, it has been observed that after several weeks of video-game training, game players showed improvements when compared with control groups on reaction time (e.g., Clark, Lanphear, & Riddick, 1987; Goldstein et al., 1997), manual dexterity (Drew & Waters, 1986), visuomotor coordination (Dustman, Emmerson, Steinhaus, Shearer, & Dustman, 1992) and executive control functions such as task switching, working memory, visual short-term memory and reasoning (Basak, Boot, Voss, & Kramer, 2008). However, there are reasons to question whether there is general transfer of video-game play to cognitive domains. Ackerman, Kanfer and Calderwood (2010) had a sample of adults between the ages of 50 and 71 complete twenty 1-hr training sessions over the course of one month using the Nintendo Wii Big Brain Academy, a completely sedentary activity. The results indicated substantial improvements on the Wii tasks themselves, but there was no significant transfer of training from the Wii practice to other measures of fluid and crystallized intelligence and perceptual speed abilities, administered before and after the month of cognitive training activities. Although a positive relation between video game training and cognition has been demonstrated, it would seem that the transfer of the video-game training to measures of cognition is not systematic, but rather may depend on several aspects of the training, such as task difficulty, motivation and arousal, feedback, and variability (cf., Green & Bavelier, 2008). Moreover the type of video games employed could have an important effect on whether transfer of training is observed. For example Basak et al. (2008) did not obtain the same improvements for visuospatial skills using a real-time strategy game that Green and Bavelier (2003, 2006) had obtained with action video games. The characteristics of the game itself could be directly related to the types of processes that are modified by playing the game (e.g., Achtman et al., 2008), meaning that transfer is not as general as claimed. The results of previous training programs using video games provide us with no clear guidance for predictions in the present study. It is possible that video-game training results in general transfer only when physical activity is involved.

Exergames and Cognition

Exergames, like the sports that they simulate, make both physiological demands for increased energy expenditure (Graves et al., 2010) and cognitive demands (Quiroga et al., 2009). For example, both in tennis and in a simulation such as Wii Tennis, one must run to the ball and strike it and, at the same time, calculate where to place the return for maximum advantage. We know that physical exercise has broad cognitive benefits, perhaps even if cardiovascular fitness is not improved. Video game playing may have cognitive benefits, but even it if does not, it is highly motivating and likely to promote exercise adherence. We are aware of only two studies using exergames. Rosenberg et al. (2010) found a reduction in depressive symptoms, improvement in mental health-related quality of life, and in global cognitive functioning after 35-min sessions three times weekly for 12 weeks, although the critically important, untrained control group was not included. Nitz, Kuys, Isles, and Fu (2009) found improved balance and lower limb muscle strength after 30-min sessions twice weekly for 10 weeks. To our knowledge, no study has examined the impact of exergames on cognitive functioning in older adults.

The Present Study

The purpose of the present study was to determine whether exergame training in physically simulated sport activity would transfer to cognitive functions in older adults. To examine this issue, we developed an active video-game training program using a pretest- posttest training design to compare an experimental group (24 x one hr of training) with a control group without treatment. We selected the Nintendo Wii gaming system owing to its accessibility for novice and older populations, the relevance of the games to actual sport, and its ready availability in the marketplace of commercial software. In order to maximize the physiological challenge and keep the spirit of physical activity, only games of physically simulated sport were selected on this exercise program: Wii Sports, Wii Fit, and Mario & Sonic on Olympic Games.

We tested two main hypotheses. The first was that exergame training would result in improved performance on the Wii sports tasks themselves. The second was that there would be practice-related improvements on a wide range of neuropsychological tests, including executive control tasks, visuospatial tasks, and processing-speed tasks. On the basis that transfer effects have been previously found for physical activity, we expected that the exergames program would lead to favorable outcomes on measures of executive control (e.g., Colcombe & Kramer, 2003; Kramer et al., 1999). Further, to the extent that exergames make mental demands similar to those of sedentary video games, we expected, based on findings of practice effects for video games, that performance on visuospatial tasks (e.g., Green & Bavelier, 2003, 2006) and on processing-speed tasks (e.g., Clark, Lanphear, & Riddick, 1987; Drew & Waters, 1986; Dustman et al., 1992; Goldstein et al., 1997) would be enhanced. Because we were not certain that Wii games would be sufficiently challenging to produce a change in cardiovascular fitness, we did not make a prediction about changes in physical function.

Method

Participants

Potential participants were contacted through flyers posted in town halls and community senior centers. People responding were contacted by phone and they provided an estimation of their physical activity, video-game use and health status. All potential participants also rated their health on a 5-point health scale (1 = *very bad*, 2 = *bad*, 3 = *fair*, 4 = *good*, 5 = *excellent*), and those who rated their health as very bad or bad were excluded. We included only those individuals who reported never playing video games and living a sedentary lifestyle. We based our selection criteria on the recommendations of several health guides (including the Canadian Health Network in Canada and the Institut National de Prévention et d'Education pour la Santé in France).

