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Can Training in a Real-Time Strategy Video Game Attenuate Cognitive Decline in Older Adults?

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Declines in various cognitive abilities, particularly executive control functions, are observed in older adults. An important goal of cognitive training is to slow or reverse these age-related declines. However, opinion is divided in the literature regarding whether cognitive training can engender transfer to a variety of cognitive skills in older adults. In the current study, the authors trained older adults in a real-time strategy video game for 23.5 hr in an effort to improve their executive functions. A battery of cognitive tasks, including tasks of executive control and visuospatial skills, were assessed before, during, and after video-game training. The trainees improved significantly in the measures of game performance. They also improved significantly more than the control participants in executive control functions, such as task switching, working memory, visual short-term memory, and reasoning. Individual differences in changes in game performance were correlated with improvements in task switching. The study has implications for the enhancement of executive control processes of older adults.

Keywords: cognitive training, aging, executive control, video game, transfer of training

Age-related declines in fluid abilities have been observed on a variety of cognitive tasks (Hedden & Gabrieli, 2004; Nilsson, 2003; Salthouse, 2003a). Some of these abilities for which age-related differences are observed include (to name a few) processing speed (Schaie, 1996), episodic memory (Nilsson, 2003; Salthouse, 2003a), working memory (Bopp & Verhaeghen, 2005), spatial orientation or mental rotation (Schaie, 1996; Sliwinski & Hall, 1998), reasoning (Schaie, 1996) and dual-task processing (Verhaeghen, Steitz, Sliwinski, & Cerella, 2003). One theoretical position is that because this age-related decline is quite widespread, it may be due to general slowing (Lindenberger & Baltes, 1994, 1997; Salthouse, 2003b). Another position treats general slowing as a null hypothesis because research suggests that this single factor slowing hypothesis may be an oversimplified explanation of the observed phenomenon. Because many of the declines are in tasks that involve executive control processes, it is plausible that there are limited, finite aspects of executive control that may be responsible for such age-related declines (Braver & Barch, 2002). Although age-related declines are observed in various cognitive abilities, some abilities appear to be relatively spared with age. Meta-analyses of different cognitive processes have shown that no specific age-related difference exists in selective attention (Stroop, negative priming) or local task switching (Verhaeghen & Cerella, 2002). Some types of memory, such as procedural memory (Fleischman et al., 2004) and short-term memory (Nilsson, 2003), do not display much decline with age; vocabulary (Schaie, 1996; Verhaeghen, 2003) and numeric ability (Schaie, 1996) are also relatively spared. In sum, the abilities that show greatest impairment with age, particularly after 60 years, are those associated with executive control processes or cognitive control, in which goal-directed behaviors have to be flexibly maintained, monitored, and implemented in face of changing memory loads, distractions, task sets, and other possibilities. In fact, further support of the above claim is evidenced by age-related declines in selective brain areas, such as frontal lobe, that are considered to subserve, in part, executive control processes (Braver & Barch, 2002; Raz, 2000).

Research on cognitive training (Advanced Cognitive Training for Independent and Vital Elderly [ACTIVE]) in older adults by Ball and colleagues (Ball et al., 2002) has found that if specific cognitive skills are trained separately—such as memory, attention, and problem solving—trainees improve in the particular skill on which they are trained. Yet, there is no transfer of training to the other two untrained cognitive skills, particularly reasoning or memory.[1] Recently, the ACTIVE study group (Willis et al., 2006) found that training in reasoning transfers to self-reported instrumental activities of daily living. This transfer of training is not observed in speed of processing or memory training.

Instead of training older adults on individual tasks or processes, research has found that transfer to executive control functions, and particularly multitasking, are observed if the training paradigm is

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[1] For an exception, see Willis et al. (2006), in which booster training on speed of processing improved performance on everyday speed of processing, but processing speed was not considered to be an executive control process.

variable or flexible (Bherer et al., 2005; Kramer, Larish, & Strayer, 1995; Kramer, Larish, Weber, & Bardell, 1999) or integrated (Craik et al., 2007; Winocur et al., 2007). Kramer and colleagues (Bherer et al., 2005; Erickson et al., 2007; Kramer et al., 1995; Kramer et al., 1999) have found that variable priority training of attentional control can improve performance on dual tasks and transfer to untrained dual-task conditions. Variable priority training entails the requirement to rapidly shift priorities among concurrently performed tasks or task components along with the provision of individualized adaptive performance feedback. In a recent study, Winocur, Craik, and their colleagues (Craik et al., 2007; Winocur et al., 2007) have found improvements in executive control functions such as memory and problem solving if older adults are trained on multiple tasks and processes, such as memory, goal management, and psychosocial skills.

Another training paradigm that is variable or flexible and integrated is video game training. Research with older adults on first-generation video games has shown improvements in game performance but limited transfer of training. For example, Goldstein et al. (1997) found that older adults trained for 25 hr in Super Tetris improved more than nongamers in the Sternberg reaction time task, but not in the Stroop Color Word Test (a measure of inhibition, an executive control process). Typically, training in these relatively simple first-generation arcade-type video games (such as Pac-Man, Donkey Kong, Super Tetris) seems to enhance performance in response time (RT), but not in processes of executive control, such as that measured by Stroop, Trails-B or working memory paradigms (Clark, Lanphear, & Riddick, 1987; Dustman, Emmerson, Steinhaus, Shearer, & Dustman, 1992; Goldstein et al., 1997). But video games, such as Medal of Honor and Space Fortress, are more complex and variable in nature, and integrate many perceptual and cognitive skills. Research on younger adults has shown that training on complex video games, and more specifically games referred to as first-person shooters that stress rapid responding to fast-paced display changes, not only transfers to a wide variety of perceptual and attentional skills such as useful field of view, attentional blink, multiple-object tracking, and subitizing (Green & Bavelier, 2006, 2003), but also to real-world complex skills such as flight performance (Gopher, Weil, & Bareket, 1994).

Our main interest in the present study was to examine whether training in a complex real-time strategy game, which provides individualized feedback and requires frequent shifts in component task priority, would show transfer to executive control and memory processes of older adults. To examine this issue, we adopted an off-the-shelf game called Rise of Nations*:* Gold Edition (RON) developed by Big Huge Games and published by Microsoft Game Studios in 2004. RON is a real-time strategy game that combines both the speed of real-time gaming and the complexity of turn-based strategy games. In RON, one has to build new cities, improve city infrastructure, and expand one's national border. One of the important aspects of this game is that it allows for multiple ways to achieve victory. That is, the player may either win the game by conquering the neighboring nation through military conquests and gaining control over a certain percent of the world map, or he or she can gain prowess by opting for nonmilitary and quasi-military strategies, such as building a certain number of wonders. These strategies can include establishing diplomacy, technology races, building wonders, expanding territories, and espionage. Moreover, this game allows the player to either see the whole map, or parts of map, or zoom into a particular city to see a group of citizens or military unit at work. To expand new territory, one can build scouts that explore the unknown regions of the map and in the process expose enemy territories. In this game, the player has to continually assess his or her available resources, plan and expend those resources, monitor his or her expanding territories and multiple cities, and introduce methods to generate revenues and improve technology.

Previous research (Green & Bavelier, 2003, 2006) found that Medal of Honor, a first-person shooter game, improves a number of visual and attentional abilities in younger adults. It is plausible that because it is a strategy-based video game, RON may improve performance in tests of executive control (switching between various goals such as protecting one city from enemy assault, improving technology, and increasing trade in another city; maintaining multiple items in working memory such as how many cities have been built). If so, this would have important implications for training cognitive abilities of older adults. Therefore, the present study was designed to examine two main hypotheses. One, training on RON would improve performance in a wide-range of executive control tasks, such as task-switching, inhibition, working memory, and short-term memory. Second, unlike Medal of Honor, RON is not a first-person shooter action video game; hence, it may not improve basic visuospatial attentional abilities, such as selective and focused attention. That is, we predicted broad transfer to the skills and cognitive processes exercised in the game—executive control and memory processes—but lesser transfer effects to speeded visuoperceptual processes that are emphasized more in real-time strategy than in first-person shooter games.