Thirty-two independently living older adults (27 women and five men between the ages of 65 and 78 years) recruited from the region of Paris, France, volunteered to take part in this longitudinal intervention study. All participants were of European, Caucasian origin and were native French speakers. They gave their informed consent, and were not compensated for their participation. Each participant was required to have a medical certificate permitting the practice of physical activity. All participants were right-handed and had normal or corrected-to-normal vision and audition. The participants completed the Mini-Mental Status Examination (MMSE; Folstein, Robins, & Helzer, 1983), the Geriatric Depression Scale (GDS; Yesavage et al., 1982), and the Modifiable Activity Questionnaire (MAQ; Kriska et al., 1990) which assesses current (past-year) physical activity for different activity categories practiced at least 10 times per year. By random assignment, 16 participants were assigned to the exergames training group and 16 other participants were assigned to a no-training, no-contact control group. Over the course of the study, one participant in the training group gave up on the third training session reporting that it was physically too difficult. One control participant could not attend the posttest session owing to medical problems unrelated to the study. Accordingly, the analysis of results of this study was based on the 15 individuals remaining in each group. Demographic information for both groups is listed in Table 1. There were no significant differences between the two groups in age, years of education, body mass index, or scores on the MMSE, GDS, and MAQ.

Apparatus

For the exergame training we used the Nintendo Wii, a video-game console with motion-sensitive technology. The Wii Remote and the Nunchuk, the primary wireless controllers for the console, use a combination of built-in accelerometers and infrared detection to sense their positions in three-dimensional space when pointed at LEDs within the console's Sensor Bar. This design allows game players to control their avatars (graphical representations of the user) using physical gestures as well as traditional button presses. We used also the Nintendo Wii Balance Board which has a similar shape to a body-weight scale, with a flat rectangular platform 51.1 cm wide by 31.6 cm long by 5.3 cm deep. Four force sensors record the weight of the player and the trajectory of the center of pressure of the participant during the game. It communicates wirelessly with the Nintendo Wii video game console. The video game display was a Liquid Crystal Display (LCL) projector (Panasonic Model PT-AX200E) projecting on a portable screen (Epson ELPSC06) 76 cm in height and 102 cm in width.

Measures

The functional fitness battery. The physical impact of the training program was evaluated by performance on a functional fitness battery, by heart-rate measures (in beats per minute, bpm), and by ratings of perceived effort. The functional fitness battery measures the physiological capacity to perform normal everyday activities safely and independently without undue fatigue (Rikli & Jones, 1999). We used the Senior Fitness Test (SFT, Rikli & Jones, 2001), which measures the underlying physical parameters asso-

Table 1
Means of Demographic, Health, Exercise, and Subjective Well-Being Variables for Control and Training Groups

	Control		Training			
Variables	*M*	*SD*	*M*	*SD*	*t*	*p*
Age (years)	73.47	3.00	73.47	4.10	0.00	0.81
Self-rated health	3.67	0.62	3.73	0.59	0.30	0.76
Years of education	11.40	2.22	11.20	1.78	−0.27	0.78
Body Mass Index (kg/m^2)	27.62	5.89	27.40	4.46	−0.18	0.90
MMSE	29.27	0.88	28.67	1.17	−1.58	0.12
GDS	5.93	2.66	6.00	3.48	0.06	0.95
MAQ (hr/week)	0.60	0.58	0.79	0.59	0.88	0.38

Note. *M* = Mean; *SD* = Standard Deviation; MMSE = Mini Mental State Examination; GDS = Geriatric Depression Scale; MAQ = Modifiable Activity Questionnaire.

ciated with functional ability and which identifies whether an older adult may be at risk for loss of ability to perform functional movements such as walking, stair-climbing, and standing up. The SFT protocol comprises seven components completed in 30 to 40 min following a 5-min warm-up exercise. Height (m) and body weight (kg) were measured in order to calculate *Body Mass Index* (BMI, kg/m^2). The *chair-stand test* measures muscle strength for lower body, and the *arm curl test* measures upper-body strength. The *6-Min Walking Test* (6MWT) evaluates cardiorespiratory fitness. The number of meters walked, the maximum heart rate, the mean heart rate, and the rated exertion using the modified Borg scale (1982; range 0 to 10, with 0 = *complete rest* and 10 = *extremely strong*) were recorded. The *chair-sit-and-reach test* evaluates lower body flexibility and the *back-scratch test* measures upper-body flexibility. The *8-foot up-and-go test* evaluates agility and balance. Rikli and Jones (2001) give a complete description of these tests.[1] *Heart rate* (HR) was monitored using a standard chest lead connected to a digital pulse transmitter (SUUNTO T6 software SUUNTO Training Manager, version 2.3.0.15). Several recordings were made during the study: (a) at the outset of the study, (b) during the 6MWT, (c) during the pretraining and posttraining sessions (walk and rest), and (d) for the training group, during the second, twelfth, and 20-s training sessions. The *resting heart rate* (RHR) was measured for 15 minutes, with participants in the supine position, during the first assessment session. The purpose was to be able to quantify the intensity of the physical exercise throughout the course of the program through the calculation of the proportion of the heart-rate reserve according to Karvonen's method (Karvonen, 1957). Heart-rate reserve (HRR) is the difference between the estimated maximum heart rate (MHR = 205 – 0.685 x Age) and the RHR. There are various formulas to estimate MHR; this one is recommended as the most accurate univariate estimate in a thorough review by Robergs and Landwehr (2002). For any exercise bout with heart-rate HR_E (Heart-rate exercise), the proportion of HRR used is calculated as $(HR_E - RHR)/HRR$. Finally at end of the 6MWT and after every training session, participants were asked to score their perceived exertion using the Borg scale.

The cognitive battery. This battery included a number of tasks that fell into three categories: executive control tasks (Trail-Making test, Stroop Color Word Interference test, Letter Sets test, Matrix Reasoning test[2], Digit Symbol Substitution test); visuospatial tasks (Spatial Span test, Directional Headings test, Mental Rotation test); and processing-speed tasks subdivided into two categories: perceptual speed (Cancellation test and Number Comparison test) and psychomotor speed (the Reaction Time test and Plate Tapping test). Each of these tasks is described below.

Executive Control Tasks

Trail Making test. The Trail-Making test (Corrigan & Hinkeldey, 1987), originating from the Army Individual Test Battery, is a timed paper-and-pencil task that consists of two separate parts. Part A involves drawing a line to connect consecutive numbers (i.e., from 1 to 2 to 3 and so on up to 25). Part B requires the participant to connect numbers and letters in an alternating progressive sequence (i.e., 1 to A to 2 to B and so on). Without lifting their pencil from the paper, participants began at No. 1 and connected the circles in the instructed order as quickly as possible without making any errors. If an error was made, the experimenter indicated the error and allowed the participant to correct the mistake and continue the task. We measured completion times. Because Part A of the Trail-Making Test has been viewed as primarily a measure of speed, the measure we used in our analyses was the time it took to complete Part B less the time it took for Part A. Following Corrigan and Hinkeldey (1987), we reasoned that the difference would be a purer measure of executive function.

Stroop test. The Stroop test (Stroop, 1935), is a frequently used measure of executive function; we used a modified version (Bohnen, Jolles, & Twijnstra, 1992; Chatelois et al., 1996). Participants are required to verbally identify the color of the stimulus in each of four conditions. In the congruent *color-naming* condition, the stimulus is a string of symbols printed in colored ink, such as a series of red Xs. In the *color-reading* condition, the stimulus is a color name written in black ink. In the *incongruent* condition, the stimulus is a color name printed in a different ink color, such as the word "blue" printed in red ink. Finally, in the *flexibility* condition, the stimuli are the same as in the congruent condition except that the participant reads the color word rather than the ink color if the stimulus has a border. In all conditions, the number of correct answers given in 45 sec was the measure of performance. *Color-naming* and *color-reading* conditions are task-training conditions that were not included in the analysis. Only the *incongruent* and *flexibility* conditions were used as measures of the executive functioning.

Letter Sets test. Participants were given 15 items each containing five sets of letters (e.g., NOPQ DEFL ABCD HIJK UVWX) and had to choose the set that did not follow the rule defined by the four other sets. The Letter Sets test was taken from the Educational Testing Service (ETS) Kit of factor-referenced cognitive tests (Ekstrom, French, Harman, & Dermen, 1976). The score was the number of items correctly completed in 13 minutes.

Matrix reasoning test. This test consists of a sequence or group of designs, in which the individual is required to choose the one design from a number of choices that correctly completes the sequence. This test is a subtest of the Wechsler Abbreviated Scale of Intelligence (1999) and measures abstract nonverbal reasoning ability. The score was the number of items correctly completed.

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[1] *Chair stand*: Number of full stands that can be completed in 30 seconds with arms folded across chest. *Arm curl*: Number of bicep curls that can be completed in 30 seconds holding a hand weight of 5 lbs (2.27 kg) for women; 8 lbs (3.63 kg) for men. *6-Minute Walking Test*: The number of meters walked in 6 min, the maximum heart rate, the mean heart rate, and the rated exertion using the Borg scale were recorded. *Chair sit and reach*: From a sitting position at front of chair, with leg extended and hands reaching toward toes, the number of inches (cm) (+ or −) between extended fingers and tip of toe. *Back scratch*: With one hand reaching over the shoulder and one up the middle of the back, the number of inches (cm) between extended middle fingers (+ or −). *8 foot up and go test*: Number of seconds required to get up from a seated position, walk 8 feet (2.44 m), turn, and return to seated position.

[2] The Letter Sets test and the Matrix Reasoning test are classified as tests of inductive reasoning (e.g., Ackerman, 1990). Researchers have demonstrated that inductive reasoning is a higher executive function important for everyday functioning and sensitive to age-related deficits (e.g., Blaskewicz Boron, Turiano, Willis, & Schaie, 2007).

Digit symbol substitution test. Participants were provided with key matching digits to various symbols and were asked to write in the appropriate symbol for each digit in several rows of digits. The score was the number of correctly coded digits completed in 120 sec. The Digit Symbol Substitution test originated from the WAIS–R (Wechsler, 1997a).

Visuospatial Tasks

Spatial Span test. The Spatial Span test is a subtest of the Weschler Memory Scale (Wechsler, 1997b). The apparatus consists of 10 blue, wooden blocks, 3.1-cm squares, fixed to a 20- by 25-cm white, wooden board. The blocks are numbered on the sides facing the examiner as a means to facilitate administration and record the path sequences. The blocks are tapped in a predetermined sequence by the examiner using the eraser-end of a pencil at the rate of one block per sec, and participants are required to reproduce the block-tapping sequences by touching the appropriate blocks when the stimulus sequence is completed. This procedure continues with increasing numbers of blocks touched until the participant cannot correctly reproduce the sequence. The score is the largest number correctly reproduced. The *backward Spatial Span test* is the same test, except that the participant must reproduce the sequence in reverse order.