Method

Participants

Potential participants were contacted through flyers posted in campus buildings and local businesses, study notices published in local newspapers, and through advertisements posted to online bulletin boards. People responding to these flyers and advertisements completed a survey of their video game habits. We included only those individuals who reported playing video games 0 hr/week for the past 2 years.

Forty older adults from the Urbana-Champaign, Illinois, community participated in the study. All participants were right-handed and demonstrated normal visual acuity (20/30, if required, with corrective lenses) and normal color vision as assessed with the Ishihara Test Chart Book, for Color Deficiency (1989), which tests for both red-green deficiencies and total color blindness. The ratio of male versus female participants was matched between the training and control groups. Twenty novice video game players were randomly assigned to the training condition of a real-time strategy video game, RON, and 20 participants were assigned to a no-training no-contact control group. Out of the 20 videogame players, 1 player missed an entire session of cognitive tests, leaving 19 players' data to analyze. Demographics for each group are listed in Table 1. There was no significant difference between the two groups in terms of age, years of education, and score on the modified Mini-Mental Status Examination (Stern, Sano, Paulsen, & Mayeux, 1987).

Table 1
Demographic Information for Participants in Each Group

Training group	Age	Years of education	Male/Female	mMMSE scores
All participants				
CONTROL (n = 20)	69.10 (6.06)	16.88 (3.18)	5/15	55.65 (1.39)
RON (n = 19)	70.05 (4.94)	15.42 (3.49)	5/14	55.68 (1.80)
Participants who completed all tasks of executive control for Session 1 and Session 3				
CONTROL (n = 16)	68.88 (5.92)	16.41 (2.86)	5/11	55.81 (1.17)
RON (n = 18)	69.89 (5.03)	15.44 (3.58)	5/13	55.71 (1.53)

Note. Standard deviations are in parentheses. mMMSE = modified Mini-Mental State Examination (Stern, Sano, Paulsen, & Mayeux, 1987); CONTROL = the control group; RON = the Rise of Nations group.

Apparatus

Four Pentium 4–based personal computers (PCs) were used for the majority of cognitive testing and all of the game training. These computers were attached to 21-inch monitors. Additionally, one eMAC with a 17-inch monitor was used for two of the cognitive assessment tasks. For all testing and training, seating was adjusted so that participants were approximately 57 cm from the monitor. All PC-based tasks were programmed with the E-prime software package (Schneider, Eschman, & Zuccolotto, 2002). All Mac tasks were programmed with the Vision Shell software (Comtois, 2003).

Training Schedule

For each participant, the entire study spanned 7 to 8 weeks in our laboratory; this included the sessions for the cognitive battery and, for the training group, the training sessions. Participants completed a battery of cognitive tests three times: pre (1st week of the study), during (4th week from when the study started) and post (7th or 8th week). Each time, this cognitive battery was administered within 1 week over 3 consecutive days, each day with a 2-hr session. The 10 assessment tasks from two cognitive domains, 6 tests of executive control functions and 4 tests of visuospatial attention, were alternated in the following fixed order for any cognitive testing session: On the 1st day, performance of the functional field of view, task switching, and attentional blink tasks were assessed; on the 2nd day, performance of operation span, enumeration, *N*-back task, and stopping tasks were assessed; on the 3rd day, performance of visual short-term memory (VSTM), mental rotation, and Raven's Advanced Progressive Matrices (Raven, 1990) tasks were assessed. Participants completed fifteen 1.5-hr training sessions in the laboratory over a period of 4 to 5 weeks, resulting in a total training time of 23.5 hr. The participants started the training by completing a game tutorial in their first session.

At the end of each session, game progress was saved, and participants began the next session at this point. If within a session, the participant completed the game they were playing, the results of the game were saved, and the next game was started. Participants played "Quick Battle" scenarios, a type of solo game in RON. The game settings and the sequencing of the games were preset by the experimenter and constant across all participants. Difficulty level was set to "easiest." Human and computer nationalities were varied by the experimenter, as were world locations. These option changes followed a set schedule that all participants followed. All other game options were left at the default setting. The default strategy mode of RON "Quick Battle" games is "Survival of the Fittest," in which no collaboration is allowed between nations. A scenario was completed when participants reached one of the game criteria for winning. These criteria were controlling 70% of the land, destroying all other civilizations, or building a majority of the "Wonders of the World."

Game performance was recorded for each participant. At the end of each game, RON provides a measure of the time taken to complete the game, whether the game was won or lost, and a number of other statistics pertaining to the strategies used in the game, such as points awarded for wonders,[2] player speed (assessed by the number of times per minute a player clicked the mouse button or used a *hotkey*, i.e., keyboard shortcut), total game score, etc. After the end of the training sessions and the last session of cognitive tests, we invited the participants to repeat the first scenario or mission that they completed at the beginning of training; this would provide a more direct measure of the degree of improvement in the game performance. Seventeen of the 20 participants returned to play the game for this additional session. This session was played a day after the end of cognitive testing. No participant reported playing any other video game during the training.

The Cognitive Battery

The battery included a number of tasks that were completed in a fixed order, with each task taking 8–30 min to complete. Tasks fell into two general categories: executive control tasks and visuospatial attentional tasks. Three of the visuospatial tasks included in the battery (functional field of view, attentional blink, and enumeration) were similar to those used to assess transfer from training with young adults from Medal of Honor (Green & Bavelier, 2003). All tasks are described below. The total number of trials in any task refers to any single session.

[2] Wonders score is assessed by 33% of the total resource value of all the wonders the player made or controlled (if he or she took over his or her opponent's wonders). According to the RON manual, there are 14 wonders; these wonders represent great works of art, technology, and architecture. Each wonder requires substantial investment of resources to construct, and each wonder built gives a certain strategic advantage. For example, Hanging Gardens increases knowledge production and provides a discount to economic enhancer technologies; Red Fort allows the player to receive Fort upgrades for free, all forts in the player's nation have increased points, and units garrisoned in the Red Fort heal faster. In short, wonders indicate a sign of advanced civilization.

Executive Control Tasks

Operation span. Participants solved math problems (e.g., IS (9/1) + 2 = 9?) while simultaneously trying to remember sets of 3–6 words (this task is similar to Turner & Engle, 1989). After each set of 3–6 words, participants were asked to recall the words in the set in the order in which they were initially presented. Because this test was administered three times, three versions of the test were used. The primary measure of this task was accuracy of recall of word sets in the correct order.

Task switching. Participants completed a task that required them to switch between judging whether a number (1, 2, 3, 4, 6, 7, 8, or 9) was odd or even and judging whether it was low or high (i.e., smaller or larger than 5). Numbers were presented individually for 1,500 ms against a pink or blue background at the center of the screen, with the constraint that the same number did not appear twice in succession. If the background was blue, participants used one hand to report as quickly as possible whether the letter was high (the *X* key) or low (the *Z* key). If the background was pink, participants used their other hand to report as quickly as possible whether the number was odd (the *N* key) or even (the *M* key). Participants completed four single task blocks (2 blocks of odd–even and 2 blocks of high–low) of 30 trials each. They then completed a practice dual-task block in which they switched from one task to the other every five trials for 30 trials. Finally, they completed a dual-task block of 160 trials, during which the task for each trial was chosen randomly. This task is similar to that of Kramer, Hahn, and Gopher (1999) and Pashler (2000).

The primary measure in this task is switch cost during the dual-task blocks: the difference in performance for trials when the preceding trial involved the same task (nonswitch trial) and those when the preceding trial was of the other task (switch trial). Switch costs were calculated by subtracting the RT for nonswitch trials from the RT for switch trials.

N-Back task. Participants viewed displays in which letters appeared one at a time at different spatial locations and in upper- or lowercase. He or she pressed one key if the letter was same (regardless of the location and case) to the letter presented *n* items back and a different key if it was different. There were blocks of 1-back, in which the participant had to compare the current letter with the one just before it, and 2-back, in which the participant had to compare the current letter with the letter presented two items before. Each letter appeared for 500 ms with an interstimulus interval of 2,000 ms. On 75% of trials, the letter identity was different than the location of the item presented *n* items back, and on 25% of trials the identity was the same. Both speed and accuracy were stressed, and participants completed 200 trials. In 1-back trials, the participant had to maintain only one register in working memory, whereas in 2-back trials, the participant had to maintain two registers simultaneously in working memory and switch back and forth between these two registers. *Focus (or object) switch cost*, a measure of switching in and out of focus of attention in the working memory (Verhaeghen & Basak, 2005) as well as a measure of working memory load, can be calculated by subtracting the average RTs of 1-back from those of the 2-back trials. This focus switch cost can also be thought of as the cost of maintaining two simultaneous memory loads versus one, and this memory load cost is the primary measure of this task.

VSTM. Participants viewed displays containing colored lines (red, green, blue, pink, and black) at different orientations (vertical, horizontal, tilted to the left, or tilted to the right). Each line measured 0.2° × 1.6° and had a center-to-center distance of at least 3.5°. Participants first viewed a display containing two or four lines for 100 ms. This memory display was followed by a blank screen for 900 ms and then a test display. On half of all trials, one item in the test display either changed color or orientation compared with the memory display, and participants indicated whether or not anything changed. This task is similar to that of Luck & Vogel (1997). Participants completed 16 practice trials and 96 test trials. The primary measure, accuracy of change detection for Set Sizes 2 and 4, was emphasized over speed. According to Cowan (1995), capacity limits of working memory is about four items, so for subsequent analyses, we considered data of only Set Size 4, because this capacity limit may be most sensitive to training effects, unlike Set Size 2, in which change detection is highly accurate.

Raven's Advanced Progressive Matrices. Participants completed a version of the Raven's Advanced Progressive Matrices. This test involved presenting participants with a complex visual pattern with a piece cut out of it. The task of the participant was to find the missing piece that completed the pattern. The full version of the Raven's was divided into three subtests of approximately equal difficulty, with each test containing 12 items. During the first testing battery participants were given 5 min to complete a practice version of the test before the first actual test. Participants were given 20 min to complete each 12-item test, once at the beginning of the study, once in the middle, and once at the end of the study. The primary measure for this task was the proportion of items correctly completed compared with the items attempted.

Stopping task. Inhibition was measured using a stopping task. Participants were asked to respond to an *X* or an *O* as quickly as possible as soon as it appeared on screen. On 25% of trials, a tone occurred shortly after the appearance of the *X* or *O*, and participants were asked to inhibit their response when they heard this tone (stop trials). On the other 75% of trials, no tone occurred and participants were required to respond as quickly as possible by pressing one of two keys (go trials). For stop trials, the tone was initially set to play 250 ms after the appearance of the letter. If participants successfully inhibited their response when the tone occurred, the delay between the letter and the tone was increased by 50 ms, making it harder for participants to inhibit their response in time the next time the tone occurred. If participants were unsuccessful in inhibiting their response, the delay between the letter and the tone was decreased, making it easier for participants to inhibit their response. The delay between the letter and tone was adjusted in this manner after each stop trial to find the delay at which participants were as likely to make a response as to withhold a response. Assuming that responses are determined by a go signal and a stop signal reaching a response decision stage, with the first signal being executed, this would indicate a tie between the two signals. A *stop reaction time*, a measure of inhibitory control and primary measure for this task, was calculated by subtracting the average delay between the letter and the tone from the average reaction time on go trials (Logan, Schachar, & Tannock, 1997). Participants completed 224 trials during each of there administrations of the task.

Visuospatial Attentional Tasks

Functional field of view. Participants searched for a white triangle within a circle (4.3° diameter) among square distracters (4.3° × 4.3°) in a briefly presented (12 ms) display (see Green and Bavelier, 2003). Search items were arrayed in eight radial arms, and targets occurred with equal probability on each arm at eccentricities of 10°, 20°, or 30° from fixation. The search display was followed by a bright, colorful pattern mask (100 ms). After this mask, a response screen containing lines representing the radial arms of the search display appeared, and participants were instructed to click the arm that had the target. After one block of practice trials (24 trials), participants completed 120 test trials. The primary dependant variable for this task is accuracy of target detection.

Attentional Blink. As in Green and Bavelier (2003), participants viewed a rapid sequence of letters (approximately 1° high) on a gray background at the center of the screen and reported two things about each letter sequence: (a) the identity of the one white letter in the sequence of black letters and (b) whether or not an *X* was present sometime after the white letter (50% of trials). Each letter appeared for 12 ms, followed by an 84-ms blank interval before the next letter. The sequence varied in length from 16 to 22 letters, with the white letter appearing unpredictably after either the 7th, 10th, or 13th letter. This task is similar to that of Raymond, Shapiro, & Arnell (1992). The primary measure for this task is accuracy of detection of *X*, given that the first target was detected correctly. In this task, participants often fail to report the *X* when it appears approximately three items after the first target. Green and Bavelier (2003) found improved detection of the *X* following video game training, with the largest training advantage when the *X* occurred three, four, five, or six letters after the first target, so we used these lags between the white letter and the *X* (with an equal number of trials for each). Participants completed 15 practice trials and 144 test trials.

Enumeration. Participants viewed briefly presented arrays of 1–8 dots (.25° diameter) and indicated how many dots appeared. Dots were randomly positioned in a 7 × 7 matrix (7° × 7°), with the exception that no dot could appear at the center location. Each trial started with a fixation point at the center of the screen (900 ms), followed by a blank screen (600 ms), and then by the test array (50 ms). Participants entered the number of dots that appeared using the number keys at the top of the keyboard, after which the next trial began. Participants completed 32 practice trials followed by 160 test trials. The primary measure for this task was accuracy of detection of the numerosity of the dots on the screen.

Mental rotation. Participants tried to determine whether two simultaneously presented shapes were the same or different (see Cooper & Shepard, 1973). They responded as quickly and as accurately as possible by pressing one of two keys. The shape on the right was either the same shape or a mirror image of the shape on the left, and the two shapes differed in orientation by 0°, 45°, 90°, 135°, 180°, 225°, 270°, or 315°. These shapes were based on those appearing in Tetris. Each measured approximately 2.4° × 2.4° and was presented 3° from the center of the screen. Two shapes (the *Z* and the backwards *Z* shape) only appeared at orientations of 0°, 45°, 90°, and 135° because any further rotation would cause the shape to rotate into itself. All other shapes could appear equally often at each rotation from 0° to 315°. Participants completed 30 practice trials followed 128 test trials. The primary measures in this task are the speed and accuracy of performance as a function of the extent of rotation required by the display.

Results

The main question examined in our study is whether training with a real-time strategy video game improves executive control skills of older adults. This question was tested by examining whether training group (control group or RON group) interacted with testing session (Session 1, Session 2, and Session 3) with regard to performance on the tasks in the cognitive assessment battery. To reduce the influence of within-subject outliers, we analyzed median rather than mean RTs. Practice blocks were not included in any of the analyses. Analyses were conducted using SAS (Version 9.1) and SPSS (Version 11.5). To evaluate the treatment effect, effect size index was calculated from η^2 for the instrument.

Game Performance

Before analyzing the effects of video game training on performance of the cognitive battery tasks, we first examined whether training led to an improvement on the trained game. Performance on the first game played was compared with the last game played. Moreover, 17 of 20 participants replayed their first game at the end of the training session; these 17 participants are referred to as the reduced dataset. The results of the entire dataset (all participants) as well as the reduced dataset were similar. Therefore, only the results from the entire dataset are reported.

The overall time spent on the game was significantly reduced, $t(19) = 2.81$, $p = .011$, from 250.41 s ($SD = 211.09$) to 111.86 s ($SD = 58.26$) pre- and post-training, respectively. Also, following training, the players significantly increased the score related to the number of wonders built, $t(19) = 3.83$, $p < .01$, from 878.9 ($SD = 589.73$) to 1418.10 ($SD = 448.44$) points pre-and post-training, respectively, as well as the score associated with the speed with which game was played, $t(19) = 4.28$, $p < .01$, from 9.85 ($SD = 7.16$) to 14.25 ($SD = 8.03$) points pre- and post-training, respectively.