Directional Headings test. This is a speeded paper-and-pencil test of spatial ability (Cobb & Mathews, 1972). Each item is comprised of three pieces of information that reflect cardinal points on a compass (e.g., the letter “W”, a symbol “←”, and the notation “270”, each denote “West”). The individual is asked to determine the direction indicated (if all information is consistent), or indicate that the information is inconsistent. The score is the number of correct items completed in 60 sec.

Mental rotation test. The mental rotation test is a variant of the Shepard and Metzler figures (1971) introduced by Vandenberg and Kuse (1978), who used the original figures to create a pencil-and-paper test for spatial abilities. The 20 figures are presented as two-dimensional visual images that are constructed of 10 cubes, and are perceived as three-dimensional objects. The subject’s task is to decide, quickly and accurately, whether a pair of two figures shows the same object or different objects. The score is the number of items completed correctly in 10 min.

Processing Speed Tasks

Cancellation test. This is a perceptual speed test (Ackerman, 1990) consisting of a page of randomly generated uppercase English letters. All letters occurred with equal probability and participants were instructed to place a line through each occurrence of a target letter (A) in 60 seconds. The score was the number correctly marked.

Number comparison test. This is another perceptual speed test (Ackerman & Cianciolo, 2000) consisting of two 50-item columns of digits. Participants are instructed to place a check mark between adjacent numbers that match exactly. The score is the number of correct items in 90 seconds.

Reaction time test. Speed of response in ms was measured for *simple reaction time* (SRT; a single stimulus) and *choice reaction time* (CRT; four stimuli). Both SRT and CRT can be decomposed into *decision time* (DT; the time to lift a finger from a start button to begin movement toward a target button) and *movement time* (MT; the time from lifting the finger until the target button is pressed). Instructions and stimuli were presented with a Pentium 4 PC, with standard keyboards and E-Prime software, which recorded accuracy and response time (version 1.1 beta 1.0, Schneider, Eschman, & Zuccolotto, 2002). The stimulus was a red circle. For SRT, the red circle appeared only at the left corner of the screen and the participant responded by pressing the spacebar as quickly as possible. For CRT, the red circle could appear at one of four positions along an imaginary circular arc. The participant responded by pressing the a key on the numeric keypad corresponding to the position of the red circle—1 for lower left, 7 for upper left, 9 for upper right, and 3 for lower right. Performance was measured as the mean SRT and CRT in ms on a block of 12 trials.

Plate-Tapping test. The Plate-Tapping test, a part of the Eurofit Testing Battery, is a response-speed test using an alternating tapping action that measures upper-body reaction time, hand-eye quickness, and coordination (Bovend’eerdt, Kemper, & Verschuur, 1980). Two green disks (20-cm diameter) are placed with their centers 60 cm apart on a table, and a rectangle (30 by 20 cm) is placed equidistant between the disks. One hand is placed on the rectangle. The subject moves the other hand back and forth over the hand in the middle alternately tapping the two disks as quickly as possible. This action is repeated for 30 sec. The score is the number of taps. Participants had two trials with each hand; the mean scores were recorded.

Procedure

The entire study spanned 14 weeks. This included the pretraining (first week) and posttraining (fourteenth week) sessions for assessment and, for the training group, the training sessions. Participants completed a battery of neuropsychological tests, assessing executive-control functions (five tests with a total of six measures), visuospatial functions (three tests with a total of four measures), and processing speed (four tests with a total of eight measures), to measure the cognitive impact of the program, and a battery of functional fitness tests to measure the physical impact of the program. Each time, the cognitive battery and the functional fitness batteries were administered over two days within one week, with a 90 minute session each day. The 12 cognitive-assessment tasks were presented in the following fixed order: On the first day, performance on executive control and processing speed was assessed; on the second day, performance on visuospatial tasks and functional fitness were assessed.

Participants in the training group completed two 1-hr exergame sessions per week over a period of 12 weeks, resulting in total training time of 24 hr. Each participant was paired with another for each session with the intention of making the exergame playing more enjoyable and motivating adherence to the regimen. Participants were asked not to play exergames, except for this study. Each session began with a warm-up and finished with a cool-down in order to reduce the risk of injury (e.g., Jones & Hammig, 2009).

Each training session was divided into three periods. During the first period, participants played in pairs at the Wii Tennis or Wii Boxing game, alternating each session. On the first, twelfth and 24th sessions, they played the Wii Bowling game. During the second period, participants took turns using the balance board to play the Wii Soccer Headers, the Wii Ski Jump, and the Wii

Marbles games. During the final period, participants played four games on which we recorded performance: Wii Ski Slalom, Wii Hula Hoop, Wii Trampoline, and Wii Tennis Return of Serve. We classified each of these four tasks based on the primary skill required: The Ski Slalom game requires *balance*; the Hula Hoop game requires *energy* and stamina; the Trampoline game requires *cognitive* judgment; and the Tennis game requires a variety of skills so we classified it as *global*.

For the balance task (Ski Slalom), the participants "slalomed" by shifting their weight to alternate between blue and red doors as quickly as possible. The performance score is a function of the time to complete the course and the number of doors cleared. For the energy task (Hula Hoop), the score was the number of successful rotations of the hoop in 70 sec. For the cognitive task (Trampoline), the participants achieved up to 10 points by making the indicated movements for optimal control of the avatar. For the global task (Tennis Return of Serve), the score was the number of serves from the computer's ball machine successfully returned before an error occurred.

Each training session was supervised by a physical trainer. The coach's functions were (a) to implement the training schedule and give any necessary explanations, (b) to ensure the safety of the participants and particularly to prevent the risk of fall, (c) to prevent participants from using incorrect postures or movements or cheating movements, and (d) to give participants feedback on their performance and note their exercise adherence. The participants were urged to try to increase the level of challenge and to improve their performance on each activity over the course of the training. At the end of the training program, the participants completed a questionnaire that measured their subjective impression of the program. Six questions were asked, two in the form of 5-point scales on the similarity between the exergame session and conventional forms of physical activity (1 = *very much*, 2 = *much*, 3 = *relatively*, 4 = *not much*, 5 = *none*), and on the difficulty of the training sessions (1 = *very easy*, 2 = *easy*, 3 = *reachable*, 4 = *difficult*, 5 = *very difficult*), and four other yes-no questions on whether their body knowledge had improved, whether they would like to continue an exergames practicum, whether they would like to begin a program of physical activity, and whether they would like to acquire an exergame game console.

The participants in the control group committed themselves not to modify their sedentary lifestyle and not to begin playing video exergames games or engage in other physical activity over the 14 weeks of the study.

Results

The first step in the analysis was to verify that the training and control groups were equivalent at the outset of the program. The pretraining scores on both physical and psychological measures were compared using *t* tests for those who would later be assigned to the training and control groups. The descriptive and inferential statistics are given in Table 2. Among the 35 comparisons, only one was significant. Those who would be assigned to the training group rated the 6-min walk as more taxing than did those who would be assigned to the control. Because there was only this one difference and that in a subjective assessment, we deemed the two groups equivalent.

The second step in the analysis was to characterize the participants in the training group, as well as the nature and effect of their training. The number of completed sessions for the 15 participants ranged from 20 to 24 ($M = 23.40$). Overall adherence was 97.50%, with 351 out of a possible 360 sessions (15 participants for 12 weeks with 2 sessions per week) completed by participants. The final questionnaire indicated that the exergame training was manageable for older persons (80% agreed), and seemed comparable to other physical activity (80% of results ranged between very much and relatively). All participants reported that they would like to continue with exergame activity, however only 40% contemplated acquiring a game console. Finally, 67% of participants thought that their body knowledge improved with the training program, and 47% were considering beginning a program of physical activity. Participants showed significant improvement in performance across training sessions on all four of the exergames: for the balance task, $F(23, 207) = 10.79$, $p < .01$, $\eta^2 = .55$; for the cognitive task, $F(23, 207) = 14.25$, $p < .01$, $\eta^2 = .61$; for the energy task, $F(23, 138) = 2.66$, $p < .01$, $\eta^2 = .31$; and for the global task, $F(23, 230) = 6.70$, $p < .01$, $\eta^2 = .40$. Follow-up tests using Tukey's Honestly Significant Difference test (HSD), showed significant improvement over the first session by the sixth session in the balance task (Ski Slalom), by

Table 2
Comparison on Pre-Test Measures by Condition

	Control		Training			
	M	*SD*	*M*	*SD*	*t*	*p*
Resting Heart Rate (bpm)	63.60	8.08	64.57	8.33	−0.32	0.75
Max Heart Rate 6-Min Walk (bpm)	107.87	16.02	116.57	17.45	−1.40	0.17
Mean Heart Rate 6-Min Walk (bpm)	100.27	15.10	106.86	11.63	−1.31	0.20
Chair Stands (Number)	14.27	3.67	12.93	2.66	1.14	0.26
Arm Curls (Number)	16.80	2.57	16.53	3.25	0.25	0.80
6-Min Walk (Meters Covered)	429.84	61.58	411.17	84.69	0.69	0.50
8-Foot Up-and-Go (sec)	7.12	1.64	7.42	1.38	−0.56	0.58
Back Scratch "Lower Right" (cm)	0.87	6.17	3.67	8.17	−1.06	0.30
Back Scratch "Lower Left" (cm)	0.90	6.74	3.40	8.73	−0.88	0.39
Back Scratch "Upper Right" (cm)	5.57	9.08	5.63	8.29	−0.02	0.98
Back Scratch "Upper Left" (cm)	14.43	13.51	13.03	10.85	0.31	0.76
Perceived Effort 6-Min Walk	2.87	1.06	4.00	1.47	−2.40	0.02

Note. *M* = Mean; *SD* = Standard Deviation.

the seventh session in the cognitive task (Trampoline), by the tenth session in the global task (Tennis Return of Serve), and by the 23rd session in the energy task (Hula Hoop). We note that only six of the participants continued the energy task until the final training session. In addition, heart rate was measured during the second, twelfth, and 20th training sessions. There were no significant changes across these three sessions in mean heart rate, $F(2, 26) = 0.78$, $p = .47$; in maximum heart rate, $F(2, 26) = 1.97$, $p = .16$; or in proportion of heart-rate reserve achieved, $F(2, 26) = 2.00$, $p = .16$.