Training Effects on Cognitive Battery: Executive Control Tasks

Table 2 presents group means and standard deviations of all cognitive tests in the assessment battery, including their primary and ancillary measures, across the three cognitive testing sessions for the training and control groups. A multivariate analysis of covariance (MANCOVA) was conducted to determine the effects of training (video game training, control) on the primary measures of executive control functions. For VSTM task, only Set Size 4 was considered. For this analysis, the difference in post- (Session 3) and pre- (Session 1) performance was considered. Because some participants in each group failed to complete either the pre- or post-training sessions for all tests of executive control functions, the demographic information of these individuals are different from that of the whole dataset (see Table 1). Although the two groups did not significantly differ in age, education, and modified Mini-Mental Status Examination scores, control participants were on average a year more educated and a year younger than the gamers. Therefore, age and education were included as covariates

Table 2
Means (and Standard Deviations) for All Cognitive Measures at the Three Assessment Sessions

Task	Session 1		Session 2		Session 3	
	CONTROL	RON	CONTROL	RON	CONTROL	RON
Executive control tasks						
Operation span ($n_c = 19$, $n_{vg} = 18$)	13.00 (6.55)	14.16 (8.15)	13.10 (6.21)	15.42 (8.92)	16.00 (9.56)	15.68 (11.01)
Task switching ($n_c = 18$, $n_{vg} = 18$)						
Switch cost	283.52 (100.60)	298.48 (111.94)	267.23 (95.39)	240.37 (83.83)	275.95 (90.37)	190.14 (77.13)
Nonswitch RT	761.25 (102.02)	755.82 (106.75)	718.02 (104.64)	769.01 (115.32)	726.18 (112.85)	753.14 (110.73)
Accuracy	.89 (.13)	.88 (.12)	.92 (.13)	.96 (.07)	.92 (.16)	.96 (.06)
N-Back task ($n_c = 18$, $n_{vg} = 19$)						
Memory load cost	237.83 (120.12)	251.80 (130.00)	244.92 (137.42)	194.60 (153.56)	265.42 (136.96)	146.02 (153.84)
1-back RT	847.27 (158.87)	842.66 (153.12)	779.06 (159.54)	837.24 (134.80)	797.37 (198.02)	842.56 (114.05)
1-back accuracy	.95 (.04)	.95 (.04)	.96 (.05)	.95 (.04)	.96 (.04)	.95 (.07)
2-back accuracy	.86 (.10)	.89 (.05)	.84 (.10)	.85 (.08)	.88 (.07)	.87 (.07)
VSTM ($n_c = 20$, $n_{vg} = 19$)	.83 (.06)	.82 (.05)	.83 (.06)	.82 (.06)	.83 (.06)	.84 (.07)
Raven's Adv. Mat. ($n_c = 19$, $n_{vg} = 19$)	.47 (.22)	.44 (.22)	.47 (.17)	.51 (.19)	.47 (.22)	.59 (.22)
Stopping task						
Stop RT	179.79 (41.72)	230.03 (90.45)	188.83 (52.99)	195.54 (75.14)	181.53 (41.86)	197.92 (63.89)
Go RT	688.75 (205.69)	720.57 (266.64)	667.43 (228.60)	691.30 (201.74)	706.26 (250.29)	659.34 (165.01)
Stop probability	.54 (.03)	.57 (.04)	.53 (.10)	.55 (.05)	.50 (.05)	.52 (.05)
Visuospatial attentional tasks						
FFOV, across degrees	.23 (.13)	.29 (.14)	.29 (.17)	.31 (.17)	.34 (.16)	.36 (.20)
Attentional blink, across lags	.54 (.34)	.49 (.33)	.68 (.27)	.55 (.34)	.61 (.35)	.55 (.34)
Enumeration, across numbers	.82 (.11)	.80 (.09)	.82 (.12)	.84 (.07)	.83 (.11)	.82 (.07)
Mental rotation, across degrees						
RT (ms)	2227 (1007)	2579 (993)	2293 (820)	2384 (736)	2255 (699)	2232 (629)
Accuracy	0.85 (.09)	0.84 (.13)	0.87 (.10)	0.91 (.09)	0.90 (.11)	0.95 (.04)

Note. Number of participants in any task for CONTROL and RON groups are denoted by n_c and n_{vg}, respectively. CONTROL = the control group; RON = the Rise of Nations groups; RT = response time; VSTM = visual short-term memory; Raven's Adv. Mat. = Raven's Advanced Progressive Matrices (Raven, 1990); FFOV = functional field of view.

in the MANCOVA. Although age was not significant, Wilks's $\Lambda = 0.865$, $F < 1$, and education was marginally significant, Wilks's $\Lambda = 0.584$, $F(6, 25) = 2.28$, $p = .069$, $\eta^2 = .42$, the effect of group was significant, Wilks's $\Lambda = 0.584$, $F(6, 25) = 2.97$, $p = .025$, $\eta^2 = .42$. Therefore, this analysis was followed by repeated measures analyses of variance (ANOVAs) across all three testing sessions on each of the executive control tasks separately. Participants were removed if their performance was outside the range of 2.5 times standard deviations from the means.[3]

Operation Span

The primary measure in this task was the number of correctly recalled words in the right order on each test (see Table 2 for data from all cognitive tests). Overall, performance did not improve across testing sessions, $F(2, 70) = 1.84$, $p = .17$, $\eta^2 = .05$, and it did not differ across the training and control groups ($F < 1$). It is important that the training group did not interact with testing session ($F < 1$), suggesting no effect of video game training.

Task Switching

It was clear from error rates that 2 participants in the control group confused the response mappings during the first administration of the task, as indicated by the near chance performance (50% accuracy). Data from these participants were excluded. There was failure to collect data from 1 participant in the RON group in Session 2 on some of the tasks because of experimenter or computer error.

If video game training is beneficial, the primary measure of this task, switch costs, should decrease more for participants trained on video games; such a trend is seen in Figure 1a. Regarding switch costs, there was no main effect of group, $F(1, 34) = 2.09$, $p = .16$, $\eta^2 = .06$. It is important that switch costs diminished with repeated testing, $F(2, 68) = 4.88$, $p = .01$, $\eta^2 = .13$, and this decrease was larger for the RON group than for the control group, $F(2, 68) = 3.63$, $p = .03$, $\eta^2 = .10$. Difference contrasts suggest that the interaction

[3] As a result of this statistical criterion, 2 participants (1 from each group) from the full sample were excluded in the operation span task, 1 participant from the control group was excluded in the *N*-back task, 1 participant from the control group in Raven's Advanced Progressive Matrices task, and 1 participant each from the two groups in stopping task. Because of a computer error, game scores were lost for 1 participant from the control group from the *N*-back task, for 1 participant in the training group for the VSTM task, for Session 3 for 2 participants from each group in the useful field of view task, for 2 participants in the control group and 1 participant in the training group in either Session 2 or Session 3 in the attentional blink task, and for 2 participants in the training group in Session 2 for mental rotation task.