The central step in the analysis was to determine whether the training regimen resulted in greater change in the trained group than the untrained controls. We calculated the change score by subtracting the pretest score from the posttest score for each measure. First, we explored the possibility of test-retest improvement in the control group using one-group t tests to test the observed change against zero. There was no significant change. In order to determine whether the change was significantly greater in the trained group than in the controls, we used the following approach: First, we carried out a MANOVA with all the measures within a set as dependent variables; then, if the overall difference between treatment and control was significant, we carried out t tests on each of the component measures, using the modified Bonferroni procedure to protect against an inflated chance of a Type I error (Holm, 1979). The first set of comparisons was for measures of physical performance. The descriptive and inferential statistics for those change scores are given in Table 3. Physical improvement was significantly greater in the treatment group, *Wilk's* $\Lambda = .31$, $F(10, 18) = 4.06$, $p = .005$, $\eta^2 = .693$. The Borg Scale judgments of exercise intensity for the 6-min walk, which are subjective measures, were omitted from this analysis. Follow-up tests showed that greater improvement in the training group than in the controls was observed for all the physical measures except the Back-Scratch measures of flexibility. With unprotected tests, there were significant differences on three of the four flexibility measures. There was also no significant difference in the Borg Scale ratings. The second set of comparisons was for measures of processing speed, for which descriptive and inferential statistics are given in Table 4. The effect of group was significant, *Wilk's* $\Lambda = .21$, $F(8, 21) = 9.75$, $p < .001$, $\eta^2 = .788$. Follow-up tests showed that improvement for all of these measures was significantly greater in the training group than in the control group. The third set of comparisons was for measures of visuospatial function, for which descriptive and inferential statistics are given in Table 4. The difference between the treatment and control groups was not significant, *Wilk's* $\Lambda = .77$, $F(4, 25) = 1.87$, *ns*, $\eta^2 = .230$. The fourth set of comparisons was for measures of executive function, for which descriptive and inferential statistics are also given in Table 4. Here, the improvement was significantly greater in the treatment than in the control group, *Wilk's* $\Lambda = .19$, $F(6, 23) = 15.79$, $p < .001$, $\eta^2 = .805$, and follow-up tests showed that this was true for all of the measures.

Discussion

The purpose of the present study was to determine the potential of training in physically simulated sport play as a mode of activity that could have cognitive benefits for older adults. The training program was modeled on programs of physical activity and programs of sedentary video-game play that had previously shown cognitive benefits.

The first hypothesis was that exergame training would produce gains in performance on the Wii sports tasks themselves. We found that practice did result in improved performance on the Wii tasks. Participants showed significant and substantial gains in performance on the four performance tasks, which challenged a variety of abilities over the course of 24 hours of practice across 12 weeks. These improvements showed that this inactive population could benefit from the stimulation of exergames. This finding is strengthened by the high levels of exercise adherence (97.50%) and the questionnaire reports that participants appreciated and would like to continue exergame activity. Graves et al. (2010) showed that Wii tasks generated more enjoyment than sedentary video-game or treadmill exercise in older adults. Our results underscore the potential of exergames in terms of accessibility and intrinsic attractiveness for older adults. Thus, interactive physical-activity video

Table 3
Comparison of Pretest-Posttest Change Scores on Physical Measures for Training and Control Groups

	Control		Training				
	M	*SD*	*M*	*SD*	*t*	*p*	η^2
Physical Measures							0.693
Max Heart Rate 6-Min Walk (bpm)	−4.07	10.15	10.50	15.92	−2.96	<0.01	0.227
Mean Heart Rate 6-Min Walk (bpm)	−3.80	11.62	7.43	13.52	−2.40	0.01	0.169
Chair Stands (Number)	−1.07	1.94	2.73	2.28	−4.91	<0.01	0.528
Arm Curls (Number)	0.00	2.73	3.00	2.70	−3.02	<0.01	0.262
6-Min Walk (Meters covered)	3.07	26.54	58.05	40.45	−4.40	<0.01	0.408
8-Foot Up and Go (sec)	0.48	1.05	−0.94	0.62	4.53	<0.01	0.424
Back Scratch “Lower Right” (cm)	2.00	5.80	−2.78	6.20	2.18	0.02	0.130
Back Scratch “Lower Left” (cm)	2.10	6.88	−2.22	6.27	1.80	0.04	0.107
Back Scratch “Upper Right” (cm)	−3.85	10.35	−0.50	5.33	−1.12	0.14	0.051
Back Scratch “Upper Left” (cm)	−9.40	18.04	0.25	3.90	−2.03	0.03	0.017
Perceived Exertion (Borg Scale)	0.67	1.11	0.64	1.82	.043	0.48	0.001

Note. *M* = Mean; *SD* = Standard Deviation; η^2 = Effect Size (Cohen, 1988). For heart rate, chair stand and arm curl, a positive mean corresponds to an improvement between pre- and posttest. For 8-Foot Up and Go, and Back Scratch, a negative mean corresponds to an improvement between pre- and posttest. All p values smaller than $p = .05$ remain significant after Bonferroni correction.