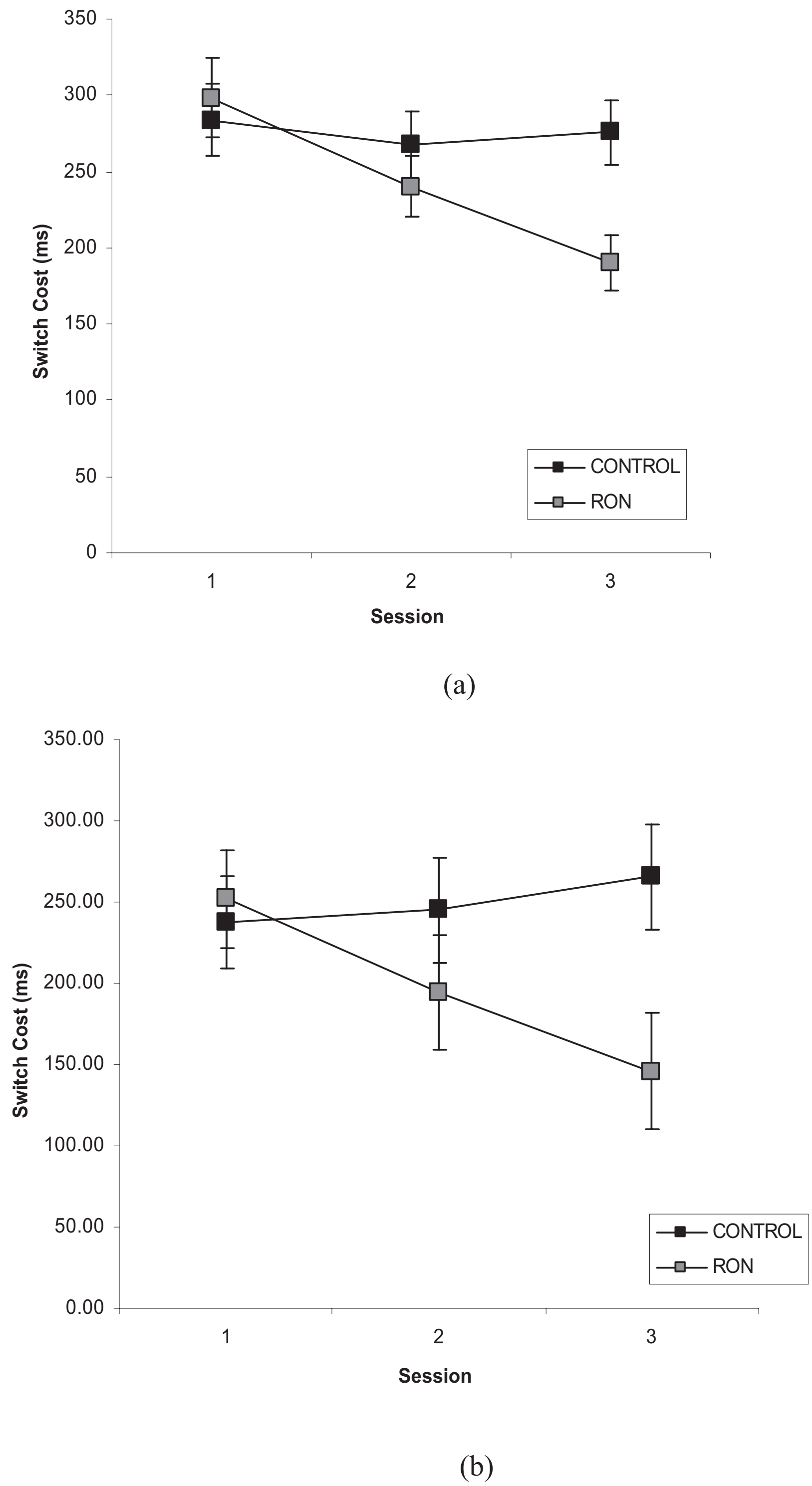

Figure 1. Average task switch cost in the task-switching paradigm (a) and focus switch cost in the *N*-back task (b) as a function of testing session for the two groups. Error bars represent plus and minus 1 standard error. CONTROL = control group; RON = the Rise of Nations group.

between groups and session is not significant between Sessions 1 and 2, $F(1, 34) = 1.11$, $p = .30$, $\eta^2 = .03$, but is significant between Sessions 2 and 3, $F(1, 34) = 6.78$, $p = .01$, $\eta^2 = .17$. Therefore, video game training had a beneficial effect on the ability to quickly switch between two tasks, particularly after 23.5 hr of training.

To assess whether the training benefits on switch costs are the result of group differences in baseline scores, we analyzed the nonswitch RTs as a function of testing session. Unlike switch costs, nonswitch RTs did not decrease with repeated testing, $F(2, 68) = 1.29$, $p = .28$, $\eta^2 = .04$, and they did not interact with group, $F(2, 68) = 2.60$, $p = .08$, $\eta^2 = .07$.

Accuracy increased over repeated testing. This trend was significant as there was a marginal effect of testing session, $F(2, 68) = 3.16$, $p = .05$, $\eta^2 = .09$. There was no main effect of group, $F(1, 34) = 0.70$, $p = .41$, $\eta^2 = .02$, nor did group interact with testing session, $F(2,68) = 0.67$, $p = .51$, $\eta^2 = .02$. Thus, video game training had a beneficial effect on the switch costs, but not on nonswitch RTs or accuracy of task-switching paradigm.

N-Back Task

The primary measure for this task is the focus switch cost, or memory load cost, that is measured by the difference in latency in the 2-back trials and 1-back trials. Data for memory load cost [RT (2-back) – RT (1-back)] suggest that the RON group got faster at maintaining two registers versus one register in working memory with repeated testing, whereas the control group did not (see Figure 1b). To test whether there was an interaction between the training group and testing session, switch costs were submitted to a 2 (training groups) × 3 (testing sessions) repeated measures ANOVA with difference contrasts. There was no main effect of group, $F(1, 35) = 2.07$, $p = .16$, $\eta^2 = .06$, and no effect of testing session, $F(2, 70) = 1.31$, $p = .128$, $\eta^2 = .04$. But it is important that there was significant Group × Testing Session interaction, $F(2, 70) = 3.71$, $p = .03$, $\eta^2 = .10$. Difference contrasts for the Group × Testing Session interaction suggests that although there is no significant difference between the two groups at Session 2 versus Session 1, $F(1, 35) = 1.79$, $p = .19$, $\eta^2 = .05$, memory load cost decreased more for the RON group than for the control group at Session 3 versus Session 2, $F(1, 36) = 5.49$, $p = .02$, $\eta^2 = .14$. Video game training benefited the maintaining and coordinating of two registers in working memory compared with one register, especially between 11 and 23.5 hr of training.

To assess whether this training benefit is the result of baseline differences between groups, we analyzed the RTs of 1-back trials as a function of testing session. Similar to RTs of nonswitch trials in task switching, the RTs of the control group seemed to decline more rapidly than the RON group, but this difference was not significant in either of the two tasks. These RTs did not decrease with repeated testing, $F(2, 70) = 1.79$, $p = .17$, $\eta^2 = .05$, nor did they interact with group, $F(2, 70) = 1.39$, $p = .25$, $\eta^2 = .04$.

Accuracy data was submitted to a 2 (training group) × 2 (*N*-back: 1-back, 2-back) × 3 (testing session). Accuracy in 1-back task was better than 2-back task, $F(1, 70) = 68.99$, $p < .001$, $\eta^2 = .66$, and accuracy increased with repeated testing, $F(2, 70) = 3.29$, $p = .04$, $\eta^2 = .09$. But there was no interaction between group and session, $F(2, 70) = 1.59$, $p = .21$, $\eta^2 = .04$. Over time, performance change in accuracy was larger for 2-back task than for 1-back task, $F(2, 70) = 5.29$, $p < .01$, $\eta^2 = .13$, but this pattern did not significantly differ between the two groups ($F < 1$). In general, video game training improved switching between items in working memory between 11 and 23.5 hr of training, but it had no effect on the accuracy of the *N*-back task.

VSTM

The primary measure in this task is the accuracy of change detection. If the magical number of the capacity of focus of attention inside the short-term memory is indeed four (Cowan, 1995) when items are presented simultaneously, then it is possible that video game training is most beneficial for items inside the focus of attention—items that are immediately accessible, that is, Set Sizes 2 and 4. In fact, we hypothesized that benefits of transfer of training on VSTM, if any, would be more for Set Size 4 than Set Size 2 because the latter is highly accurate, whereas the former is the edge of this capacity limit. A 2 (Set Sizes 2 and 4) × 3 (testing sessions) × 2 (training groups) ANOVA with age and education as covariates revealed that amongst the three main effects, set size was significant, $F(1, 8) = 54.51$, $p < .001$, $\eta^2 = .81$; that is, Set Size 2 was better detected than Set Size 4 (overall means for Set Size 2 and 4 were 0.93 [$SD = 0.04$] and 0.73 [$SD = 0.07$], respectively). It is important that the three-way interaction between testing session, set size, and group was significant, $F(2, 16) = 5.75$, $p = .01$, $\eta^2 = .09$. Data from this task (see Figure 2) indicate that the video game training group performed better over time compared with the nontrainers, particularly for Set Size 4 than for Set Size 2.

Hence, we further analyzed the data for the two set sizes separately. For Set Size 2, accuracy increased over testing session, $F(2, 16) = 6.36$, $p < .01$, $\eta^2 = .07$, but it did not interact with group, $F(2, 16) = 2.26$, $p = .14$, $\eta^2 = .03$. For Set Size 4, there was no significant effect of testing session ($F < 1$) or training group ($F < 1$), but the interaction between testing session and group was significant with gamers improving more than the control participants over time in accuracy of detection, $F(2, 16) = 4.02$, $p = .04$, $\eta^2 = .06$. Therefore, video game training improved performance over time, particularly at the capacity limit of the focus of attention in the VSTM task.

Raven's Advanced Progressive Matrices

Accuracy data for the subtests of Raven's Advanced Progressive Matrices task shows an increasing trend in performance of the RON group, but not for the control group, across sessions (see Figure 3). Considering age and education as covariates, we found no main effect of group ($F < 1$) and no significant effect of time, $F(2, 68) = 1.01$, $p = .37$, $\eta^2 = .03$, but the Group × Time interaction was significant, $F(2, 68) = 4.12$, $p = .02$, $\eta^2 = .11$. Marginal means show that the RON group improved in this test over time more than the control group; this differential increase was significant between the second and third testing session, $F(1, 34) = 8.17$, $p < .01$, $\eta^2 = .19$, but not between the first and second testing sessions ($F < 1$). Therefore, strategy video game training significantly improved reasoning abilities over time, particularly after 23.5 hr of training.

Stopping Task

The primary measure for this task was stop reaction time, which was calculated by subtracting the average delay between the letter and the tone from the average reaction time on go trials (results are

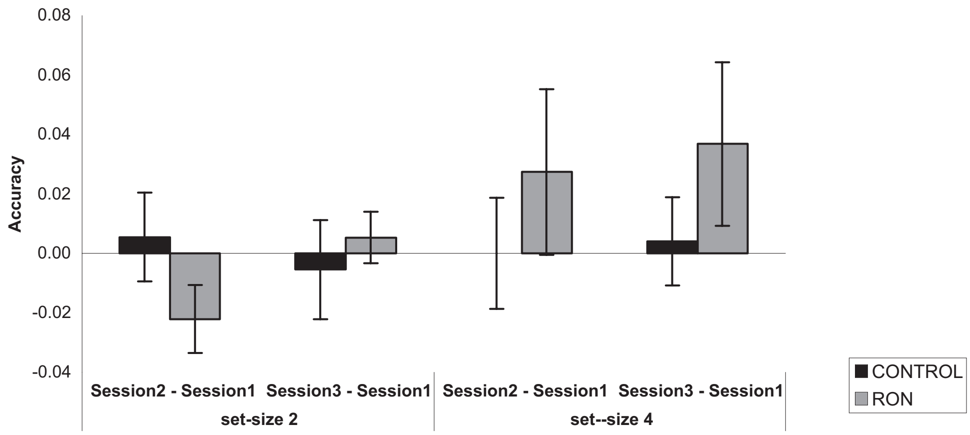

Figure 2. Improvement in the accuracy detection from Session 1 to Session 2 and Session 1 to Session 3 in the visual short-term memory task for both set sizes (2 and 4) and both groups. Error bars represent plus and minus 1 standard error. CONTROL = control group; RON = the Rise of Nations group.

displayed in Figure 4). Two participants, 1 from each group, were dropped from analyses as their accuracy was around chance level (50%) for at least one of the three sessions; we failed to collect data for all three testing sessions for 1 participant in the control group. Accuracy did not change between the two groups, $F(1, 32) = 1.79$, $p = .19$, $\eta^2 = .05$, across sessions ($F < 1$), and there was no significant interaction between group and session ($F < 1$). Stopping probability, expected to be around 50%, is maintained (see Table 2). Regarding average reaction time on go trials, there was no main effect of group ($F < 1$), no main effect of session ($F < 1$), and no significant interaction between session and group ($F < 1$).

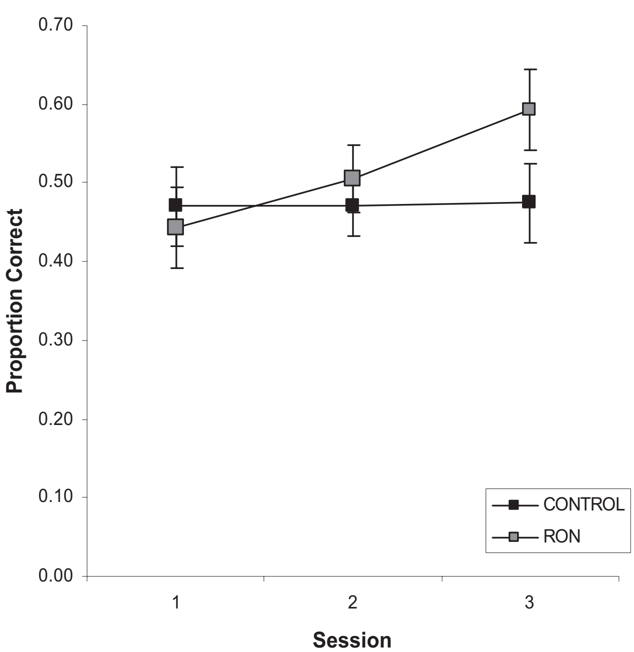

Figure 3. Accuracy in Raven's Advanced Progressive Matrices (Raven, 1990) subtests for the two groups as a function of testing sessions. Error bars represent plus and minus 1 standard error. CONTROL = control group; RON = the Rise of Nations group.

Stop reaction time, a measure of inhibitory control, shows a decreasing trend in the RON group but remains relatively constant in the control group. But, like RTs for go trials, there was no main effect of group ($F < 1$), session ($F < 1$), or interaction between group and session ($F < 1$). Therefore, there was no significant benefit of video game training on the stop reaction time.

Training Effects on Cognitive Battery: Visuospatial Attentional Tasks

Functional Field of View Task

The accuracies were subjected to a repeated measure ANOVA with training group as a between-subjects factor, and testing session and eccentricity (10°, 20°, and 30°) as within-subjects factors. Both groups improved in the ability to detect and localize the

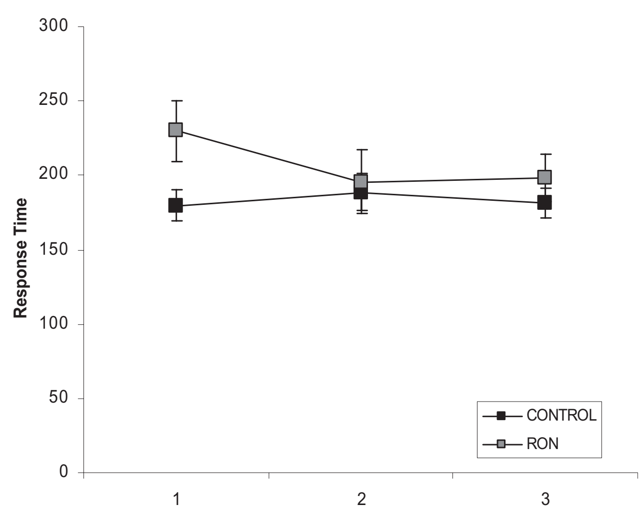

Figure 4. Stop reaction time (ms) in the stopping task for the two groups as a function of testing session. Error bars represent plus and minus 1 standard error. CONTROL = control group; RON = the Rise of Nations group.

target over time; main effect of testing session was significant, $F(2, 68) = 11.96$, $p < .01$, $\eta^2 = .26$, but training group did not interact significantly with testing session ($F < 1$) nor did it interact with testing session and eccentricity ($F < 1$). The interaction between testing session and eccentricity was significant, $F(4, 136) = 3.88$, $p < .01$, $\eta^2 = .10$, such that accuracy for items closer to fixation improved more; to explore this further, we conducted separate ANOVAs for the three different degrees of eccentricity. We found a significant effect of session for all three degrees of separation between fixation and target—that is, accuracy for all eccentricities increased across Testing Sessions 1 to 3—but we found no interaction between session and training group for any of the three eccentricities ($F < 1$). Therefore, training in a real-time strategy game did not enhance the functional field of view beyond what occurred simply by performing the task three times.