Table 4

Comparison of Pretest-Posttest Change Scores on Executive Function, Processing Speed, and Visuospatial Measures for Training and Control Groups

	Control		Training				
Tasks	*M*	*SD*	*M*	*SD*	*t*	*p*	η^2
Executive Function							0.805
Trail Making Test Part B − Part A (sec)	3.70	28.54	−15.42	20.27	−2.12	0.04	0.138
Stroop: Incongruent (Number)	0.60	4.05	9.13	8.80	−3.412	<0.01	0.294
Stroop: Task Switching (Number)	0.27	4.68	8.27	5.73	−4.189	<0.01	0.385
Letter Sets (Number)	0.07	1.03	1.87	1.85	−3.30	<0.01	0.279
Matrix Reasoning Test (Number)	−0.53	3.02	4.20	1.21	−5.636	<0.01	0.531
Digit-Symbol Substitution (Number)	0.20	5.65	9.07	7.97	−3.516	<0.01	0.306
Visuospatial							0.230
Spatial Span Test (Number)	−0.27	1.28	0.33	1.40	−1.226	0.12	0.051
Backwards Spatial Span Test (Number)	0.27	0.96	0.07	1.67	0.402	0.35	0.006
Direction Headings (Number)	−0.67	3.22	2.13	3.68	−2.217	0.02	0.149
Mental Rotation (Number)	−0.20	2.35	0.40	2.17	−.726	0.24	0.019
Processing Speed							0.788
Perceptual Speed							
Cancellation (Number)	−2.53	6.56	10.00	6.09	−5.423	<.01	0.512
Number Comparison (Number)	−0.73	2.02	2.87	2.72	−4.116	<.01	0.377
Psychomotor Speed							
Movement Time: Simple RT (ms)	21.59	64.55	−38.55	74.36	2.365	.03	0.166
Movement Time: Choice RT (ms)	21.84	57.16	−42.75	67.24	2.835	<.01	0.223
Decision Time: Simple RT (ms)	30.98	92.77	−103.07	92.57	3.962	<.01	0.359
Decision Time: Choice RT (ms)	−16.26	81.74	−104.15	74.28	3.082	<.01	0.253
Tapping (Right Hand, Number)	−0.53	3.75	7.00	6.81	−3.755	<.01	0.335
Tapping (Left Hand, Number)	−0.80	3.37	5.10	6.03	−3.306	<.01	0.281

Note. *M* = Mean; *SD* = Standard Deviation; η^2 = Effect Size (Cohen, 1988). For timed tests, a negative mean corresponds to an improvement between pre- and posttest. For scored tests (indicated by Number), a positive mean corresponds to an improvement between pre- and posttest. All *p* values smaller than $p = .05$ remain significant after Bonferroni correction.

games could be an enjoyable alternative to unmediated physical activity (e.g., Hughes et al., 2009; Schutzer & Graves, 2004).

The second hypothesis of this study was that interactive physical-activity video-game training was a mode of activity that could have cognitive benefits for older adults. First, we expected a range of practice-related improvements on cognition as previously found in programs of physical activity. In fact, the results demonstrated significant benefits of exergame training on executive control and processing speed tasks from before to after training. Out of six measures of executive functions, we found significant transfer of exergame training on all measures ($\eta^2 = 0.80$). Out of eight measures of processing speed, all measures showed significant improvement ($\eta^2 = 0.79$). This large beneficial effect of training on cognition is in line with findings of many empirical studies on aerobic exercise (e.g., Dustman et al., 1984; Hawkins, Kramer & Capaldi, 1992; Kramer et al., 1999). The results are also consistent with the meta-analytic review of Colcombe and Kramer (2003), which indicated a large effect of physical exercise on executive-function tasks ($ES = 0.68$). It has been argued executive-function tasks are particularly sensitive to the effects of aging (West, 1996). They also found positive but somewhat smaller effects of physical activity on processing-speed tasks ($ES = 0.27$).

Dustman and collaborators (1984, 1992) compared the cognitive benefits in older adults among several groups who had followed different training regimens (two of which were aerobic exercise and sedentary video-game playing). The aerobic-exercise training showed more transfer of training to executive control and processing speed than did video-game training. They hypothesized that the important difference between sedentary video-game playing and aerobic-fitness training may be the improvement in oxygen transport and utilization that results from aerobic fitness. Dustman and collaborators (1984, 1992) suggested that the increased availability of oxygen for cerebral metabolic activity may be responsible for the improved neurocognitive performance that occurs with fitness training. Consistent with this hypothesis, our results showed significant effects of training on physical status, and more particularly on cardio-respiratory fitness (e.g., 6MWT). Furthermore, the mean heart rate measured during exergame playing was 102.5 ± 7.9 beats/min, which corresponded to 41.5 ± 9.48% of the estimated heart-rate reserve (HRR). This level of HRR is within the American College of Sports Medicine's (ACSM, 2006) recommended "moderate" intensity range of 40–59% HRR (e.g., Howley, 2001). Therefore, we speculate that the improvements in cognitive performance with exergame training are in part due to the gains in cardiovascular fitness achieved through regular physical activity, which increased the ability of the heart to deliver oxygen to working muscle and which is indicative of an increase in cardiovascular fitness. So, in this view our results generated positive benefits on cognition in the same manner as physical activity programs. However, one limitation of this interpretation is that we are simply comparing our results with the existing empirical literature rather than including a conventional treatment group in our study which included only physical activity and not exergames. It would be necessary to carry out another intervention study that included a physical-activity training group in order to determine how much of the exergame benefits are due to the physical activity.