Attentional Blink

An improvement in this task because of video game training (Green & Bavelier, 2003) would mean that participants improved in their ability to process two targets in close temporal proximity. Data were entered into an ANOVA with T2 lag (3, 4, 5, 6), testing session as within-subjects factors, and group as a between-subjects factor. Participants demonstrated the classic attention blink effect. A Lag (T2 following T1 by 3, 4, 5, or 6 items) × Testing Session × Training Group ANOVA revealed no effect of lag, $F(3, 105) = 2.47$, $p = .07$, $\eta^2 = .06$. Accuracy did not improve across testing sessions, $F(2, 70) = 1.27$, $p = .29$, $\eta^2 = .03$. Also, group did not interact with testing session, $F(6, 210) = 1.17$, $p = .32$, $\eta^2 = .03$, nor was the three-way interaction among group, testing session, and lag significant ($F < 1$). Therefore, training in a real-time strategy game did not enhance performance on attentional blink paradigm.

To rule out the possibility that differences in T1 performance influenced T2 performance, we compared T1 accuracy across testing sessions and groups. This analysis revealed no reliable effects of group, $F(1, 35) = 1.20$, $p = .28$, $\eta^2 = .03$, of testing session, $F(2, 70) = 2.78$, $p = .07$, $\eta^2 = .07$, or in the interaction between group and testing session ($F < 1$). Thus, the groups did not differ reliably in their ability to detect T1.

Enumeration

Data from the enumeration task (see Table 3) were submitted to a 2 (training group) × 3 (testing session) × 8 (number of objects) ANOVA with testing session and number of objects as a within-subjects factor and training groups as a between-subjects factor. For this task, if the training in the video game is beneficial, then improvements should be observed when the number of objects in the display exceeds the subitizing range, as indicated by a Testing Session × Group × Number of Objects interaction. The results indicate that as the number of objects increased, accuracy decreased, $F(7, 266) = 54.12$, $p < .001$, $\eta^2 = .58$, but there was no effect of testing session ($F < 1$) or group ($F < 1$). Neither of the two-way interactions with group were significant ($ps > .61$), and most important, the three-way interaction between the three factors was not found to be significant ($F < 1$). These results suggest that enumeration ability did not improve substantially with practice or with video game training.

Mental Rotation

Data obtained from this task are depicted in Table 4. Because of a computer error in Session 3, data from 1 participant from the RON group was unavailable for analyses. RTs showed a classic mental rotation pattern, with slower responses up to 180° of rotation in either direction, $F(7, 252) = 24.92$, $p < .01$, $\eta^2 = .40$. There was no main effect of repeated testing ($F < 1$) or group ($F < 1$). Testing session interacted with the extent of rotation such that response latencies improved more for greater degrees of rotation, $F(14, 504) = 35.26$, $p < .01$, $\eta^2 = .49$, but it is important that this pattern did not interact with the training group ($F < 1$). This implies that video game training had no effect on the latency data in the mental rotation task.

Accuracy data, on the other hand, show an improving trend in the performance of the video game players compared with the control group. Also, similar to the RT data, accuracy displayed classic mental rotation pattern with participants being less accurate for rotations closer to 180° from either side, $F(7, 252) = 18.20$, $p < .01$, $\eta^2 = .32$; this interacted significantly with group, $F(7, 252) = 3.08$, $p < .01$, $\eta^2 = .05$. There was a marginal main effect of repeated testing, $F(2, 72) = 2.80$, $p = .067$, $\eta^2 = .07$, and this interacted with the extent of rotation such that accuracies increased more for greater degrees of rotation, $F(14, 504) = 6.34$, $p < .01$, $\eta^2 = .14$. Of importance, unlike RT data, this pattern interacted with the training group, $F(14, 504) = 2.36$, $p < .01$, $\eta^2 = .05$. Thus, the video game training effect was evident in accuracy data, but not for RT.

Because we are ultimately interested in whether there is a significant difference in improvement of accuracies between the two groups from Session 1 to Session 3, we submitted the difference in accuracy (Session 3 – Session 1) to an 8 (extent of

Table 3
Average Accuracy of Each Group, Number of Objects, and Testing Session for the Enumeration Task

		Number of objects							
Training group	Session	1	2	3	4	5	6	7	8
CONTROL	1	0.98	0.97	0.95	0.89	0.86	0.79	0.66	0.51
	2	0.97	0.96	0.95	0.88	0.85	0.81	0.67	0.53
	3	0.98	0.98	0.95	0.87	0.84	0.82	0.67	0.57
RON	1	0.98	0.96	0.93	0.82	0.78	0.79	0.66	0.52
	2	0.98	0.99	0.97	0.93	0.84	0.82	0.70	0.51
	3	0.99	0.99	0.94	0.88	0.84	0.79	0.67	0.51

Note. CONTROL = the control group; RON = the Rise of Nations group.

Table 4
Average Response Time (RT) and Accuracy of Each Group, Rotation, and Testing Session for the Mental Rotation Task

			Rotation (in degrees)							
Variable	Training group	Session	0	45	90	135	180	225	270	315
RT (ms)	CONTROL	1	1825	2400	2996	2878	3248	3106	3001	2365
		2	1531	2011	2408	2384	2899	2699	2403	2006
		3	1492	2005	2406	2379	2895	2558	2343	1959
	RON	1	1878	2266	2799	2625	3058	2840	2828	2340
		2	1761	2098	2525	2452	2870	2719	2557	2086
		3	1555	2055	2402	2291	2822	2445	2389	1896
Accuracy	CONTROL	1	0.94	0.90	0.88	0.84	0.72	0.80	0.81	0.91
		2	0.96	0.90	0.90	0.86	0.75	0.80	0.86	0.92
		3	0.96	0.95	0.92	0.89	0.80	0.84	0.91	0.93
	RON	1	0.88	0.91	0.85	0.81	0.77	0.79	0.85	0.83
		2	0.93	0.94	0.91	0.89	0.86	0.89	0.89	0.94
		3	0.97	0.96	0.93	0.96	0.95	0.94	0.94	0.97

Note. CONTROL = the control group; RON = the Rise of Nations group.

rotation) × 2 (training group) ANOVA.[4] There was a marginal effect of group, $F(1, 38) = 3.91$, $p = .055$, $\eta^2 = .09$, a significant effect of rotation, $F(7, 266) = 2.86$, $p < .01$, $\eta^2 = .07$, and the Group × Rotation interaction was significant, $F(7, 266) = 2.08$, $p < .05$, $\eta^2 = .05$. We also submitted the difference in accuracy of Session 1 from Session 2 to an 8 (extent of rotation) × 2 (training group) ANOVA, but except for a significant effect of group, $F(1, 36) = 4.87$, $p < .03$, $\eta^2 = .12$, there was no effect of rotation or the interaction term (ps $> .22$). These results suggest that although video game training enhances accuracy of detection in the mental rotation task, this improvement is observed after about 23.5 hr of training; about 11 hr or less is not sufficient to see this transfer effect of video game training.

Is there any correlation between change in video game performance and change in performance on executive control tasks?

We had expected that a real-time strategy game like RON would mostly influence executive control processes, given its emphasis on switching between tasks, planning, scheduling, and executing different strategies. In the previous analyses, we found that there is evidence of transfer of the RON video game training to several tasks of executive control, namely task switching, focus-switching in *N*-back, and VSTM. These results at least partially support our hypothesis that a real-time strategy-based video game may engender transfer to executive control tasks for older adults.

Additionally, from an individual differences perspective, one may ask whether improvements in game performance are related to improvements in executive control tasks. More specific, do greater improvements in game performance imply greater improvements in executive control processes? This question can be answered by first computing changes in game measures (game completion time and speed) for the first and last game played, then by computing changes in performance in transfer tasks for Session 1 and Session 3, followed by correlating these changes between game performance and transfer tasks. We considered only the tasks of executive control in which evidence of transfer was observed. Partial correlations, after controlling for age, between the variables of change in game performance and change in transfer tasks yielded the following results. Change in task switch cost was significantly correlated with change in the speed measure of the game, $r(15) = -.68$, $p < .01$; that is, a greater decrease in task switch cost was associated with a greater increase in game speed. Although a greater decrease in focus switch cost in the *N*-back task was related to greater decrease in game time, $r(16) = .42$, $p = .079$, this correlation was not significant at $p = .05$. Because the end game was not necessarily the same game as the first game, measures of game performance for end game span over a wide variety of games. Therefore, in subsequent correlation analyses, we examined a subset of participants who played the same game before and after video game training. As before, change in task switch cost, after controlling for age, was significantly correlated with change in speed measure of the game, $r(12) = -.69$; $p < .01$. It is interesting that focus switch cost in the *N*-back task was also significantly related to greater decrease in game time, $r(12) = .54$, $p < .05$.

Discussion

First, we found significant benefits of strategy-based video game training on executive control functions following training. The significant findings were accompanied by acceptable effect sizes as measured by η^2 (Cohen, 1988). The executive control functions improved substantially with 23.5 hr of training, with large effect size ($\eta^2 = .42$). Moreover, out of five tasks of executive control function, we found significant transfer of video game training to four tasks (task switching, focus or object switching in the *N*-back task, VSTM, and Raven's Advanced Progressive Matrices task). Task switching revealed substantial improvement, with a medium effect size over all three testing sessions ($\eta^2 = .10$) and large effect size for 11 to 23.5 hr of training ($\eta^2 = .17$). In memory measures, *N*-back task also revealed similar substantial improvement, with a medium effect size over all three testing

[4] Data were obtained from all 40 participants in both Sessions 1 and 3, but there were 38 participants in Session 2, resulting in increased degrees of freedom when difference accuracy data of Session 3 – Session 1 is analyzed compared with other analyses.

sessions ($\eta^2 = .10$) and large effect size for 11 to 23.5 hr of training ($\eta^2 = .14$). VSTM also displayed a medium effect size ($\eta^2 = .09$) that accompanied the improvement of gamers more in Set Size 4 than 2 over testing session than nongamers. Reasoning, as measured by performance on Raven's Advanced Progressive Matrices test, also improved substantially with medium effect size ($\eta^2 = .11$); this improvement was greater from 11 to 23.5 hr of training (large effect size, $\eta^2 = .19$).

In contrast to results from younger adults (Green & Bavelier, 2003, 2006), in which training on a first-person shooter video game improved selective visual attentional skills, we found evidence of transfer to only one (mental rotation) out of four visuospatial attentional tasks. Although the results of mental rotation show significant improvement in accuracy over time, the effect size was small ($\eta^2 = .05$).

In short, our study of older adults, in which the participants are trained on a strategy-based real-time video game, transfer of training is, as predicted, found mostly in tasks that tap executive control functions, with the exception of mental rotation, which is a spatial task. It is interesting that benefits of video game training were observed in tasks in which one had to juggle or switch from one item to another in the working memory (*N*-back task), but not in the capacity of working memory per se (operation span task); this is in concordance with the results from Craik et al. (2007), in which the authors found no benefit in the Alpha Span Test from an integrative rehabilitation program that included memory training.

Second, regarding whether transfer is proximal or distal, it is possible that because we used a strategy-based video game that involves maintaining items in short-term memory, juggling things back and forth in a short span of time, and making decisions on various strategies and resources, transfer to tasks tapping VSTM, switching between objects, and reasoning abilities may be judged as proximal or near transfer. Yet, one can argue that laboratory-based tasks of executive control are quite different from video games, and the fact that gamers improve in these laboratory-based tasks is evidence of wider transfer. It is interesting that we also observed transfer of training from video game training to the mental rotation task. In RON, the stimuli do not ever appear rotated (for example, people or trees are not hanging upside down, the map on the screen is never rotated), yet game players improved more in the accuracy of mental rotation task than control subjects. We speculate that such transfer may be the result of the requirement to quickly perceive the relations between multiple objects and events in the video game, albeit not in rotated orientations. This speculation would also be consistent with the benefit for the video game subjects in the VSTM task.

Third, we also observed that individual differences in improvements in game performance were correlated with individual differences in improvements in task-switching and *N*-back paradigms, but not with other measures of executive control such as VSTM or Raven's Advanced Progressive Matrices test. The correlations between changes in game performance and changes in executive control tasks imply that learning a complex skill (such as RON) is related to the amount of transfer to cognitive abilities. This has implications in designing an appropriate training paradigm in older adults: One should take into account complexity of the primary task, because greater improvement in learning of the complex skill could possibly lead to larger transfer effects, particularly to executive control tasks. Also, the transfer benefits observed were mostly observed after 23.5 hr of video game training, and these effects were moderate to large; about half of these hours were not enough to observe these beneficial effects. It would be of interest to determine whether increasing the hours of training would induce transfer to other tasks of executive control or enhance the strength of the transfer effects.

It is encouraging to observe in our study, with a real-time strategy game, modest transfer benefits to executive control function, which are linked to frontal lobe functions that control and direct high-level cognitive functions. Aging is known to substantially affect the frontal lobes, particularly prefrontal cortex (Raz, 2000); functionally, it also affects higher level cognitive functions that collectively form executive control, such as dual tasking, working memory, and inhibition. Not only do we see evidence of transfer to tasks of executive control, we find that the more one improves in the video game performance, the more he or she improves on switching between task sets. Such a positive, albeit weaker, correlation is also observed between improvements in game performance and working memory (*N*-back). Therefore, real-time strategy-based video game training appears to enhance executive control functions in the elderly not only at the group level, but also at the individual level.

One possibility of why we see improvements in performance of the training group in the transfer tasks could be that RON keeps the player on his or her toes; one is always changing priorities, albeit voluntarily, in which sometimes one may focus on building wonders, generating resources, maintaining multiple cities, attacking the enemy, or defending one's own territories. It is known that training in which different subtasks are individually emphasized in the context of the whole task (variable priority training) improves performance (and potentially transfers) more than training that emphasizes performance in the whole task (Gopher et al., 1994; Kramer et al., 1995, 1999). Variable priority training could be further incorporated into game training by having trainees emphasize different aspects of each game performance at different times. In the current game, it is possible that the trainees are prioritizing different aspects of games at different times depending on their reasoning skills and status of game, among other factors. RON is not merely variable or flexible; it is also an integrative video game.

One limitation of our study was that our control group did not play a video game. Hence, it is conceivable, though unlikely given the specific transfer benefits that we observed, that similar transfer effects would be observed for any video game, whether it emphasizes the learning and flexible deployment of complex strategies or fast-paced responses to multimodal stimuli (as is the case in first-person shooter video games). Clearly, one important future direction is to systematically examine the relationship between types of video game (e.g., real-time strategy, first-person shooter, or social interaction game) and the nature of transfer benefits.

Also, future research should assess not only whether video game training improves performance on laboratory-based tasks, but whether it improves performance on everyday cognitive abilities and real-world tasks, such as driving skills, working in a busy office, or leisure time pursuits and sports. Gopher et al. (1994) have observed transfer of video game training skills to flight training in younger adults. Whether similar transfer effects would be observed with video-game based training to everyday cognition in older adults is a both theoretically as well as practically important question, especially given the rapid expansion of commercial products and computer programs touted to improve the cognitive abilities of older adults.

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