Although the exergame play engenders a significant increase of energy expenditure (e.g., Graves et al., 2010), a recent study on the cardiovascular and metabolic responses to Wii Fit video-game playing found differences among the Wii games in the HRR (Guderian et al., 2010). Moreover, although for many of our participants, HRR fell within the ACSM-recommended “moderate” intensity range, it is also true that for some participants, HRR were below that level. Thus the exercise intensity of Wii exergame playing may not be sufficient to explain the improvements on executive-control and processing-speed tasks. We speculate that some other aspects of the activity may also account for portions of the improvements we observed. Indeed, the intrinsic characteristics of exergames, such as motivation and arousal, task difficulty, or feedback (Green & Bavelier, 2008), may well be partly responsible for cognitive improvements as we will discuss below.

The positive benefits on executive-control and processing-speed performance that we have found with exergames training are also consistent with benefits previously reported with sedentary video-game training. Consistent with the results of Basak et al. (2008), in which training on a strategy-based game was found to improve executive function, we found evidence for transfer on executive-control tasks. Our results also showed a significant transfer of training to processing-speed tasks. Other studies using sedentary video games have reported a robust benefit specifically on psychomotor speed, especially reaction time (e.g., Clark et al., 1987; Drew & Waters, 1986; Dustman et al., 1992; Goldstein et al., 1997). Our participants showed improvement, not only for measures of psychomotor speed (e.g., tapping), but also for measures of perceptual speed (e.g., cancellation). Perceptual speed is the ability to rapidly and accurately search, compare, and identify elements presented side by side or separated in the visual field. To our knowledge, this is the first time that a positive effect on perceptual speed has been shown with video-game training in older adults.

Moreover, we speculate that, in addition to physical activity or video-game play, the wider transfer of exergame training that we observed may also be due to other aspects of this training. Our complex training regimen embodied a combination of aspects, including the variability of the tasks and the interactions with other players during the training sessions. The rich environment involved alternation between a wide range of motivating tasks that required several different modes of interaction and varying task difficulty. This training context required the player to alternate between tasks that varied in the priority placed on rapidity (such as the soccer headers game), accuracy (such as the bowling game), strategy (such as the marble game), cognitive judgment (such as the trampoline game) and more global combinations (such as the tennis game). This highly variable environment also engendered physical adjustment to the required activity, either using only the top part of the body, only the lower part of the body, or the whole body. The natural attractiveness of the activities and the motivation of individual feedback are other factors that could have aided in learning a new skill or improving and developing one (e.g., Herzog & Fahle, 1997). An important aspect of what subjects appear to have learned from this training was the ability to distribute their skills among multiple tasks with different processing priorities, and consequently develop the accommodation of their skills to different tasks.

Finally, there was no transfer of training on visuospatial measures. Our results are consistent with those of Basak et al. (2008), who also observed no significant training transfer in older adults on visuospatial tasks with a sedentary strategy game. This absence of transfer could be dependent on the specific types of video games used. Indeed, positive benefits have only been reported with video games that involve “action” even though they are sedentary, such as shooting galleries (Green & Bavelier, 2003, 2006). Games such as this share a set of qualitative features that may be important for transfer to visuospatial tasks, including extraordinary finger speed and a high degree of perceptual, cognitive, and motor load in the service of an accurate motor plan, unpredictability, and an emphasis on peripheral processing (Green & Bavelier, 2010). The games that we used in our study did not share these specific characteristics.

One limitation of our study was that we did not have a comparison group that played sedentary video games or one that engaged only in a social-participation or interpersonal-interaction program. Hence, we cannot distinguish conclusively between the physical-activity component, the cognitive content, and the social stimulation of the training regimen as the possible sources of improvement. Many studies have shown that social interaction may longitudinally protect against cognitive decline (e.g., Glei et al., 2005; Zunzunegui, Alvarado, Del Ser, & Otero, 2003). However, there is no evidence that social interaction produces immediate improvements in cognition. Future research should assess whether the exergames provided an additive effect of physical-activity and sedentary video gaming, or whether benefits of exergame training reflected an interactive effect of cognitive and physical demand. Clearly, this important direction might permit us to understand more accurately the real potential of this new mode of physical activity.

In summary, our study suggests that exergame training, which combines cognitive and physical demands in an intrinsically attractive activity, might be an effective way to promote physical and cognitive improvements among older adults. Indeed, one current health issue is to improve the level of physical activity of elderly adults, particularly those with sedentary lifestyle (American College of Sports Medicine, 2006). Thus, exergames could be an entree to vigorous physical exercise and a complement to the conventional physical activity for sedentary older adults. It was encouraging to observe, in physically simulated sport games, transfer benefits to cognitive and physical skills that are directly involved in functional abilities that older adults need in everyday living (e.g., Tomaszewski et al., 2009). Indeed, previous studies have demonstrated relationships between neuropsychological performance and everyday function in older adults (e.g., Royall, Palmer, Chiodo, & Polk, 2004). Several attributes of exergames make them promising for widespread adoption. First, exergame play can be home-based, mitigating against environmental barriers to exercise. Second, the games allow for choice among activities, which could lead to sustained play and foster autonomy, and thus result in a personalized intervention for people with diverse physical abilities. Finally, the games are fun and affordable.

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